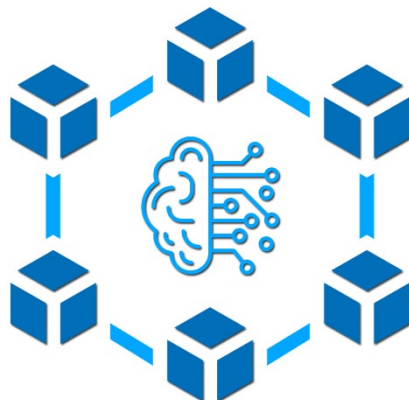




**NANCY**

**An Artificial Intelligent Aided Unified Network for Secure Beyond 5G Long Term  
Evolstution [GA: 101096456]**

## **Deliverable 6.3**

### **NANCY Integrated System – Final Version**

*Programme: HORIZON-JU-SNS-2022-STREAM-A-01-06*

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## Document Control Page

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|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
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## List of Acronyms

| Acronym         | Explanation                                                     |
|-----------------|-----------------------------------------------------------------|
| <b>5G</b>       | 5 <sup>th</sup> Generation                                      |
| <b>AI</b>       | Artificial Intelligence                                         |
| <b>AI Virt</b>  | AI Virtualizer                                                  |
| <b>AINQM</b>    | AI Network Quality Module                                       |
| <b>API</b>      | Application Programming Interface                               |
| <b>ASL</b>      | American Sign Language                                          |
| <b>AR/VR</b>    | Augmented Reality/ Virtual Reality                              |
| <b>BC</b>       | Blockchain Component                                            |
| <b>B5G</b>      | Beyond 5 <sup>th</sup> Generation                               |
| <b>BSS</b>      | Business Support System                                         |
| <b>B-RAN</b>    | Blockchain RAN                                                  |
| <b>CA</b>       | Certificate Authority                                           |
| <b>CI/CD</b>    | Continuous Integration/ Continuous Delivery                     |
| <b>CNN</b>      | Convolutional Neural Network                                    |
| <b>COW</b>      | Coherent-One-Way                                                |
| <b>CSV</b>      | Comma-separated values                                          |
| <b>CV-QKD</b>   | Continuous-Variable Quantum Key Distribution                    |
| <b>DAC</b>      | Digital Agreement Creator                                       |
| <b>D-ADM</b>    | Distributed Anomaly Detection and Mitigation                    |
| <b>DevOps</b>   | Development and Operations                                      |
| <b>DID</b>      | Decentralised Identifier                                        |
| <b>DT</b>       | Digital Twin                                                    |
| <b>ETSI</b>     | European Telecommunications Standards Institute                 |
| <b>FL</b>       | Federated Learning                                              |
| <b>FL-IDS</b>   | Federated Learning-Intrusion Detection System                   |
| <b>GRPC</b>     | gRPC Remote Procedure Call                                      |
| <b>HA</b>       | Highly Available                                                |
| <b>HTTPS</b>    | Hypertext Transfer Protocol Secure                              |
| <b>ID Mgnt</b>  | Identity Management                                             |
| <b>JSON</b>     | JavaScript Object Notation                                      |
| <b>K8s</b>      | Kubernetes                                                      |
| <b>K8s-aaS</b>  | Kubernetes-as-a-Service                                         |
| <b>KMS</b>      | Key Management System                                           |
| <b>KPI</b>      | Key Performance Indicator                                       |
| <b>LaaS</b>     | Localisation-as-a-Service                                       |
| <b>LLM</b>      | Large Language Model                                            |
| <b>MARL</b>     | Multi-Agent Reinforcement Learning                              |
| <b>MEC</b>      | Multi-Access Edge Computing                                     |
| <b>ML</b>       | Machine Learning                                                |
| <b>MLOps</b>    | Machine Learning Operations                                     |
| <b>MRAT-NCP</b> | Multi Radio Access Technologies – Nomadic Connectivity Provider |
| <b>MTG-RM</b>   | Memory Traffic Generator-Resource Monitor                       |
| <b>NAOMI</b>    | Network AI Workflow Democratisation                             |
| <b>NBI</b>      | Northbound Interface                                            |
| <b>NFVO</b>     | Network Functions Virtualisation Orchestrator                   |
| <b>NI</b>       | NANCY Interface                                                 |

|                 |                                                                                    |
|-----------------|------------------------------------------------------------------------------------|
| <b>NIS</b>      | NANCY Interface Set                                                                |
| <b>NIF</b>      | Network Information Framework                                                      |
| <b>OBU</b>      | Onboard Unit                                                                       |
| <b>OP-TEE</b>   | Open Trusted Execution Environment                                                 |
| <b>OSS</b>      | Operations Support System                                                          |
| <b>OQS</b>      | Open Quantum Safe                                                                  |
| <b>P2P</b>      | Point-to-Point                                                                     |
| <b>PQC</b>      | Post-Quantum Cryptography                                                          |
| <b>PC5 / Uu</b> | Interfaces from 3GPP context (i.e., Device-to-Device, Cellular UE-to-Network link) |
| <b>QBER</b>     | Quantum Bit Error Rate                                                             |
| <b>QKDSim</b>   | Quantum Key Distribution Network Simulator                                         |
| <b>RAN</b>      | Radio Access Network                                                               |
| <b>RIC</b>      | RAN Intelligent Controller                                                         |
| <b>RICMgr</b>   | RAN Intelligent Controller Manager                                                 |
| <b>RSU</b>      | Roadside Unit                                                                      |
| <b>SAE</b>      | Secure Application Entity                                                          |
| <b>SEMR</b>     | Self-Evolving Model Repository                                                     |
| <b>SLA</b>      | Service Level Agreement                                                            |
| <b>SM</b>       | Slice Manager                                                                      |
| <b>SO</b>       | Service Orchestrator                                                               |
| <b>SP</b>       | Smart Pricing                                                                      |
| <b>SPP</b>      | Smart Pricing Policies                                                             |
| <b>SSI</b>      | Self-Sovereign Identity                                                            |
| <b>SSL</b>      | Secure Sockets Layer                                                               |
| <b>TEE</b>      | Trusted Execution Environment                                                      |
| <b>TLS</b>      | Transport Layer Security                                                           |
| <b>TFS</b>      | Traffic Forecasting Service                                                        |
| <b>TMF</b>      | TeleManagement Forum                                                               |
| <b>UE</b>       | User Equipment                                                                     |
| <b>V2X</b>      | Vehicle-to-Everything                                                              |
| <b>VNF</b>      | Virtual Network Function                                                           |
| <b>vOBU</b>     | Virtual Onboard Unit                                                               |
| <b>VPN</b>      | Virtual Private Network                                                            |
| <b>XAI</b>      | Explainable AI                                                                     |
| <b>YAML</b>     | YAML Ain't Markup Language                                                         |
| <b>IMSI</b>     | International Mobile Subscriber Identity                                           |
| <b>SMF</b>      | Session Management Function                                                        |

## Executive summary

This deliverable presents in detail the final results of *T6.3 - Interoperability check and joint-optimization* related to NANCY integration activities, which aim to incorporate the outcomes of the development tasks (WP2-WP5) into the final release of the NANCY unified platform. To this end, this deliverable builds on the outcomes of T6.1 and T6.2 relative to the integration points specifications and the associated functional and integration testing plans, as well as the platform's initial deployment view (reported in [1] and [2]). More specifically, it initially describes how the interconnection among NANCY platform's operation domains and the different testbeds/demonstrators was achieved. Then it delves into the specifics of functional and bilateral integration tests (initially described in [2]) providing their detailed execution specifications. The test specifications follow a common template including information on the test objectives, configuration and detailed description of the testing steps. In this context, the updates with respect to [2] concerning the initially envisioned integration points are also highlighted providing the details about newly identified or dropped integration points.

Moreover, D6.3 provides the implemented system level validation workflows, as the advanced validation/verification of selected NANCY integrated system operations to be demonstrated within the different testbeds/demonstrators. These workflows, often horizontal (i.e., common) across different NANCY use cases, represent end-to-end processes which involve multiple steps among multiple NANCY integration points towards a specific objective (e.g., get authenticated and authorized to use a specific service, or create a Service Level Agreement (SLA) between the end-users and different operators).

To this end, the final release of the NANCY unified platform, validated through comprehensive tests at different levels, provides a prototype suitable for the final use-case specific tests and evaluation at the different NANCY pilots.

## 1. Introduction

### 1.1. Purpose of the Document

This document presents the final version of the NANCY integrated system. It illustrates how NANCY brings together secure and intelligent resource management and flexible networking using cutting-edge research in Artificial Intelligence, Blockchain, Orchestration, etc. In terms of networking, novel architectures, namely point-to-point (P2P) connectivity for device-to-device communication, mesh networking, and relay-based communications, are introduced to build a secure core platform for B5G communications.

The project realizes its ambitious approach to the provision of the necessary Beyond 5G functionalities, bringing together a multitude of disparate and complex technologies to create its core platform, on top of five unique experimental testbeds. The deployment view of the core platform is presented herein, along with results from the functional, integration, and end-to-end testing that was performed by the Consortium in order to validate the NANCY workflows “from start to finish”.

### 1.2. Relation to Other Tasks and Deliverables

This document concludes the integration work that was first presented in D6.2 “*NANCY Integrated System – Initial Version*”. The first iteration showcased the progress up to M25 of the project, while the current version provides the details of the final version of the NANCY Core Platform.

As also stated in [2], the Integration task received inputs from the key technical work packages, namely:

- WP2 “*Usage Scenario and B-RAN Modelling, Network Requirements and Performance assessment*” for requirements and modelling of B-RAN and Network Information Framework,
- WP3 “*NANCY Architecture and Orchestration*” for the core artificial intelligence and orchestration components,
- WP4 “*Dynamic Resource Management and Smart Pricing*” for the components implementing the computational off-loading, caching, resource elasticity, cell-free cooperative access, smart pricing and beyond-Shannon performance, and
- WP5 “*Security, Privacy and Trust Mechanisms*” for the quantum key distribution, blockchain-based security and privacy, self-healing/self-recovery, and explainable AI.

The remaining integration activities that took place after the initial release of the NANCY integrated system, following the integration timeline presented in [2] and in conjunction with the guidelines delineated in [3], were strongly related to the initial validation/testing activities carried-out at the different testbeds and demonstrators (T6.5-T6.9), and thus they provided valuable feedback for refinements with respect to NANCY components and integration points. These activities led to the final release of the NANCY integrated system, described analytically in the current deliverable. This release serves as a prototype ready to be further tested, validated and evaluated within the use cases of the different testbeds and demonstrators (T6.5-T6.9). The results of this evaluation will be analytically reported in D6.10: “*NANCY Pilots’ Documentation and Evaluations*”.

### 1.3. Structure of the Deliverable

This document is structured as follows:

- **Chapter 1 - Introduction** defines the structure and purpose of the document.
- **Chapter 2 - Deployment View of NANCY Reference Architecture** describes the central management and inter-operator domains, as well as their connection to the NANCY testbeds and demonstrators.
- **Chapter 3 - Functional Testing of NANCY Components** details the specification and results of the functional testing of each component of the project's platform to ensure that they work according to their requirements and within their specifications.
- **Chapter 4 - Updates on Integration of NANCY Components and Services** provides an update on the project integration points, the specifications, and results of inter-component integration tests.
- **Chapter 5 – NANCY Platform – System-Level Validation Workflows** provides the results of system-level tests to verify the readiness of the NANCY platform for execution at the different demonstrations.
- **Chapter 6 – Conclusions** summarizes and concludes the document.

## 2. Deployment View of NANCY Reference Architecture

In the current section, information is provided regarding the interconnection of NANCY's main operation domains: *Central Management*, *Inter-Operator* and *Testbeds/Demonstrators sites* (Figure 1). The objective is to provide a high-level view of the components of each domain invoked at each testbed or demonstrator, as well as information on how the networking/interfacing among these components is implemented (e.g., VPN setups, etc.).

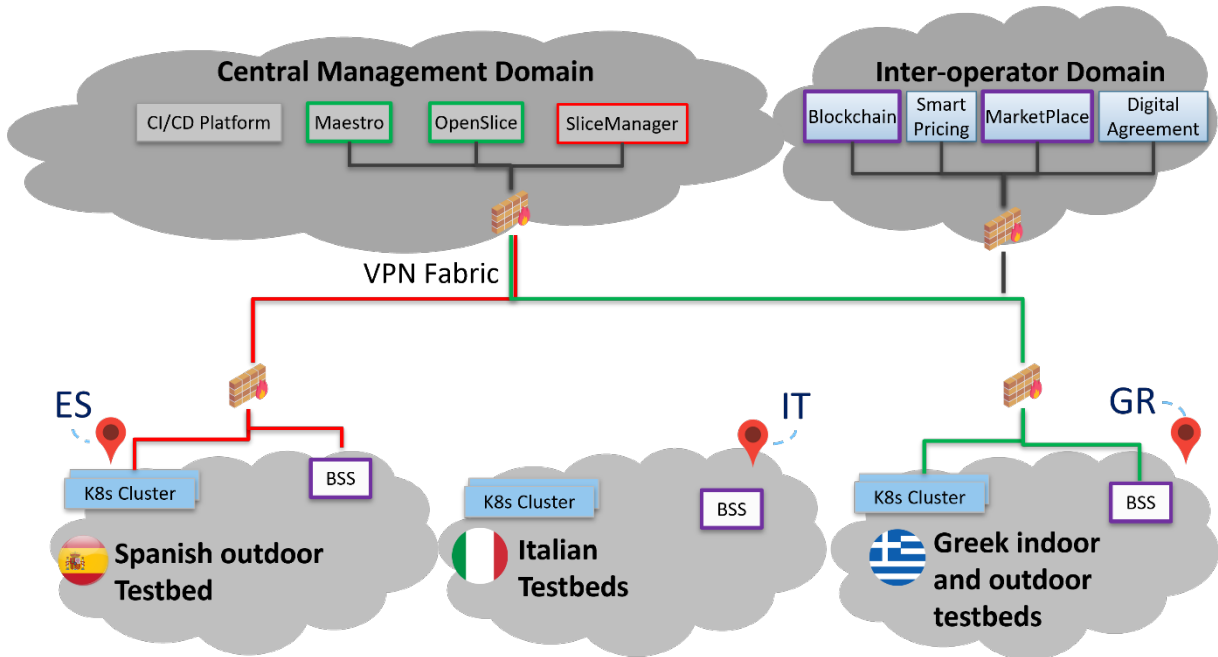


Figure 1: NANCY platform operation domains and deployment of the NANCY architecture.

### 2.1. Central Management Domain and Testbeds/Demonstrators

#### 2.1.1. Maestro and OpenSlice Connection with Greek testbeds/demonstrators

Maestro acts as the NANCY service orchestrator and OpenSlice acts as the NANCY resource orchestrator as per the NANCY integration architecture introduced in [1]. Both orchestrators serve the Greek indoor testbed and Greek outdoor demonstrator in applying the SLAs and corresponding service configurations and automating the deployment of the corresponding components at the subsequent Kubernetes clusters (indoor testbed or outdoor demonstrator). This integration is depicted in Figure 1. Maestro and OpenSlice (outlined with green color) reside in the NANCY Central Management Domain, establishing a connection (also outlined with green color) with the Greek facilities at the bottom right part in Figure 1. As part of this integration, Maestro interacts with the BSS components of the two experimental sites. To do so, two private network connections are established from the Maestro location (hosted by INTRA under Hetzner's cloud) towards (i) the UOWM Greek indoor testbed over OpenVPN (see Figure 2) and (ii) the OTE Greek outdoor demonstrator over an IPsec tunnel (see Figure 3). The integration specifics are provided in Section 5.2

```

● openvpn-client@uowm.service - OpenVPN tunnel for uowm
Loaded: loaded (/lib/systemd/system/openvpn-client@.service; enabled; vendor preset: enabled)
Active: active (running) since Mon 2025-09-15 08:04:05 UTC; 2 days ago
Docs: man:openvpn(8)
      https://community.openvpn.net/openvpn/wiki/Openvpn24ManPage
      https://community.openvpn.net/openvpn/wiki/HowTo
Main PID: 2091360 (openvpn)
Status: "Initialization Sequence Completed"
Tasks: 1 (Limit: 37554)
Memory: 2.2M
CPU: 5.953s
CGroup: /system.slice/system-openvpn.slice/openvpn-client@uowm.service
        └─2091360 /usr/sbin/openvpn --suppress-timestamps --nobind --config uowm.conf

Sep 15 08:04:05 k8s-single-node openvpn[2091360]: WARNING: this configuration may cache passwords in memory -- use the auth-nocache option to prevent this
Sep 15 08:04:06 k8s-single-node openvpn[2091360]: [VPNServer Certificate] Peer Connection Initiated with [AF_INET]83.212.19.48:1195
Sep 15 08:04:07 k8s-single-node openvpn[2091360]: Options error: option 'route' cannot be used in this context ([PUSH-OPTIONS])
Sep 15 08:04:07 k8s-single-node openvpn[2091360]: Options error: option 'route' cannot be used in this context ([PUSH-OPTIONS])
Sep 15 08:04:07 k8s-single-node openvpn[2091360]: Options error: option 'route' cannot be used in this context ([PUSH-OPTIONS])
Sep 15 08:04:07 k8s-single-node openvpn[2091360]: TUN/TAP device tun0 opened
Sep 15 08:04:07 k8s-single-node openvpn[2091360]: net iface mtu set: mtu 1500 for tun0
Sep 15 08:04:07 k8s-single-node openvpn[2091360]: net iface up: set tun0 up
Sep 15 08:04:07 k8s-single-node openvpn[2091360]: net addr_v4 add: 10.20.40.3/24 dev tun0
Sep 15 08:04:07 k8s-single-node openvpn[2091360]: Initialization Sequence Completed

```

Figure 2: OpenVPN client connected to UOWM Greek indoor testbed site.

| Status / IPsec / Overview |                                     |                                                                           |                                                                             |                    |                                                                                |                                                                      |                                                                                                                           |
|---------------------------|-------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------|--------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| Overview Leases SADs SPDs |                                     |                                                                           |                                                                             |                    |                                                                                |                                                                      |                                                                                                                           |
| IPsec Status              |                                     |                                                                           |                                                                             |                    |                                                                                |                                                                      |                                                                                                                           |
| ID                        | Description                         | Local                                                                     | Remote                                                                      | Role               | Timers                                                                         | Algo                                                                 | Status                                                                                                                    |
| con1<br>#428              | INTRA-OTE IPsec site-to-site<br>VPN | ID: 49.13.236.13<br>Host:<br>49.13.236.13:500<br>SPI:<br>eff3c2336951c6c9 | ID: 195.167.80.39<br>Host:<br>195.167.80.39:500<br>SPI:<br>ab60eb45fd1be975 | IKEv2<br>Responder | Rekey: 70305s<br>(19:31:45)<br>Reauth: Disabled                                | AES_CBC (256)<br>HMAC_SHA2_256_128<br>PRF_HMAC_SHA2_256<br>MODP_2048 | Established<br>7079 seconds (01:57:59)<br>ago<br><button>Disconnect P1</button>                                           |
| ID                        | Description                         | Local                                                                     | SPI(s)                                                                      | Remote             | Times                                                                          | Algo                                                                 | Stats                                                                                                                     |
| con1:<br>#4266            | k8s-cluster                         | 10.30.0.3/32                                                              | Local: ce3ffbcc<br>Remote: cf8f1a9f                                         | 10.10.10.0/24      | Rekey: 1714s (00:28:34)<br>Life: 2386s (00:39:46)<br>Install: 1214s (00:20:14) | AES_CBC (256)<br>HMAC_SHA2_256_128<br>MODP_2048<br>IPComp: None      | Bytes-In: 0 (0 B)<br>Packets-In: 0<br>Bytes-Out: 0 (0 B)<br>Packets-Out: 0<br>Installed<br><button>Disconnect P2</button> |

Figure 3: IPsec tunnel established with OTE Greek outdoor demonstrator site.

Figure 4 visualizes the Maestro services provisioned in INTRA's Hetzner cloud premises. These services are instantiated as Kubernetes pods in a Kubernetes cluster acting as a management cluster where both Maestro and OpenSlice are deployed.

|         |                                                      |     |           |                |      |
|---------|------------------------------------------------------|-----|-----------|----------------|------|
| maestro | maestro-grafana-7b554f4f4b-2j2dq                     | 3/3 | Running   | 20 (15d ago)   | 107d |
| maestro | maestro-unfinispan-549697d6f6-58jwq                  | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-kafka-controller-0                           | 1/1 | Running   | 0              | 2d5h |
| maestro | maestro-keycloak-0                                   | 1/1 | Running   | 675 (10d ago)  | 107d |
| maestro | maestro-kube-prometheus-st-operator-67f4654d6d-gtl2t | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-kube-state-metrics-6b9d6f9548-mxl4m          | 1/1 | Running   | 879 (10d ago)  | 107d |
| maestro | maestro-loki-0                                       | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-loki-chunks-cache-0                          | 2/2 | Running   | 12 (15d ago)   | 107d |
| maestro | maestro-loki-gateway-f6d6b45d5-l7mhg                 | 1/1 | Running   | 7 (15d ago)    | 107d |
| maestro | maestro-mongodb-0                                    | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-otel-collector-76df67c7c7-l8tx7              | 1/1 | Running   | 3489 (10d ago) | 107d |
| maestro | maestro-peering-api-6b695845dd-c8tdl                 | 1/1 | Running   | 20 (10d ago)   | 107d |
| maestro | maestro-pgadmin-756c6bc6c9-652tp                     | 1/1 | Running   | 158 (15d ago)  | 107d |
| maestro | maestro-portal-cart-6849c74c7c-flpzz                 | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-postgresql-db-0                              | 1/1 | Running   | 16 (15d ago)   | 107d |
| maestro | maestro-prometheus-node-exporter-pdzpf               | 1/1 | Running   | 2453 (10d ago) | 107d |
| maestro | maestro-promtail-rxdzd                               | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-registry-api-6b864545b4-bjxvf                | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-registry-server-bc655ff67-2fsb2              | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-registry-ui-796c66fb69-15lv9                 | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-sonata-core-58c79597d9-tnxpg                 | 1/1 | Running   | 1 (15d ago)    | 40d  |
| maestro | maestro-sonata-helm-engine-599fb5db9c-vktdd          | 1/1 | Running   | 405 (2d5h ago) | 107d |
| maestro | maestro-sonata-oss-client-5964fcd548-8srmm           | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-telemetry-api-9666bdf9-5zcf5                 | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-tempo-0                                      | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-tmfs-api-845655b694-lsq7p                    | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-vault-server-55948f8c88-tc6v8                | 1/1 | Running   | 6 (15d ago)    | 107d |
| maestro | maestro-ztc-client-574478d56b-w4759                  | 1/1 | Running   | 362 (2d5h ago) | 107d |
| maestro | prometheus-maestro-kube-prometheus-st-prometheus-0   | 2/2 | Running   | 609 (15d ago)  | 107d |
| maestro | tmf-api-hook-onboard-spec-7qf79                      | 0/1 | Completed | 0              | 107d |

Figure 4: Maestro pods deployed in a Kubernetes cluster in the NANCY Central Management domain.

Figure 5 depicts a snapshot of Maestro's swagger API showing a set of TMF Service Management APIs relevant to NANCY.

| Service Candidate           |                                                            |                                           |
|-----------------------------|------------------------------------------------------------|-------------------------------------------|
| GET                         | /tmf-api/serviceCatalogManagement/v4/serviceCandidate      | List or find all ServiceCandidate objects |
| POST                        | /tmf-api/serviceCatalogManagement/v4/serviceCandidate      | Creates a valid ServiceCandidate          |
| GET                         | /tmf-api/serviceCatalogManagement/v4/serviceCandidate/{id} | Retrieves a ServiceCandidate by ID        |
| DELETE                      | /tmf-api/serviceCatalogManagement/v4/serviceCandidate/{id} | Deletes a ServiceCandidate by ID          |
| PATCH                       | /tmf-api/serviceCatalogManagement/v4/serviceCandidate/{id} | Updates partially a ServiceCandidate      |
| Service Catalog             |                                                            |                                           |
| GET                         | /tmf-api/serviceCatalogManagement/v4/serviceCatalog        | List or find all ServiceCatalogue objects |
| POST                        | /tmf-api/serviceCatalogManagement/v4/serviceCatalog        | Creates a valid ServiceCatalogue          |
| GET                         | /tmf-api/serviceCatalogManagement/v4/serviceCatalog/{id}   | Retrieves a ServiceCatalogue by ID        |
| DELETE                      | /tmf-api/serviceCatalogManagement/v4/serviceCatalog/{id}   | Deletes a ServiceCatalogue by ID          |
| PATCH                       | /tmf-api/serviceCatalogManagement/v4/serviceCatalog/{id}   | Updates partially a ServiceCatalogue      |
| Service Category            |                                                            |                                           |
| GET                         | /tmf-api/serviceCatalogManagement/v4/serviceCategory       | List or find all ServiceCategory objects  |
| POST                        | /tmf-api/serviceCatalogManagement/v4/serviceCategory       | Creates a valid ServiceCategory           |
| GET                         | /tmf-api/serviceCatalogManagement/v4/serviceCategory/{id}  | Retrieves a ServiceCategory by ID         |
| DELETE                      | /tmf-api/serviceCatalogManagement/v4/serviceCategory/{id}  | Deletes a ServiceCategory by ID           |
| PATCH                       | /tmf-api/serviceCatalogManagement/v4/serviceCategory/{id}  | Updates partially a ServiceCategory       |
| Service Inventory           |                                                            |                                           |
| GET                         | /tmf-api/serviceInventory/v4/service                       | List or find all Service objects          |
| POST                        | /tmf-api/serviceInventory/v4/service                       | Creates a valid Service                   |
| GET                         | /tmf-api/serviceInventory/v4/service/count                 | Count of Services                         |
| GET                         | /tmf-api/serviceInventory/v4/service/{id}                  | Retrieves a Service by ID                 |
| DELETE                      | /tmf-api/serviceInventory/v4/service/{id}                  | Deletes a Service by ID                   |
| PATCH                       | /tmf-api/serviceInventory/v4/service/{id}                  | Updates partially a Service               |
| Service Ordering Management |                                                            |                                           |
| GET                         | /tmf-api/serviceOrdering/v4/serviceOrder                   | List or find all ServiceOrder objects     |
| POST                        | /tmf-api/serviceOrdering/v4/serviceOrder                   | Creates a valid ServiceOrder              |
| GET                         | /tmf-api/serviceOrdering/v4/serviceOrder/count             | Count of ServiceOrders                    |
| GET                         | /tmf-api/serviceOrdering/v4/serviceOrder/{id}              | Retrieves a ServiceOrder by ID            |
| DELETE                      | /tmf-api/serviceOrdering/v4/serviceOrder/{id}              | Deletes a ServiceOrder by ID              |
| PATCH                       | /tmf-api/serviceOrdering/v4/serviceOrder/{id}              | Updates partially a ServiceOrder          |

Figure 5: Maestro swagger API showing a set of TMF Service Management APIs relevant for NANCY.

Figure 6 visualizes an existing service order made by Maestro towards the Greek outdoor demonstrator testbed of OTE. The JSON body of this service order shows a service order made in October 2025 for the Minds AR/VR application (Viewcube) that participates in the Greek outdoor demonstrator hosted by OTE.

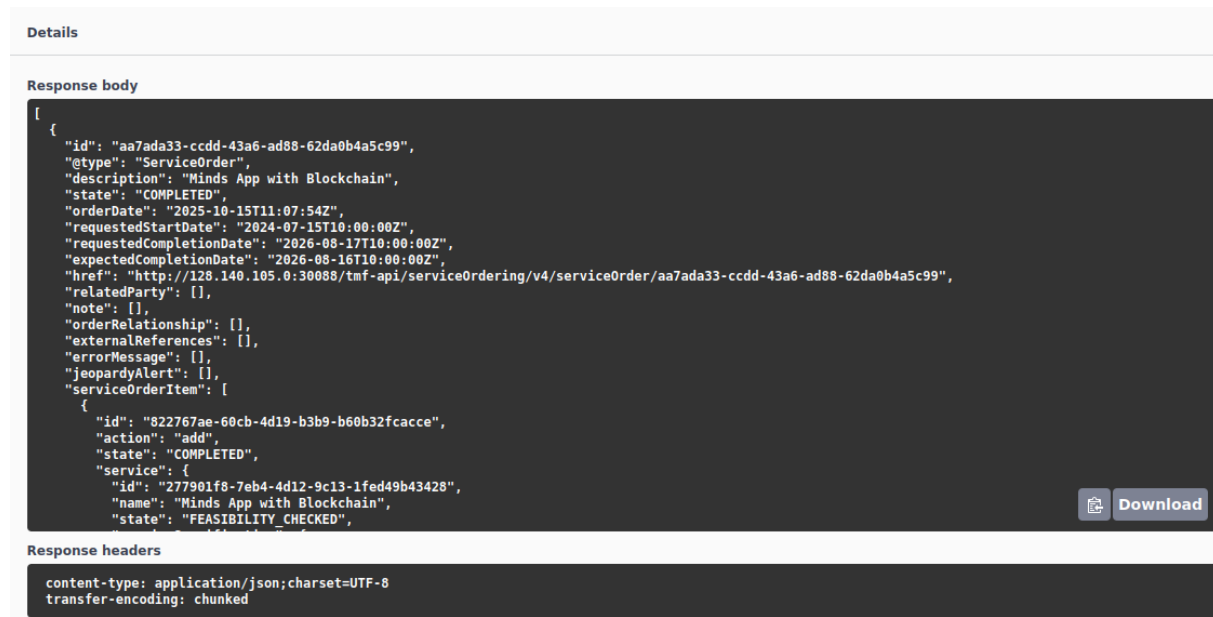


Figure 6: Maestro swagger API with a service order request towards the Greek outdoor demonstrator at OTE premises.

### 2.1.2. SliceManager Connection with Spanish demonstrator

In the Spanish demonstrator, the SliceManager orchestrator is responsible for enforcing the SLA of requested services by deploying the corresponding applications in the MEC and applying relevant radio network configurations, involving reconfiguring their allocated resources (e.g., CPU, memory, PRB). The demonstrator's testbed in EHU and the SliceManager in i2CAT premises reach each other via a VPN established in a MEC server in EHU towards the corporate Cloudflare VPN server in i2CAT (outlined in red color in Figure 1), allowing the Kubernetes cluster in the MEC and the srsRAN-based 5G to be registered in SliceManager. The connection is established using the Warp CLI, which sets up a CloudflareWARP interface in the MEC server (Figure 7).

```
ubuntu@sm-131:~$ warp-cli status
Status update: Connected
ubuntu@sm-131:~$ warp-cli debug network
IPv4: [eno4; 10.98.1.131; Ethernet; Gateway: Some(10.98.1.1)]
DNS servers:
  127.0.2.2:0
  127.0.2.3:0
  [::ffff:127.0.2.2]:0
  [::ffff:127.0.2.3]:0
  158.227.98.25:0
  10.10.13.107:0
  8.8.8.8:0

WARP Tunnel Interface:
Interface Index: 37893
Interface Name: CloudflareWARP
Interface Addresses: IPv4: 100.96.2.63, IPv6: 2606:4700:cf1:1000::1a
```

Figure 7: Warp CLI interface in the MEC server

SliceManager provides a REST API in an instance listening at 192.168.123.67:8989 as shown in the following figure:

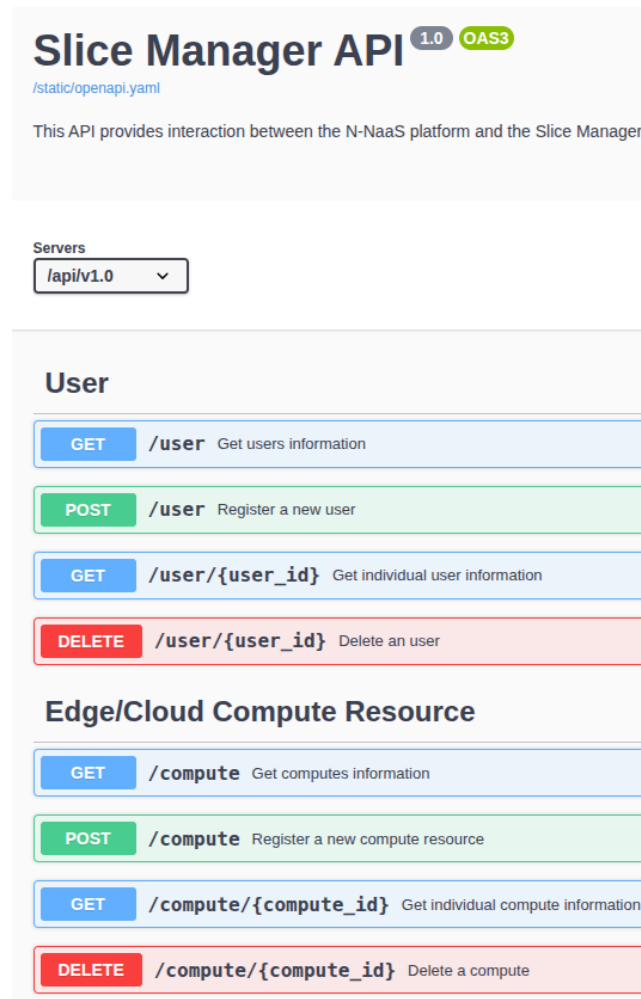


Figure 8: Slice Manager API

This API is reachable from EHU using the VPN tunnel. As part of the initial setup, the Kubernetes cluster is first registered using the `/compute/post` endpoint, which accepts the cluster's kubeconfig file.

**POST**
**/compute**
Register a new compute resource

Compute registration method

**Parameters**

No parameters

**Request body** required

The body of the request

Example Value
Schema

```

{
  "name": "nova",
  "user_id": "5b63089158f568073093f70d",
  "location": {
    "latitude": 2.3,
    "longitude": 2.4
  },
  "compute_type": "openstack|fos|k8s",
  "trusted": false,
  "compute_data": {
    "openstack": {
      "project name": "admin",
      "availability_zone": "nova",
      "password": "admin",
      "auth url": "http://localhost/identity/v3",
      "domain_name": "default",
      "username": "admin"
    },
    "k8s": {
      "kubeconfig_path": "/usr/app/src/conf/kubeconfig/",
      "kubeconfig_name": "pledger-k8s-config"
    }
  }
}

```

**Responses**

Figure 9: Compute post API from Slice Manager

The helm charts used by EHU's services are uploaded using the `/network_service/post` endpoint. Then, upon a user request, the corresponding service is instantiated using the `/network_service_instance/post` endpoint.

POST

/network\_service\_instance

Create a new network service instance

Network service instance registration method

Parameters

No parameters

Request body required

The body of the request

Example Value

Schema

```

{
  "user_id": "5b63089158f568073093f70d",
  "slic3_id": "5b63089158f568073093f70d",
  "network_service_id": "5b63089158f568073093f70d",
  "description": "Instance example",
  "osm_id": "61724abe0f49700913f4053a",
  "ports": [
    80
  ],
  "trusted": false,
  "input_node_id": "ce5ccb70-2722-4693-a1f9-1793a3b01c7a",
  "ns_placement_data": {
    "vnf": [
      {
        "member-vnf-index": "1",
        "vimAccountId": "0e008f85-800e-49c5-9de7-15c3e530bb71"
      }
    ]
  },
  "cnf_requirements": {
    "request_cpu": "100m",
    "limit_cpu": "200m",
    "request_memory": "100Mi",
    "limit_memory": "200Mi"
  },
  "additional_instantiation_params": {
    "nodeName": "node1"
  }
}
```

Figure 10: network\_service\_instance post endpoint from Slice Manager

## 2.2. Inter-Operator Domain and Testbeds/Demonstrators

The Inter-operator Domain typically includes the NANCY Blockchain together with its smart contracts (deployed on-chain), its oracles (deployed off-chain), and the Smart Pricing and DAC components. The set of these components is utilized for the use cases of the Greek in-lab testbed. Specifically, the NANCY Blockchain is a NEC-hosted, Hyperledger Fabric v2.2.0-based blockchain, with some security and privacy improvements. Both the Marketplace and the SLARegistry smart contracts are deployed on the NANCY Blockchain (thus, hosted by NEC in its Heidelberg laboratory), together with the Blockchain oracles; while the Smart Pricing and DAC components are deployed at 8Bells and DRAXIS premises respectively, in Greece. Oracles and off-chain components communicate using HTTPS requests.

As indicated in [4], the NANCY wallet is a Kotlin gRPC server that exposes calls for working with the NANCY blockchain, the PQC component, and the SSI infrastructure. This means that the Greek in-Lab testbed, which is *the one that demonstrates operations in the Inter-operator Domain*, must be – and is – equipped with NANCY wallets, specifically for the service orchestrator and business support system (BSS) of the operators working inside the in-Lab testbed.

By adding resources in the Marketplace, the BSS of a given operator can make them available to other domains. Consequently, any local operator, by means of the wallet of its service orchestrator, can search for available resources in *other* domains that are able to fulfill an SLA that the local operator's capabilities cannot fulfill. More information can be found again in [4] and later in this deliverable (Section 5.4).

There is no VPN fabric between the Greek in-Lab testbed and the Inter-operator Domain. The NANCY wallet stores user identities, which typically include "(1) X.509 certificates as issued by the Fabric's Certificate Authority (CA) to authenticate a user or organization's identity, (2) the user's self-generated DIDs, and (3) private keys used to sign transactions on behalf of the user". Therefore, communication between the wallet and the blockchain is secured under TLS and said certificates/keys. Requests are visible in the transaction history in the ledger.

### 3. Functional Testing of NANCY Components

This section presents the functional testing activities performed on all NANCY components integrated within the NANCY reference architecture. Each subsection corresponds to a distinct component and provides its objectives, testing configuration, preconditions, test sequence, and final verdict. The testing activities aim to verify that each module operates according to its technical specifications and achieves functional readiness for system-level integration.

#### 3.1. Multi Radio Access Technologies – Nomadic Connectivity Provider (MRAT-NCP)

The MRAT-NCP component, as described in [5], is responsible for extending coverage and optimizing connectivity in 5G networks, particularly in rural or densely populated urban areas where traditional infrastructure is limited or costly. It leverages PC5 links for direct device-to-device (D2D) and multi-hop communications, allowing data to be relayed through nearby nodes until it reaches the 5G infrastructure or the MRAT-NCP itself, enhancing network coverage, resilience, and reliability. In addition, it integrates Identity Management and secure data storage mechanisms using encrypted caching to ensure authentication, data integrity, and low latency in dynamic multi-hop scenarios. Furthermore, MRAT-NCP works in conjunction with machine learning models to continuously select the optimal network operator for each UE and to infer the location of remote UEs based on network metrics, enabling more efficient resource allocation and improved service quality. Table 1 summarizes the functional tests, while Figure 11, Figure 12, and Figure 13 illustrate the test results.

Table 1: MRAT-NCP functional tests summary

| Functional Test ID                   |                                                                                                                              | Objective                                                                                                                                                                                                                                                                                     | Status (Completed, Dropped, New and completed)                            |        |
|--------------------------------------|------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|--------|
| MRAT-NCP_F001                        | Test PC5 link reliability and requirements.                                                                                  |                                                                                                                                                                                                                                                                                               | Completed                                                                 |        |
| MRAT-NCP_F002                        | Test the tandem connection for PC5 and 5G connectivity.                                                                      |                                                                                                                                                                                                                                                                                               | Completed                                                                 |        |
| MRAT-NCP_F003                        | Test intra-network connectivity to compute nodes.                                                                            |                                                                                                                                                                                                                                                                                               | Completed                                                                 |        |
| Analytic Functional Test Description |                                                                                                                              |                                                                                                                                                                                                                                                                                               |                                                                           |        |
| Test type                            | Functional                                                                                                                   |                                                                                                                                                                                                                                                                                               |                                                                           |        |
| Identifier                           | MRAT-NCP_F001, MRAT-NCP_F002, MRAT-NCP_F003                                                                                  |                                                                                                                                                                                                                                                                                               |                                                                           |        |
| Tester                               | UMU                                                                                                                          |                                                                                                                                                                                                                                                                                               |                                                                           |        |
| Test Purpose                         | Allow access to 5G network for a remote non-5G subscriber, but NANCY subscriber.                                             |                                                                                                                                                                                                                                                                                               |                                                                           |        |
| References                           | [5], Section 3.2 "Multi-hop Coverage Extension"<br>[5], Section 3.6 Trustworthy Grant/Cell-free Cooperative Access Workflow" |                                                                                                                                                                                                                                                                                               |                                                                           |        |
| Configuration                        | Cohda MK6, Raspberry Pi 5 and LattePanda                                                                                     |                                                                                                                                                                                                                                                                                               |                                                                           |        |
| Pre-test conditions                  |                                                                                                                              |                                                                                                                                                                                                                                                                                               |                                                                           |        |
|                                      |                                                                                                                              | There must be Ethernet connectivity between each of the Cohda devices and their respective module (Raspberry Pi or Lattepanda).<br>The provider module must have connectivity with at least one of the 5G operators.<br>The Cohda devices must have GPS signal and PC5 coverage between them. |                                                                           |        |
| Test Sequence                        | Step                                                                                                                         | Type                                                                                                                                                                                                                                                                                          | Description                                                               | Result |
| 1                                    | 1                                                                                                                            | Stimulus                                                                                                                                                                                                                                                                                      | Measure and verify latency, bandwidth, and packet loss over the PC5 link. | Pass   |

|                     |                                                                                                                                                                                                                                                |       |                                                                                                                                                  |             |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
|                     | 2                                                                                                                                                                                                                                              | Check | Test connection stability and reliability.                                                                                                       | Pass        |
| 2                   | 3                                                                                                                                                                                                                                              | Check | Validate that the connectivity between the MRAT-NCP and both operators is properly established and functioning.                                  | Pass        |
|                     | 4                                                                                                                                                                                                                                              | Check | Confirm that the tandem configuration can switch between provider operators correctly, according to the selected interface.                      | Pass        |
|                     | 5                                                                                                                                                                                                                                              | Check | Ensure that this tandem connection functions correctly, without service interruptions and with a smooth user experience (Figure 11 - Figure 13). | Pass        |
|                     | 6                                                                                                                                                                                                                                              | Check | Verify that data transmission through the selected operator occurs without errors or interruptions.                                              | Pass        |
|                     | 7                                                                                                                                                                                                                                              | Check | Verify that there is end-to-end connectivity from the PC5 link to each of the operators.                                                         | Pass        |
|                     | 8                                                                                                                                                                                                                                              | Check | Integrate the ML models to select the optimal operator, the throughput forecast estimation and the models to infer the UE ubication.             | On going    |
| <b>Test Verdict</b> | <b>The PC5 connection and tandem configuration operate stably and continuously, with correct switching between operators, error-free transmission, and the integration of machine learning models to optimise UE performance and location.</b> |       |                                                                                                                                                  | <b>Pass</b> |

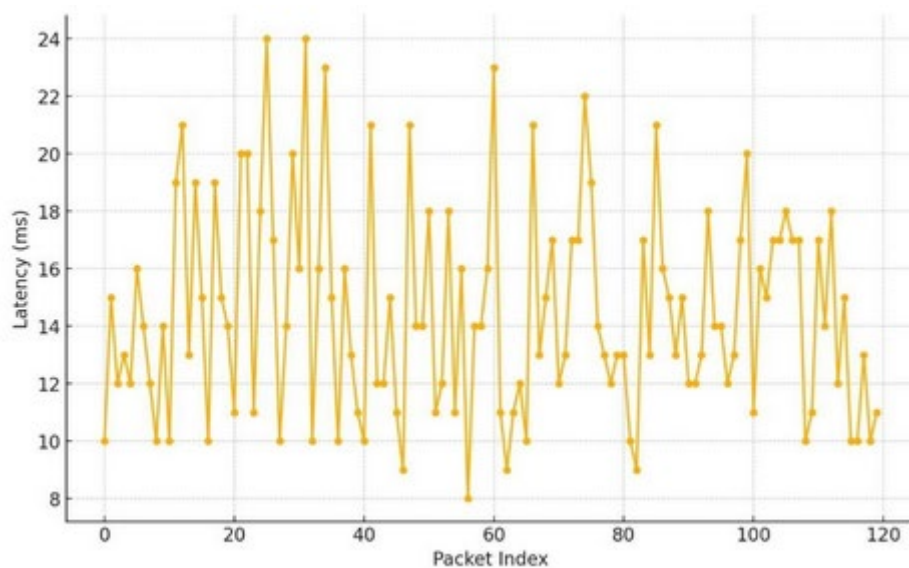


Figure 11: Latency Analysis for PC5 Interface

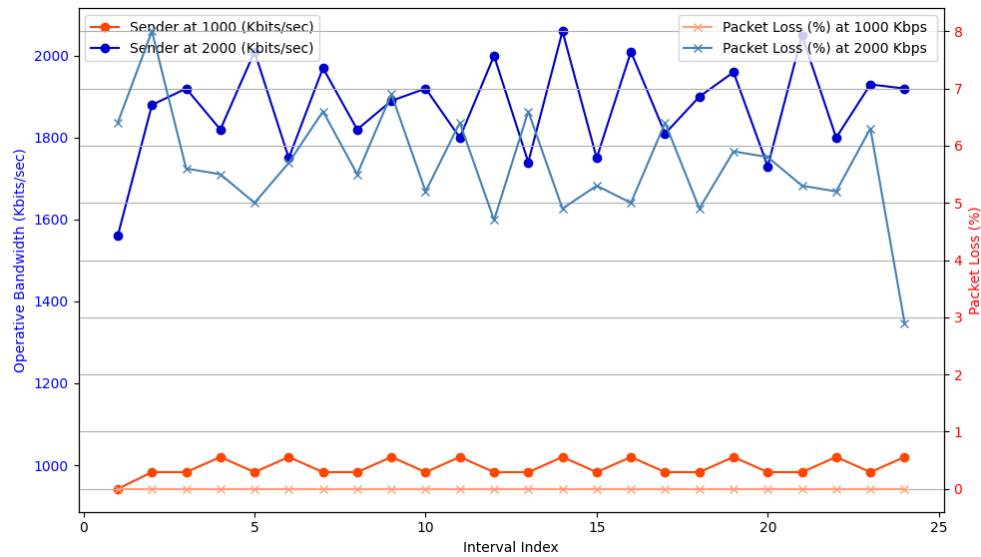


Figure 12: Comparison of bandwidth and packet loss at different data rates

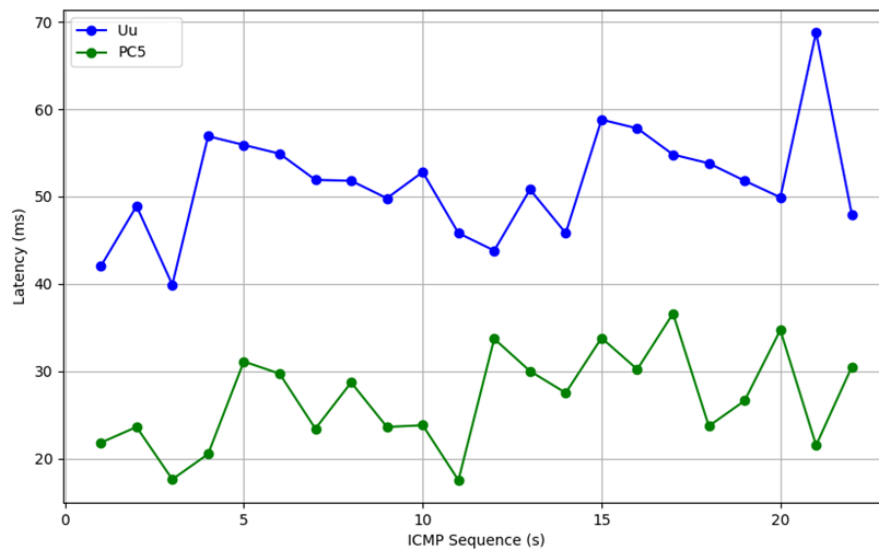


Figure 13: Latency comparison using Uu and PC5 interfaces

### 3.2. Identity Management

The Identity Management, as described in [5] and [4], is responsible for ensuring secure device authentication. It integrates with MRAT-NCP so that a remote user can reliably and privately access the services offered by the provider. In this context, the remote UE generates a credential using its p-ABC wallet, ensuring it complies with the format and requirements specified by the provider. The MRAT-NCP then verifies this credential by checking its authenticity against the issuer's public key stored on the blockchain. Only after successful verification is the UE granted access to the requested services, maintaining both security and privacy throughout the process. Table 2 summarizes the functional tests.

Table 2: ID Management functional tests summary

| Functional Test ID                   |                                                                                                                                                                                                           | Objective | Status (Completed, Dropped, New and completed) |        |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|------------------------------------------------|--------|
| ID_Mgnt_F001                         | Test key derivation and generation of credentials.                                                                                                                                                        |           | Completed                                      |        |
| ID_Mgnt_F002                         | Test Configuration of the wallet.                                                                                                                                                                         |           | Completed                                      |        |
| ID_Mgnt_F003                         | Test verification of credentials.                                                                                                                                                                         |           | Completed                                      |        |
| Analytic Functional Test Description |                                                                                                                                                                                                           |           |                                                |        |
| Test type                            | Functional                                                                                                                                                                                                |           |                                                |        |
| Identifier                           | ID_Mgnt_F001, ID_Mgnt_F002, ID_Mgnt_F003                                                                                                                                                                  |           |                                                |        |
| Tester                               | UMU                                                                                                                                                                                                       |           |                                                |        |
| Test Purpose                         | The main purpose of the test is to validate the entire verification flow.                                                                                                                                 |           |                                                |        |
| References                           | [5] Section 3.6 "Trustworthy Grant/Cell-free Cooperative Access Workflow"<br><br>[6] Section 3.3 "Further Mechanisms for Ensuring the Security and Privacy of the Users"                                  |           |                                                |        |
| Configuration                        | Cohda MK6, Raspberry Pi 5 and LattePanda                                                                                                                                                                  |           |                                                |        |
| Pre-test conditions                  | The remote UE and the MRAT-NCP have correctly configured their own p-ABC wallet (both of them) and blockchain wallet (only the MRAT-NCP)<br>There is connectivity between the MRAT-NCP and the remote UE. |           |                                                |        |
| Test Sequence                        | Step                                                                                                                                                                                                      | Type      | Description                                    | Result |
| 1                                    | 1                                                                                                                                                                                                         | Check     | Correct configuration of the wallet.           | Pass   |
|                                      | 2                                                                                                                                                                                                         | Check     | Credential generation.                         | Pass   |
|                                      | 3                                                                                                                                                                                                         | Check     | Credential validation                          | Pass   |
| Test Verdict                         | It is confirmed that the wallet configuration, credential generation, and verification are performed correctly.                                                                                           |           |                                                | Pass   |

### 3.3. Digital Agreement Creator (DAC)

The DAC component is responsible for generating and managing smart contracts within the NANCY framework. It exposes a RESTful interface built in Spring Boot, allowing the creation of SLA-based smart contracts for the Hyperledger Fabric Ledger. Specifically, it:

- Accepts structured JSON input describing service-level agreements.
- Dynamically generates chain code files.
- Stores them locally using a hash of the contract as a unique filename.
- Supports downloading these smart contract files via a REST endpoint.
- Interacts with the **NANCY marketplace** and **NANCY Blockchain**.

Table 3 summarizes the functional tests of the Digital Agreement Creator.

Table 3: DAC functional tests summary

| Functional Test ID                   |  | Objective                                                        | Status (Completed, Dropped, New and completed) |
|--------------------------------------|--|------------------------------------------------------------------|------------------------------------------------|
| DAC_F001                             |  | Test API endpoint for creating smart contracts with valid input. | Completed                                      |
| DAC_F002                             |  | Test API endpoint with invalid or missing input data.            | Completed                                      |
| DAC_F003                             |  | Test API response time and ensure it meets performance criteria. | Completed                                      |
| Analytic Functional Test Description |  |                                                                  |                                                |

|                            |                                                                                                                                                                                                              |          |                                                                      |                            |
|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------------------------------------------------------------------|----------------------------|
| <b>Test type</b>           | <b>Functional</b>                                                                                                                                                                                            |          |                                                                      |                            |
| <b>Identifier</b>          | <b>DAC_F001, DAC_F002, DAC_F003</b>                                                                                                                                                                          |          |                                                                      |                            |
| <b>Tester</b>              | <b>DRAXIS</b>                                                                                                                                                                                                |          |                                                                      |                            |
| <b>Test Purpose</b>        | To verify the correctness, robustness, and performance of the API endpoints for smart contract generation and retrieval.                                                                                     |          |                                                                      |                            |
| <b>References</b>          | [7] , paragraph 4.3.1<br>[4], paragraph 2.3.2.1                                                                                                                                                              |          |                                                                      |                            |
| <b>Configuration</b>       | <ul style="list-style-type: none"> <li>- DAC service deployed as Spring Boot REST API (Docker containerized)</li> <li>- Preconfigured Swagger/OpenAPI interface</li> <li>- JVM 17, Maven build</li> </ul>    |          |                                                                      |                            |
| <b>Pre-test conditions</b> | <ul style="list-style-type: none"> <li>- DAC REST service is deployed and reachable</li> <li>- Java runtime and Docker environment running</li> <li>- Valid SLARequest JSON available for testing</li> </ul> |          |                                                                      |                            |
| <b>Test Sequence</b>       | Step                                                                                                                                                                                                         | Type     | Description                                                          | Result                     |
|                            | 1                                                                                                                                                                                                            | Stimulus | Call POST /DAC/createSLA with a valid SLARequest payload             | <b>Chaincode generated</b> |
|                            | 2                                                                                                                                                                                                            | Stimulus | Call GET /DAC/getSmartContract/{hash} using returned hash            | <b>File is downloaded</b>  |
|                            | 3                                                                                                                                                                                                            | Check    | Call POST /DAC/createSLA with malformed JSON or missing fields       | <b>Error 400 or 500</b>    |
|                            | 4                                                                                                                                                                                                            | Check    | <i>Response times consistently &lt; 500ms, all contracts created</i> | <b>Pass</b>                |
|                            | 5                                                                                                                                                                                                            | Check    | Downloaded file content matches the generated smart contract         | <b>Pass</b>                |
|                            | 6                                                                                                                                                                                                            | Check    | Error message returned, no file is created                           | <b>Pass</b>                |
|                            | 7                                                                                                                                                                                                            | Stimulus | Repeat POST /DAC/createSLA for 100 valid inputs (performance test)   | <b>Monitor API timing</b>  |
| <b>Test Verdict</b>        |                                                                                                                                                                                                              |          |                                                                      | <b>Pass</b>                |

### 3.4. Blockchain

Blockchain provides a shared platform for different users and partners to publish, verify, and look up information. Its decentralized nature avoids a single point of failure and allows any partner to validate a request and reach consensus on the updated data state. More specifically, validation is conducted by smart contracts as small applet copies deployed on each user/partner's blockchain client, and the consensus protocol run by all blockchain clients helps them to reach an agreement on the latest system state.

NANCY Blockchain is a permissioned blockchain maintained by the consortium of NANCY partners, where a user can only access the blockchain by providing the certificates acquired from the CA of the blockchain. This provides the first level of access control to the blockchain. On the NANCY blockchain, we deployed several smart contracts used for our different use cases as follows:

- Marketplace: allows posts of 5G services and automates the process of service search and proposes initial SLA contracts for matched services with smart pricing.
- SLARegistry: manages SLA creation and SLA signature verification process.
- DIDRegistry: manages DID document registration.

- VCRegistry: manages VC (verifiable credentials) revocation registration.

Table 4 summarizes the functional tests of the Blockchain.

Table 4: Blockchain functional tests summary

| Functional Test ID                   |                                                                                                                                                                                                                                                                                                  | Objective                                                                                                                                                                                   |                                                                                                                                                 | Status (Completed, Dropped, New and completed) |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| BC_F001                              |                                                                                                                                                                                                                                                                                                  | <u>Adding new user:</u><br>The network administrator uses their admin identity to register a new user with the CA. This step associates the new user with a specific role and organisation. |                                                                                                                                                 | Completed                                      |
| BC_F002                              |                                                                                                                                                                                                                                                                                                  | <u>Smart contract unit tests:</u><br>Test the functionalities in each smart contract                                                                                                        |                                                                                                                                                 | Completed                                      |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
| Test type                            | Functional                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
| Identifier                           | BC_F001                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
| Tester                               | NEC                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
| Test Purpose                         | Verify the access to the blockchain network.                                                                                                                                                                                                                                                     |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
| References                           | Architecture and component interaction described in [4].                                                                                                                                                                                                                                         |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
| Configuration                        | Permissioned blockchain network has been set up and the CA service is up and running. The allowed organization list is configured in the CA service in the affiliation attribute. CA (and TLSCA) certificates as well as admin credentials are deployed to the tester for server authentication. |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
|                                      |                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
| Pre-test conditions                  | Not applicable                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
|                                      |                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                             |                                                                                                                                                 |                                                |
| Test Sequence                        | Step                                                                                                                                                                                                                                                                                             | Type                                                                                                                                                                                        | Description                                                                                                                                     | Result                                         |
| 1                                    | 1                                                                                                                                                                                                                                                                                                | Stimulus                                                                                                                                                                                    | Send a request to the CA service to register a new user using the admin credentials                                                             |                                                |
|                                      | 2                                                                                                                                                                                                                                                                                                | Check                                                                                                                                                                                       | If the enrollment ID of the new user is new, registration is successful the enrollment ID is returned.                                          | Pass                                           |
|                                      | 3                                                                                                                                                                                                                                                                                                | Check                                                                                                                                                                                       | If the enrollment ID of the new user is already seen, registration fails, and the corresponding error message is returned.                      | Pass                                           |
|                                      | 4                                                                                                                                                                                                                                                                                                | Check                                                                                                                                                                                       | If the enrollment ID is malformed, registration fails and corresponding error message is returned.                                              | Pass                                           |
| 2                                    | 1                                                                                                                                                                                                                                                                                                | Stimulus                                                                                                                                                                                    | Send a request to the CA service to enroll an unregistered user.                                                                                | Pass                                           |
|                                      | 2                                                                                                                                                                                                                                                                                                | Check                                                                                                                                                                                       | Registration fails and an error message is returned.                                                                                            | Pass                                           |
| 3                                    | 1                                                                                                                                                                                                                                                                                                | Stimulus                                                                                                                                                                                    | Send a request to the CA service to enroll the newly registered user providing a random password.                                               | Pass                                           |
|                                      | 2                                                                                                                                                                                                                                                                                                | Check                                                                                                                                                                                       | User receives the enrollment certificate referring to the corresponding enrollment ID.                                                          | Pass                                           |
| 4                                    | 1                                                                                                                                                                                                                                                                                                | Stimulus                                                                                                                                                                                    | Send a request to the CA service to enroll the newly registered user without providing password.                                                | Pass                                           |
|                                      | 2                                                                                                                                                                                                                                                                                                | Check                                                                                                                                                                                       | User receives the enrollment certificate referring to the corresponding enrollment ID and returns a random password supplied by the CA service. | Pass                                           |
| Test Verdict                         |                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                             |                                                                                                                                                 | Pass                                           |

### 3.5. Wallet

NANCY wallet provides SSI capabilities to users and devices of NANCY partners, and at the same time, simplifies the interaction between the partner applications and the blockchain. Table 5 summarizes the functional tests of the Wallet component.

Firstly, the wallet creates and manages the DIDs and their credentials for the partner applications and takes care of the DID registration to the NANCY blockchain, which serves as the public data registry to look up DID authentication methods. It further implements the VC issuance and verification procedure so that the authorization process for application services follows the VC data model defined by W3C standards.

Secondly, the wallet also wraps the blockchain queries with gRPC APIs that simplify communication with the Blockchain. The wallet serves as a registrar for NANCY partners to register and enroll each of their users and devices to access the blockchain. All access credentials are bound to their DID, so that smart contracts will apply access control checks on DID-related operations such as DID records update or SLA signature verification.

Table 5: Wallet functional tests summary

| Functional Test ID                   | Objective                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Status    |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Wallet_F001                          | SSI capabilities: User DID creation and registration:<br>Start the wallet gateway provided with a specified uid. A unique and anonymous DID is created for this uid and a certificate corresponding to the created DID is acquired from the CA of this organisation. The public DID document is registered to the DIDRegistry smart contract in the blockchain, so that other users are able to look up for the verification methods of this DID.                                            | Completed |
| Wallet_F002                          | SSI capabilities II: acquire and verify verifiable credentials (Provided Wallet_F001) Start a wallet gateway on an ID holder, a credential issuer, and a service verifier. respectively. The holder acquires a verifiable credential from the issuer by means of their wallets, then the holder wallet generates a verifiable presentation from the acquired verifiable credential and delivers it to the verifier's wallet service for verification. The verification returns successfully. | Completed |
| Wallet_F003                          | SSI capabilities III: revoke the verifiable credential<br>Same setup as in Wallet_F002, but the issuer revokes the previous verifiable credential issued to the holder. The last verification step then fails.                                                                                                                                                                                                                                                                               | Completed |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |           |
| Test type                            | Functional                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |           |
| Identifier                           | Wallet_F001, Wallet_F002, Wallet_F003                                                                                                                                                                                                                                                                                                                                                                                                                                                        |           |
| Tester                               | NEC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |           |
| Test Purpose                         | Test the SSI capabilities of the wallet                                                                                                                                                                                                                                                                                                                                                                                                                                                      |           |
| References                           | The wallet functions and interfaces are described in D5.2.                                                                                                                                                                                                                                                                                                                                                                                                                                   |           |
| Configuration                        | The blockchain network, which is used as the public data registry in the VC data model, is set up and the access credentials are available for the wallet service. Additionally, the required smart contracts, i.e., DIDRegistry and VCRegistry, are deployed in the blockchain.                                                                                                                                                                                                             |           |

| <b>Pre-test conditions</b> |      | Unit tests for the deployed smart contracts are passed successfully. |                                                                                                                                                                                                               |        |
|----------------------------|------|----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| Test Sequence              | Step | Type                                                                 | Description                                                                                                                                                                                                   | Result |
| 1                          | 1    | Stimulus                                                             | Start the wallet gateway service on a given port with a specified new uid in non-UE (PQC) mode.                                                                                                               |        |
|                            | 2    | Check                                                                | The wallet has created a new DID derived from the provided ui and a corresponding ECDSA keypair is generated for the DID.                                                                                     | Pass   |
|                            | 3    | Check                                                                | The wallet has successfully enrolled the DID in the blockchain and acquired and saved the enrolment certificate locally.                                                                                      | Pass   |
|                            | 4    | Check                                                                | The wallet has registered the corresponding DID document in the DIDRegistry smart contract.                                                                                                                   | Pass   |
|                            | 5    | Check                                                                | The wallet has saved the generated keypairs of the new DID locally.                                                                                                                                           | Pass   |
|                            | 6    | Check                                                                | Invoke listDIDs API calls to the wallet service returns all saved DID ids in the wallet.                                                                                                                      | Pass   |
|                            | 7    | Check                                                                | Invoke lookDID API calls with the new DID id to any wallet service returns the DID document information.                                                                                                      | Pass   |
|                            | 8    | Check                                                                | The wallet gateway service started listening on the given port.                                                                                                                                               | Pass   |
| 2                          | 1    | Stimulus                                                             | Start the wallet gateway service with an existing uid on a given port.                                                                                                                                        |        |
|                            | 2    | Check                                                                | The corresponding DID of the existing uid is loaded as the default DID of the wallet.                                                                                                                         | Pass   |
|                            | 3    | Check                                                                | The wallet gateway service started listening on the given port.                                                                                                                                               | Pass   |
| 3                          | 1    | Stimulus                                                             | Start the wallet gateway service with a specified new uid in EU (PQC) mode in simulation mode on a given port.                                                                                                |        |
|                            | 2    | Check                                                                | The wallet has created a new DID derived from the provided ui and a corresponding PQC keypair is generated from the simulation library.                                                                       | Pass   |
|                            | 3    | Check                                                                | Same check as in 1.3-1.8                                                                                                                                                                                      | Pass   |
| 4                          | 1    | Stimulus                                                             | Start a holder wallet service and an issuer wallet service, invoke the requestCredential API call to the holder wallet service by providing the holder DID information and the issuer wallet service address. |        |
|                            | 2    | Check                                                                | If referred holder DID information does not exist in the holder wallet, holder wallet returns error with a corresponding error message.                                                                       | Pass   |
|                            | 3    | Check                                                                | If the issuer wallet service is not accessible at the referred address, holder wallet returns error with corresponding error message.                                                                         | Pass   |
|                            | 4    | Check                                                                | If provided information in the request is all correct and valid, holder wallet returns a VC (verifiable credential) acquired from the issuer wallet service.                                                  | Pass   |
|                            | 5    | Check                                                                | The returned VC contains the correct information, e.g., issuer DID, holder DID, holder claims, issuer signature, etc.                                                                                         | Pass   |

|                     |   |          |                                                                                                                                                                                                                                                                     |      |
|---------------------|---|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
|                     | 6 | Check    | Invoke listVCs API call to the holder wallet and the issuer wallet service returns the newly created VC overview.                                                                                                                                                   | Pass |
| 5                   | 1 | Stimulus | Keep the holder wallet service in test 5 running and start a verifier wallet service, invoke the requestAuthorization API call to the holder wallet service by providing the holder DID information, the VC used for authorization and the verifier wallet address. |      |
|                     | 2 | Check    | Check 4.2 and 4.3 (with verifier address)                                                                                                                                                                                                                           | Pass |
|                     | 3 | Check    | If referred VC does not exist in the holder's wallet, holder wallet returns error with a corresponding error message.                                                                                                                                               | Pass |
|                     | 4 | Check    | If provided information in the request is all correct and valid, holder wallet returns the VC verification result acquired from the verifier wallet service.                                                                                                        | Pass |
|                     | 5 | Check    | Invoke listAuthorizationResults API call to the verifier wallet service, the returned authorization results show a successful authorization record regarding this test with a correct timestamp.                                                                    | Pass |
| 6                   | 1 | Stimulus | Invoke the revokeVC API call to the issuer wallet service referring to the VC used in test 5. Repeat test 5 to invoke the requestAuthorization API call to the holder wallet service with the same input.                                                           |      |
|                     | 2 | Check    | The holder wallet returns error with an error message that the authorization failed because of revoked VC.                                                                                                                                                          | Pass |
|                     | 3 | Check    | Invoke listAuthorizationResults API call to the verifier wallet service, the returned authorization results show a failed authorization record regarding this test with a correct timestamp.                                                                        | Pass |
| <b>Test Verdict</b> |   |          |                                                                                                                                                                                                                                                                     | Pass |

### 3.6. AI Virtualizer

The developed AI-Virtualizer is a Multi-Agent Reinforcement Learning (MARL) model that enables adaptive and conflict-free orchestration of shared computing resources across multiple network slices. Each slice is represented by an autonomous agent that observes local traffic conditions and resource states and jointly learns optimal CPU allocation policies through interaction with the environment. The agents operate under a cooperative reward scheme that penalizes resource conflicts and latency, thereby promoting balanced performance across services. To improve learning efficiency and coordination, the model integrates two key mechanisms: an Information Bottleneck (IB) encoder that compresses observations into task-relevant latent representations, and an emergent communication layer through which agents exchange discrete coordination messages. Together, these mechanisms allow agents to develop lightweight communication protocols and context-aware decisions, achieving faster convergence and higher stability. The AI-Virtualizer model has been fully integrated with the Slice Manager via REST APIs, enabling real-time enforcement of learned policies over Kubernetes namespaces in a cloud-native testbed. Table 6 summarizes the functional tests of the AI Virtualizer.

Table 6: AI Virtualizer functional tests summary

| Functional Test ID                   |                                                                                                              | Objective                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Status (Completed, Dropped, New and completed)                     |        |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|--------|
| AI-virtualizer _F001                 |                                                                                                              | Test the Kafka bus communication between agents.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Completed                                                          |        |
| AI-virtualizer _F002                 |                                                                                                              | Test the Slice Manager API response to IJS remote calls.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Completed                                                          |        |
| AI-virtualizer _F003                 |                                                                                                              | Test Grafana visualisation.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Completed                                                          |        |
| Analytic Functional Test Description |                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                    |        |
| Test type                            |                                                                                                              | Functional                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                    |        |
| Identifier                           |                                                                                                              | AI-Virtualizer_F001 - AI-Virtualizer_F003                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                    |        |
| Tester                               |                                                                                                              | i2CAT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                    |        |
| Test Purpose                         |                                                                                                              | Test the minimization of conflicts during the training of the AI-Virtualizer using a cloud-native environment.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                    |        |
| References                           |                                                                                                              | [8]                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                    |        |
| Configuration                        |                                                                                                              | The experiment involved three slice-agents deployed as independent Kubernetes Pods, each representing a network slice with default CPU shares of th =15,15,10 Gcycles/s. The agents were trained for 500 episodes, exchanging discrete messages via a Kafka message bus at every reinforcement-learning cycle. The shared infrastructure capacity was fixed at 40 Gcycles/s, ensuring that contention could occur when cumulative allocations exceeded this limit. Conflicts were automatically logged whenever the aggregated CPU demand surpassed the total available capacity. All metrics, including the conflict rate per episode, were collected through Prometheus and visualized in Grafana dashboards, enabling real-time monitoring of convergence behavior and the effectiveness of inter-agent communication in reducing contention across slices. |                                                                    |        |
|                                      |                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                    |        |
| Pre-test conditions                  |                                                                                                              | Before executing the conflict-rate evaluation, the cloud-native testbed must be fully operational, with all components correctly deployed and interconnected. The Kubernetes cluster should be running with at least three active namespaces, each corresponding to an instantiated slice-agent Pod. The Slice Manager must be reachable through its REST API and properly configured to modify the CPU quotas of each namespace via the ResourceQuota mechanism.                                                                                                                                                                                                                                                                                                                                                                                              |                                                                    |        |
|                                      |                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                    |        |
| Test Sequence                        | Step                                                                                                         | Type                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Description                                                        | Result |
|                                      | 1                                                                                                            | Stimulus                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Use Simulated traffic to train the models                          | Pass   |
|                                      | 2                                                                                                            | Check                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Obtain training results after the final episode                    | Pass   |
|                                      | 3                                                                                                            | Check                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Visualize the conflicts for both models after the training is done | Pass   |
| Test Verdict                         | We successfully trained the model with the simulated traffic and gathered the models conflicts through time. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                    | Pass   |

### 3.7. B-RAN Model

The NANCY's B-RAN analytical model described in [9], evaluates both single-chain and Hierarchical (with a nested secondary) blockchain. The model allows configuration of multiple key parameters, including the number of requests in a block, incoming request traffic rate, mining rate, and service rate across multiple scenarios. The model finally provides the average latency metrics for performance analysis of the system. Table 7 summarizes the functional tests of the B-RAN Model.

Table 7: B-RAN Model functional tests summary

| Functional Test ID                   |                                                                                                                                                                                                                                                     | Objective                                                                     | Status (Completed, Dropped, New and completed)                                                                   |        |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|--------|
| BRAN-model_F001                      |                                                                                                                                                                                                                                                     | Test the B-RAN model estimated performance for various system configurations. | Completed                                                                                                        |        |
| BRAN-model_F002                      |                                                                                                                                                                                                                                                     | Test the functionality of the B-RAN model for various extreme cases.          | Completed                                                                                                        |        |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                     |                                                                               |                                                                                                                  |        |
| Test type                            | Functional                                                                                                                                                                                                                                          |                                                                               |                                                                                                                  |        |
| Identifier                           | BRAN-model_F001 & BRAN-model_F002                                                                                                                                                                                                                   |                                                                               |                                                                                                                  |        |
| Tester                               | INNO                                                                                                                                                                                                                                                |                                                                               |                                                                                                                  |        |
| Test Purpose                         | Evaluation of the B-RAN architecture's performance and robustness across dynamic network loads and resource capacities                                                                                                                              |                                                                               |                                                                                                                  |        |
| References                           | [9]                                                                                                                                                                                                                                                 |                                                                               |                                                                                                                  |        |
| Configuration                        | This test focuses on the single-chain B-RAN architecture (BRAN-model_F001) and the Hierarchical B-RAN (HB-RAN) model (BRAN-model_F002), which uses nested blockchains for coverage expansion scenarios..                                            |                                                                               |                                                                                                                  |        |
|                                      |                                                                                                                                                                                                                                                     |                                                                               |                                                                                                                  |        |
| Pre-test conditions                  | Analytic prerequisites require establishing network stability (arrival rate must be less than service capacity), defining the initial request processing states, and configuring all network rates, including the necessary number of confirmations |                                                                               |                                                                                                                  |        |
|                                      |                                                                                                                                                                                                                                                     |                                                                               |                                                                                                                  |        |
| Test Sequence                        | Step                                                                                                                                                                                                                                                | Type                                                                          | Description                                                                                                      | Result |
|                                      | 1                                                                                                                                                                                                                                                   | Stimulus                                                                      | Define transition rate matrix Q from B-RAN configuration and solve for steady-state probability distribution P.  | Pass   |
|                                      | 2                                                                                                                                                                                                                                                   | Check                                                                         | Calculate expected number of waiting requests using steady-state probabilities.                                  | Pass   |
|                                      | 3                                                                                                                                                                                                                                                   | Stimulus                                                                      | Vary key parameters (traffic intensity, block capacity, service links, confirmations) across multiple scenarios. | Pass   |
|                                      | 4                                                                                                                                                                                                                                                   | Check                                                                         | Compute average latency using queuing models with confirmation delays.                                           | Pass   |
| Test Verdict                         |                                                                                                                                                                                                                                                     |                                                                               |                                                                                                                  | Pass   |

### 3.8. SemCom

The SemCom model, which is described in [10], consists of two main architectures. The first model demonstrates the enhanced performance and data efficiency in a DT model for V2X communications, where semantic encoders on the devices (car, RSU, drone) extract only the essential information from the videos and transfer them to a semantic decoder on an edge server for the DT reconstruction. The second model evaluates the SemCom efficiency for ASL transmission, using a CNN semantic encoder, to extract and modulate meaningful symbols from source images with a custom modulation scheme (24QAM). Both configurations support resource utilization measurement in order to compare performance against conventional methods. Table 8 summarizes the SemCom functional tests.

Table 8: SemCom functional tests summary

| Functional Test ID |  | Objective                                        | Status (Completed, Dropped, New and completed) |
|--------------------|--|--------------------------------------------------|------------------------------------------------|
| SemCom_F001        |  | Test SemCom performance for V2x and DT creation. | Completed                                      |

|                                      |                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                                                                                                               |           |
|--------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| SemCom_F002                          | Test SemCom energy and data efficiency improvement for ASL transmission.                                                                                                                                                                                                                                                                                          |          |                                                                                                                                                                                               | Completed |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                                                                                                               |           |
| Test type                            | Functional                                                                                                                                                                                                                                                                                                                                                        |          |                                                                                                                                                                                               |           |
| Identifier                           | SemCom_F001                                                                                                                                                                                                                                                                                                                                                       |          |                                                                                                                                                                                               |           |
| Tester                               | INNO                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                                                                                                               |           |
| Test Purpose                         | Demonstrate the enhanced performance and data efficiency of SemCom in successful Digital Twin (DT) creation for Vehicle-to-Everything (V2x) communications.                                                                                                                                                                                                       |          |                                                                                                                                                                                               |           |
| References                           | [10]                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                                                                                                               |           |
| Configuration                        | Goal-oriented SemCom architecture deployed for V2x DT creation. Semantic encoders on network nodes (car, RSU, drone cameras) extract only essential object coordinates from video frames, transferring this minimal data to an edge server equipped with the semantic decoder for DT reconstruction. The configuration supports resource utilization measurement. |          |                                                                                                                                                                                               |           |
|                                      |                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                                                                                                               |           |
| Pre-test conditions                  | Semantic encoders must be trained and deployed on V2x source devices for effective object detection and semantic information extraction. A precise quantitative baseline for data volume must be established using conventional systems transmitting full video frames to enable the measurement of SemCom data efficiency gains.                                 |          |                                                                                                                                                                                               |           |
|                                      |                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                                                                                                               |           |
| Test Sequence                        | Step                                                                                                                                                                                                                                                                                                                                                              | Type     | Description                                                                                                                                                                                   | Result    |
|                                      | 1                                                                                                                                                                                                                                                                                                                                                                 | Stimulus | Network devices capturing video of the observed location (e.g., car, RSU, drone cameras) activate the SemCom encoder module via a request (e.g., through task offloading to the base station) | Pass      |
|                                      | 2                                                                                                                                                                                                                                                                                                                                                                 | Stimulus | The semantic encoder processes the video frames and extracts only the essential semantic information, such as the coordinates of detected objects, for transmission                           | Pass      |
|                                      | 3                                                                                                                                                                                                                                                                                                                                                                 | Check    | Verify that this minimal semantic information is successfully transferred through the network to the semantic decoder deployed on the edge server                                             | Pass      |
|                                      | 4                                                                                                                                                                                                                                                                                                                                                                 | Check    | Confirm the data efficiency increases by comparing the volume of transferred semantic against the established baseline of full frames.                                                        | Pass      |
|                                      | 5                                                                                                                                                                                                                                                                                                                                                                 | Check    | Confirm that the semantic decoder successfully reconstructs the Digital Twin scene (a top view map showing the cameras and identified objects)                                                | Pass      |
| Test Verdict                         |                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                                                                                                               | Pass      |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                                                                                                               |           |
| Test type                            | Functional                                                                                                                                                                                                                                                                                                                                                        |          |                                                                                                                                                                                               |           |
| Identifier                           | SemCom_F002                                                                                                                                                                                                                                                                                                                                                       |          |                                                                                                                                                                                               |           |
| Tester                               | INNO                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                                                                                                               |           |
| Test Purpose                         | Evaluate the Semantic Communications (SemCom) system's efficiency by confirming improved data and energy performance for American Sign Language (ASL) transmission                                                                                                                                                                                                |          |                                                                                                                                                                                               |           |
| References                           | [10]                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                                                                                                               |           |
| Configuration                        | Goal-oriented SemCom architecture deployed for ASL transmission. This configuration uses a CNN semantic encoder to extract and modulate meaningful symbols (e.g., one of 24 letters) from source images, utilizing a specialized modulation scheme (e.g., 24QAM). The setup is ready to measure resource usage for comparison with conventional methods.          |          |                                                                                                                                                                                               |           |
|                                      |                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                                                                                                               |           |

| <b>Pre-test conditions</b> |      | The CNN semantic encoder must be trained and deployed for ASL image processing. A precise quantitative baseline for data volume and power consumption must be established using conventional systems that transmit the full, unprocessed source image data. |                                                                                                                                                                                                                                                         |             |
|----------------------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Test Sequence              | Step | Type                                                                                                                                                                                                                                                        | Description                                                                                                                                                                                                                                             | Result      |
|                            | 1    | Stimulus                                                                                                                                                                                                                                                    | Input ASL image data into the Semantic Communications (SemCom) system; the CNN-based semantic encoder processes the image data and extracts the essential semantic information, which corresponds to one of the 24 distinct letters in the ASL alphabet | Pass        |
|                            | 2    | Stimulus                                                                                                                                                                                                                                                    | The extracted semantic information (e.g., requiring 5 bits) is converted into symbols and modulated using the proposed 24QAM scheme for transmission over the physical channel                                                                          | Pass        |
|                            | 3    | Check                                                                                                                                                                                                                                                       | Measure the required data volume and power consumption for transmitting the semantic information and compare it against the established quantitative baseline of conventional full-image transmission.                                                  | Pass        |
|                            | 4    | Check                                                                                                                                                                                                                                                       | The received signal is decoded and demodulated at the destination using the 24-QAM decision regions, identifying the corresponding symbol and bit representation                                                                                        | Pass        |
|                            | 5    | Check                                                                                                                                                                                                                                                       | The semantic decoder interprets the extracted message (the identified letter) based on its knowledge base and converts it into its ASL image representation, verifying that the system achieved semantic equivalence                                    | Pass        |
| <b>Test Verdict</b>        |      |                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                         | <b>Pass</b> |

### 3.9. Quantum Key Distribution Network Simulator (QKDSim)

The QKDSim model described in [11] verifies the successful deployment and operability of a containerized QKD simulator that exposes the classical KMS layer via the ETSI-014 REST API, enabling Secure Application Entities (SAEs) to authenticate and retrieve cryptographic keys. The simulation deploys QKDSim and SAEs (such as Base Station demonstrators BS1/BS2) using Docker containers, configured to run protocols like COW, with SAEs initiating key requests via the ETSI-014 KMS interface. Additionally, the model evaluates QKDSim performance under extreme conditions infeasible in laboratory settings by simulating maximum physical degradation through extreme fiber distances and high loss, measuring impacts on QBER and key generation rates, while stressing security mechanisms through maximum eavesdropping interference using the CV-QKD simulation environment. The model supports comprehensive resource utilization and performance analysis under both operational and extreme degradation scenarios. Table 9 summarizes the QKDSim functional tests.

Table 9: QKDSim functional tests summary

| Functional Test ID                   |      | Objective                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                  | Status (Completed, Dropped, New and completed) |        |
|--------------------------------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|--------|
| QKDSim _F001                         |      | Test the deployment and communication with the dockerised QKDSim.                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                  | Completed                                      |        |
| QKDSim _F002                         |      | Test the functionality of QKDSim for various extreme cases                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                  | Completed                                      |        |
| Analytic Functional Test Description |      |                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                  |                                                |        |
| Test type                            |      | Functional                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                  |                                                |        |
| Identifier                           |      | QKDSim _F001                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                  |                                                |        |
| Tester                               |      | INNO                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                  |                                                |        |
| Test Purpose                         |      | Verify the successful deployment and operability of the QKDSim running in a container technology. Confirm that the QKDSim exposes the classical Key Management System (KMS) layer via the ETSI-014 REST API. Validate that Secure Application Entities can authenticate and retrieve cryptographic material keys. |                                                                                                                                                                                                                  |                                                |        |
| References                           |      | [11]                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                  |                                                |        |
| Configuration                        |      | Deploy the QKDSim and a SAE, such as one of the Base Station demonstrator applications (BS1/BS2), using Docker containers. The QKDSim should be configured to run a specific protocol, such as Coherent-One-Way (COW). The SAE will initiate a key request via the ETSI-014 KMS interface.                        |                                                                                                                                                                                                                  |                                                |        |
| Pre-test conditions                  |      | The QKDSim must be operational, mocking the KMS functionality and classical communication stack. The SAE Docker container must have a pre-deployed client certificate used for mutual TLS authentication with the QKD device. Both QKD simulation and SAE must have the same IP.                                  |                                                                                                                                                                                                                  |                                                |        |
|                                      |      |                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                  |                                                |        |
| Test Sequence                        | Step | Type                                                                                                                                                                                                                                                                                                              | Description                                                                                                                                                                                                      |                                                | Result |
|                                      | 1    | Stimulus                                                                                                                                                                                                                                                                                                          | Start the QKDSim and a Secure Application Entity (SAE), such as BS1 or BS2, as Docker containers.                                                                                                                |                                                | Pass   |
|                                      | 2    | Stimulus                                                                                                                                                                                                                                                                                                          | The SAE (e.g., BS1) initiates a key request to the QKDSim via the ETSI-014 REST API                                                                                                                              |                                                | Pass   |
|                                      | 3    | Check                                                                                                                                                                                                                                                                                                             | The QKDSim/KMS must successfully authenticate the SAE using the pre-deployed client certificate via mutual TLS.                                                                                                  |                                                | Pass   |
|                                      | 4    | Check                                                                                                                                                                                                                                                                                                             | The SAE must receive the requested cryptographic material key and key identifier (KeyID) from the QKDSim, confirming the KMS layer is operational.                                                               |                                                | Pass   |
|                                      | 5    | Check                                                                                                                                                                                                                                                                                                             | The SAE (BS1) uses the received key to encrypt a payload via AES256, and subsequently, a second SAE (BS2) requests the same key from the QKDSim/KMS to successfully decrypt the payload, storing the clear text. |                                                | Pass   |
|                                      | 6    | Check                                                                                                                                                                                                                                                                                                             | Deployment and communication are successful if the key request, authentication, and subsequent encryption/decryption process are completed without errors.                                                       |                                                | Pass   |
| Test Verdict                         |      |                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                  |                                                | Pass   |
| Analytic Functional Test Description |      |                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                  |                                                |        |
| Test type                            |      | Functional                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                  |                                                |        |
| Identifier                           |      | QKDSim _F002                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                  |                                                |        |
| Tester                               |      | INNO                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                  |                                                |        |
| Test Purpose                         |      | Evaluate the QKDSim's performance under conditions that are challenging or unfeasible to replicate in a laboratory setting. Simulate maximum physical degradation by setting                                                                                                                                      |                                                                                                                                                                                                                  |                                                |        |

|                            | extreme fiber distance and high loss. Measure the resulting impact on QBER (Quantum Bit Error Rate) and key generation rate. Additionally, Stress the protocol's security mechanisms by simulating maximum eavesdropping interference.                                                                                 |          |                                                                                                                                                                                                                                              |             |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| <b>References</b>          | D5.1                                                                                                                                                                                                                                                                                                                   |          |                                                                                                                                                                                                                                              |             |
| <b>Configuration</b>       | Utilize the Continuous-Variable QKD (CV-QKD) simulation environment. Configure the following parameters for maximum degradation: Distance set to an extreme length, Loss set to maximum value, and Eve Presence set to exclude.                                                                                        |          |                                                                                                                                                                                                                                              |             |
| <b>Pre-test conditions</b> | The QKDSim must be initialized for CV-QKD simulation. A clear baseline measurement (e.g., low distance/loss) must be established for comparison. The simulation output should display an anticipated high average QBER, reflecting that high fiber loss causes a significant rise in QBER regardless of eavesdropping. |          |                                                                                                                                                                                                                                              |             |
| Test Sequence              | Step                                                                                                                                                                                                                                                                                                                   | Type     | Description                                                                                                                                                                                                                                  | Result      |
|                            | 1                                                                                                                                                                                                                                                                                                                      | Stimulus | Configure the QKDSim to run the Continuous-Variable QKD (CV-QKD) simulation. Set the Distance parameter to an extreme length (longest possible) and the Loss parameter to its maximum value.                                                 | Pass        |
|                            | 2                                                                                                                                                                                                                                                                                                                      | Stimulus | <i>Run the simulation for a defined Number of Transmissions</i>                                                                                                                                                                              | Pass        |
|                            | 3                                                                                                                                                                                                                                                                                                                      | Check    | Observe the output chart for QBER (Quantum Bit Error Rate). The QBER value must be unacceptably high, reflecting that high fiber loss causes a significant rise in QBER regardless of eavesdropping                                          | Pass        |
|                            | 4                                                                                                                                                                                                                                                                                                                      | Check    | Observe the output chart for Key Generation Rate. The rate must be severely degraded or approach zero, consistent with the high QBER                                                                                                         | Pass        |
|                            | 5                                                                                                                                                                                                                                                                                                                      | Check    | Simulation is successful if the measured QBER is near the maximum possible value and the Key Generation Rate is minimal due to the extreme physical channel degradation                                                                      | Pass        |
|                            | 6                                                                                                                                                                                                                                                                                                                      | Stimulus | Configure the QKDSim for Discrete-Variable QKD (DV-QKD), selecting a protocol like BB84 or B92.                                                                                                                                              | Pass        |
|                            | 7                                                                                                                                                                                                                                                                                                                      | Stimulus | Enable Eve Presence and set the Eve Scale parameter to its maximum interference level                                                                                                                                                        | Pass        |
|                            | 8                                                                                                                                                                                                                                                                                                                      | Stimulus | Run the simulation for a defined Number of Transmissions                                                                                                                                                                                     | Pass        |
|                            | 9                                                                                                                                                                                                                                                                                                                      | Check    | Observe the output chart for Key Generation Rate. The rate, particularly for the 32-bit key length, must plummet to practically nil (values around 0), confirming substantial interruption due to eavesdropping combined with large key size | Pass        |
|                            | 10                                                                                                                                                                                                                                                                                                                     | Check    | Observe the output chart for QBER. The QBER value must register a significant increase, generally higher than in the non-eavesdropping scenario, indicating the intruder successfully intercepted the quantum states.                        | Pass        |
|                            | 11                                                                                                                                                                                                                                                                                                                     | Check    | Simulation is successful if the combination of maximum eavesdropping and the large key size results in the lowest possible Key Generation Rate (near 0), highlighting the sensitivity of performance to large key lengths under attack       | Pass        |
| <b>Test Verdict</b>        |                                                                                                                                                                                                                                                                                                                        |          |                                                                                                                                                                                                                                              | <b>Pass</b> |

### 3.10. VoSysMonitor

The VOSySmonitor is a low-level firmware that accommodates the consolidation of multiple, isolated bare-metal Operating Systems or Compartments in a single ARMv8 board. VOSySmonitor serves as core component of NANCY and is detailed in [8], in [12] and in [5]. VOSySmonitor is part of two concrete NANCY solutions:

#### 1. A novel, bare-metal virtualization solution for VNFs execution at the network edge

Extensions to VOSySmonitor have been provided to NANCY to realize this solution, namely the **vManager** (result reported in [8]) and the **Cross-compartment Virtio-loopbak** (result reported in [12]). The first two functional tests will address the vManager and the Cross-compartment Virtio-loopback testing, respectively. The solution is validated at the Italian In-lab testbed [T6.7].

#### 2. A secure data store solution with OPTEE and VOSySmonitor

This result has been reported in [5]. The third functional test will address the Secure data storage with VOSySmonitor. The solution is validated at the Spanish Extension In-lab testbed.

Table 10 summarizes the functional tests of VoSysMonitor.

Table 10: VoSysMonitor functional tests summary

| Functional Test ID                     |                                                                                                                                                                                          | Objective                                                                                                                         | Status                                                                                               |        |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|--------|
| VOSySmonitor_F001                      |                                                                                                                                                                                          | Test vManager partitions operations (create, deploy, destroy etc.).                                                               | Completed                                                                                            |        |
| VOSySmonitor_F002                      |                                                                                                                                                                                          | Test availability of virtio devices inside the partitions for deploying VNFs (Cross-compartment Virtio-loopback solution testing) | Completed                                                                                            |        |
| VOSySmonitor_F003                      |                                                                                                                                                                                          | Test OPTEE Secure Storage service functions with VOSySmonitor (store, load sensitive content).                                    | Completed                                                                                            |        |
| vManager Partitions Operations Testing |                                                                                                                                                                                          |                                                                                                                                   |                                                                                                      |        |
| Test type                              | Functional                                                                                                                                                                               |                                                                                                                                   |                                                                                                      |        |
| Identifier                             | VOSySmonitor_F001                                                                                                                                                                        |                                                                                                                                   |                                                                                                      |        |
| Tester                                 | VOS                                                                                                                                                                                      |                                                                                                                                   |                                                                                                      |        |
| Test Purpose                           | The purpose of the test is to validate the behaviour of the vManager when it comes to operations carried out on the partitions.                                                          |                                                                                                                                   |                                                                                                      |        |
| References                             | [8], Section 3: “AI Virtualiser and Edge-level Resource Exploitation”                                                                                                                    |                                                                                                                                   |                                                                                                      |        |
| Configuration                          | For this scenario we need an ARMv8 board with VOSySmonitor firmware deployed and one management partition (a Linux OS) booted.                                                           |                                                                                                                                   |                                                                                                      |        |
|                                        |                                                                                                                                                                                          |                                                                                                                                   |                                                                                                      |        |
| Pre-test conditions                    | To start the testing, we load the vManager driver on the management partition (making /dev/vmanager available) and we verify the availability of the vmanctl vManager controller binary. |                                                                                                                                   |                                                                                                      |        |
|                                        |                                                                                                                                                                                          |                                                                                                                                   |                                                                                                      |        |
| Test Sequence                          | Step                                                                                                                                                                                     | Type                                                                                                                              | Description                                                                                          | Result |
|                                        | 1                                                                                                                                                                                        | Stimulus                                                                                                                          | vmactl create-partition -cores <number_of_cores> -memsize <partition_memory_GB> -secure <true/false> |        |

|                                           |                                                                                                                               |                                                                                                                                                                                                                                                                                                                                     |                                                                                                                               |      |
|-------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|------|
|                                           | 2                                                                                                                             | Check                                                                                                                                                                                                                                                                                                                               | New device /dev/vmanX appears (X: new partition ID)                                                                           | Pass |
|                                           | 3                                                                                                                             | Check                                                                                                                                                                                                                                                                                                                               | vManager marks partition as READY                                                                                             | Pass |
|                                           | 4                                                                                                                             | Stimulus                                                                                                                                                                                                                                                                                                                            | vmactl deploy -kernel path/to/kernel_image -dtb path/to/device_tree_blob <partition_ID>                                       |      |
|                                           | 5                                                                                                                             | Check                                                                                                                                                                                                                                                                                                                               | vManager marks partition as DEPLOYED                                                                                          | Pass |
|                                           | 6                                                                                                                             | Stimulus                                                                                                                                                                                                                                                                                                                            | vmactl reboot <partition_ID>                                                                                                  |      |
|                                           | 7                                                                                                                             | Check                                                                                                                                                                                                                                                                                                                               | vManager stops CPUs execution, reloads the partition's assets and executes again. Partition is marked as DEPLOYED in the end. | Pass |
|                                           | 8                                                                                                                             | Stimulus                                                                                                                                                                                                                                                                                                                            | vmactl suspend <partition_ID>                                                                                                 |      |
|                                           | 9                                                                                                                             | Check                                                                                                                                                                                                                                                                                                                               | vManager marks partition as SUSPENDED.                                                                                        | Pass |
|                                           | 10                                                                                                                            | Stimulus                                                                                                                                                                                                                                                                                                                            | vmactl restore <partition_ID>                                                                                                 |      |
|                                           | 11                                                                                                                            | Check                                                                                                                                                                                                                                                                                                                               | vManager marks a previously SUSPENDED partition as DEPLOYED.                                                                  | Pass |
|                                           | 12                                                                                                                            | Stimulus                                                                                                                                                                                                                                                                                                                            | vmactl shutdown <partition_ID>                                                                                                |      |
|                                           | 13                                                                                                                            | Check                                                                                                                                                                                                                                                                                                                               | vManager marks a previously DEPLOYED partition as READY. Partition can be re-deployed afterwards on the same resources.       | Pass |
|                                           | 14                                                                                                                            | Stimulus                                                                                                                                                                                                                                                                                                                            | vmactl destroy-partition <partition_ID>                                                                                       |      |
|                                           | 15                                                                                                                            | Check                                                                                                                                                                                                                                                                                                                               | vManager releases the resources of a previously READY partition. Note that a DEPLOYED partition cannot be destroyed.          | Pass |
| Test Verdict                              | All the available operations on vManager's partitions are tested through the vmanctl tool and provided the expected outcomes. |                                                                                                                                                                                                                                                                                                                                     |                                                                                                                               | Pass |
| Cross-compartment Virtio-loopback Testing |                                                                                                                               |                                                                                                                                                                                                                                                                                                                                     |                                                                                                                               |      |
| Test type                                 |                                                                                                                               | Functional                                                                                                                                                                                                                                                                                                                          |                                                                                                                               |      |
| Identifier                                |                                                                                                                               | VOSySmonitor_F002                                                                                                                                                                                                                                                                                                                   |                                                                                                                               |      |
| Tester                                    |                                                                                                                               | VOS                                                                                                                                                                                                                                                                                                                                 |                                                                                                                               |      |
| Test Purpose                              |                                                                                                                               | The purpose of the test is to validate the availability of virtio devices inside an ARMv8 bare-metal partition/compartment, when the Cross-compartment Virtio-loopback technology (solution that extends VOSySmonitor) is employed. This test will focus in particular on a virtio block device, to test operations on this device. |                                                                                                                               |      |
| References                                |                                                                                                                               | [12], Section 2.5: "Resource handling at the edge" and Section 3.2.8: "Edge-resource management"                                                                                                                                                                                                                                    |                                                                                                                               |      |
| Configuration                             |                                                                                                                               | For this scenario, we need an ARMv8 board with VOSySmonitor firmware deployed and two partitions/compartments up and running. One of the two partitions will be the main one (or "server side") and the other one will be a secondary one (or "client side"). The "server side" has access to all peripherals of the board.         |                                                                                                                               |      |
|                                           |                                                                                                                               |                                                                                                                                                                                                                                                                                                                                     |                                                                                                                               |      |
| Pre-test conditions                       |                                                                                                                               | To start the testing, on the server side, we need to have available the "loopback_driver_server" module and the "crossworld" driver module. On the client side, we need to have available the "loopback_driver_client" module and the "crossworld" driver module.                                                                   |                                                                                                                               |      |

|                                               |                                                                                                                               | Also, on the server side, the "vhost-user-blk" executable should be available, as well as the “adapter” executable. Last but not least, on the server side, a demo.img” disk image should be ready to use.                                                          |                                                                                                                                                                                                                                             |        |
|-----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
|                                               |                                                                                                                               |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                             |        |
| Test Sequence                                 | Step                                                                                                                          | Type                                                                                                                                                                                                                                                                | Description                                                                                                                                                                                                                                 | Result |
|                                               | 1                                                                                                                             | Stimulus                                                                                                                                                                                                                                                            | insmod loopback_driver_client.ko (client side)                                                                                                                                                                                              | Pass   |
|                                               | 2                                                                                                                             | Stimulus                                                                                                                                                                                                                                                            | insmod crossworld.ko (client side)                                                                                                                                                                                                          | Pass   |
|                                               | 3                                                                                                                             | Stimulus                                                                                                                                                                                                                                                            | insmod loopback_driver_server.ko (server side)                                                                                                                                                                                              | Pass   |
|                                               | 4                                                                                                                             | Stimulus                                                                                                                                                                                                                                                            | insmod crossworld.ko (server side)                                                                                                                                                                                                          | Pass   |
|                                               | 5                                                                                                                             | Stimulus                                                                                                                                                                                                                                                            | vhost-user-blk -s <socket_path> -b demo.img (server side). The <socket path> is to connect with the adapter through the following command.                                                                                                  | Pass   |
|                                               | 6                                                                                                                             | Stimulus                                                                                                                                                                                                                                                            | adapter -s <socket_path> -d vhublk (server side)                                                                                                                                                                                            | Pass   |
|                                               | 7                                                                                                                             | Check                                                                                                                                                                                                                                                               | New device /dev/vdX is now available on the client side.                                                                                                                                                                                    | Pass   |
|                                               | 8                                                                                                                             | Stimulus                                                                                                                                                                                                                                                            | mount /dev/vdX <mount_path> && ls <mount_path> (client side)                                                                                                                                                                                | Pass   |
|                                               | 9                                                                                                                             | Check                                                                                                                                                                                                                                                               | Able to see the contents of the demo.img on the client side (secondary partition)                                                                                                                                                           | Pass   |
|                                               | 10                                                                                                                            | Check                                                                                                                                                                                                                                                               | Able to create new files, write data into files, delete files or data of the demo.img from the client side. Verified that the status persists when unmounting the device and mounting it again, either in the client or in the server side. | Pass   |
| Test Verdict                                  | All the available operations on vManager’s partitions are tested through the vmanctl tool and produced the expected outcomes. |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                             | Pass   |
| VOSySmonitor and OPTEE Secure Storage Testing |                                                                                                                               |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                             |        |
| Test type                                     |                                                                                                                               | Functional                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                             |        |
| Identifier                                    |                                                                                                                               | VOSySmonitor_F003                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                             |        |
| Tester                                        |                                                                                                                               | VOS                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                             |        |
| Test Purpose                                  |                                                                                                                               | The purpose of the test is to validate the Secure Storage solution with OPTEE and VOSySmonitor for secure data caching at the edge.                                                                                                                                 |                                                                                                                                                                                                                                             |        |
| References                                    |                                                                                                                               | D4.3                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                             |        |
| Configuration                                 |                                                                                                                               | For this scenario we need a Trustzone-capable ARMv8 board with VOSySmonitor firmware deployed with one main, non-Secure partition with Linux OS booted and an OPTEE OS deployed at the Secure world.                                                                |                                                                                                                                                                                                                                             |        |
|                                               |                                                                                                                               |                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                             |        |
| Pre-test conditions                           |                                                                                                                               | To start the testing, the REE_FS Secure Storage Service should be available. Parts of it are established in the main, Non-Secure OS (e.g., TEE Supplciant module to be available) and parts of it are established in the Secure OS (e.g., the Trusted Application). |                                                                                                                                                                                                                                             |        |

| <p>Regarding the workflow, a Client Application on the Non-Secure OS is the starting point to invoke Secure Storage Operations towards the Trusted Application on the Secure OS. Each operation always passes through the secure firmware (VOSySmonitor), ensuring the security of the operations.</p> <p>For this test, we employ two Client Applications on the Non-Secure OS: a "store" application and a "load" application, that respectively store and load a secure asset to/from the data store. The storage happens on a key-value fashion.</p> |      |          |                                                                                                                                                                    |        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| Test Sequence                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Step | Type     | Description                                                                                                                                                        | Result |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1    | Stimulus | store "userA" "serviceA, serviceB, serviceC"<br><br>(Invoke the client application to store a user in the data store with specific capabilities on NANCY services) | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 2    | Check    | Prepare session with the TA..Session ready!                                                                                                                        | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 3    | Check    | Store object in the TA secure storage..Object stored!                                                                                                              | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 4    | Check    | Session closed                                                                                                                                                     | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 5    | Stimulus | load "userA"<br><br>(Invoke the client application to load the capabilities of a specific user from the data store)                                                | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 6    | Check    | Prepare session with the TA..Session ready!                                                                                                                        | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 7    | Check    | Find and load object "userA"..                                                                                                                                     | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 8    | Check    | Object Found. Id=userA, Value=serviceA, serviceB, serviceC                                                                                                         | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 9    | Check    | Session closed                                                                                                                                                     | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 10   | Stimulus | load "userB"<br><br>(Invoke the client application to load the capabilities of a specific user that is not part of the data store)                                 | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 11   | Check    | Prepare session with the TA..Session ready!                                                                                                                        | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 12   | Check    | Find and load object "userB"..                                                                                                                                     | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 13   | Check    | load: Failed to read an object from the secure storage                                                                                                             | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 14   | Check    | Session closed                                                                                                                                                     | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 15   | Stimulus | ls /var/lib/tee<br><br>(Check the persistent data)                                                                                                                 | Pass   |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 16   | Check    | 0<br>1<br>2<br>dirf.db<br><br>(Expected amount of items, in encrypted format)                                                                                      | Pass   |

|                     |                                                                                                                                                                              |             |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| <b>Test Verdict</b> | <b>The REE_FS Secure Storage service of OPTEE is validated to work fine with the new Client Applications “load” and “store”, to store data assets in a key-value format.</b> | <b>Pass</b> |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|

### 3.11. Marketplace

The marketplace is the NANCY component where all the details about available operators and services are gathered for allowing offloading processes. It is based on smart contracts having been deployed in the NANCY Blockchain network and, consequently, all the interactions happen through the NANCY Blockchain wallets. The operation of the marketplace for an offloading process requires internal interactions with the Smart Pricing and Digital Agreement Creator. The marketplace and its operation have been deeply described in [4]. Table 11 summarizes the Marketplace functional tests.

Table 11: Marketplace functional tests summary

| Functional Test ID                   |      | Objective                                                                                                                                          | Status                                                                                                                                              |        |
|--------------------------------------|------|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| Marketplace _F001                    |      | Test connection with SP.                                                                                                                           | Completed                                                                                                                                           |        |
| Marketplace _F002                    |      | Test connection with DAC.                                                                                                                          | Completed                                                                                                                                           |        |
| Marketplace _F003                    |      | Test connection with Blockchain wallet (receive requests).                                                                                         | Completed                                                                                                                                           |        |
| Marketplace _F004                    |      | Test connection with other smart contracts.                                                                                                        | Completed                                                                                                                                           |        |
| Analytic Functional Test Description |      |                                                                                                                                                    |                                                                                                                                                     |        |
| Test type                            |      | Functional                                                                                                                                         |                                                                                                                                                     |        |
| Identifier                           |      | Marketplace _F001, Marketplace _F002, Marketplace _F003, Marketplace _F004                                                                         |                                                                                                                                                     |        |
| Tester                               |      | TECNALIA, NEC                                                                                                                                      |                                                                                                                                                     |        |
| Test Purpose                         |      | The marketplace complete operation is validated for an offloading process following the inter-operator flow described in [4].                      |                                                                                                                                                     |        |
| References                           |      | [4] describes the complete inter-operator flow as well as wallet, marketplace and DAC interactions.<br>[13] describes the smart pricing operation. |                                                                                                                                                     |        |
| Configuration                        |      | Not needed                                                                                                                                         |                                                                                                                                                     |        |
|                                      |      |                                                                                                                                                    |                                                                                                                                                     |        |
| Pre-test conditions                  |      | Different operators and services have already been registered in the marketplace.                                                                  |                                                                                                                                                     |        |
|                                      |      |                                                                                                                                                    |                                                                                                                                                     |        |
| Test Sequence                        | Step | Type                                                                                                                                               | Description                                                                                                                                         | Result |
|                                      | 1    | Stimulus                                                                                                                                           | A suitable service request is received from the wallet in the marketplace                                                                           | Pass   |
|                                      | 2    | Check                                                                                                                                              | The marketplace automatically selects suitable services according to the search definition                                                          | Pass   |
|                                      | 3    | Check                                                                                                                                              | The marketplace makes a request to the SP for the most suitable service and price: https://nancy-smart-pricing.8bellsresearch.com/price_calculation | Pass   |
|                                      | 4    | Check                                                                                                                                              | The marketplace sends the selected service details to the DAC for the agreement creation: http://188.245.61.44:8090/DAC/createSLA.                  | Pass   |
|                                      | 5    | Check                                                                                                                                              | The marketplace automatically sends the created agreement to the signature management smart contract                                                | Pass   |

|                     |  |             |
|---------------------|--|-------------|
| <b>Test Verdict</b> |  | <b>Pass</b> |
|---------------------|--|-------------|

### 3.12. Maestro

Maestro [14] is a service orchestration platform for managing the lifecycle of end-to-end services atop geo-distributed heterogeneous infrastructures. At the northbound, Maestro exposes a set of open, standardized service and resource management APIs based on TMForum, to facilitate interaction with stakeholders (e.g., end-users, service providers, etc.), while at the southbound Maestro peers with one or more Operations Support Systems (OSS), such as ETSI OpenSlice [15], i.e., the NANCY Resource Orchestrator, to consume resource-as-a-service APIs for accommodating end-to-end services atop compute and network (e.g., 5G) resources. A detailed description of Maestro can be found in [16].

A summary of functional tests conducted for Maestro's integration into the NANCY platform is provided in Table 12. All these integration activities are now concluded as Maestro demonstrates readiness for the final NANCY use case demonstration and validation activities.

Table 12: Maestro functional tests summary

| Functional Test ID                   |      | Objective                                                                                                                                                               | Status (Completed, Dropped, New and completed)                                                          |        |
|--------------------------------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|--------|
| Maestro_F001                         |      | Test connection with Resource Orchestrator via NIS2                                                                                                                     | Completed                                                                                               |        |
| Maestro_F002                         |      | Test connection with Compute Controller via NIS6.                                                                                                                       | Completed                                                                                               |        |
| Maestro_F003                         |      | Test connection with service Telemetry via NIS5.                                                                                                                        | Completed                                                                                               |        |
| Maestro_F004                         |      | Test compute enforcement APIs via Compute Controller and NIS1.                                                                                                          | Completed                                                                                               |        |
| Maestro_F005                         |      | Test connection with Service Repository/Registry via NIS3.                                                                                                              | Completed                                                                                               |        |
| Maestro_F006                         |      | Test Connection with BSS via NIS1.                                                                                                                                      | Completed                                                                                               |        |
| Analytic Functional Test Description |      |                                                                                                                                                                         |                                                                                                         |        |
| Test type                            |      | Functional                                                                                                                                                              |                                                                                                         |        |
| Identifier                           |      | Maestro_F001                                                                                                                                                            |                                                                                                         |        |
| Tester                               |      | UBITECH                                                                                                                                                                 |                                                                                                         |        |
| Test Purpose                         |      | Test connection with the NANCY Resource Orchestrator (OpenSlice) via interface NIS2                                                                                     |                                                                                                         |        |
| References                           |      | [16], [1], and [2]                                                                                                                                                      |                                                                                                         |        |
| Configuration                        |      | -                                                                                                                                                                       |                                                                                                         |        |
|                                      |      |                                                                                                                                                                         |                                                                                                         |        |
| Pre-test conditions                  |      | Maestro and OpenSlice instances deployed. IP connectivity between Maestro and OpenSlice already established. OpenSlice has available services in its service catalogue. |                                                                                                         |        |
|                                      |      |                                                                                                                                                                         |                                                                                                         |        |
| Test Sequence                        | Step | Type                                                                                                                                                                    | Description                                                                                             | Result |
|                                      | 1    | Stimulus                                                                                                                                                                | User login to Maestro portal or swagger API                                                             | Pass   |
|                                      | 2    | Check                                                                                                                                                                   | POST command to Maestro TMF Party Management API to create an OpenSlice organization                    | Pass   |
|                                      | 3    | Check                                                                                                                                                                   | POST command to Maestro peering API to initiate peering with the OpenSlice organization added in Step 2 | Pass   |

|                                      |                                                                                                   |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
|--------------------------------------|---------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
|                                      | 4                                                                                                 | Check                                                                                                                                                                                                                                                           | POST command to OpenSlice TMF Party Management API to initiate peering with Maestro                                                                                                     | Pass   |
|                                      | 5                                                                                                 | Check                                                                                                                                                                                                                                                           | GET command to OpenSlice TMF Service Catalog API to fetch all available service specifications                                                                                          | Pass   |
|                                      | 6                                                                                                 | Check                                                                                                                                                                                                                                                           | User selects the desired specifications to import from the OpenSlice catalog                                                                                                            | Pass   |
|                                      | 7                                                                                                 | Check                                                                                                                                                                                                                                                           | GET command to Maestro TMF Service Catalog API to verify that the selected service specifications from the OpenSlice service catalog are now onboarded into the Maestro service catalog | Pass   |
| Test Verdict                         | Maestro successfully peers with OpenSlice and fetches services from the OpenSlice service catalog |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         | Pass   |
| Analytic Functional Test Description |                                                                                                   |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Test type                            | Functional                                                                                        |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Identifier                           | Maestro_F002                                                                                      |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Tester                               | UBITECH                                                                                           |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Test Purpose                         | Test connection with the NANCY Compute Controller (Kubernetes) via interface NIS6                 |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| References                           | [16], [1], and [2]                                                                                |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Configuration                        | -                                                                                                 |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Pre-test conditions                  |                                                                                                   |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
|                                      |                                                                                                   | Test Maestro_F001 already conducted, thus Maestro is already peered with OpenSlice and relevant OpenSlice services are already in Maestro’s service catalogue. The Kubernetes cluster exposed by OpenSlice (to Maestro) is reachable from the Maestro instance. |                                                                                                                                                                                         |        |
| Test Sequence                        |                                                                                                   |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Test Sequence                        | Step                                                                                              | Type                                                                                                                                                                                                                                                            | Description                                                                                                                                                                             | Result |
|                                      | 1                                                                                                 | Stimulus                                                                                                                                                                                                                                                        | POST command to Maestro TMF service order API to order a K8saaS service from OpenSlice                                                                                                  | Pass   |
|                                      | 2                                                                                                 | Check                                                                                                                                                                                                                                                           | POST command to OpenSlice TMF service order API to order this service                                                                                                                   | Pass   |
|                                      | 3                                                                                                 | Check                                                                                                                                                                                                                                                           | GET command to OpenSlice TMF service order API to periodically check the status of this order (until state=COMPLETED)                                                                   | Pass   |
|                                      | 4                                                                                                 | Check                                                                                                                                                                                                                                                           | GET command to OpenSlice TMF Service Inventory API to fetch the kubeconfig service characteristic                                                                                       | Pass   |
|                                      | 5                                                                                                 | Check                                                                                                                                                                                                                                                           | GET command to Maestro TMF service order API to verify that the service order is now completed                                                                                          | Pass   |
|                                      | 6                                                                                                 | Check                                                                                                                                                                                                                                                           | Get command to Maestro TMF Service Inventory API to verify that the kubeconfig file is also reflected in Maestro                                                                        | Pass   |
|                                      | 7                                                                                                 | Check                                                                                                                                                                                                                                                           | POST command to Maestro TMF service order API to order a K8saaS service from OpenSlice                                                                                                  | Pass   |
|                                      | 8                                                                                                 | Check                                                                                                                                                                                                                                                           | Maestro establishes a connection with the Kubernetes cluster via the terminal window on its portal                                                                                      | Pass   |
|                                      | 9                                                                                                 | Check                                                                                                                                                                                                                                                           | Maestro issues a test ‘kubect!’ command to verify that the exposed cluster offers the right permissions                                                                                 | Pass   |
| Test Verdict                         | Maestro successfully orders a K8saaS and connects to the Kubernetes cluster                       |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         | Pass   |
| Analytic Functional Test Description |                                                                                                   |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Test type                            | Functional                                                                                        |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Identifier                           | Maestro_F003                                                                                      |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |
| Tester                               | UBITECH                                                                                           |                                                                                                                                                                                                                                                                 |                                                                                                                                                                                         |        |

|                                      |                                                                                                                                                                                                                            |          |                                                                                                                                                                                        |        |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| Test Purpose                         | Test connection with the NANCY Telemetry service via interface NIS5                                                                                                                                                        |          |                                                                                                                                                                                        |        |
| References                           | [16], [1], and [2]                                                                                                                                                                                                         |          |                                                                                                                                                                                        |        |
| Configuration                        | -                                                                                                                                                                                                                          |          |                                                                                                                                                                                        |        |
|                                      |                                                                                                                                                                                                                            |          |                                                                                                                                                                                        |        |
| Pre-test conditions                  | Test Maestro_F002 already conducted, thus Maestro has already onboarded a compute cluster (with a telemetry service already there). An end user service specification is already available on Maestro’s service catalogue. |          |                                                                                                                                                                                        |        |
|                                      |                                                                                                                                                                                                                            |          |                                                                                                                                                                                        |        |
| Test Sequence                        | Step                                                                                                                                                                                                                       | Type     | Description                                                                                                                                                                            | Result |
|                                      | 1                                                                                                                                                                                                                          | Stimulus | POST command to Maestro TMF service order API to order an end user service on top of an existing Kubernetes cluster                                                                    | Pass   |
|                                      | 2                                                                                                                                                                                                                          | Check    | Maestro ensures that the Kubernetes cluster to host the end user’s service is accessible and offers enough resources for this service                                                  | Pass   |
|                                      | 3                                                                                                                                                                                                                          | Check    | Maestro Package Manager validates that the end user service is a valid (deployable) service package                                                                                    | Pass   |
|                                      | 4                                                                                                                                                                                                                          | Check    | Maestro Package Manager connects to the underlying Kubernetes cluster                                                                                                                  | Pass   |
|                                      | 5                                                                                                                                                                                                                          | Check    | Maestro Package Manager performs end user service deployment (e.g., helm install) on the Kubernetes cluster                                                                            | Pass   |
|                                      | 6                                                                                                                                                                                                                          | Check    | Maestro pulls the necessary container images from the service repository/registry (Maestro_F0005 via NIS3)                                                                             | Pass   |
|                                      | 7                                                                                                                                                                                                                          | Check    | Maestro Package Manager activates the deployed service                                                                                                                                 | Pass   |
|                                      | 8                                                                                                                                                                                                                          | Check    | Maestro dispatches a request to the Maestro telemetry service to create a telemetry dashboard                                                                                          | Pass   |
|                                      | 9                                                                                                                                                                                                                          | Check    | Maestro telemetry service instructs the Telemetry service of the cluster to federate specific service-level metrics to the Maestro Telemetry engine                                    | Pass   |
|                                      | 10                                                                                                                                                                                                                         | Check    | Validate that the service metrics are correctly federated to Maestro Telemetry service                                                                                                 | Pass   |
|                                      | 11                                                                                                                                                                                                                         | Check    | Maestro creates telemetry dashboards and exposes the dashboard endpoints to the user via a Portal view and the TMF Service Inventory API (customer facing service exposed to the user) | Pass   |
| Test Verdict                         | Maestro successfully creates service-level telemetry dashboards using interface NIS5                                                                                                                                       |          |                                                                                                                                                                                        | Pass   |
| Analytic Functional Test Description |                                                                                                                                                                                                                            |          |                                                                                                                                                                                        |        |
| Test type                            | Functional                                                                                                                                                                                                                 |          |                                                                                                                                                                                        |        |
| Identifier                           | Maestro_F004                                                                                                                                                                                                               |          |                                                                                                                                                                                        |        |
| Tester                               | UBITECH                                                                                                                                                                                                                    |          |                                                                                                                                                                                        |        |
| Test Purpose                         | Test compute enforcement APIs via Compute Controller and NIS1                                                                                                                                                              |          |                                                                                                                                                                                        |        |
| References                           | [16], [1], and [2]                                                                                                                                                                                                         |          |                                                                                                                                                                                        |        |
| Configuration                        | -                                                                                                                                                                                                                          |          |                                                                                                                                                                                        |        |
|                                      |                                                                                                                                                                                                                            |          |                                                                                                                                                                                        |        |
| Pre-test conditions                  | Test Maestro_F002 already conducted, thus Maestro has already onboarded a compute cluster.                                                                                                                                 |          |                                                                                                                                                                                        |        |
|                                      |                                                                                                                                                                                                                            |          |                                                                                                                                                                                        |        |
| Test Sequence                        | Step                                                                                                                                                                                                                       | Type     | Description                                                                                                                                                                            | Result |

|                                      |                                                                                                                   |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
|--------------------------------------|-------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
|                                      | 1                                                                                                                 | Stimulus                                                                                                                                                                                                                 | PATCH command to Maestro TMF service inventory API using the K8saaS service ID as a service identifier. The PATCH command requires to update certain service characteristics of the K8saaS service, such as the number of worker nodes of the cluster. | Pass   |
|                                      | 2                                                                                                                 | Check                                                                                                                                                                                                                    | Maestro translates this TMF API request to an action towards the Compute Controller, which requests a new worker node to join the compute cluster                                                                                                      | Pass   |
|                                      | 3                                                                                                                 | Check                                                                                                                                                                                                                    | Compute controller verifies the new state of the cluster by checking that the number of worker nodes is indeed increased                                                                                                                               | Pass   |
|                                      | 4                                                                                                                 | Check                                                                                                                                                                                                                    | Maestro reflects the cluster’s new state on its API by showing an increased number of working nodes at the TMF API level                                                                                                                               | Pass   |
| Test Verdict                         | Maestro successfully enforces a compute cluster decision (e.g., cluster scale out) through the compute controller |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        | Pass   |
| Analytic Functional Test Description |                                                                                                                   |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Test type                            | Functional                                                                                                        |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Identifier                           | Maestro_F005                                                                                                      |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Tester                               | UBITECH                                                                                                           |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Test Purpose                         | Test connection with Service Repository/Registry via NIS3                                                         |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| References                           | [16], [1], and [2]                                                                                                |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Configuration                        | -                                                                                                                 |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Pre-test conditions                  |                                                                                                                   |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
|                                      |                                                                                                                   | Test Maestro_F002 already conducted, thus Maestro has already onboarded a compute cluster (with a telemetry service already there). An end user service specification is already available on Maestro’s service catalog. |                                                                                                                                                                                                                                                        |        |
| Test Sequence                        |                                                                                                                   |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Test Sequence                        | Step                                                                                                              | Type                                                                                                                                                                                                                     | Description                                                                                                                                                                                                                                            | Result |
|                                      | 1                                                                                                                 | Stimulus                                                                                                                                                                                                                 | Repeat test Maestro_F003 up until step 6                                                                                                                                                                                                               | Pass   |
| Test Verdict                         | Maestro successfully pulls service artefacts from a service repository/registry                                   |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        | Pass   |
| Analytic Functional Test Description |                                                                                                                   |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Test type                            | Functional                                                                                                        |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Identifier                           | Maestro_F006                                                                                                      |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Tester                               | UBITECH                                                                                                           |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Test Purpose                         | Test connection with the NANCY BSS via interface NIS1                                                             |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| References                           | [16], [1], and [2]                                                                                                |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Configuration                        | -                                                                                                                 |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Pre-test conditions                  |                                                                                                                   |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
|                                      |                                                                                                                   | Repeats Maestro_F003 but now the request comes from an upper layer system (i.e., BSS) which translates a product order to the order of one or more services related to this product.                                     |                                                                                                                                                                                                                                                        |        |
| Test Sequence                        |                                                                                                                   |                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                        |        |
| Test Sequence                        | Step                                                                                                              | Type                                                                                                                                                                                                                     | Description                                                                                                                                                                                                                                            | Result |
|                                      | 1                                                                                                                 | Stimulus                                                                                                                                                                                                                 | Execute a service order from BSS towards Maestro as per Maestro_F003                                                                                                                                                                                   | Pass   |
|                                      | 2                                                                                                                 | Check                                                                                                                                                                                                                    | BSS periodically performs a GET command towards Maestro TMF Service Order API to get the status of the service order (until state = COMPLETED)                                                                                                         | Pass   |

|                     |                                                      |             |
|---------------------|------------------------------------------------------|-------------|
| <b>Test Verdict</b> | <b>BSS verifies the outcome of the service order</b> | <b>Pass</b> |
|---------------------|------------------------------------------------------|-------------|

### 3.13. Models

The tested component consists of three machine learning models offering inference capabilities as API endpoints. These include:

- **Localization model**
- **Anomaly detection model**
- **Spectrum sensing model**

Each model is packaged as a containerized service for flexible deployment across cloud or edge infrastructures. The APIs provide access to inference routines, returning predictions for supplied input features. The models rely on pre-trained weights stored in serialized Python pickle files. This test verifies the basic functionality, availability, and inference capability of these APIs. The functional tests are summarized in Table 13, while Figure 14 illustrates a snapshot of the test.

Table 13: Models functional tests summary

| Functional Test ID                   |                                                                                                                                      | Objective                                                                                                          | Status (Completed, Dropped, New and completed) |          |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------|----------|
| Models_F001                          |                                                                                                                                      | Testing ML algorithms to make prediction on the location of the users, providing Localisation as a Service (LaaS). | Completed                                      |          |
| Models_F002                          |                                                                                                                                      | Testing ML algorithms to detect anomaly in the signals with key network performance indicators.                    | Completed                                      |          |
| Models_F003                          |                                                                                                                                      | To assess the spectrum occupancy with ML-based Radio spectrum sensing techniques.                                  | Completed                                      |          |
| Analytic Functional Test Description |                                                                                                                                      |                                                                                                                    |                                                |          |
| Test type                            | Functional                                                                                                                           |                                                                                                                    |                                                |          |
| Identifier                           | Models_F001, Models_F002, Models_F003                                                                                                |                                                                                                                    |                                                |          |
| Tester                               | IJS                                                                                                                                  |                                                                                                                    |                                                |          |
| Test Purpose                         | Test FastAPI Endpoint for localization (e.g., Figure 14), anomaly detection and spectrum sensing services.                           |                                                                                                                    |                                                |          |
| References                           | Detailed model description in [17] and [18]<br>Integration point description in [2]                                                  |                                                                                                                    |                                                |          |
| Configuration                        | Requirement: API for model inference has to be containerized so that we are able to deploy it on different operating infrastructure. |                                                                                                                    |                                                |          |
|                                      |                                                                                                                                      |                                                                                                                    |                                                |          |
| Pre-test conditions                  | A valid pickle file containing a trained model exists at the given path.                                                             |                                                                                                                    |                                                |          |
|                                      |                                                                                                                                      |                                                                                                                    |                                                |          |
| Test Sequence                        | Step                                                                                                                                 | Type                                                                                                               | Description                                    | Result   |
|                                      | 1                                                                                                                                    | Stimulus                                                                                                           | User runs push or pull request command         |          |
|                                      | 2                                                                                                                                    | Check                                                                                                              | Checkout code for test-localization-api        | Finished |
|                                      | 3                                                                                                                                    | Check                                                                                                              | Spawn docker container                         | Pass     |
| Test Verdict                         | Step-by-step report of the executed steps and elapse time in github.                                                                 |                                                                                                                    |                                                | Pass     |

[← Test FastAPI Endpoint for localization services](#)

## ✓ Running the test #11


[Summary](#)

Jobs

[✓ test-localization-api](#)
[Run details](#)
[Usage](#)
[Workflow file](#)

### test-localization-api

succeeded 1 minute ago in 1m 54s



|                                                  |     |
|--------------------------------------------------|-----|
| > ✓ Set up job                                   | 1s  |
| > ✓ Checkout code                                | 0s  |
| > ✓ Set up Python                                | 0s  |
| > ✓ Install test tools                           | 9s  |
| > ✓ Set up Docker network                        | 0s  |
| > ✓ Build and Run api_tcp_aw2s Docker container  | 29s |
| > ✓ Build and Run api_tcp_nokia Docker container | 24s |
| > ✓ Build and Run api_udp_aw2s Docker container  | 23s |
| > ✓ Build and Run api_udp_nokia Docker container | 23s |
| > ✓ Run API tests                                | 1s  |
| > ✓ Cleanup containers                           | 1s  |
| > ✓ Post Set up Python                           | 0s  |
| > ✓ Post Checkout code                           | 0s  |
| > ✓ Complete job                                 | 0s  |

Figure 14: Snapshot of the expected outcome of one of the tests (localization service)

### 3.14. Self-Evolving Model Repository (SEMR)

The Self-Evolving Model Repository (SEMR) is a key component in the NANCY system, enabling the lifecycle management of deployed AI/ML models. SEMR automates model evolution, tracks performance metrics, and supports retraining workflows. It is deployed on the NAOMI orchestration framework [19] using Kubernetes (K8s) and Helm. Table 14 summarizes the functional tests, while Figure 15 illustrates an instance of the k8s cluster.

Table 14: SEMR functional tests summary

| Functional Test ID                   | Objective                                                 | Status    |
|--------------------------------------|-----------------------------------------------------------|-----------|
| SEMR_F001                            | Testing on NAOMI [19] for AI workflow orchestration.      | Completed |
| Analytic Functional Test Description |                                                           |           |
| Test type                            | Functional                                                |           |
| Identifier                           | SEMR_F001                                                 |           |
| Tester                               | IJS                                                       |           |
| Test Purpose                         | Verify deployment and scalability of the SEMR (Figure 15) |           |
| References                           | Detailed description in [18]                              |           |

|                            |                                                                        |                                                         |                               |                |
|----------------------------|------------------------------------------------------------------------|---------------------------------------------------------|-------------------------------|----------------|
| <b>Configuration</b>       |                                                                        | Scenario assumption: Deployment of SEMR on k8s cluster. |                               |                |
| <b>Pre-test conditions</b> |                                                                        | HELM chart description file.                            |                               |                |
| <b>Test Sequence</b>       | <b>Step</b>                                                            | <b>Type</b>                                             | <b>Description</b>            | <b>Result</b>  |
|                            | 1                                                                      | Stimulus                                                | Run HELM chart                |                |
|                            | 2                                                                      | Check                                                   | Status of all SEMR components | <b>Running</b> |
| <b>Test Verdict</b>        | <b>Manual inspection of running components in k8s cluster console.</b> |                                                         |                               | <b>Pass</b>    |

```
(base) bbertalanic@e6-mlops:~$ helm list
NAME      NAMESPACE    REVISION    UPDATED      STATUS    CHART      APP VERSION
(base) bbertalanic@e6-mlops:~$ helm list -A
NAME      NAMESPACE    REVISION    UPDATED      STATUS    CHART      APP VERSION
naom      slice         7           2025-03-19 07:46:28.306821303 +0100 CET    deployed  NAOMI-0.1.0  0.1.0
(base) bbertalanic@e6-mlops:~$ kubectl get pods -n slice
NAME                                             READY   STATUS    RESTARTS   AGE
alertmanager-naom-kube-prometheus-stack-alertmanager-0  2/2     Running   0           4d23h
kuberay-operator-579d696474-svjp7                1/1     Running   1 (4d23h ago)  4d23h
naom-flyte-binary-6d775f44d8-hsgkp              1/1     Running   0           4d23h
naom-grafana-69c8bd7c7-kmgvw                    3/3     Running   0           4d23h
naom-kube-prometheus-stack-operator-56bcd449-cznmv    1/1     Running   0           4d23h
naom-kube-state-metrics-79c8cbf847-bm7q8          1/1     Running   0           4d23h
naom-minio-fbf7f844-b9tt2                       1/1     Running   0           4d23h
naom-mlflow-run-7dd6f6d554-v7qgm                 1/1     Running   0           4d23h
naom-mlflow-tracking-5bdffd86b6-4s96m             1/1     Running   0           4d23h
naom-postgresql-0                                 1/1     Running   0           4d23h
naom-prometheus-node-exporter-2h5sg               1/1     Running   1 (4d22h ago)  4d23h
naom-prometheus-node-exporter-9qtkw               1/1     Running   0           4d22h
naom-prometheus-node-exporter-bfj9c               1/1     Running   0           4d23h
naom-prometheus-node-exporter-gqbp8               1/1     Running   0           4d23h
naom-prometheus-node-exporter-hdv94               1/1     Running   0           4d23h
postgres-85c95cb987-jtpgw                        1/1     Running   0           4d23h
prometheus-naom-kube-prometheus-stack-prometheus-0  2/2     Running   0           4d23h
ray-serve-raycluster-54w7f-head-crpz5             1/1     Running   0           3h2m
ray-serve-raycluster-54w7f-worker-aarch-group-6pmnf 1/1     Running   0           3h2m
ray-serve-raycluster-54w7f-worker-aarch-group-lf447 1/1     Running   0           3h2m
ray-serve-raycluster-54w7f-worker-aarch-group-nb24r 1/1     Running   0           3h2m
ray-serve-raycluster-54w7f-worker-amd-group-4fj89   1/1     Running   0           3h2m
ray-serve-raycluster-54w7f-worker-amd-group-k5sds   1/1     Running   0           3h2m
ray-serve-raycluster-54w7f-worker-amd-group-xmllf   1/1     Running   0           3h2m
```

Figure 15: Report on running components in k8s cluster console

### 3.15. Elasticity

Table 15 summarizes the functional tests. Specifically, the Elasticity\_F001 test verifies the ability of the Localization-as-a-Service (LaaS) deployment to dynamically adapt compute resources based on fluctuating inference demand. The resource scaling is managed by a reinforcement learning-based elasticity model. This test checks whether the system can elastically scale CPU usage up and down in response to real-time changes in inference load (from 10 to 1000 concurrent requests and back). This test confirms the core functionality and stability of dynamic resource allocation.

Table 15: Elasticity functional tests summary

| Functional Test ID                          |                        | Objective                                                       | Status    |
|---------------------------------------------|------------------------|-----------------------------------------------------------------|-----------|
| <b>Elasticity_F001</b>                      |                        | Testing the developed computing resource elasticity techniques. | Completed |
| <b>Analytic Functional Test Description</b> |                        |                                                                 |           |
| <b>Test type</b>                            | <b>Functional</b>      |                                                                 |           |
| <b>Identifier</b>                           | <b>Elasticity_F001</b> |                                                                 |           |

|                            |                                                                                                                                                |             |                                                                                                                                    |               |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-------------|------------------------------------------------------------------------------------------------------------------------------------|---------------|
| <b>Tester</b>              | <b>IJS</b>                                                                                                                                     |             |                                                                                                                                    |               |
| <b>Test Purpose</b>        | Verifying elasticity of resource allocation using Localization-as-a-service (LaaS) model concurrent requests.                                  |             |                                                                                                                                    |               |
| <b>References</b>          | Model described in detail in [16]                                                                                                              |             |                                                                                                                                    |               |
| <b>Configuration</b>       | Deployed Localization-as-a-service model as a docker container in k8s cluster, dynamically changing number of localization inference requests. |             |                                                                                                                                    |               |
| <b>Pre-test conditions</b> | K8s cluster<br>Reinforcement learning elasticity model.<br>C-adviser in the localization service to monitor CPU consumption.                   |             |                                                                                                                                    |               |
| <b>Test Sequence</b>       | <b>Step</b>                                                                                                                                    | <b>Type</b> | <b>Description</b>                                                                                                                 | <b>Result</b> |
|                            | 1                                                                                                                                              | Stimulus    | API request to the localization service                                                                                            |               |
|                            | 2                                                                                                                                              | Check       | Increase the number of inferences from 10 to 1000 concurrent requests and check if it is dynamically increasing the CPU resources. | <b>Pass</b>   |
|                            | 3                                                                                                                                              | Check       | Lower the concurrent tests from 1000 to 10 and check if it is dynamically decreasing CPU resources.                                | <b>Pass</b>   |
| <b>Test Verdict</b>        | <b>Verify adapting resources and stability of the process.</b>                                                                                 |             |                                                                                                                                    | <b>Pass</b>   |

A detailed performance evaluation of this test is presented in Table 16, summarizing averaged results over 20 runs. The comparison includes three algorithms: MARLISE-Continuous, a multi-agent reinforcement learning algorithm based on the Proximal Policy Optimization (PPO) approach; MARLISE-Discrete, which follows the Deep Q-Network (DQN) paradigm; and a heuristic policy-driven method that adjusts resource allocation using CPU and memory usage trends with predefined scaling thresholds. The Continuous approach achieves the best performance, with the lowest violations (12.05%) and fastest response time (0.14 s) for microservice 3, compared to Discrete (24.53%, 0.31 s) and the heuristic (25.99%, 0.28 s). However, the heuristic allocates the fewest resources (578 mc), while Discrete and Continuous allocate 648 mc and 667 mc, respectively. This demonstrates a trade-off: MARLISE-Discrete and especially MARLISE-Continuous achieve faster responses at the cost of higher resource usage, while the heuristic remains more conservative but less responsive.

Table 16: Averaged performance metrics for dynamic load

| Metrics/Algorithm<br>Microservices | Heuristic |       |       | MARLISE-Discrete |       |       | MARLISE-Continuous |       |       |
|------------------------------------|-----------|-------|-------|------------------|-------|-------|--------------------|-------|-------|
|                                    | 1         | 2     | 3     | 1                | 2     | 3     | 1                  | 2     | 3     |
| <b>Violations (%)</b>              | 10.43     | 19.60 | 25.99 | 7.14             | 21.12 | 24.53 | 8.67               | 19.26 | 12.05 |
| <b>Mean Response time (s)</b>      | 0.09      | 0.22  | 0.28  | 0.08             | 0.24  | 0.31  | 0.08               | 0.22  | 0.14  |
| <b>Mean resource delta (mc)</b>    | 415       | 488   | 578   | 645              | 615   | 648   | 532                | 709   | 667   |

### 3.16. Post Quantum Cryptography Signature (PQCSig)

PQCSig is a middleware and smartcard provided by TDIS that will generate and verify signatures with ML\_DSA key. This package will bring the possibility to guarantee the authenticity of data. Table 17 summarizes the PQCSig functional tests.

Table 17: PQCSig functional tests summary

| Functional Test ID                   |                                                                                                                                                                   | Objective                                                                        | Status (Completed, Dropped, New and completed) |        |
|--------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------|--------|
| TC_NE_C_SignInit::testCKM_ML_DSA     |                                                                                                                                                                   | Initialisation of Signature sequence.                                            | Completed                                      |        |
| TC_NE_C_Sign::testCKM_ML_DSA         |                                                                                                                                                                   | Signature single-part creation using ML_DSA keys.                                | Completed                                      |        |
| TC_NE_C_SignUpdate::testCKM_ML_DSA   |                                                                                                                                                                   | Signature update of multiple-part signature operation using ML_DSA keys .        | Completed                                      |        |
| TC_NE_C_SignFinal::testCKM_ML_DSA    |                                                                                                                                                                   | Signature finalisation of a multiple-part signature operation using ML_DSA keys. | Completed                                      |        |
| TC_NE_C_VerifyInit::testCKM_ML_DSA   |                                                                                                                                                                   | Initialisation of Verification sequence.                                         | Completed                                      |        |
| TC_NE_C_Verify::testCKM_ML_DSA       |                                                                                                                                                                   | Signature single-part data verification using ML_DSA keys.                       | Completed                                      |        |
| TC_NE_C_VerifyUpdate::testCKM_ML_DSA |                                                                                                                                                                   | Signature multiple-part update verification using ML_DSA keys.                   | Completed                                      |        |
| TC_NE_C_VerifyFinal::testCKM_ML_DSA  |                                                                                                                                                                   | Signature multiple -part data verification using ML_DSA keys.                    | Completed                                      |        |
| Analytic Functional Test Description |                                                                                                                                                                   |                                                                                  |                                                |        |
| Test type                            | Functional                                                                                                                                                        |                                                                                  |                                                |        |
| Identifier                           | TC_NE_C_SignInit::testCKM_ML_DSA, TC_NE_C_Sign::testCKM_ML_DSA, TC_NE_C_VerifyInit::testCKM_ML_DSA, TC_NE_C_Verify::testCKM_ML_DSA                                |                                                                                  |                                                |        |
| Tester                               | TDIS                                                                                                                                                              |                                                                                  |                                                |        |
| Test Purpose                         | Signature single-part creation and verification using ML_DSA keys using the PKCS#11 functions<br><br>Returns CKR_MECHANISM_INVALID if mechanism is not supported. |                                                                                  |                                                |        |
| References                           |                                                                                                                                                                   |                                                                                  |                                                |        |
| Configuration                        | Smartcard personalized                                                                                                                                            |                                                                                  |                                                |        |
|                                      |                                                                                                                                                                   |                                                                                  |                                                |        |
| Pre-test conditions                  | Smartcard inserted into the reader and personalized                                                                                                               |                                                                                  |                                                |        |
|                                      |                                                                                                                                                                   |                                                                                  |                                                |        |
| Test Sequence                        | Step                                                                                                                                                              | Type                                                                             | Description                                    | Result |
|                                      | 1                                                                                                                                                                 | Stimulus                                                                         | C_SignInit                                     | Pass   |
|                                      | 2                                                                                                                                                                 | Check                                                                            | Check the API answer                           | Pass   |
|                                      | 3                                                                                                                                                                 | Stimulus                                                                         | C_Sign                                         | Pass   |
|                                      | 4                                                                                                                                                                 | Check                                                                            | Check the API answer                           | Pass   |
|                                      | 5                                                                                                                                                                 | Stimulus                                                                         | C_VerifyInit                                   | Pass   |
|                                      | 6                                                                                                                                                                 | Check                                                                            | Check the API answer                           | Pass   |

|                                      |                                                                                                                                                                                                                                      |          |                      |        |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------------------|--------|
|                                      | 7                                                                                                                                                                                                                                    | Stimulus | C_Verify             | Pass   |
|                                      | 8                                                                                                                                                                                                                                    | Check    | Check the API answer | Pass   |
| Test Verdict                         |                                                                                                                                                                                                                                      |          |                      | Pass   |
| Analytic Functional Test Description |                                                                                                                                                                                                                                      |          |                      |        |
| Test type                            | Functional                                                                                                                                                                                                                           |          |                      |        |
| Identifier                           | TC_NE_C_SignInit::testCKM_ML_DSA,<br>TC_NE_C_SignUpdate::testCKM_ML_DSA,<br>TC_NE_C_SignFinal::testCKM_ML_DSA,<br>TC_NE_C_VerifyInit::testCKM_ML_DSA,<br>TC_NE_C_VerifyUpdate::testCKM_ML_DSA<br>TC_NE_C_VerifyFinal::testCKM_ML_DSA |          |                      |        |
| Tester                               | TDIS                                                                                                                                                                                                                                 |          |                      |        |
| Test Purpose                         | Signature multi-part creation and verification using ML_DSA keys using the PKCS#11 functions<br><br>Returns CKR_MECHANISM_INVALID if mechanism is not supported.                                                                     |          |                      |        |
| References                           |                                                                                                                                                                                                                                      |          |                      |        |
| Configuration                        | Smartcard personalized                                                                                                                                                                                                               |          |                      |        |
|                                      |                                                                                                                                                                                                                                      |          |                      |        |
| Pre-test conditions                  | Smartcard inserted into the reader and personalized                                                                                                                                                                                  |          |                      |        |
|                                      |                                                                                                                                                                                                                                      |          |                      |        |
| Test Sequence                        | Step                                                                                                                                                                                                                                 | Type     | Description          | Result |
|                                      | 1                                                                                                                                                                                                                                    | Stimulus | C_SignInit           | Pass   |
|                                      | 2                                                                                                                                                                                                                                    | Check    | Check the API answer | Pass   |
|                                      | 3                                                                                                                                                                                                                                    | Stimulus | C_SignUpdate         | Pass   |
|                                      | 4                                                                                                                                                                                                                                    | Check    | Check the API answer | Pass   |
|                                      | 5                                                                                                                                                                                                                                    | Stimulus | C_SignFinal          | Pass   |
|                                      | 6                                                                                                                                                                                                                                    | Check    | Check the API answer | Pass   |
|                                      | 7                                                                                                                                                                                                                                    | Stimulus | C_VerifyInit         | Pass   |
|                                      | 8                                                                                                                                                                                                                                    | Check    | Check the API answer | Pass   |
|                                      | 9                                                                                                                                                                                                                                    | Stimulus | C_VerifyUpdate       | Pass   |
|                                      | 10                                                                                                                                                                                                                                   | Check    | Check the API answer | Pass   |
|                                      | 11                                                                                                                                                                                                                                   | Stimulus | C_VerifyFinal        | Pass   |
|                                      | 12                                                                                                                                                                                                                                   | Check    | Check the API answer | Pass   |
| Test Verdict                         |                                                                                                                                                                                                                                      |          |                      | Pass   |

### 3.17. Traffic Forecasting Service (TFS)

TFS is an AI-driven tool provided by CERTH, which aims to provide a real-time prediction of near future actual bitrate, that is, throughput values. The Throughput Forecasting Service has not only been delineated but also analyzed in depth and breadth in [17]. It is actually a tool tightly connected to two distinct functionalities, namely analytics and decision-making. There is a connection between TFS and

the software MRAT-NCP component. Also, TFS is a part of the Telemetry and AI/Analytics NANCY architectural element. Table 18 summarizes the functional tests of the Traffic Forecasting Service.

Table 18: TFS functional tests summary

| Functional Test ID                   |                                                                                                                                                                                                                                  | Objective                                                                                                                   | Status (Completed, Dropped, New and completed)                                                                         |           |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|-----------|
| TFS_F001                             |                                                                                                                                                                                                                                  | Throughput forecasting intended for network analytics purposes.                                                             | Completed                                                                                                              |           |
| TFS_F002                             |                                                                                                                                                                                                                                  | Throughput forecasting for assessment of upcoming network performance and mitigation of anticipated performance degradation | Completed                                                                                                              |           |
| Analytic Functional Test Description |                                                                                                                                                                                                                                  |                                                                                                                             |                                                                                                                        |           |
| Test type                            | Functional                                                                                                                                                                                                                       |                                                                                                                             |                                                                                                                        |           |
| Identifier                           | TFS_F001, TFS_F002                                                                                                                                                                                                               |                                                                                                                             |                                                                                                                        |           |
| Tester                               | CERTH                                                                                                                                                                                                                            |                                                                                                                             |                                                                                                                        |           |
| Test Purpose                         | Verify the receipt and plausibility of forecasts for an immediate future time horizon                                                                                                                                            |                                                                                                                             |                                                                                                                        |           |
| References                           | [17]                                                                                                                                                                                                                             |                                                                                                                             |                                                                                                                        |           |
| Configuration                        | High-end commercial workstation or Docker Container API Environment<br>Pre-processed Dataset available, comprising of 118 separate time-series<br>AI model complete with fine-tuning and testing via validation and testing data |                                                                                                                             |                                                                                                                        |           |
|                                      |                                                                                                                                                                                                                                  |                                                                                                                             |                                                                                                                        |           |
| Pre-test conditions                  | The Docker Container RESTful API has already been built, alongside with its multitude of dependencies, in the workstation, which has been prepared for execution.                                                                |                                                                                                                             |                                                                                                                        |           |
|                                      |                                                                                                                                                                                                                                  |                                                                                                                             |                                                                                                                        |           |
| Test Sequence                        | Step                                                                                                                                                                                                                             | Type                                                                                                                        | Description                                                                                                            | Result    |
|                                      | 1                                                                                                                                                                                                                                | Stimulus                                                                                                                    | Docker Component/service is executed/run within the testing environment                                                | Completed |
|                                      | 2                                                                                                                                                                                                                                | Stimulus                                                                                                                    | A value is inserted for the android walk time-series number                                                            | Completed |
|                                      | 3                                                                                                                                                                                                                                | Stimulus                                                                                                                    | A value is inserted for the number of steps the forecasting has to take place and both sent (via POSTMAN or curl tool) | Completed |
|                                      | n                                                                                                                                                                                                                                | Check                                                                                                                       |                                                                                                                        | Pass      |
| Test Verdict                         |                                                                                                                                                                                                                                  |                                                                                                                             |                                                                                                                        | Pass      |

### 3.18. RAN Intelligent Controller Manager (RICMgr)

The RIC Manager in NANCY acts a Non-RT RIC which exposes A1 policies to external entities, such as the Slice Manager. Particularly, once receiving a request of the Slicer Manager (via REST API) to modify the priority of a given RAN slice, it generates O-RAN-compliant slice SLA policy which is sent to the O-RAN Near-RT RIC from O-RAN Software Community (version adapted for srsRAN deployments<sup>1</sup>). Once receiving the policy, the Near-RT RIC follows it to the Slicing xApp, which applies slicing prioritization by modifying the PRB allocation of the UEs available in the slice (E2 RAN Control Service Model). The

<sup>1</sup> <https://docs.srsran.com/projects/project/en/latest/tutorials/source/near-rt-ric/source/index.html>

RICMgr functional tests are summarized in Table 19, while Figure 16 to Figure 21 showcase the steps of deploying a near-RT RIC.

Table 19: RICMgr functional tests summary

| Functional Test ID                   |      | Objective                                                                                                                                                                                                                                                                                                       | Status                                                                                   |        |
|--------------------------------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|--------|
| RICMgr_F001                          |      | Successful communication with the Slice Manager via the defined interface.                                                                                                                                                                                                                                      | Completed                                                                                |        |
| RICMgr_F002                          |      | Successful communication with the near-RT RIC via A1 interface.                                                                                                                                                                                                                                                 | Completed                                                                                |        |
| RICMgr_F003                          |      | Successful implementation of the required control-loop workflow.                                                                                                                                                                                                                                                | Ongoing, to be completed in Spanish demonstrator                                         |        |
| Analytic Functional Test Description |      |                                                                                                                                                                                                                                                                                                                 |                                                                                          |        |
| Test type                            |      | Functional                                                                                                                                                                                                                                                                                                      |                                                                                          |        |
| Identifier                           |      | RICMgr_F001, RICMgr_F002                                                                                                                                                                                                                                                                                        |                                                                                          |        |
| Tester                               |      | I2CAT                                                                                                                                                                                                                                                                                                           |                                                                                          |        |
| Test Purpose                         |      | The purpose of this test is to validate the workflow required to apply an A1 policy in a specific xApp, once generated by the Slice Manager: i.e., Slice Manager sends request to RIC Manager/rApp, the rApp creates an A1 policy and sends it to the Near-RT RIC, and the Near-RT RIC forwards it to the xApp. |                                                                                          |        |
| References                           |      |                                                                                                                                                                                                                                                                                                                 |                                                                                          |        |
| Configuration                        |      | We have two RAN slices pre-deployed, with equal priority. We have the Slicing SLA A1 policy type defined in both the Non-RT and Near-RT RIC                                                                                                                                                                     |                                                                                          |        |
|                                      |      |                                                                                                                                                                                                                                                                                                                 |                                                                                          |        |
| Pre-test conditions                  |      | srRAN with two slices, Slice Manager reaches RIC Manager, which reaches the OSC Near-RT RIC.                                                                                                                                                                                                                    |                                                                                          |        |
|                                      |      |                                                                                                                                                                                                                                                                                                                 |                                                                                          |        |
| Test Sequence                        | Step | Type                                                                                                                                                                                                                                                                                                            | Description                                                                              | Result |
|                                      | 1    | Stimulus                                                                                                                                                                                                                                                                                                        | The Slice Manager requests a modification of the slice priority (update or delete)       | Pass   |
|                                      | 2    | Check                                                                                                                                                                                                                                                                                                           | The rApp receives the request, decodes it and generates an A1 policy.                    | Pass   |
|                                      | 3    | Check                                                                                                                                                                                                                                                                                                           | The A1 policy is received by the Non-RT RIC, evaluated and forwarded to the Near-RT RIC. | Pass   |
|                                      | 4    | Check                                                                                                                                                                                                                                                                                                           | The A1 policy is received by the Near-RT RIC, evaluated and forwarded to the xApp.       | Pass   |
|                                      | 5    | Check                                                                                                                                                                                                                                                                                                           | The xApp executes the policy according to the number of UEs in the slice.                | Pass   |
| Test Verdict                         |      |                                                                                                                                                                                                                                                                                                                 |                                                                                          | Pass   |

| Curl                                                                                                                      |                                                                                                                                                                                                                                                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <pre>curl -X 'GET' \ 'http://192.168.40.50:30000/nearRT-RIC?nearrt_ric_name=srsRAN' \ -H 'accept: application/json'</pre> |                                                                                                                                                                                                                                                                                                                        |
| Request URL                                                                                                               |                                                                                                                                                                                                                                                                                                                        |
| <pre>http://192.168.40.50:30000/nearRT-RIC?nearrt_ric_name=srsRAN</pre>                                                   |                                                                                                                                                                                                                                                                                                                        |
| Server response                                                                                                           |                                                                                                                                                                                                                                                                                                                        |
| Code                                                                                                                      | Details                                                                                                                                                                                                                                                                                                                |
| 200                                                                                                                       | <div>Response body<pre>[   {     "id": 2,     "a1_protocol": "REST",     "o1_protocol": "REST",     "a1_topics": "policytypes",     "o1_topics": "o1",     "nonrt_ric_id": 4,     "friendly_name": "srsRAN",     "ip": "192.168.40.100",     "port": 8000,     "xapps": [],     "ric_type": "srsRAN"   } ]</pre></div> |

Figure 16: Definition of the Near-RT RIC in the Non-RT RIC framework

```

Curl
curl -X 'POST' \
  'http://192.168.40.50:30000/policy_type/srsRAN' \
  -H 'accept: application/json' \
  -H 'Content-Type: application/json' \
  -d '{
    "id": 3,
    "policytype_id": 3,
    "name": "NANCY_slicing",
    "description": "Policy based on 0-RAN Slicing SLA policy for NANCY",
    "create_schema": {
      "$schema": "https://json-schema.org/draft/2020-12/schema",
      "$id": "https://schemas.o-ran.org/jonschemas/a1td/oran_sliceslatarget_4.0.0-nancy",
      "description": "0-RAN slice SLA policy - adapted for NANCY project",
      "type": "object",
      "properties": {
        "scope": {
          "type": "object",
          "properties": {
            "sliceId": { "$ref": "#/$defs/SliceId" }
          },
          "additionalProperties": false,
          "required": ["sliceId"]
        },
        "sliceSlaObjectives": {
          "type": "object",
          "properties": {
            "dlslicePriority": {

```

Request URL

```
http://192.168.40.50:30000/policy_type/srsRAN
```

Server response

| Code | Details                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 201  | <p>Response body</p> <pre> {   "id": 3,   "policytype_id": 3,   "name": "NANCY_slicing",   "description": "Policy based on 0-RAN Slicing SLA policy for NANCY",   "create_schema": {     "\$schema": "https://json-schema.org/draft/2020-12/schema",     "\$id": "https://schemas.o-ran.org/jonschemas/a1td/oran_sliceslatarget_4.0.0-nancy",     "description": "0-RAN slice SLA policy - adapted for NANCY project",     "type": "object",     "properties": {       "scope": { </pre> |

Figure 17: Definition of the A1 policy type in the Non-RT RIC

```

received policy with sliceid 1-000001-001-02
[CREATE] Creating new policy instance<main.SlicePolicy object at 0x72354e644e50>
[ACTION] Sending policy instance
INFO: 127.0.0.1:42228 - "PUT /policyupdate HTTP/1.1" 200 OK
received policy with sliceid 1-000001-001-02
[UPDATE] Updating new policy instance<main.SlicePolicy object at 0x72354e644e50>
[ACTION] Sending policy instance
INFO: 127.0.0.1:32768 - "PUT /policyupdate HTTP/1.1" 200 OK
[UPDATE] Updating new policy instance<main.SlicePolicy object at 0x72354e644e50>
[ACTION] Sending policy instance
[ACTION] Deleting policy instance
INFO: 127.0.0.1:36728 - "DELETE /policyupdate HTTP/1.1" 200 OK

```

Figure 18: Reception of Slice Manager requests by the rApp (create, update, delete)

Figure 19: Reception of the A1 policy by the Non-RT RIC and forwarding to the Near-RT RIC

Figure 20: Generated A1 policy instance in the Non-RT RIC

```

nuc-hpminif1311@nucf1311:~$ uvicorn sliceA1listenerv1:app --host 0.0.0.0 --port 8000 --reload
INFO: Will watch for changes in these directories: ['/home/nuc-hpminif1311']
INFO: Uvicorn running on http://0.0.0.0:8000 (Press CTRL+C to quit)
INFO: Started reloader process [250021] using watchgod
INFO: Started server process [250023]
INFO:uvicorn.error:Started server process [250023]
INFO: Waiting for application startup.
INFO:uvicorn.error:Waiting for application startup.
INFO: Application startup complete.
INFO:uvicorn.error:Application startup complete.
INFO: 192.168.40.50:45468 - "GET /policytypes HTTP/1.1" 404 Not Found
✓ Received A1 Policy PUT Message (policyTypeId=3, policyId=301):
  Action: create, Slice SST: 1, SD: 000001, PLMN: MCC=001, MNC=02
  DL Priority: 10, UL Priority: 10
  Status: enforced, Last Modified: 1759490244
INFO:root:Updated UE: ue_1 -> {'du_id': '0', 'ue_id': '1', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
INFO:root:Updated UE: ue_4 -> {'du_id': '0', 'ue_id': '4', 'cu_ue_id': '2', 'du_ue_id': '2', 'slice_id': '01-000001'}
INFO:root:Updated UE: ue_6 -> {'du_id': '0', 'ue_id': '6', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
Found 3 UEs for slice SST=1,SD=000001:
- UE: {'du_id': '0', 'ue_id': '1', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
- UE: {'du_id': '0', 'ue_id': '4', 'cu_ue_id': '2', 'du_ue_id': '2', 'slice_id': '01-000001'}
- UE: {'du_id': '0', 'ue_id': '6', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
INFO: 192.168.40.50:49166 - "PUT /policytypes/3/policies/301 HTTP/1.1" 200 OK
✓ Received A1 Policy PUT Message (policyTypeId=3, policyId=301):
  Action: create, Slice SST: 1, SD: 000001, PLMN: MCC=001, MNC=02
  DL Priority: 50, UL Priority: 50
  Status: enforced, Last Modified: 1759490304
INFO:root:Updated UE: ue_1 -> {'du_id': '0', 'ue_id': '1', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
INFO:root:Updated UE: ue_4 -> {'du_id': '0', 'ue_id': '4', 'cu_ue_id': '2', 'du_ue_id': '2', 'slice_id': '01-000001'}
INFO:root:Updated UE: ue_6 -> {'du_id': '0', 'ue_id': '6', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
Found 3 UEs for slice SST=1,SD=000001:
- UE: {'du_id': '0', 'ue_id': '1', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
- UE: {'du_id': '0', 'ue_id': '4', 'cu_ue_id': '2', 'du_ue_id': '2', 'slice_id': '01-000001'}
- UE: {'du_id': '0', 'ue_id': '6', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
INFO: 192.168.40.50:35252 - "PUT /policytypes/3/policies/301 HTTP/1.1" 200 OK
✓ Received A1 Policy PUT Message (policyTypeId=3, policyId=301):
  Action: create, Slice SST: 1, SD: 000001, PLMN: MCC=001, MNC=02
  DL Priority: 100, UL Priority: 100
  Status: enforced, Last Modified: 1759490350
INFO:root:Updated UE: ue_1 -> {'du_id': '0', 'ue_id': '1', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
INFO:root:Updated UE: ue_4 -> {'du_id': '0', 'ue_id': '4', 'cu_ue_id': '2', 'du_ue_id': '2', 'slice_id': '01-000001'}
INFO:root:Updated UE: ue_6 -> {'du_id': '0', 'ue_id': '6', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
Found 3 UEs for slice SST=1,SD=000001:
- UE: {'du_id': '0', 'ue_id': '1', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
- UE: {'du_id': '0', 'ue_id': '4', 'cu_ue_id': '2', 'du_ue_id': '2', 'slice_id': '01-000001'}
- UE: {'du_id': '0', 'ue_id': '6', 'cu_ue_id': '1', 'du_ue_id': '1', 'slice_id': '01-000001'}
INFO: 192.168.40.50:46820 - "PUT /policytypes/3/policies/301 HTTP/1.1" 200 OK

```

Figure 21: Near-RT RIC and xApp validation and application of the A1 policy

### 3.19. Artificial Intelligence Network Quality Module (AINQM)

The Artificial Intelligence Network Quality Module is a module designed to carry out predictions about upcoming network outages. Outages are essentially events and intervals of highly dissatisfactory service. The AINQM in the form of its Docker Container API in fact delivers probability outputs, which measure how probable the event of an outage is. Additionally, post-processing was put to use, so that the final output of the module is in actuality binary: outage (1) or uptime/available (0). The work carried out in this framework is meticulously laid out in [20]. Table 20 summarizes the AINQM functional tests.

Table 20: AINQM functional tests summary

| Functional Test ID                   | Objective                                                                                                               | Status    |
|--------------------------------------|-------------------------------------------------------------------------------------------------------------------------|-----------|
| AINQM_F001                           | Prediction of network outage probability for analytics.                                                                 | Completed |
| AINQM_F002                           | Prediction of network outage probability to anticipate network events and support decision-making.                      | Completed |
| Analytic Functional Test Description |                                                                                                                         |           |
| Test type                            | Functional                                                                                                              |           |
| Identifier                           | AINQM_F001, AINQM_F002                                                                                                  |           |
| Tester                               | CERTH                                                                                                                   |           |
| Test Purpose                         | Verify the receipt and plausibility of probability predictions for upcoming network outages.                            |           |
| References                           | [20]                                                                                                                    |           |
| Configuration                        | High-end commercial workstation or Docker Container API Environment<br>Pre-processed Dataset (COLOSSEUM) [21] available |           |

|                                                                                |      |                                                                                                                                                                   |                                                                                                                    |           |
|--------------------------------------------------------------------------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|-----------|
| AI model complete with fine-tuning and testing via validation and testing data |      |                                                                                                                                                                   |                                                                                                                    |           |
|                                                                                |      |                                                                                                                                                                   |                                                                                                                    |           |
| Pre-test conditions                                                            |      | The Docker Container RESTful API has already been built, alongside with its multitude of dependencies, in the workstation, which has been prepared for execution. |                                                                                                                    |           |
|                                                                                |      |                                                                                                                                                                   |                                                                                                                    |           |
| Test Sequence                                                                  | Step | Type                                                                                                                                                              | Description                                                                                                        | Result    |
|                                                                                | 1    | Stimulus                                                                                                                                                          | Docker Component/service is executed/run within the testing environment                                            | Completed |
|                                                                                | 2    | Stimulus                                                                                                                                                          | Values are inserted as body arguments/payload parameters (CSV, range) and both sent (via the POSTMAN or curl tool) | Completed |
|                                                                                | 3    | Check                                                                                                                                                             | Get a prediction that is plausible for upcoming outages                                                            | Pass      |
| Test Verdict                                                                   |      |                                                                                                                                                                   |                                                                                                                    | Pass      |

### 3.20. Network Information Framework (NIF)

This component describes the development and validation of the **Network Information Framework (NIF)**, a comprehensive system designed to assess and optimize **Blockchain-based Radio Access Networks**. The framework incorporates **three AI-driven predictive models** addressing key performance indicators:

- **Coverage Probability Prediction Model** – Estimates network coverage reliability across urban environments, leveraging datasets such as the **University of Murcia's 5G deployment** produced by **NANCY**.
- **Outage Probability Prediction Model** – Predicts the likelihood of network outages using datasets like the **Colosseum urban simulation** [21].
- **Latency Prediction Model** – Evaluates blockchain consensus-induced latency across multiple consensus mechanisms, enabling comparison and optimization of performance and security trade-offs.

The **NIF** is integrated into an **interactive web-based platform**, allowing users to upload datasets, execute model predictions, and visualize performance outcomes in real time. More information can be found in [20]. The functional tests for the Network Information Framework are summarized in Table 21.

Table 21: NIF functional tests summary

| Functional Test ID                          | Objective                                                              | Status    |
|---------------------------------------------|------------------------------------------------------------------------|-----------|
| <b>NIF_F001</b>                             | AI model testing with synthetic data to ensure reasonable predictions. | Completed |
| <b>NIF_F002</b>                             | Ensure the AI model's loss function converges without overfitting.     | Completed |
| <b>NIF_F003</b>                             | Successful creation of users and data upload process.                  | Completed |
| <b>Analytic Functional Test Description</b> |                                                                        |           |
| <b>Test type</b>                            | <b>Functional</b>                                                      |           |
| <b>Identifier</b>                           | <b>NIF_F001, NIF_F002, NIF_F003</b>                                    |           |

|                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |             |                                                                                    |                  |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|------------------------------------------------------------------------------------|------------------|
| <b>Tester</b>              | <b>8BELLS</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |             |                                                                                    |                  |
| <b>Test Purpose</b>        | Verify the NIF's AI models training, prediction quality, and user/data handling functionalities.                                                                                                                                                                                                                                                                                                                                                                                    |             |                                                                                    |                  |
| <b>References</b>          | <b>[20]</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |             |                                                                                    |                  |
| <b>Configuration</b>       | <ul style="list-style-type: none"> <li>•Test environment deployed with default system settings</li> <li>•AI models configured with baseline hyperparameters (batch size, learning rate, epochs)</li> <li>•Synthetic dataset stored in designated test data directory</li> <li>•Database schema applied and connection strings configured</li> <li>•User management and authentication modules enabled</li> <li>•Logging and monitoring services configured for test runs</li> </ul> |             |                                                                                    |                  |
| <b>Pre-test conditions</b> | <ul style="list-style-type: none"> <li>•Services running</li> <li>•Test accounts created and accessible</li> <li>•Synthetic dataset available and valid</li> <li>•Database initialized and empty</li> <li>•Admin credentials verified</li> <li>•Logging and monitoring enabled</li> <li>•Network connectivity verified</li> <li>•Compute resources allocated (GPU/CPU/memory)</li> </ul>                                                                                            |             |                                                                                    |                  |
| <b>Test Sequence</b>       | <b>Step</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>Type</b> | <b>Description</b>                                                                 | <b>Result</b>    |
|                            | 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Stimulus    | Start services and verify endpoints are reachable.                                 | <b>Completed</b> |
|                            | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Stimulus    | Load synthetic dataset into the test environment.                                  | <b>Completed</b> |
|                            | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Check       | Dataset format and validity confirmed.                                             | <b>Pass</b>      |
|                            | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Stimulus    | Train AI models (all three) using synthetic dataset with baseline hyperparameters. | <b>Completed</b> |
|                            | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Check       | Training losses decrease and converge within expected range for all models.        | <b>Pass</b>      |
|                            | 6                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Stimulus    | Create new user account.                                                           | <b>Completed</b> |
|                            | 7                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Check       | User record stored in database and accessible.                                     | <b>Pass</b>      |
|                            | 8                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Stimulus    | Upload sample dataset via user account.                                            | <b>Completed</b> |
|                            | 9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Check       | Data upload completes successfully and is retrievable.                             | <b>Pass</b>      |

|                     |  |             |
|---------------------|--|-------------|
| <b>Test Verdict</b> |  | <b>Pass</b> |
|---------------------|--|-------------|

### 3.21. Smart Pricing Policies (SPP)

The Smart Pricing Module (SPM) is part of Task 4.5 “Smart Pricing Policies” and is described in detail in [13] - Smart Pricing Policies. It provides AI-driven pricing and resource allocation mechanisms for the B-RAN, leveraging Multi-Agent Reinforcement Learning (MARL) and multi-round blind reverse auctions to ensure fair and competitive pricing. Within the NANCY framework, the SPM interacts closely with the NANCY Marketplace through a dedicated API service, enabling dynamic price discovery. Table 22 summarizes the functional test for the Smart Pricing Policies component. Moreover, Figure 22 to Figure 26 illustrate indicative instances of the tests.

Table 22: SPP functional tests summary

| Functional Test ID                   |      | Objective                                                                                                                              |                                                                         | Status (Completed, Dropped, New and completed) |                              |
|--------------------------------------|------|----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|------------------------------------------------|------------------------------|
| SPP_F001                             |      | Simulation environment testing (Boundary conditions, auction rules etc) with synthetic data.                                           |                                                                         | Completed                                      |                              |
| SPP_F002                             |      | Ensure the neural network loss function converges without overfitting.                                                                 |                                                                         | Completed                                      |                              |
| SPP_F003                             |      | Performance testing under load to measure and improve latency and throughput.                                                          |                                                                         | Completed                                      |                              |
| SPP_F004                             |      | Reinforcement learning model testing with synthetic data to ensure reasonable behaviour.                                               |                                                                         | Completed                                      |                              |
| Analytic Functional Test Description |      |                                                                                                                                        |                                                                         |                                                |                              |
| Test type                            |      | Functional                                                                                                                             |                                                                         |                                                |                              |
| Identifier                           |      | SPM_F001                                                                                                                               |                                                                         |                                                |                              |
| Tester                               |      | 8BELLS                                                                                                                                 |                                                                         |                                                |                              |
| Test Purpose                         |      | Validate that the SPM simulation PettingZoo environment correctly enforces boundary conditions and auction rules using synthetic data. |                                                                         |                                                |                              |
| References                           |      | [13] (Section 3.2 Multi-round Blind Reverse Auction, Section 3.3 Training Environment Parameters)                                      |                                                                         |                                                |                              |
| Configuration                        |      | PettingZoo-based MARL environment with randomized providers, 10 auction rounds, bid limits 20–100.                                     |                                                                         |                                                |                              |
|                                      |      |                                                                                                                                        |                                                                         |                                                |                              |
| Pre-test conditions                  |      | Environment initialized, at least 3 synthetic providers defined.                                                                       |                                                                         |                                                |                              |
|                                      |      |                                                                                                                                        |                                                                         |                                                |                              |
| Test Sequence                        | Step | Type                                                                                                                                   | Description                                                             |                                                | Result                       |
|                                      | 1    | Stimulus                                                                                                                               | Initialize auction environment with synthetic providers and random bids |                                                | Environment setup succeeds   |
|                                      | 2    | Check                                                                                                                                  | Boundary conditions (min/max bids, number of rounds) applied correctly  |                                                | Constraints respected        |
|                                      | 3    | Check                                                                                                                                  | Auction completes after fixed number of rounds without invalid states   |                                                | Auction terminates correctly |
| Test Verdict                         |      |                                                                                                                                        |                                                                         |                                                | Pass                         |
| Analytic Functional Test Description |      |                                                                                                                                        |                                                                         |                                                |                              |

|                                      |                                                                                                                                                                                       |          |                                                                                              |                         |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------------------------------------------------------------------------------------------|-------------------------|
| Test type                            | Functional                                                                                                                                                                            |          |                                                                                              |                         |
| Identifier                           | SPM_F002 + SPM_F004                                                                                                                                                                   |          |                                                                                              |                         |
| Tester                               | 8BELLS                                                                                                                                                                                |          |                                                                                              |                         |
| Test Purpose                         | Ensure that the neural network loss converges without overfitting and that the reinforcement learning agents display reasonable, sustainable bidding strategies under synthetic data. |          |                                                                                              |                         |
| References                           | [13], (Section 3.3 Training Process, Section 3.3.3 Reward Function, Section 5 Performance Evaluation)                                                                                 |          |                                                                                              |                         |
| Configuration                        | PPO training with PettingZoo MARL environment, 500 training steps, 2–10 providers, randomized bid limits between 20–100.                                                              |          |                                                                                              |                         |
|                                      |                                                                                                                                                                                       |          |                                                                                              |                         |
| Pre-test conditions                  | Training environment initialized, RL agents seeded with default hyperparameters.                                                                                                      |          |                                                                                              |                         |
|                                      |                                                                                                                                                                                       |          |                                                                                              |                         |
| Test Sequence                        | Step                                                                                                                                                                                  | Type     | Description                                                                                  | Result                  |
|                                      | 1                                                                                                                                                                                     | Stimulus | Start PPO training in auction environment                                                    | Training begins         |
|                                      | 2                                                                                                                                                                                     | Check    | Training loss decreases and stabilizes within threshold                                      | Loss converges          |
|                                      | 3                                                                                                                                                                                     | Check    | Agents produce competitive but not excessively low bids (≈30–35 range on average, Figure 23) | Stable pricing behavior |
|                                      | 4                                                                                                                                                                                     | Check    | Agents avoid collusion or repetitive degenerate strategies                                   | Behavior reasonable     |
| Test Verdict                         |                                                                                                                                                                                       |          |                                                                                              | Pass                    |
| Analytic Functional Test Description |                                                                                                                                                                                       |          |                                                                                              |                         |
| Test type                            | Functional                                                                                                                                                                            |          |                                                                                              |                         |
| Identifier                           | SPM_F003                                                                                                                                                                              |          |                                                                                              |                         |
| Tester                               | 8BELLS                                                                                                                                                                                |          |                                                                                              |                         |
| Test Purpose                         | Evaluate the SPM’s latency and throughput when subjected to high-frequency auction simulations.                                                                                       |          |                                                                                              |                         |
| References                           | [13] (Section 5.1 Results from Testing and Simulations, Section 5.2 Performance Benchmarks).                                                                                          |          |                                                                                              |                         |
| Configuration                        | Containerized SPM testbed running 100 simulated auctions/minute with randomized provider parameters.                                                                                  |          |                                                                                              |                         |
|                                      |                                                                                                                                                                                       |          |                                                                                              |                         |
| Pre-test conditions                  | Containerised SPM live, Load generator active                                                                                                                                         |          |                                                                                              |                         |
|                                      |                                                                                                                                                                                       |          |                                                                                              |                         |
| Test Sequence                        | Step                                                                                                                                                                                  | Type     | Description                                                                                  | Result                  |
|                                      | 1                                                                                                                                                                                     | Stimulus | Run bulk auction simulations with randomized parameters                                      | Requests processed      |
|                                      | 2                                                                                                                                                                                     | Check    | Average response time (Figure 26)                                                            | Latency acceptable      |
|                                      | 3                                                                                                                                                                                     | Check    | Throughput with no dropped auctions                                                          | Throughput acceptable   |
| Test Verdict                         |                                                                                                                                                                                       |          |                                                                                              | Pass                    |

```

=== Reverse Auction Env Initialized ===
Number of bidders: 4
Bid limits: [Provider_0: 32-95, Provider_1: 28-91, Provider_2: 37-99, Provider_3: 22-84]
Initial bids: [67.4, 72.1, 80.9, 45.2]
Max rounds: 10

Bids within constraints
[Round 1] Lowest bid: Provider_3 @ 45.2
Bids within constraints
[Round 2] Lowest bid: Provider_0 @ 44.8
Bids within constraints
[Round 3] Lowest bid: Provider_0 @ 43.6
Bids within constraints
[Round 4] Lowest bid: Provider_1 @ 42.9
Bids within constraints
[Round 5] Lowest bid: Provider_1 @ 42.1
Bids within constraints
[Round 6] Lowest bid: Provider_0 @ 41.7
Bids within constraints
[Round 7] Lowest bid: Provider_2 @ 41.2
Bids within constraints
[Round 8] Lowest bid: Provider_2 @ 40.6
Bids within constraints
[Round 9] Lowest bid: Provider_0 @ 40.1
Bids within constraints
[Round 10] Lowest bid: Provider_0 @ 39.7

=== Auction Complete ===
Winner: Provider_0
Final winning bid: 39.7
Constraints respected, env terminated

```

Figure 22: Environment test terminal output

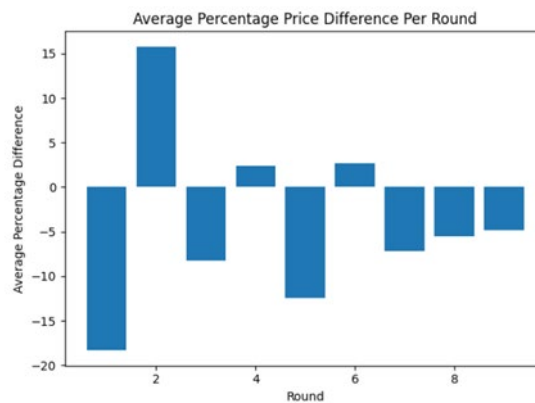


Figure 23: Average Agent Behavior

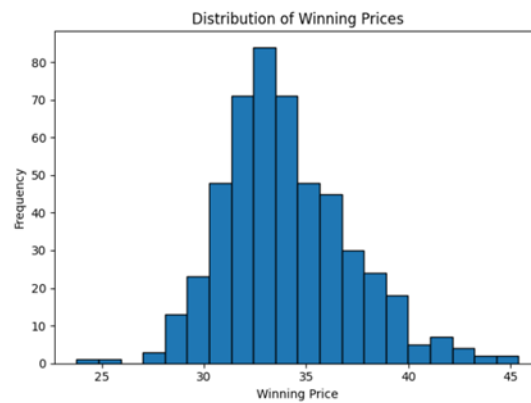


Figure 24: Winning Prices Distribution



Figure 25: Training Rewards

```
Starting load test: 100 auctions/min

[Batch 1] 103 requests | Avg latency: 790.7 ms | Success: 100% (0 dropped)
[Batch 2] 108 requests | Avg latency: 787.4 ms | Success: 100% (0 dropped)
[Batch 3] 112 requests | Avg latency: 811.9 ms | Success: 100% (0 dropped)
[Batch 4] 105 requests | Avg latency: 799.3 ms | Success: 100% (0 dropped)
[Batch 5] 107 requests | Avg latency: 778.6 ms | Success: 100% (0 dropped)

=== Load Test Summary ===
Total requests: 535
Successful: 535 (100%)
Dropped: 0 (0.0%)
Average response time: 793.58 ms
```

Figure 26: Load test terminal output

### 3.22. Explainable AI (XAI)

The NANCY Explainable AI (XAI) Component is a core building block of the NANCY framework, designed to enhance transparency and interpretability of AI models across multiple network domains. As detailed in [22], the component integrates several state-of-the-art explainability techniques including SHAP for global interpretability, LIME for local instance level explanations, and GradCAM/SHAP hybrid methods for vision based semantic communication scenarios. These techniques produce both visual artifacts such as plots, bar charts, and heatmaps, and structured JSON outputs, enabling explanations to be consumed by other NANCY components.

The XAI Component interacts with:

- FL IDS: Provides explainability for intrusion detection models, including those trained using federated learning approaches.
- AINQM: Offers interpretability for outage prediction in 5G networks, clarifying the influence of performance metrics such as PRBs, CQI, and buffer sizes.
- Semantic Communications models (ASL recognition and V2X object detection): Applies GradCAM and SHAP to highlight how CNN and YOLO models focus on semantic features within images.
- XAI Dashboard: Feeds structured explanations in both visual and JSON formats into the interactive visualization platform for operator use.
- LLM Powered Analysis Component: Passes SHAP-derived feature attributions to the LLM, which generates natural language explanations suitable for human decision makers.

Through this integration, the component ensures that AI driven predictions within NANCY are explainable, auditable, and actionable. It serves as the central explainability layer, connecting model outputs to human operators via dashboards and LLM interpretation. The functional tests of the XAI component are summarized in Table 23.

Table 23: XAI functional tests summary

| Functional Test ID                   | Objective                                                                                                                                                                                                                            | Status    |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| XAI_F001                             | Validation of system ability to load a saved model and retain its prediction methods.                                                                                                                                                | Completed |
| XAI_F002                             | Check that traffic data is preprocessed correctly.                                                                                                                                                                                   | Completed |
| XAI_F003                             | Validation of system generation of SHAP-based global explanations.                                                                                                                                                                   | Completed |
| XAI_F004                             | Validation of system generation of LIME-based local explanations.                                                                                                                                                                    | Completed |
| Analytic Functional Test Description |                                                                                                                                                                                                                                      |           |
| Test type                            | Functional                                                                                                                                                                                                                           |           |
| Identifier                           | XAI_F001                                                                                                                                                                                                                             |           |
| Tester                               | MINDS                                                                                                                                                                                                                                |           |
| Test Purpose                         | Verifies that a pre-trained model can be loaded successfully and works as expected. The goal is to confirm that the model remains usable after loading, keeping its ability to make predictions with both predict and predict_proba. |           |
| References                           | From anomaly_detection_explainer.py module, the load_model method.                                                                                                                                                                   |           |
| Configuration                        | <ul style="list-style-type: none"> <li>• A mock RandomForestClassifier is trained on random synthetic data.</li> <li>• The trained model is serialized and saved as a pickle file in a temporary directory.</li> </ul>               |           |

|                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  |                                              |
|--------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------------------------------------------------------------------------------------------------|----------------------------------------------|
|                                      | <ul style="list-style-type: none"><li>Required libraries (scikit-learn, numpy, pickle, pytest framework) are installed in the test environment.</li></ul>                                                                                                                                                                                                                                                                                                                    |          |                                                                                                  |                                              |
|                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  |                                              |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>A valid pickle file containing a trained model exists at the given path.</li><li>The environment permits reading the model file from disk.</li></ul>                                                                                                                                                                                                                                                                                   |          |                                                                                                  |                                              |
|                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  |                                              |
| Test Sequence                        | Step                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Type     | Description                                                                                      | Result                                       |
|                                      | 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Stimulus | Call <u>load_model</u> method with the path to the saved model file.                             | Model object returned                        |
|                                      | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Check    | Verify that the loaded object is not None.                                                       | Pass                                         |
|                                      | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Check    | Verify that the loaded object has the method predict.                                            | Pass                                         |
|                                      | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Check    | Verify that the loaded object has the method predict_proba.                                      | Pass                                         |
| Test Verdict                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  | Pass                                         |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  |                                              |
| Test type                            | Functional                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                  |                                              |
| Identifier                           | XAI_F002                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |          |                                                                                                  |                                              |
| Tester                               | MINDS                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |          |                                                                                                  |                                              |
| Test Purpose                         | This test verifies that the <u>preprocess_data</u> method correctly prepares network traffic data for machine learning models. The goal is to ensure that irrelevant columns are removed, missing or infinite values are handled, and numerical features are properly scaled using a provided pre-trained scaler, while preserving the target labels.                                                                                                                        |          |                                                                                                  |                                              |
| References                           | From anomaly_detection_explainer.py module the preprocess_data method.                                                                                                                                                                                                                                                                                                                                                                                                       |          |                                                                                                  |                                              |
| Configuration                        | <ul style="list-style-type: none"><li>A sample dataset simulating network traffic is generated with 50 instances, including metadata columns (Flow ID, Src IP, Dst IP, Protocol, Timestamp, Label) and numerical features used for modeling.</li><li>A pre-trained StandardScaler is created and saved to a temporary file to simulate the original scaler used.</li><li>Required libraries (pandas, numpy, scikit-learn, joblib, pytest framework) are available.</li></ul> |          |                                                                                                  |                                              |
|                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  |                                              |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>The sample data and scaler file exist and are accessible.</li><li>The environment permits reading the model and scaler files from disk.</li></ul>                                                                                                                                                                                                                                                                                      |          |                                                                                                  |                                              |
|                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  |                                              |
| Test Sequence                        | Step                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Type     | Description                                                                                      | Result                                       |
|                                      | 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Stimulus | Call preprocess_data with the sample dataset and mock scaler.                                    | Returns X_scaled DataFrame and y_true Series |
|                                      | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Check    | Verify X_scaled is a pandas DataFrame.                                                           | Pass                                         |
|                                      | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Check    | Verify y_true is a pandas Series.                                                                | Pass                                         |
|                                      | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Check    | Verify non-feature columns (Flow ID, Src IP, Dst IP, Protocol, Label) are removed from X_scaled. | Pass                                         |
|                                      | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Check    | Ensure that X_scaled contains no NaN values.                                                     | Pass                                         |
|                                      | 6                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Check    | Ensure that X_scaled contains no infinite values.                                                | Pass                                         |
| Test Verdict                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  | Pass                                         |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |          |                                                                                                  |                                              |
| Test type                            | Functional                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |          |                                                                                                  |                                              |
| Identifier                           | XAI_F003                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |          |                                                                                                  |                                              |
| Tester                               | MINDS                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |          |                                                                                                  |                                              |

|                                      |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                              |                                                            |
|--------------------------------------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------|
| Test Purpose                         |      | Verifies that the global_explain function can successfully generate global feature importance explanations for a machine learning model using SHAP. The test ensures that the function can process input data, calculate SHAP values, and save both visual (PNG) and JSON outputs without raising exceptions.                                                                                                                                                                                                              |                                                                              |                                                            |
| References                           |      | From anomaly_detection_explainer.py module the preprocess_data, load_model and global_explain methods.                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                              |                                                            |
| Configuration                        |      | <ul style="list-style-type: none"><li>Raw sample_data DataFrame containing network traffic features.</li><li>A mock RandomForestClassifier saved as a pickle file (mock_model).</li><li>A mock StandardScaler saved as a joblib file (mock_scaler), used for preprocessing the numeric features.</li><li>Temporary path (tmp_path/global_output) where explanation files (plots and JSON) are stored.</li><li>Required packages (shap, matplotlib, pandas, numpy, pytest framework) are installed and available.</li></ul> |                                                                              |                                                            |
| Pre-test conditions                  |      | <ul style="list-style-type: none"><li>The mock model has been trained and saved to disk.</li><li>The mock scaler has been trained and saved to disk.</li><li>Sample network traffic data has been created and contains all required columns, including the features used by the model.</li><li>The environment has write access to the temporary output directory (tmp_path) and read access to load the model and scaler.</li></ul>                                                                                       |                                                                              |                                                            |
| Test Sequence                        | Step | Type                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Description                                                                  | Result                                                     |
|                                      | 1    | Stimulus                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Preprocess the sample_data using preprocess_data and the mock scaler         | Returns X_scaled DataFrame                                 |
|                                      | 2    | Check                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Load the mock model from file using load_model.                              | Returns the trained model object                           |
|                                      | 3    | Check                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Call global_explain method to generate explanations                          | Generates PNG plots and JSON files in the output directory |
|                                      | 4    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Verify that no exceptions are raised during the execution of global_explain. | Pass                                                       |
| Test Verdict                         |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                              | Pass                                                       |
| Analytic Functional Test Description |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                              |                                                            |
| Test type                            |      | Functional                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                              |                                                            |
| Identifier                           |      | XAI_F004                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                              |                                                            |
| Tester                               |      | MINDS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                              |                                                            |
| Test Purpose                         |      | Verifies that the local_explain function can generate local explanations for a network flow without raising exceptions. The test ensures that the function executes properly.                                                                                                                                                                                                                                                                                                                                              |                                                                              |                                                            |
| References                           |      | From anomaly_detection_explainer.py module the preprocess_data, load_model and local_explain methods.                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                              |                                                            |
| Configuration                        |      | <ul style="list-style-type: none"><li>Sample data (raw network flow dataset, not scaled).</li><li>A mock model pretrained RandomForestClassifier and saved.</li><li>A Mock Scaler used in preprocessing to scale numeric features.</li><li>Flow ID set to 0 (first row of the dataset).</li><li>Temporary directory tmp_path / "local_output" for storing PNG and JSON files.</li><li>Required packages (LIME, matplotlib, json, pandas, numpy, pytest framework) are installed and available.</li></ul>                   |                                                                              |                                                            |

| <b>Pre-test conditions</b> |      | <ul style="list-style-type: none"> <li>Sample data has been created (DataFrame with 50 network flows and relevant features).</li> <li>The mock model has been trained and saved to disk.</li> <li>The mock scaler has been trained and saved to disk.</li> <li>The environment has write access to the temporary output directory (tmp_path) and read access to load the model and scaler.</li> </ul> |                                                                             |                                                            |
|----------------------------|------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------|
| Test Sequence              | Step | Type                                                                                                                                                                                                                                                                                                                                                                                                  | Description                                                                 | Result                                                     |
|                            | 1    | Stimulus                                                                                                                                                                                                                                                                                                                                                                                              | Preprocess the sample_data using preprocess_data and the mock scaler.       | Returns X_scaled DataFrame                                 |
|                            | 2    | Stimulus                                                                                                                                                                                                                                                                                                                                                                                              | Load the mock model from file using load_model.                             | Returns the trained model object                           |
|                            | 3    | Stimulus                                                                                                                                                                                                                                                                                                                                                                                              | Call local_explain method to generate explanations for the first flow.      | Generates PNG plots and JSON files in the output directory |
|                            | 4    | Check                                                                                                                                                                                                                                                                                                                                                                                                 | Verify that no exceptions are raised during the execution of local_explain. | Pass                                                       |
| <b>Test Verdict</b>        |      |                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                             | Pass                                                       |

### 3.23. Federated Learning Intrusion Detection System (FL-IDS)

The FL-IDS component provides a privacy-preserving and scalable security mechanism for detecting anomalies and cyber threats in Beyond 5G (B5G) and 6G networks. It leverages Federated Learning (FL) to train intrusion detection models collaboratively across distributed clients, without centralizing sensitive network traffic data. This approach aligns with the O-RAN distributed architecture, minimizing bandwidth consumption and reducing privacy risks, while maintaining strong detection performance.

The system, first detailed in [6], is implemented on the Flower (Flwr) framework and supports flexible aggregation strategies (e.g., FedAdagrad), dynamic client scaling, containerized deployment, and robust error handling. It includes a streaming-based preprocessing pipeline that transforms raw network traffic into ML-ready features, ensuring consistency across clients and preserving privacy.

Beyond the FL-IDS neural network-based architecture, a second methodology has also been developed for Federated Random Forest (FedRF) anomaly detection in cellular networks. This consensus-based approach, as described in [6] and related publications, enables fully decentralized feature selection and improves resilience against central points of failure.

Interactions with other NANCY components:

- **Data Processing Pipelines:** FL-IDS integrates with NANCY's data collection and traffic preprocessing components to extract flows and features.
- **Orchestration & Deployment:** Its Docker/Kubernetes-based deployment ensures smooth integration with NANCY's orchestration layer for scalable, distributed environments.

The tests for the FL-IDS are summarized in Table 24.

Table 24: FL-IDS functional tests summary

| Functional Test ID                   |                                                                                                                                                                                        | Objective                                                                                                  | Status                                             |                             |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|----------------------------------------------------|-----------------------------|
| FL-IDS_F001                          |                                                                                                                                                                                        | Validation that the client returns the correct model parameters.                                           | Completed                                          |                             |
| FL-IDS_F002                          |                                                                                                                                                                                        | Validation that the client model fit works as expected.                                                    | Completed                                          |                             |
| FL-IDS_F003                          |                                                                                                                                                                                        | Validation of the client model evaluation (loss, evaluation metrics).                                      | Completed                                          |                             |
| FL-IDS_F004                          |                                                                                                                                                                                        | Validation that the client saves the model and handles the directory creation correctly.                   | Completed                                          |                             |
| FL-IDS_F005                          |                                                                                                                                                                                        | Validation that the server initializes without starting a real server (mocked model and server functions). | Completed                                          |                             |
| FL-IDS_F006                          |                                                                                                                                                                                        | Validation that the client initializes, without connecting to a server (mocked data and start function).   | Completed                                          |                             |
| FL-IDS_F007                          |                                                                                                                                                                                        | Validation that the run_experiment script can be imported.                                                 | Completed                                          |                             |
| FL-IDS_F008                          |                                                                                                                                                                                        | Verify that the weighted average of metrics is calculated correctly.                                       | Completed                                          |                             |
| Analytic Functional Test Description |                                                                                                                                                                                        |                                                                                                            |                                                    |                             |
| Test type                            | Functional                                                                                                                                                                             |                                                                                                            |                                                    |                             |
| Identifier                           | FL-IDS_F001                                                                                                                                                                            |                                                                                                            |                                                    |                             |
| Tester                               | MINDS                                                                                                                                                                                  |                                                                                                            |                                                    |                             |
| Test Purpose                         | Verify that the client can return its model parameters in the expected format                                                                                                          |                                                                                                            |                                                    |                             |
| References                           | From NancyClient class in the src.client.client module, the get_parameters method.                                                                                                     |                                                                                                            |                                                    |                             |
| Configuration                        | <ul style="list-style-type: none"><li>Test environment using unittest with numpy package installed.</li><li>Mock training data with 100 samples, 10 features, and 3 classes.</li></ul> |                                                                                                            |                                                    |                             |
|                                      |                                                                                                                                                                                        |                                                                                                            |                                                    |                             |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>NancyClient instance initialized with training and testing data.</li><li>Random seed set to ensure reproducibility.</li></ul>                    |                                                                                                            |                                                    |                             |
|                                      |                                                                                                                                                                                        |                                                                                                            |                                                    |                             |
| Test Sequence                        | Step                                                                                                                                                                                   | Type                                                                                                       | Description                                        | Result                      |
|                                      | 1                                                                                                                                                                                      | Stimulus                                                                                                   | Call get_parameters method with the argument ({}). | List of parameters returned |
|                                      | 2                                                                                                                                                                                      | Check                                                                                                      | Verify output is a list                            | Pass                        |
|                                      | 3                                                                                                                                                                                      | Check                                                                                                      | Verify each parameter is a numpy.ndarray.          | Pass                        |
| Test Verdict                         |                                                                                                                                                                                        |                                                                                                            |                                                    | Pass                        |
| Analytic Functional Test Description |                                                                                                                                                                                        |                                                                                                            |                                                    |                             |
| Test type                            | Functional                                                                                                                                                                             |                                                                                                            |                                                    |                             |
| Identifier                           | FL-IDS_F002                                                                                                                                                                            |                                                                                                            |                                                    |                             |
| Tester                               | MINDS                                                                                                                                                                                  |                                                                                                            |                                                    |                             |
| Test Purpose                         | Verify that the client can fit its local model and return updated parameters, number of examples, and metrics.                                                                         |                                                                                                            |                                                    |                             |
| References                           | From NancyClient class in the src.client.client module, the fit method.                                                                                                                |                                                                                                            |                                                    |                             |
| Configuration                        | <ul style="list-style-type: none"><li>Test environment using unittest and numpy package installed.</li><li>Training dataset of 100 samples and 10 features.</li></ul>                  |                                                                                                            |                                                    |                             |
|                                      |                                                                                                                                                                                        |                                                                                                            |                                                    |                             |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>Client initialized with data and 1 training epoch.</li><li>Initial parameters obtained via get_parameters.</li></ul>                             |                                                                                                            |                                                    |                             |

| Test Sequence                        | Step                                                                                                                                                                                                                                                    | Type     | Description                                                         | Result                                                      |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------------------------------------------------------|-------------------------------------------------------------|
|                                      | 1                                                                                                                                                                                                                                                       | Stimulus | Call fit method with initial_params and 1 epoch.                    | Returns updated parameters, number of examples, and metrics |
|                                      | 2                                                                                                                                                                                                                                                       | Check    | Verify updated parameters are a list.                               | Pass                                                        |
|                                      | 3                                                                                                                                                                                                                                                       | Check    | Verify num_examples equals to 100.                                  | Pass                                                        |
|                                      | 4                                                                                                                                                                                                                                                       | Check    | Verify returned metrics is a dict containing "loss" and "accuracy". | Pass                                                        |
| Test Verdict                         |                                                                                                                                                                                                                                                         |          |                                                                     | Pass                                                        |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                         |          |                                                                     |                                                             |
| Test type                            | Functional                                                                                                                                                                                                                                              |          |                                                                     |                                                             |
| Identifier                           | FL-IDS_F003                                                                                                                                                                                                                                             |          |                                                                     |                                                             |
| Tester                               | MINDS                                                                                                                                                                                                                                                   |          |                                                                     |                                                             |
| Test Purpose                         | Verify that the client can evaluate its model and return loss, number of test examples, and evaluation metrics.                                                                                                                                         |          |                                                                     |                                                             |
| References                           | From NancyClient class in the src.client.client module, the evaluate method.                                                                                                                                                                            |          |                                                                     |                                                             |
| Configuration                        | <ul style="list-style-type: none"><li>Test environment using unittest.</li><li>Test dataset of 50 samples.</li></ul>                                                                                                                                    |          |                                                                     |                                                             |
|                                      |                                                                                                                                                                                                                                                         |          |                                                                     |                                                             |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>Client initialized with data.</li><li>Model parameters obtained via get_parameters.</li></ul>                                                                                                                     |          |                                                                     |                                                             |
|                                      |                                                                                                                                                                                                                                                         |          |                                                                     |                                                             |
| Test Sequence                        | Step                                                                                                                                                                                                                                                    | Type     | Description                                                         | Result                                                      |
|                                      | 1                                                                                                                                                                                                                                                       | Stimulus | Call evaluate method with retrieved parameters.                     | Returns loss, number of examples, and metrics               |
|                                      | 2                                                                                                                                                                                                                                                       | Check    | Verify loss is a float.                                             | Pass                                                        |
|                                      | 3                                                                                                                                                                                                                                                       | Check    | Verify num_examples equals to 50.                                   | Pass                                                        |
|                                      | 4                                                                                                                                                                                                                                                       | Check    | Verify metrics is a dict.                                           | Pass                                                        |
|                                      | 5                                                                                                                                                                                                                                                       | Check    | Verify metrics include "accuracy", "tpr", "fpr", "f1", "auc".       | Pass                                                        |
| Test Verdict                         |                                                                                                                                                                                                                                                         |          |                                                                     | Pass                                                        |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                         |          |                                                                     |                                                             |
| Test type                            | Functional                                                                                                                                                                                                                                              |          |                                                                     |                                                             |
| Identifier                           | FL-IDS_F004                                                                                                                                                                                                                                             |          |                                                                     |                                                             |
| Tester                               | MINDS                                                                                                                                                                                                                                                   |          |                                                                     |                                                             |
| Test Purpose                         | Verify that the client can save its model to a specified path.                                                                                                                                                                                          |          |                                                                     |                                                             |
| References                           | From NancyClient class in the src.client.client module, the save_model method.                                                                                                                                                                          |          |                                                                     |                                                             |
| Configuration                        | <ul style="list-style-type: none"><li>Test environment using unittest with unittest.mock.patch to replace Sequential.save and os.makedirs.</li><li>TensorFlow must be installed, because the model is instantiated in the client constructor.</li></ul> |          |                                                                     |                                                             |
|                                      |                                                                                                                                                                                                                                                         |          |                                                                     |                                                             |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>NancyClient initialized with mock data.</li><li>Sequential.save patched to prevent actual file writing.</li><li>os.makedirs patched to prevent directory creation.</li></ul>                                      |          |                                                                     |                                                             |

| Test Sequence                        | Step                                                                                                                                                                                                                                                   | Type     | Description                                                 | Result                                             |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-------------------------------------------------------------|----------------------------------------------------|
|                                      | 1                                                                                                                                                                                                                                                      | Stimulus | Call save_model with “test/path” input.                     | Model save function invoked                        |
|                                      | 2                                                                                                                                                                                                                                                      | Check    | Verify mock_save was called once with "test/path" as input. | Pass                                               |
| Test Verdict                         |                                                                                                                                                                                                                                                        |          |                                                             | Pass                                               |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                        |          |                                                             |                                                    |
| Test type                            | Functional                                                                                                                                                                                                                                             |          |                                                             |                                                    |
| Identifier                           | FL-IDS_F005                                                                                                                                                                                                                                            |          |                                                             |                                                    |
| Tester                               | MINDS                                                                                                                                                                                                                                                  |          |                                                             |                                                    |
| Test Purpose                         | Verify that the Flower server can be initialized without actually starting a real server.                                                                                                                                                              |          |                                                             |                                                    |
| References                           | From server module in the src.server directory, the start_server method.                                                                                                                                                                               |          |                                                             |                                                    |
| Configuration                        | <ul style="list-style-type: none"><li>Test environment using unittest and unittest.mock.patch to mock model creation (create_model) and Flower server start (flwr.server.start_server).</li><li>Numpy, Tensorflow, Flwr packages installed.</li></ul>  |          |                                                             |                                                    |
|                                      |                                                                                                                                                                                                                                                        |          |                                                             |                                                    |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>MagicMock model with get_weights method returning sample numpy arrays.</li><li>create_model patched to return the mock model.</li><li>flwr.server.start_server patched to prevent real server startup.</li></ul> |          |                                                             |                                                    |
|                                      |                                                                                                                                                                                                                                                        |          |                                                             |                                                    |
| Test Sequence                        | Step                                                                                                                                                                                                                                                   | Type     | Description                                                 | Result                                             |
|                                      | 1                                                                                                                                                                                                                                                      | Stimulus | Call start_server with test parameters                      | Server initialization function called successfully |
| Test Verdict                         |                                                                                                                                                                                                                                                        |          |                                                             | Pass                                               |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                        |          |                                                             |                                                    |
| Test type                            | Functional                                                                                                                                                                                                                                             |          |                                                             |                                                    |
| Identifier                           | FL-IDS_F006                                                                                                                                                                                                                                            |          |                                                             |                                                    |
| Tester                               | MINDS                                                                                                                                                                                                                                                  |          |                                                             |                                                    |
| Test Purpose                         | Verify that a Flower client can be initialized without actually connecting to a server.                                                                                                                                                                |          |                                                             |                                                    |
| References                           | From client module in the src.client directory, the start_client and load_data methods.                                                                                                                                                                |          |                                                             |                                                    |
| Configuration                        | <ul style="list-style-type: none"><li>Test environment with unittest</li><li>Packages numpy, pandas, joblib, tensorflow and flwr installed.</li><li>Mocks for load_data and flwr.client.start_numpy_client</li></ul>                                   |          |                                                             |                                                    |
|                                      |                                                                                                                                                                                                                                                        |          |                                                             |                                                    |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>Mock load_data returns synthetic train/test datasets (100 train, 50 test samples, 10 features, 3 classes)</li><li>flwr.client.start_numpy_client patched to avoid real server communication</li></ul>            |          |                                                             |                                                    |
| 1                                    |                                                                                                                                                                                                                                                        |          |                                                             |                                                    |
|                                      |                                                                                                                                                                                                                                                        |          |                                                             |                                                    |
| Test Sequence                        | Step                                                                                                                                                                                                                                                   | Type     | Description                                                 | Result                                             |
|                                      | 1                                                                                                                                                                                                                                                      | Stimulus | Call start_client with test parameters.                     | Client initialization function called              |
|                                      | 3                                                                                                                                                                                                                                                      | Check    | Verify start_numpy_client is called once                    | Pass                                               |
|                                      | 4                                                                                                                                                                                                                                                      | Check    | Verify server_address argument matches expected.            | Pass                                               |
| Test Verdict                         |                                                                                                                                                                                                                                                        |          |                                                             | Pass                                               |
| Analytic Functional Test Description |                                                                                                                                                                                                                                                        |          |                                                             |                                                    |
| Test type                            | Functional                                                                                                                                                                                                                                             |          |                                                             |                                                    |

|                                      |                                                                                                                                               |          |                                                                   |                              |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|----------|-------------------------------------------------------------------|------------------------------|
| Identifier                           | FL-IDS_F007                                                                                                                                   |          |                                                                   |                              |
| Tester                               | MINDS                                                                                                                                         |          |                                                                   |                              |
| Test Purpose                         | Verify that the run_experiment script can be imported and contains a main function.                                                           |          |                                                                   |                              |
| References                           | From scripts directory the run_experiment module.                                                                                             |          |                                                                   |                              |
| Configuration                        | <ul style="list-style-type: none"><li>Test environment with unittest.</li></ul>                                                               |          |                                                                   |                              |
|                                      |                                                                                                                                               |          |                                                                   |                              |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>Script run_experiment.py exists in the expected location.</li></ul>                                     |          |                                                                   |                              |
|                                      |                                                                                                                                               |          |                                                                   |                              |
| Test Sequence                        | Step                                                                                                                                          | Type     | Description                                                       | Result                       |
|                                      | 1                                                                                                                                             | Stimulus | From scripts import run_experiment.                               | Module imported successfully |
|                                      | 2                                                                                                                                             | Check    | Verify the module has a main attribute.                           | Pass                         |
| Test Verdict                         |                                                                                                                                               |          |                                                                   | Pass                         |
| Analytic Functional Test Description |                                                                                                                                               |          |                                                                   |                              |
| Test type                            | Functional                                                                                                                                    |          |                                                                   |                              |
| Identifier                           | FL-IDS_F008                                                                                                                                   |          |                                                                   |                              |
| Tester                               | MINDS                                                                                                                                         |          |                                                                   |                              |
| Test Purpose                         | Verify that the weighted_average function correctly computes a weighted average of a list of metric values.                                   |          |                                                                   |                              |
| References                           | From server module in the src.server directory, the weighted_average method.                                                                  |          |                                                                   |                              |
| Configuration                        | <ul style="list-style-type: none"><li>Test environment with unittest and numpy package installed.</li></ul>                                   |          |                                                                   |                              |
|                                      |                                                                                                                                               |          |                                                                   |                              |
| Pre-test conditions                  | <ul style="list-style-type: none"><li>Sample list of metrics, corresponding weights and the expected weighted average pre-computed.</li></ul> |          |                                                                   |                              |
|                                      |                                                                                                                                               |          |                                                                   |                              |
| Test Sequence                        | Step                                                                                                                                          | Type     | Description                                                       | Result                       |
|                                      | 1                                                                                                                                             | Stimulus | Call weighted_average with sample metrics and weights.            | Returns a numeric result     |
|                                      | 2                                                                                                                                             | Check    | Verify the result is approximately equal to the expected average. | Pass                         |
| Test Verdict                         |                                                                                                                                               |          |                                                                   | Pass                         |

### 3.24. Memory Traffic Generator - Resource Monitor (MTG-RM)

The Memory Traffic Generator – Resource Monitor (MTG-RM) component is designed to evaluate, stress, and control system behavior under memory traffic conditions. It provides a controlled framework for generating and monitoring high levels of memory activity, which are representative of both legitimate high-performance workloads and potentially malicious memory-bound applications.

The MTG-RM module serves a dual purpose:

1. **Memory Traffic Generation (MTG):** This subsystem is capable of producing intense and configurable memory access patterns to simulate interference scenarios or denial-of-service (DoS) conditions at the memory subsystem level.
2. **Resource Monitoring (RM):** The monitoring subsystem provides fine-grained insight into CPU-level resource utilization and memory traffic intensity through the use of Performance Monitoring Units (PMUs).

The MTG-RM framework is therefore used for assessing the resilience of computing systems to improve real-time performance and security. Table 25 summarizes the MTG-RM functional tests.

Table 25: MTG-RM functional tests summary

| Functional Test ID                   |      | Objective                                                                                                                                                                                                                                                                                    |                                                                                                                                                        | Status    |
|--------------------------------------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| MTG-RM_F001                          |      | Demonstrate capability of generating intense memory traffic to simulate malicious behavior.                                                                                                                                                                                                  |                                                                                                                                                        | Completed |
| MTG-RM_F002                          |      | Monitor the system resource usage at the CPU level as provided by Performance Measurement Units.                                                                                                                                                                                             |                                                                                                                                                        | Completed |
| MTG-RM_F003                          |      | Limit the CPU resources assigned to malicious application.                                                                                                                                                                                                                                   |                                                                                                                                                        | Completed |
| Analytic Functional Test Description |      |                                                                                                                                                                                                                                                                                              |                                                                                                                                                        |           |
| Test type                            |      | Functional                                                                                                                                                                                                                                                                                   |                                                                                                                                                        |           |
| Identifier                           |      | MTG-RM_F001                                                                                                                                                                                                                                                                                  |                                                                                                                                                        |           |
| Tester                               |      | SSS                                                                                                                                                                                                                                                                                          |                                                                                                                                                        |           |
| Test Purpose                         |      | The test aims to demonstrate the capability of generating intense memory traffic by continuously accessing memory areas with a limit-case access pattern that maximizes interference. The memory traffic generator application is further protected by SCHED_DEADLINE to control its impact. |                                                                                                                                                        |           |
| References                           |      |                                                                                                                                                                                                                                                                                              |                                                                                                                                                        |           |
| Configuration                        |      | Selection of amount of memory to be accessed, selection of period and runtime for SCHED_DEADLINE                                                                                                                                                                                             |                                                                                                                                                        |           |
|                                      |      |                                                                                                                                                                                                                                                                                              |                                                                                                                                                        |           |
| Pre-test conditions                  |      | None.                                                                                                                                                                                                                                                                                        |                                                                                                                                                        |           |
|                                      |      |                                                                                                                                                                                                                                                                                              |                                                                                                                                                        |           |
| Test Sequence                        | Step | Type                                                                                                                                                                                                                                                                                         | Description                                                                                                                                            | Result    |
|                                      | 1    | Stimulus                                                                                                                                                                                                                                                                                     | Launch a script with the following command:<br><br>taskset -c \$core chrt -d -T \$runtime -D \$period -P \$period 0 ./dos-attack-sim-endless -m 131072 |           |
|                                      | 2    | Check                                                                                                                                                                                                                                                                                        | The test is successful when a meaningful slowdown of any other memory-bound application is observed.                                                   |           |
| Test Verdict                         |      | Pass                                                                                                                                                                                                                                                                                         |                                                                                                                                                        |           |
| Analytic Functional Test Description |      |                                                                                                                                                                                                                                                                                              |                                                                                                                                                        |           |
| Test type                            |      | Functional                                                                                                                                                                                                                                                                                   |                                                                                                                                                        |           |
| Identifier                           |      | MTG-RM_F002                                                                                                                                                                                                                                                                                  |                                                                                                                                                        |           |
| Tester                               |      | SSS                                                                                                                                                                                                                                                                                          |                                                                                                                                                        |           |
| Test Purpose                         |      | The test aims to demonstrate the capability of the memory traffic monitor tool to analyze the memory traffic of any application. The test consists in running the memory traffic analyzer tool to read the ARM performance counters of a memory-intensive application.                       |                                                                                                                                                        |           |
| References                           |      |                                                                                                                                                                                                                                                                                              |                                                                                                                                                        |           |
| Configuration                        |      | The application to be monitored is selected from the IsolBench benchmark suite, specifically the "latency" application.                                                                                                                                                                      |                                                                                                                                                        |           |
|                                      |      |                                                                                                                                                                                                                                                                                              |                                                                                                                                                        |           |
| Pre-test conditions                  |      | None.                                                                                                                                                                                                                                                                                        |                                                                                                                                                        |           |

| Test Sequence                        | Step | Type                                                                                                                                                             | Description                                                                                                                                                                                                                                                                     | Result |
|--------------------------------------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
|                                      | 1    | Stimulus                                                                                                                                                         | The script used to test the monitor is "test-monitor.sh" in the "sss_malicious_appl/monitor" folder. What it does is launching the following command:<br><br>taskset -c 1 chrt -r 99 ../appl/dos-attack-sim -m 1 -i 100000000 & ./start-monitor.sh \$!                          |        |
|                                      | 2    | Check                                                                                                                                                            | The test is successful when the monitor creates a .csv file in the "results" folder named with the PID of the monitored application containing the value of the counters read by the monitor, thus proving that the monitor is able to read the performance counter of the PMU. |        |
| Test Verdict                         |      |                                                                                                                                                                  |                                                                                                                                                                                                                                                                                 | Pass   |
| Analytic Functional Test Description |      |                                                                                                                                                                  |                                                                                                                                                                                                                                                                                 |        |
| Test type                            |      | Functional                                                                                                                                                       |                                                                                                                                                                                                                                                                                 |        |
| Identifier                           |      | MTG-RM_F003                                                                                                                                                      |                                                                                                                                                                                                                                                                                 |        |
| Tester                               |      | SSS                                                                                                                                                              |                                                                                                                                                                                                                                                                                 |        |
| Test Purpose                         |      | This test aims at assessing the capability of SCHED_DEADLINE Linux’s scheduling class of controlling the amount of CPU interference generated by software tasks. |                                                                                                                                                                                                                                                                                 |        |
| References                           |      |                                                                                                                                                                  |                                                                                                                                                                                                                                                                                 |        |
| Configuration                        |      | Selection of a CPU-eager application (yes), as well as SCHED_DEADLINE period, runtime pair and target processor core.                                            |                                                                                                                                                                                                                                                                                 |        |
| Pre-test conditions                  |      | None                                                                                                                                                             |                                                                                                                                                                                                                                                                                 |        |
| Test Sequence                        | Step | Type                                                                                                                                                             | Description                                                                                                                                                                                                                                                                     | Result |
|                                      | 1    | Stimulus                                                                                                                                                         | Launch the following command to execute “yes’ protected by SCHED_DEADLINE:<br><br>taskset -c \$core chrt -d -T \$runtime -D \$period -P \$period 0 yes > /dev/null                                                                                                              |        |
|                                      | 2    | Check                                                                                                                                                            | Monitor the CPU interference (i.e., usage) of ‘yes' and corresponding impact of other processes.                                                                                                                                                                                |        |
| Test Verdict                         |      |                                                                                                                                                                  |                                                                                                                                                                                                                                                                                 | Pass   |

### 3.25. Post Quantum Cryptography – Secure Communications (PQC-SC)

This component enables MQTT communication secured with TLS through the Mosquitto broker, leveraging OpenSSL for cryptographic operations. It supports both classical and post-quantum algorithms, with the OpenSSL provider facilitating modular integration of PQC algorithms from the Open Quantum Safe (OQS) library. This setup ensures encrypted, authenticated, and quantum-resistant communication between MQTT clients and the broker. Further details can be found in [11]-Section 5: PQC for Secure Communications.

Table 26: PQC-SC functional tests summary

| Functional Test ID                   |      | Objective                                                                                                            |                                                                                                                                                      | Status    |
|--------------------------------------|------|----------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| PQC-SC_F001                          |      | Successful integration of PQC algorithms into OpenSSL library.                                                       |                                                                                                                                                      | Completed |
| PQC-SC_F002                          |      | Successful communication using TLS of a specific MQTT application.                                                   |                                                                                                                                                      | Completed |
| Analytic Functional Test Description |      |                                                                                                                      |                                                                                                                                                      |           |
| Test type                            |      | Functional                                                                                                           |                                                                                                                                                      |           |
| Identifier                           |      | PQC-SC_F001                                                                                                          |                                                                                                                                                      |           |
| Tester                               |      | TEI                                                                                                                  |                                                                                                                                                      |           |
| Test Purpose                         |      | Integrate PQC algorithms for key exchange and digital signatures within the TLS protocol considering OpenSSL library |                                                                                                                                                      |           |
| References                           |      | [11] - Section 5 PQC for Secure Communications                                                                       |                                                                                                                                                      |           |
| Configuration                        |      | Containerized testbed environment with docker.                                                                       |                                                                                                                                                      |           |
|                                      |      |                                                                                                                      |                                                                                                                                                      |           |
| Pre-test conditions                  |      | Network connectivity among the various elements of the testbed.                                                      |                                                                                                                                                      |           |
|                                      |      |                                                                                                                      |                                                                                                                                                      |           |
| Test Sequence                        | Step | Type                                                                                                                 | Description                                                                                                                                          | Result    |
|                                      | 1    | Stimulus                                                                                                             | Run a container using modified version of OpenSSL integrated with OQS (Open Quantum Safe) as a specific provider.                                    | Pass      |
|                                      | 2    | Check                                                                                                                | Use the specific “openssl list” command to check if post-quantum cryptography (PQC) signature algorithms are available.                              | Pass      |
|                                      | 3    | Check                                                                                                                | Run the appropriate “openssl list” command to verify that post-quantum cryptography (PQC) Key Encapsulation Mechanism (KEM) algorithms are available | Pass      |
| Test Verdict                         |      |                                                                                                                      |                                                                                                                                                      | Pass      |
| Analytic Functional Test Description |      |                                                                                                                      |                                                                                                                                                      |           |
| Test type                            |      | Functional                                                                                                           |                                                                                                                                                      |           |
| Identifier                           |      | PQC-SC_F002                                                                                                          |                                                                                                                                                      |           |
| Tester                               |      | TEI                                                                                                                  |                                                                                                                                                      |           |
| Test Purpose                         |      | Demonstrate PQC algorithms integrated in OpenSSL TLS library in an MQTT protocol communication scenario.             |                                                                                                                                                      |           |
| References                           |      | [11] - Section 5 PQC for Secure Communications                                                                       |                                                                                                                                                      |           |
| Configuration                        |      | Containerized testbed environment with docker.                                                                       |                                                                                                                                                      |           |
|                                      |      |                                                                                                                      |                                                                                                                                                      |           |
| Pre-test conditions                  |      | Network connectivity among the various element of the testbed.                                                       |                                                                                                                                                      |           |
|                                      |      |                                                                                                                      |                                                                                                                                                      |           |
| Test Sequence                        | Step | Type                                                                                                                 | Description                                                                                                                                          | Result    |
|                                      | 1    | Stimulus                                                                                                             | Run Mosquitto MQTT broker integrated with OpenSSL PQC enabled library                                                                                | Pass      |
|                                      | 2    | Stimulus                                                                                                             | Run the Mosquitto client (publisher or subscriber) with OpenSSL and the PQC library enabled, then connect to the broker.                             | Pass      |
|                                      | 3    | Check                                                                                                                | Capture the communication using the tcpdump utility to generate a pcap file, then verify in the TLS                                                  | Pass      |

|                     |  |                                                                     |             |
|---------------------|--|---------------------------------------------------------------------|-------------|
|                     |  | handshake that post-quantum cryptography algorithms are being used. |             |
| <b>Test Verdict</b> |  |                                                                     | <b>Pass</b> |

### 3.26. Distributed Anomaly Detection and Mitigation (D-ADM)

This component enables distributed anomaly detection and compensation on the edge. For the anomaly detection part, it is based on machine learning models to detect anomalies in the edge servers' workload (e.g., CPU, RAM, disk, network usages), while for the anomaly compensation part it is based on a game-theory algorithm for balancing network and computing resources in order to dynamically equalize a certain metric (defined by the operator) among the different users, to reach a so-called Wardrop User Equilibrium. Both components are detailed in [6], and in particular in sections 2.3 and 2.7 respectively. A summary of the functional tests of the FL-IDS is included in Table 27.

Table 27: FL-IDS functional tests summary

| Functional Test ID                   |      | Objective                                                                                                                                                                                                        | Status                                                                                                                                                       |        |
|--------------------------------------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| D-ADM_F001                           |      | Application and validation of the automatic anomaly detection methodology within a testbed with data from malicious server applications.                                                                         | Completed                                                                                                                                                    |        |
| D-ADM_F002                           |      | Testing of anomaly compensation techniques in a testbed for load balancing purposes.                                                                                                                             | Completed                                                                                                                                                    |        |
| Analytic Functional Test Description |      |                                                                                                                                                                                                                  |                                                                                                                                                              |        |
| Test type                            |      | Functional                                                                                                                                                                                                       |                                                                                                                                                              |        |
| Identifier                           |      | D-ADM_F001                                                                                                                                                                                                       |                                                                                                                                                              |        |
| Tester                               |      | CRAT                                                                                                                                                                                                             |                                                                                                                                                              |        |
| Test Purpose                         |      | Demonstrate the correctness of the implementation of the components and of the interfaces                                                                                                                        |                                                                                                                                                              |        |
| References                           |      | [6], Section 2.3: “Federated Learning Algorithm for Improved Anomaly Detection in Cellular Networks“                                                                                                             |                                                                                                                                                              |        |
| Configuration                        |      | The machine learning models have been trained using ITL datasets 2 and 3 (respectively for normal operation and under attack). The configuration is taken by a Docker Compose script associated with an ENV file |                                                                                                                                                              |        |
| Pre-test conditions                  |      | Receiving metrics from the testbed or synthetic data for the prediction of anomalies.                                                                                                                            |                                                                                                                                                              |        |
| Test Sequence                        | Step | Type                                                                                                                                                                                                             | Description                                                                                                                                                  | Result |
|                                      | 1    | Stimulus                                                                                                                                                                                                         | Send a normal operation sample (unseen at training stage) to the anomaly detection module                                                                    |        |
|                                      | 2    | Check                                                                                                                                                                                                            | Check that the anomaly detection modules classify it as normal execution and send the correct data to the visualization dashboard (if connected) (Figure 27) | Pass   |

|                                      |                                                                                           |          |                                                                                                                                                     |        |
|--------------------------------------|-------------------------------------------------------------------------------------------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------|--------|
|                                      | 3                                                                                         | Stimulus | Send a normal operation sample (unseen at training stage) to the anomaly detection module                                                           |        |
|                                      | 4                                                                                         | Check    | Check that the anomaly detection modules classify it as anomaly and send the correct data to the visualization dashboard (if connected) (Figure 28) | Pass   |
| Test Verdict                         |                                                                                           |          |                                                                                                                                                     | Pass   |
| Analytic Functional Test Description |                                                                                           |          |                                                                                                                                                     |        |
| Test type                            | Functional                                                                                |          |                                                                                                                                                     |        |
| Identifier                           | D-ADM_F002                                                                                |          |                                                                                                                                                     |        |
| Tester                               | CRAT                                                                                      |          |                                                                                                                                                     |        |
| Test Purpose                         | Demonstrate the correctness of the implementation of the components and of the interfaces |          |                                                                                                                                                     |        |
| References                           | [6], Section 2.7 “Adversarial Dynamic Healing based on Wardrop Equilibrium“               |          |                                                                                                                                                     |        |
| Configuration                        | The configuration is passed at class instantiation time by the caller module              |          |                                                                                                                                                     |        |
|                                      |                                                                                           |          |                                                                                                                                                     |        |
| Pre-test conditions                  | Receiving metrics from the testbed or synthetic data for load balancing                   |          |                                                                                                                                                     |        |
|                                      |                                                                                           |          |                                                                                                                                                     |        |
| Test Sequence                        | Step                                                                                      | Type     | Description                                                                                                                                         | Result |
|                                      | 1                                                                                         | Stimulus | Call the load balancing module to get the data rates of the IoT device towards the different available edge servers                                 |        |
|                                      | 2                                                                                         | Check    | Check that the defined metric is equalized among the different edge servers (e.g., load of the servers in terms of received requests/s)             | Pass   |
|                                      | 3                                                                                         | Stimulus | Reduce the load capacity of a server (by altering its reported metric) at timestep 400                                                              |        |
|                                      | 4                                                                                         | Check    | Check that a new equilibrium is reached considering the new capacity of the edge server                                                             | Pass   |
| Test Verdict                         |                                                                                           |          |                                                                                                                                                     | Pass   |

Figure 27 and Figure 28 show specific steps of the tests, while the respective test results are illustrated in Figure 29.

```

anomalydetectionmodule-1 | 2025-09-29 10:05:56,062 - waitress - INFO - Serving on http://0.0.0.0:8080
anomalydetectionmodule-1 | 2025-09-29 10:06:29,092 - AnomalyDetectionModule - DEBUG - b'\r\n "timestamp": 2,\r\n "sensitivity": 0.6,\r\n "data":{\r\n {\r\n "timestamp": 1,\r\n "cpu1":0.022,\r\n "cpu2":0.011,\r\n "cpu3":0.001,\r\n "cpu4":0.004,\r\n "disk_a":0.0148,\r\n "disk_u":0.59,\r\n "mem_u":0.2463,\r\n "mem_c":0.7728,\r\n "mem_f":0.0585,\r\n "net_d":0.0017,\r\n "net_u":0.1454\r\n }\r\n }\r\n}'
anomalydetectionmodule-1 | 2025-09-29 10:06:29,092 - AnomalyDetectionModule - INFO - AnomalyDetection requested
anomalydetectionmodule-1 | 2025-09-29 10:06:29,092 - AnomalyDetectionModule - DEBUG - {'timestamp': 2, 'sensitivity': 0.6, 'data': [{'timestamp': 1, 'cpu1': 0.022, 'cpu2': 0.011, 'cpu3': 0.001, 'cpu4': 0.004, 'disk_a': 0.0148, 'disk_u': 0.59, 'mem_u': 0.2463, 'mem_c': 0.7728, 'mem_f': 0.0585, 'net_d': 0.0017, 'net_u': 0.1454}]}
anomalydetectionmodule-1 | 2025-09-29 10:06:29,092 - AnomalyDetectionModule - DEBUG - Timestamp: 2
anomalydetectionmodule-1 | 2025-09-29 10:06:29,102 - AnomalyDetectionModule - DEBUG - Parameters after conversion: [{'cpu1': 0.022, 'cpu2': 0.011, 'cpu3': 0.001, 'cpu4': 0.004, 'disk_a': 0.0148, 'disk_u': 0.59, 'mem_u': 0.2463, 'mem_c': 0.7728, 'mem_f': 0.0585, 'net_d': 0.0017, 'net_u': 0.1454}]}
anomalydetectionmodule-1 | 2025-09-29 10:06:29,119 - AnomalyDetectionModule - DEBUG - SHAP values: (array(['cpu1', 'cpu2', 'cpu3', 'cpu4', 'disk_a', 'disk_u', 'mem_u', 'mem_c', 'mem_f', 'net_d', 'net_u'], dtype=object), array([[ 2.75949885e-02, -2.75949885e-02], [ 4.22685420e-03, -4.22685420e-03], [-1.79851042e-04, 1.79851042e-04], [ 2.77701783e-05, -2.77701783e-05], [ 1.08661833e-02, -1.08661833e-02], [-3.88756893e-01, 3.88756893e-01], [ 8.21754306e-02, -8.21754306e-02], [ 1.66927483e-02, -1.66927483e-02], [ 5.92494478e-03, -5.92494478e-03], [-2.58228469e-03, 2.58228469e-03], [ 2.27587526e-03, -2.27587526e-03]]))
anomalydetectionmodule-1 | 2025-09-29 10:06:29,119 - AnomalyDetectionModule - DEBUG - Most important feature: disk_u
anomalydetectionmodule-1 | 2025-09-29 10:06:29,119 - AnomalyDetectionModule - DEBUG - Anomaly count: 0 out of 1
anomalydetectionmodule-1 | 2025-09-29 10:06:29,120 - AnomalyDetectionModule - DEBUG - Anomaly: False, Message: None

```

Figure 27: Step 2 of the FL-ADM\_001 test

```

anomalydetectionmodule-1 | 2025-09-29 10:08:14,331 - AnomalyDetectionModule - DEBUG - b'\r\n "timestamp": 2,\r\n "sensitivity": 0.6,\r\n "data":{\r\n {\r\n "timestamp": 2,\r\n "cpu1":0.965,\r\n "cpu2":0.004,\r\n "cpu3":0.0771,\r\n "cpu4":0.003,\r\n "disk_a":0.0856,\r\n "disk_u":1,\r\n "mem_u":0.0992,\r\n "mem_c":0.4676,\r\n "mem_f":0.4644,\r\n "net_d":0.0001,\r\n "net_u":0.1253\r\n }\r\n }\r\n}'
anomalydetectionmodule-1 | 2025-09-29 10:08:14,331 - AnomalyDetectionModule - INFO - AnomalyDetection requested
anomalydetectionmodule-1 | 2025-09-29 10:08:14,331 - AnomalyDetectionModule - DEBUG - {'timestamp': 2, 'sensitivity': 0.6, 'data': [{'timestamp': 2, 'cpu1': 0.965, 'cpu2': 0.004, 'cpu3': 0.0771, 'cpu4': 0.003, 'disk_a': 0.0856, 'disk_u': 1, 'mem_u': 0.0992, 'mem_c': 0.4676, 'mem_f': 0.4644, 'net_d': 0.0001, 'net_u': 0.1253}]}
anomalydetectionmodule-1 | 2025-09-29 10:08:14,331 - AnomalyDetectionModule - DEBUG - Timestamp: 2
anomalydetectionmodule-1 | 2025-09-29 10:08:14,336 - AnomalyDetectionModule - DEBUG - Parameters after conversion: [{'cpu1': 0.965, 'cpu2': 0.004, 'cpu3': 0.0771, 'cpu4': 0.003, 'disk_a': 0.0856, 'disk_u': 1.0, 'mem_u': 0.0992, 'mem_c': 0.4676, 'mem_f': 0.4644, 'net_d': 0.0001, 'net_u': 0.1253}]}
anomalydetectionmodule-1 | 2025-09-29 10:08:14,353 - AnomalyDetectionModule - DEBUG - SHAP values: (array(['cpu1', 'cpu2', 'cpu3', 'cpu4', 'disk_a', 'disk_u', 'mem_u', 'mem_c', 'mem_f', 'net_d', 'net_u'], dtype=object), array([[ -9.83418763e-02, 9.83418763e-02], [-9.51264214e-04, 9.51264214e-04], [-1.51017423e-03, 1.51017423e-03], [-5.65615407e-04, 5.65615407e-04], [-1.16414902e-02, 1.16414902e-02], [-3.15509466e-01, 3.15509466e-01], [-3.34335608e-01, 3.34335608e-01], [ 8.77400907e-03, -8.77400907e-03], [ 1.67084835e-03, -1.67084835e-03], [ 2.27885346e-04, -2.27885346e-04], [ 4.47718284e-04, -4.47718284e-04]]))
anomalydetectionmodule-1 | 2025-09-29 10:08:14,353 - AnomalyDetectionModule - DEBUG - Most important feature: mem_u
anomalydetectionmodule-1 | 2025-09-29 10:08:14,353 - AnomalyDetectionModule - DEBUG - Anomaly count: 1 out of 1
anomalydetectionmodule-1 | 2025-09-29 10:08:14,354 - AnomalyDetectionModule - DEBUG - Anomaly: True, Message: Anomaly Detected: mem_u

```

Figure 28: Step 4 of the FL-ADM\_001 test

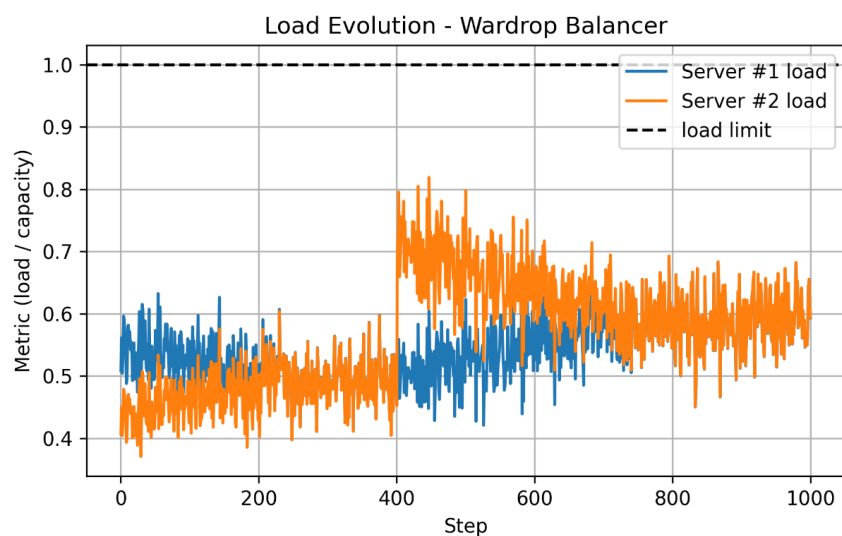


Figure 29: Results of steps 2 and 4 of D-ADM\_F002

### 3.27. ETSI Openslice

A summary of functional tests conducted for OpenSlice integration into the NANCY platform is provided in Table 28. All these integration activities are now concluded as OpenSlice demonstrates readiness for the final NANCY use case demonstration and validation activities.

Table 28: OpenSlice functional tests summary

| Functional Test ID                   |                                                                                                   | Objective                                                                                                                                                                                                                 |                                                                                                                                | Status                                                                                |
|--------------------------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| OSL_F001                             |                                                                                                   | Test connection with Service Orchestrator via NIS2.                                                                                                                                                                       |                                                                                                                                | Completed                                                                             |
| OSL_F002                             |                                                                                                   | Test connection with Service Repository/Registry via NIS3.                                                                                                                                                                |                                                                                                                                | Completed                                                                             |
| OSL_F003                             |                                                                                                   | Test connection with resource Telemetry via NIS5.                                                                                                                                                                         |                                                                                                                                | Completed                                                                             |
| OSL_F004                             |                                                                                                   | Test connection with Compute Controller via NIS6.                                                                                                                                                                         |                                                                                                                                | Completed                                                                             |
| OSL_F005                             |                                                                                                   | Test connection with NFVO.                                                                                                                                                                                                |                                                                                                                                | Dropped due to no availability of NFVO in the Greek testbeds where OpenSlice was used |
| Analytic Functional Test Description |                                                                                                   |                                                                                                                                                                                                                           |                                                                                                                                |                                                                                       |
| Test type                            |                                                                                                   | Functional                                                                                                                                                                                                                |                                                                                                                                |                                                                                       |
| Identifier                           |                                                                                                   | OSL_F001                                                                                                                                                                                                                  |                                                                                                                                |                                                                                       |
| Tester                               |                                                                                                   | UBITECH                                                                                                                                                                                                                   |                                                                                                                                |                                                                                       |
| Test Purpose                         |                                                                                                   | Test connection with the NANCY Service Orchestrator (Maestro) via interface NIS2                                                                                                                                          |                                                                                                                                |                                                                                       |
| References                           |                                                                                                   | [16], [1], and [2]                                                                                                                                                                                                        |                                                                                                                                |                                                                                       |
| Configuration                        |                                                                                                   | -                                                                                                                                                                                                                         |                                                                                                                                |                                                                                       |
|                                      |                                                                                                   |                                                                                                                                                                                                                           |                                                                                                                                |                                                                                       |
| Pre-test conditions                  |                                                                                                   | Maestro and OpenSlice instances deployed. IP connectivity between Maestro and OpenSlice already established. OpenSlice has available services in its service catalogue.                                                   |                                                                                                                                |                                                                                       |
|                                      |                                                                                                   |                                                                                                                                                                                                                           |                                                                                                                                |                                                                                       |
| Test Sequence                        | Step                                                                                              | Type                                                                                                                                                                                                                      | Description                                                                                                                    | Result                                                                                |
|                                      | 1                                                                                                 | Stimulus                                                                                                                                                                                                                  | Repeat Maestro_F001                                                                                                            | Pass                                                                                  |
| Test Verdict                         | Maestro successfully peers with OpenSlice and fetches services from the OpenSlice service catalog |                                                                                                                                                                                                                           |                                                                                                                                | Pass                                                                                  |
| Analytic Functional Test Description |                                                                                                   |                                                                                                                                                                                                                           |                                                                                                                                |                                                                                       |
| Test type                            |                                                                                                   | Functional                                                                                                                                                                                                                |                                                                                                                                |                                                                                       |
| Identifier                           |                                                                                                   | OSL_F002                                                                                                                                                                                                                  |                                                                                                                                |                                                                                       |
| Tester                               |                                                                                                   | UBITECH                                                                                                                                                                                                                   |                                                                                                                                |                                                                                       |
| Test Purpose                         |                                                                                                   | Test connection with the NANCY service repository/registry via interface NIS3                                                                                                                                             |                                                                                                                                |                                                                                       |
| References                           |                                                                                                   | [16], [1], and [2]                                                                                                                                                                                                        |                                                                                                                                |                                                                                       |
| Configuration                        |                                                                                                   | -                                                                                                                                                                                                                         |                                                                                                                                |                                                                                       |
|                                      |                                                                                                   |                                                                                                                                                                                                                           |                                                                                                                                |                                                                                       |
| Pre-test conditions                  |                                                                                                   | OpenSlice and the NANCY service registry instances are deployed. A service specification is onboarded onto the OSL catalogue and a Kubernetes cluster is already linked with OpenSlice’s resource and service catalogues. |                                                                                                                                |                                                                                       |
|                                      |                                                                                                   |                                                                                                                                                                                                                           |                                                                                                                                |                                                                                       |
| Test Sequence                        | Step                                                                                              | Type                                                                                                                                                                                                                      | Description                                                                                                                    | Result                                                                                |
|                                      | 1                                                                                                 | Stimulus                                                                                                                                                                                                                  | User logs in to OSL portal                                                                                                     | Pass                                                                                  |
|                                      | 2                                                                                                 | Check                                                                                                                                                                                                                     | User orders the deployment of a helm-based service (located in the NANCY service registry) atop an existing Kubernetes cluster | Pass                                                                                  |

|                                      |                                                                                                                              |          |                                                                                                                                                         |        |
|--------------------------------------|------------------------------------------------------------------------------------------------------------------------------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
|                                      | 3                                                                                                                            | Check    | OpenSlice initiates order and pulls service artifact (i.e., helm chart) from the service registry                                                       | Pass   |
|                                      | 4                                                                                                                            | Check    | OpenSlice successfully deploys service on the test cluster                                                                                              | Pass   |
| Test Verdict                         | OpenSlice successfully pulls service artefacts from the NANCY service registry                                               |          |                                                                                                                                                         | Pass   |
| Analytic Functional Test Description |                                                                                                                              |          |                                                                                                                                                         |        |
| Test type                            | Functional                                                                                                                   |          |                                                                                                                                                         |        |
| Identifier                           | OSL_F003                                                                                                                     |          |                                                                                                                                                         |        |
| Tester                               | UBITECH                                                                                                                      |          |                                                                                                                                                         |        |
| Test Purpose                         | Test connection with resource telemetry via interface NIS5                                                                   |          |                                                                                                                                                         |        |
| References                           | [16], [1], and [2]                                                                                                           |          |                                                                                                                                                         |        |
| Configuration                        | -                                                                                                                            |          |                                                                                                                                                         |        |
|                                      |                                                                                                                              |          |                                                                                                                                                         |        |
| Pre-test conditions                  | Maestro_F002 is already done, therefore a Kubernetes cluster is already created by OpenSlice                                 |          |                                                                                                                                                         |        |
|                                      |                                                                                                                              |          |                                                                                                                                                         |        |
| Test Sequence                        | Step                                                                                                                         | Type     | Description                                                                                                                                             | Result |
|                                      | 1                                                                                                                            | Stimulus | OpenSlice orders a Prometheus helm service atop the created Kubernetes cluster                                                                          | Pass   |
|                                      | 2                                                                                                                            | Check    | Prometheus get deployed on a specific port of the cluster                                                                                               | Pass   |
|                                      | 3                                                                                                                            | Check    | OpenSlice exposes the Prometheus port through ingress                                                                                                   | Pass   |
|                                      | 4                                                                                                                            | Check    | User verifies that Prometheus API is indeed exposed                                                                                                     | Pass   |
| Test Verdict                         | OpenSlice successfully instantiates resource-level telemetry on existing Kubernetes cluster using interface NIS5             |          |                                                                                                                                                         | Pass   |
| Analytic Functional Test Description |                                                                                                                              |          |                                                                                                                                                         |        |
| Test type                            | Functional                                                                                                                   |          |                                                                                                                                                         |        |
| Identifier                           | OSL_F004                                                                                                                     |          |                                                                                                                                                         |        |
| Tester                               | UBITECH                                                                                                                      |          |                                                                                                                                                         |        |
| Test Purpose                         | Test connection with compute controller via interface NIS6                                                                   |          |                                                                                                                                                         |        |
| References                           | [16], [1], and [2]                                                                                                           |          |                                                                                                                                                         |        |
| Configuration                        | -                                                                                                                            |          |                                                                                                                                                         |        |
|                                      |                                                                                                                              |          |                                                                                                                                                         |        |
| Pre-test conditions                  | OpenSlice instance already deployed. An OpenStack instance already deployed. IP connectivity between OpenSlice and OpenStack |          |                                                                                                                                                         |        |
|                                      |                                                                                                                              |          |                                                                                                                                                         |        |
| Test Sequence                        | Step                                                                                                                         | Type     | Description                                                                                                                                             | Result |
|                                      | 1                                                                                                                            | Stimulus | OpenSlice user issues an order of a compute resource (e.g., a VM) via the OpenSlice Resource Order API                                                  | Pass   |
|                                      | 2                                                                                                                            | Check    | OpenSlice establishes connection with an OpenStack Virtual Infrastructure Manager                                                                       | Pass   |
|                                      | 3                                                                                                                            | Check    | OpenSlice requests an OpenStack VM                                                                                                                      | Pass   |
|                                      | 4                                                                                                                            | Check    | OpenSlice attaches VM resource characteristics (e.g., flavour info, IP, ssh key, etc.) to a resource entry in its TMF Resource Inventory Management API | Pass   |
|                                      | 5                                                                                                                            | Check    | OpenSlice user consumes this information to access the created VM                                                                                       | Pass   |

|                 |                                                                                |             |
|-----------------|--------------------------------------------------------------------------------|-------------|
| Test<br>Verdict | OpenSlice successfully instantiates a compute resource using interface<br>NIS6 | <i>Pass</i> |
|-----------------|--------------------------------------------------------------------------------|-------------|

## 4. Updates on Integration of NANCY Components and Services

This section presents the integration activities conducted to combine the diverse NANCY components. Building upon the outcomes of the functional testing described in Section 3, the integration work focused on ensuring the correct interaction among the NANCY components. The section first outlines the final set of NANCY integration points, providing their final implementation status and possible updates in their descriptions compared to the previous platform version documented in [2]. Subsequently, it provides a detailed description of the integration tests performed for each interaction between components, including objectives, configuration details, execution steps, and test results. Finally, the section reports the monitoring and coordination mechanisms used to oversee the integration process, ensuring stability and consistency across all domains of the NANCY architecture. The results confirm that the NANCY system has reached a high level of integration maturity, enabling its readiness for end-to-end platform validation and deployment in the project.

### 4.1. Integration Points Updates

Table 29 is the updated NANCY integration matrix, which was initially presented in [2]. In this table, there are a few integration points which have been dropped (marked with a strikethrough), as well as new ones (highlighted in yellow) compared to what was shown in [2]. Table 30 provides the updated summary of integration points specifications (initially identified and fully specified in [2]). For the integration points that were dropped compared to [2], a justification is provided.



Table 29: NANCY integration matrix

| Integration Points | 1 | 2   | 3 | 4 | 5   | 6 | 7 | 8   | 9 | 10   | 11   | 12   | 13   | 14    | 15    | 16 | 17    | 18 | 19    | 20    | 21 | 22    | 23    | 24    | 25    | 26 | 27    |
|--------------------|---|-----|---|---|-----|---|---|-----|---|------|------|------|------|-------|-------|----|-------|----|-------|-------|----|-------|-------|-------|-------|----|-------|
| 1. MRAT-NCP        |   | 1,2 |   |   |     |   |   | 1,8 |   |      |      |      | 1,13 |       |       |    | 1,17  |    |       |       |    |       |       |       |       |    |       |
| 2. ID-Mngt         |   |     |   |   | 2,5 |   |   |     |   | 2,10 |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 3. DAC             |   |     |   |   |     |   |   |     |   |      | 3,11 |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 4. BC              |   |     |   |   | 4,5 |   |   |     |   |      | 4,11 |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 5. Wallet          |   |     |   |   |     |   |   |     |   |      | 5,11 | 5,12 |      |       |       |    |       |    |       |       |    |       |       |       |       |    | 5,27  |
| 6. AI Virtualizer  |   |     |   |   |     |   |   |     |   | 6,10 |      |      |      | 6,14  |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 7. BRAN-model      |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 8. SemCom          |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 9. QKDSim          |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 10. VOSyS Monitor  |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 11. Marketplace    |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       | 11,21 |    |       |       |       |       |    |       |
| 12. Maestro        |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    | 12,27 |
| 13. Models         |   |     |   |   |     |   |   |     |   |      |      |      |      | 13,14 | 13,15 |    | 13,17 |    |       |       |    |       |       |       |       |    |       |
| 14. SEMR           |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    | 14,19 |       |    |       | 14,23 |       |       |    |       |
| 15. Elasticity     |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 16. PQC Sign.      |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       | 16,25 |    |       |
| 17. TFS            |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 18. RIC-mngr       |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 19. AINQM          |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       | 19,20 |    | 19,22 |       |       |       |    |       |
| 20. NIF            |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 21. SPP            |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 22. XAI            |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       | 22,23 |       |    |       |
| 23. FL-IDS         |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 24. MTG-RM         |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 25. PQC-SecCom     |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 26. D-ADM          |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |
| 27. BSS            |   |     |   |   |     |   |   |     |   |      |      |      |      |       |       |    |       |    |       |       |    |       |       |       |       |    |       |

Table 30: Integration points specification summary

| NANCY Integration Points                    | NANCY Platform Interface | Objective                                                                                                                                                                                                                          | Protocol                                    | Integration in testbeds/demonstrators | Status                                                                |
|---------------------------------------------|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|---------------------------------------|-----------------------------------------------------------------------|
| <b>MRAR-NCP-ID Mngnt (1,2)</b>              | NIS13, Uu, PC5           | Allow access for 5G network usage for a remote non-5G subscriber.                                                                                                                                                                  | HTTP over PC5                               | Spanish expansion                     | Completed                                                             |
| <b>MRAT-NCP – SemCom (1,8)</b>              | Uu, S1, NIS7, NIS5, NIS8 | Send encoded video and decode at the edge                                                                                                                                                                                          | Offline data transfer                       | Spanish expansion                     | Completed                                                             |
| <b>MRAT-NCP – Models – TFS (1,13, 1,17)</b> | Uu, S1, NIS7, NIS5, NIS8 | Infer location and coverage depending on radio metrics extracted from the UE. Throughput forecast based on radio metrics extracted from the UE.                                                                                    | Offline transfer                            | Spanish expansion                     | Completed                                                             |
| <b>ID Mngnt – Wallet (2,5)</b>              | N/A                      | Configure the wallet with NANCY ID credentials, use credential to authenticate towards NANCY services.                                                                                                                             | gRPC                                        | Spanish expansion                     | To be completed during final integration at Spanish expansion testbed |
| <b>ID Mngnt – VoSyS Monitor (2,10)</b>      | N/A                      | Instantiate OP-TEE solution <sup>2</sup> for caching mechanisms on ARM-based far-edge device included in the MRAT-NCP. This will be used to securely store the access token of NANCY subscriber to accelerate authorisation times. | API based on Global Platform TEE Client API | Spanish expansion                     | Completed                                                             |
| <b>DAC – Marketplace (3,11)</b>             | NI11                     | <ul style="list-style-type: none"> <li>• Provide the required information for creating the digital agreement.</li> <li>• Receive the generated digital</li> </ul>                                                                  | REST API over HTTPS                         | All                                   | Completed                                                             |

<sup>2</sup> Introduced in D4.3: Trustworthy Grant/cell-free Cooperative Access Mechanisms

| NANCY Integration Points           | NANCY Platform Interface | Objective                                                                                                                                                                                                                        | Protocol | Integration in testbeds/demonstrators | Status                                                                                              |
|------------------------------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------------------------|-----------------------------------------------------------------------------------------------------|
|                                    |                          | agreement to be signed                                                                                                                                                                                                           |          |                                       |                                                                                                     |
| <b>BC – Wallet (4,5)</b>           | NIS13                    | Once the identity is in the wallet, the user connects to the Fabric network using a connection profile (YAML or JSON file). Once connected, the user can submit transactions or query the ledger through the smart contract API. | gRPC     | All                                   | Completed                                                                                           |
| <b>BC – Marketplace (4,11)</b>     | NI10                     | Deploy the Smart Contracts of the marketplace on the Blockchain network                                                                                                                                                          | N/A      | All                                   | Completed                                                                                           |
| <b>Wallet – Marketplace (5,11)</b> | NI9                      | Send the required transactions to the Blockchain based marketplace for any operation (both read and write). All the interactions with the marketplace happen through the wallet (or the oracles in specific cases)               | gRPC     | All                                   | Completed                                                                                           |
| <b>Wallet – Maestro (5, 12)</b>    | N/A                      | Query the blockchain-based marketplace for potential service providers and sign SLA transactions. All the interactions with the blockchain happen through the wallet (which acts as a client app).                               | gRPC     | All                                   | Dropped, because the wallet is deployed at the BSS, which then interacts with Maestro (section 5.2) |
| <b>Wallet – BSS (5,27)</b>         | TBD                      | Publish services in the blockchain-based marketplace and become aware of signed SLAs involving current clients. All the interactions with the                                                                                    | gRPC     | All                                   | Dropped because it's not really an integration but rather an independent app (wallet)               |

| NANCY Integration Points              | NANCY Platform Interface | Objective                                                                                                                                                                                                                                                | Protocol            | Integration in testbeds/demonstrators          | Status                                                                         |
|---------------------------------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|------------------------------------------------|--------------------------------------------------------------------------------|
|                                       |                          | blockchain happen through the wallet (which acts as a client app).                                                                                                                                                                                       |                     |                                                | deployed at the BSS side                                                       |
| <b>MAESTRO – BSS (12,27)</b>          | NIS1                     | Issue service orders to MAESTRO to trigger the instantiation of the corresponding services at the remote target Kubernetes cluster <sup>3</sup> .                                                                                                        | REST API            | Greek In-lab testbed and Outdoor demonstrator. | New and Completed                                                              |
| <b>AI_Virt – VoSys Monitor (6,10)</b> | N/A                      | Allow to deploy VNFs from OpenStack Nova into vManager partitions                                                                                                                                                                                        | Libvirt API         | Italian InLab testbed                          | Completed                                                                      |
| <b>AI_Virt – SEMR (6,14)</b>          | NIS5                     | Integrate NAOMI in Slice Manager and further provide MLOps to models that are deployed on NAOMI.                                                                                                                                                         | REST API            | N/A                                            | Completed                                                                      |
| <b>Marketplace – SPP (11,21)</b>      | NI12                     | <ul style="list-style-type: none"> <li>• Provide the information used for calculating the most suitable price for the better service.</li> <li>• Receive the most suitable price for the most suitable service fulfilling the given features.</li> </ul> | REST API over HTTPS | Greek in-lab testbed                           | Completed                                                                      |
| <b>Models – SEMR (13,14)</b>          | N/A                      | Network AI Workflow Democratisation (NAOMI) can provide MLOps for the models that are going to be deployed in repo                                                                                                                                       | REST API            | Spanish expansion                              | Completed                                                                      |
| <b>Models – Elasticity (13,15)</b>    | NIS5                     | In-place resource elasticity technique allocating computing resources within a slice                                                                                                                                                                     | REST API            | Spanish expansion                              | Dropped as all key parameters are already measured as part of the "elasticity" |

<sup>3</sup> The integration testing among the BSS and MAESTRO is covered in section 3.12 and through the description of the workflow in section 5.2 involving the Greek outdoor demonstrator's BSS.

| NANCY Integration Points             | NANCY Platform Interface | Objective                                                                                                                                                                                                         | Protocol                | Integration in testbeds/demonstrators | Status                                                                                                                                                                                |
|--------------------------------------|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Models – TFS (13,17)</b>          | NIS8                     | Integration of the Throughput forecasting service will assist in predicting upcoming throughput optimizing AI-based network functionalities for different scenarios measuring speed and latency of model serving. | REST API                | TBD                                   | Dropped as it was identified that the two components don't need to interact directly. Both of them separately interact with MRAT-NCP, in the framework of the Spanish in-lab testbed. |
| <b>SEMR – FL-IDS (14,23)</b>         | NIS5                     | SEMR will provide a set of functionalities that cover the full ML pipeline through NAOMI tool in order to streamline the deployment of the FL-IDS model to the Greek In-lab Testbed                               | REST API                | Greek In-lab Testbed                  | Completed                                                                                                                                                                             |
| <b>SEMR – AINQM (14,19)</b>          | NIS8                     | The SEMR will be continuously monitoring the performance of the AINQM module, thus triggering and overall optimizing retraining processes in changing network conditions.                                         | REST API                | TBD                                   | Dropped as it was identified that the two components don't need to interact directly.                                                                                                 |
| <b>PQC Sign – PQC SecCom (16,25)</b> | Internal UE interface    | Integration of the HW signature token into secure communication infrastructure to use PQC HW signing capabilities                                                                                                 | API calls               | Italian Massive IoT testbed           | Completed                                                                                                                                                                             |
| <b>AINQM – NIF (19,20)</b>           | NIS8                     | Integration of Outage Probability Model in order to predict network outages for different scenarios                                                                                                               | direct code integration | None                                  | Completed                                                                                                                                                                             |
| <b>AINQM– XAI (19,22)</b>            | NIS8                     | AINQM will be utilised to calculate the                                                                                                                                                                           | REST API                | Greek In-lab Testbed                  | Completed                                                                                                                                                                             |

| NANCY Integration Points    | NANCY Platform Interface | Objective                                                                                                                                                            | Protocol | Integration in testbeds/demonstrators | Status    |
|-----------------------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------------------------|-----------|
|                             |                          | outage probability, and XAI will provide the rationale behind the decisions of the respective AI model.                                                              |          |                                       |           |
| <b>XAI – FL-IDS (22,23)</b> | NIS8                     | The output of the distributed FL Training will be the AI-enabled Intrusion Detection System that the Greek in-lab testbed will utilize to identify different attacks | TBD      | Greek In-lab Testbed                  | Completed |

## 4.2. Integration Testing of NANCY Integration Points

The current section provides the analytic integration test descriptions for each one of the NANCY integration points in Sections 4.2.1 - 4.2.18.

### 4.2.1. Multi Radio Access Technologies & ID Management (MRAT-NCP & ID-Mngnt)

Table 31 summarizes the MRAT-NCP - ID-Mngnt integration tests.

Table 31: MRAT-NCP - ID-Mngnt integration tests summary

| Integration Test ID                   | Objective                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Status    |
|---------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>MRAT-NCP_ID-Mngnt_I001</b>         | Test Issuer to generate credentials                                                                                                                                                                                                                                                                                                                                                                                                                                           | Completed |
| <b>MRAT-NCP_ID-Mngnt_I002</b>         | Test p-abc cryptographic operations with retrieved keys for verifier                                                                                                                                                                                                                                                                                                                                                                                                          | Completed |
| <b>MRAT-NCP_ID-Mngnt_I003</b>         | Test p-abc cryptographic operations with retrieved keys for pseudonym generation                                                                                                                                                                                                                                                                                                                                                                                              | Completed |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |           |
| <b>Test type</b>                      | <b>Integration</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |           |
| <b>Identifier</b>                     | <b>MRAT-NCP_ID-Mngnt_I001, MRAT-NCP_ID-Mngnt_I002, MRAT-NCP_ID-Mngnt_I003</b>                                                                                                                                                                                                                                                                                                                                                                                                 |           |
| <b>Testers</b>                        | <b>UMU</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |           |
| <b>Test Purpose</b>                   | The main purpose of the test is to validate that the entire verification flow allows a Remote OBU, with no 5G network connectivity of its own, to access the services offered by the provider or MRAT-NCP. To do this, the correct performance of each phase of the identity management process must be verified, ensuring that the wallet properly generates the credential and that the MRAT-NCP can verify it correctly in order to finally establish a secure connection. |           |
| <b>References</b>                     | <b>[5], [4]</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                               |           |
| <b>Configuration</b>                  | Cohda MK6, Raspberry Pi 5 and LattePanda                                                                                                                                                                                                                                                                                                                                                                                                                                      |           |

| <b>Pre-test conditions</b> |                                                                                                                                                                                                                                                          | There must be ethernet connectivity between each of the Cohda devices and their respective module (Raspberry Pi or LattePanda).<br>The provider module must have connectivity with at least one of the operators.<br>The Cohda devices must have GPS signal and PC5 coverage between them.<br>The remote UE and the MRAT-NCP have correctly configured their own p-abc wallet (both of them) and blockchain wallet (only the MRAT-NCP) |                                                                                                                                                                                                            |             |
|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| Test Sequence              | Step                                                                                                                                                                                                                                                     | Type                                                                                                                                                                                                                                                                                                                                                                                                                                   | Description                                                                                                                                                                                                | Result      |
| 1                          | 1                                                                                                                                                                                                                                                        | Stimulus                                                                                                                                                                                                                                                                                                                                                                                                                               | Provider (MRAT-NCP) broadcast via PC5 the required format of the credentials.                                                                                                                              | Pass        |
|                            | 2                                                                                                                                                                                                                                                        | Check                                                                                                                                                                                                                                                                                                                                                                                                                                  | The remote vOBU consults its own p-abc wallet to obtain a credential that complies with the format and requirements specified by the provider.                                                             | Pass        |
|                            | 3                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                        | The remote vOBU sends the credential and indicated the desired service to the provider.                                                                                                                    | Pass        |
|                            | 4                                                                                                                                                                                                                                                        | Check                                                                                                                                                                                                                                                                                                                                                                                                                                  | The MRAT-NCP receives and validates the credential using the p-abc wallet and collects from the blockchain the issuer's public key needed to validate the remote UE credential with the blockchain wallet. | Pass        |
| 2                          | 5                                                                                                                                                                                                                                                        | Check                                                                                                                                                                                                                                                                                                                                                                                                                                  | After validation, the consumer and provider establish an encrypted communication, one per each consumer authenticated.                                                                                     | Pass        |
| <b>Test Verdict</b>        | <b>It is confirmed that the credential authentication and validation mechanism via MRAT-NCP works correctly and that, after verification, an encrypted and secure communication is established between each authenticated consumer and the provider.</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                            | <b>Pass</b> |

#### 4.2.2. Multi Radio Access Technologies & SemCom (MRAT-NCP – SemCom)

Table 32 summarizes the MRAT-NCP – Semcom integration tests, while Figure 30 and Figure 31 illustrate the respective results.

Table 32: MRAT-NCP – Semcom integration tests summary

| Integration Test ID                   | Objective                                                                             | Status (Completed, Dropped, New and completed) |
|---------------------------------------|---------------------------------------------------------------------------------------|------------------------------------------------|
| MRAT-NCP_SemCom_I001                  | Test the provisioning of the data from different video sources to the SemCom encoder. | Completed                                      |
| MRAT-NCP_SemCom_I002                  | Test the transmission of the extracted semantic information.                          | Completed                                      |
| MRAT-NCP_SemCom_I003                  | Test the accuracy of the DT created at the edge server                                | Completed                                      |
| Analytic Integration Test Description |                                                                                       |                                                |
| Test type                             | Integration                                                                           |                                                |
| Identifier                            | MRAT-NCP_SemCom_I001, MRAT-NCP_SemCom_I002, MRAT-NCP_SemCom_I003                      |                                                |
| Testers                               | UMU, INNO                                                                             |                                                |

|                            |                                                                                                                                                                                                                                                                                                                                                                                                                       |             |                                                                                                                 |               |
|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-----------------------------------------------------------------------------------------------------------------|---------------|
| <b>Test Purpose</b>        | Validate the use of SemCom in a realistic vehicular scenario and evaluate the performance improvement attained in comparison with regular data transmission.                                                                                                                                                                                                                                                          |             |                                                                                                                 |               |
| <b>References</b>          | <b>[10]</b>                                                                                                                                                                                                                                                                                                                                                                                                           |             |                                                                                                                 |               |
| <b>Configuration</b>       | The SemCom component is comprised of two entities, namely the semantic encoder and the semantic decoder. In the simulated setup, the former is deployed on the network nodes (cars, RSUs, drones, etc.) capturing video of the observed location. The extracted semantic information will be transmitted through the network to the edge server, where the semantic decoder will be deployed in order to create a DT. |             |                                                                                                                 |               |
| <b>Pre-test conditions</b> | This vehicle has access to a DT service. It has the SemCom encoder installed but not activated. It requests the activation of the DT service from the 1st BS that it connects. The request is forwarded to the SemCom encoder of all nodes in proximity. The vehicle, a drone, and a roadside camera are identified.                                                                                                  |             |                                                                                                                 |               |
| <b>Test Sequence</b>       | <b>Step</b>                                                                                                                                                                                                                                                                                                                                                                                                           | <b>Type</b> | <b>Description</b>                                                                                              | <b>Result</b> |
|                            | 1                                                                                                                                                                                                                                                                                                                                                                                                                     | Stimulus    | The vehicle, the RSU, and the UAV receive a request to initiate their SemCom encoders.                          | Pass          |
|                            | 2                                                                                                                                                                                                                                                                                                                                                                                                                     | Check       | The data captured by the vehicle camera are provided to the onboard SemCom encoder.                             | Pass          |
|                            | 3                                                                                                                                                                                                                                                                                                                                                                                                                     | Check       | The data captured by the RSU camera are provided to the onboard SemCom encoder.                                 | Pass          |
|                            | 4                                                                                                                                                                                                                                                                                                                                                                                                                     | Check       | The data captured by the UAV camera are provided to the onboard SemCom encoder.                                 | Pass          |
|                            | 5                                                                                                                                                                                                                                                                                                                                                                                                                     | Check       | All SemCom encoders extract the semantic information from the local video data that are available at each node. | Pass          |
|                            | 6                                                                                                                                                                                                                                                                                                                                                                                                                     | Check       | Only the extracted semantic information is transmitted through the network to the simulated edge server.        | Pass          |
|                            | 7                                                                                                                                                                                                                                                                                                                                                                                                                     | Check       | The SemCom decoder at the edge server receives the semantic information from all nodes.                         | Pass          |
|                            | 8                                                                                                                                                                                                                                                                                                                                                                                                                     | Check       | The SemCom decoder at the edge server creates the DT scene.                                                     | Pass          |
| <b>Test Verdict</b>        | <b>The tests confirm that SemCom is successfully validated in a realistic vehicular scenario, enabling efficient semantic transmission and DT scene reconstruction with improved performance over regular data transmission.</b>                                                                                                                                                                                      |             |                                                                                                                 | <b>Pass</b>   |

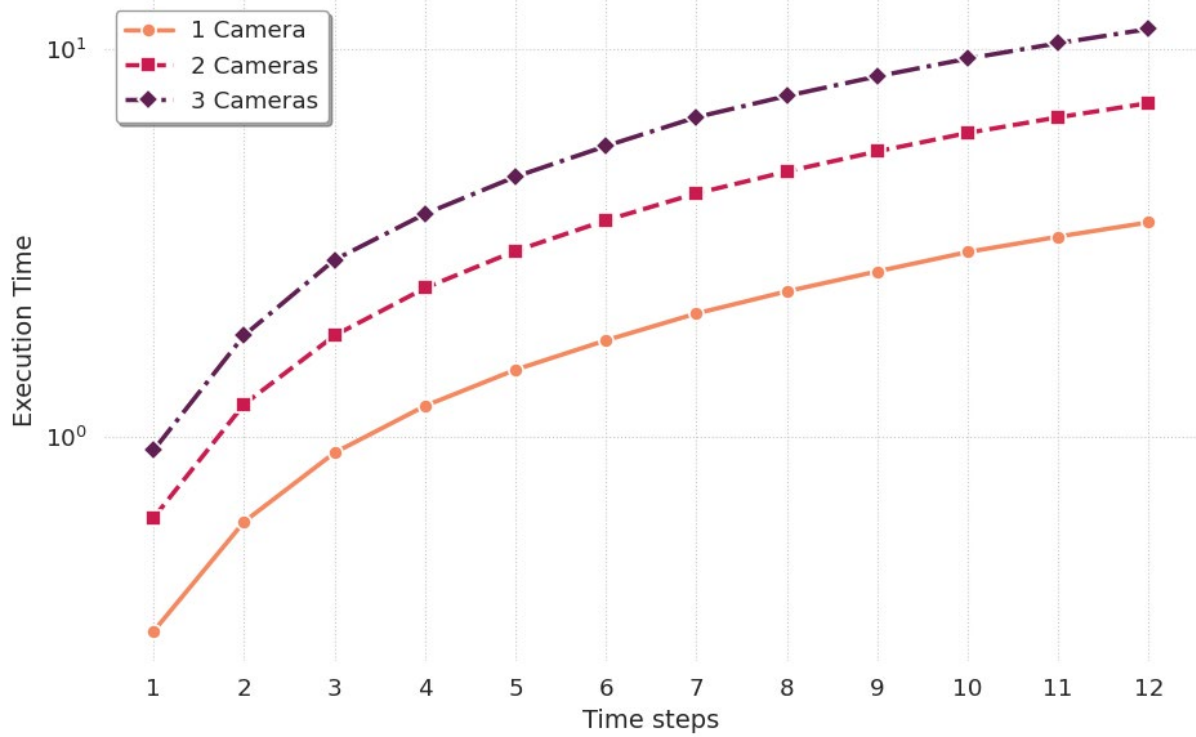


Figure 30: Execution time as a function of the number of multi-view frames (UMU dataset)

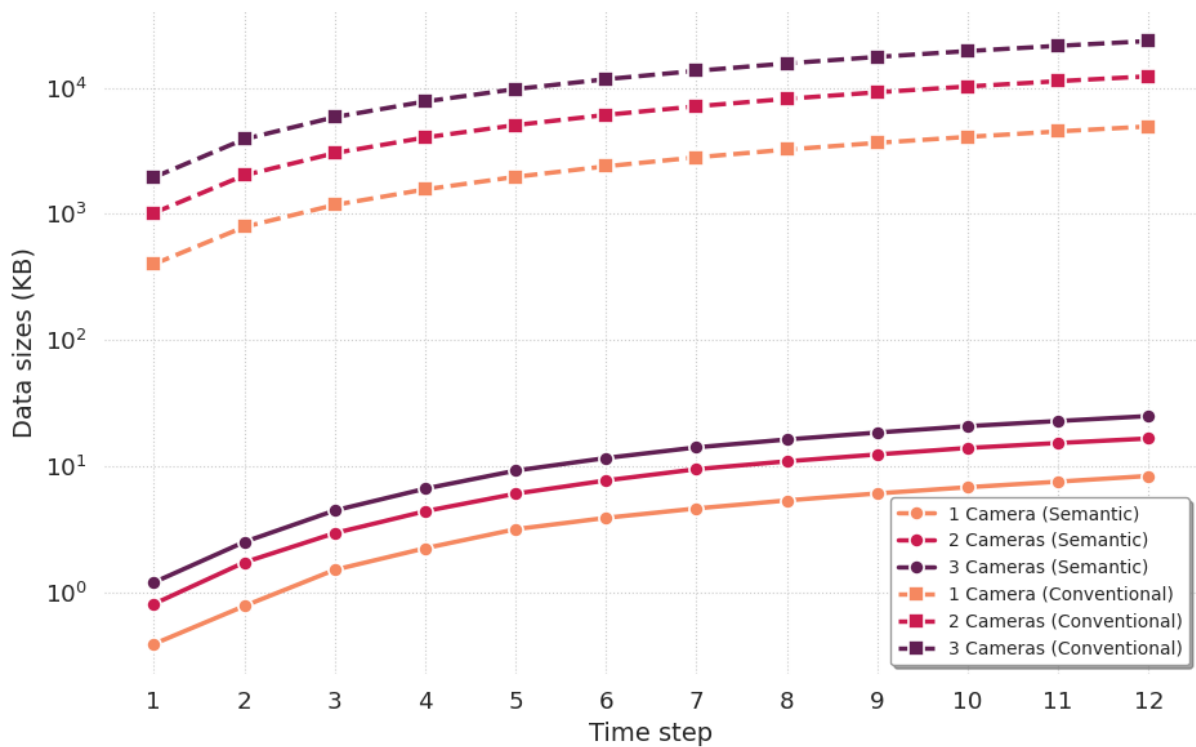


Figure 31: Required data as a function of the number of multi-view frames for conventional and SemCom systems (UMU dataset)

#### 4.2.3. Multi Radio Access Technologies, Models & Traffic Forecasting Service (MRAT-NCP – Models –TFS)

Table 33 summarizes the MRAT-NCP – Models -TFS integration tests, while Figure 32 and Figure 33 show the respective results.

Table 33: MRAT-NCP – Models -TFS integration tests summary

| Integration Test ID                   |                                                                                                                                                                                                                                                                                                                                                                     | Objective                                                                       |                                                                                                                                         | Status    |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|-----------|
| MRAT-NCP_Models_I001                  |                                                                                                                                                                                                                                                                                                                                                                     | Evaluate the decision for data path reconfiguration depending on network status |                                                                                                                                         | Completed |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                                                                                                     |                                                                                 |                                                                                                                                         |           |
| Test type                             | Integration                                                                                                                                                                                                                                                                                                                                                         |                                                                                 |                                                                                                                                         |           |
| Identifier                            | MRAT-NCP_Models_I001                                                                                                                                                                                                                                                                                                                                                |                                                                                 |                                                                                                                                         |           |
| Testers                               | UMU, IJS, CERTH, Bi2S                                                                                                                                                                                                                                                                                                                                               |                                                                                 |                                                                                                                                         |           |
| Test Purpose                          | Test the accuracy of the different ML models generated from the data extracted from the Spanish extension testbed. Decision making in terms of the optimal operator selection will be supported, via real-time ML model inference.                                                                                                                                  |                                                                                 |                                                                                                                                         |           |
| References                            | [5], [17], [20]                                                                                                                                                                                                                                                                                                                                                     |                                                                                 |                                                                                                                                         |           |
| Configuration                         | Data collected from UMU’s testbed. Such data included several uplink and downlink information and were used to test the ML models. Thus, the ML model validation process was conducted using real-world data.                                                                                                                                                       |                                                                                 |                                                                                                                                         |           |
|                                       |                                                                                                                                                                                                                                                                                                                                                                     |                                                                                 |                                                                                                                                         |           |
| Pre-test conditions                   | A 5G or 6G network should be provided for wireless connectivity<br>UEs should be able to collect and utilise data regarding their RSSI levels and other Signal Strength-related measurements<br><br>The model inference should execute on either the UE devices or to a centralised server<br>Python libraries should be supported for the model inference process. |                                                                                 |                                                                                                                                         |           |
|                                       |                                                                                                                                                                                                                                                                                                                                                                     |                                                                                 |                                                                                                                                         |           |
| Test Sequence                         | Step                                                                                                                                                                                                                                                                                                                                                                | Type                                                                            | Description                                                                                                                             | Result    |
| 1                                     | 1                                                                                                                                                                                                                                                                                                                                                                   | Stimulus                                                                        | (JSI)Pinging containerized version of the localization model with new test data:                                                        | Pass      |
|                                       | 2                                                                                                                                                                                                                                                                                                                                                                   | Check                                                                           | (JSI)Inference with the localization model (LaaS)                                                                                       | Pass      |
|                                       | 3                                                                                                                                                                                                                                                                                                                                                                   | Check                                                                           | (JSI)Comparing results to the ground truth and evaluating the error between model error and new test data error with statistical t-test | Pass      |
|                                       | 4                                                                                                                                                                                                                                                                                                                                                                   | Stimulus                                                                        | (CERTH)A value is inserted for the android walk time-series number                                                                      | Pass      |
|                                       | 5                                                                                                                                                                                                                                                                                                                                                                   | Stimulus                                                                        | (CERTH)A value is inserted for the number of steps the forecasting has to take place and both sent (via POSTMAN or curl tool)           | Pass      |
|                                       | 6                                                                                                                                                                                                                                                                                                                                                                   | Check                                                                           | (CERTH)Receipt of results and their plausibility to justify operator selection                                                          | Pass      |
| 2                                     | 1                                                                                                                                                                                                                                                                                                                                                                   | Stimulus                                                                        | (BI2S) Feeding the model with data which are collected from the field (UMU’s testbed)                                                   | Pass      |
|                                       | 2                                                                                                                                                                                                                                                                                                                                                                   | Check                                                                           | (BI2S) Check the model outputs, after inference is completed                                                                            | Pass      |
|                                       | 3                                                                                                                                                                                                                                                                                                                                                                   | Check                                                                           | (BI2S) Assess the model’s outputs against the ground truth that is available from the collected data.                                   | Pass      |
| Test Verdict                          | Based on computed statistical significance, the test was passed.                                                                                                                                                                                                                                                                                                    |                                                                                 |                                                                                                                                         | Pass      |

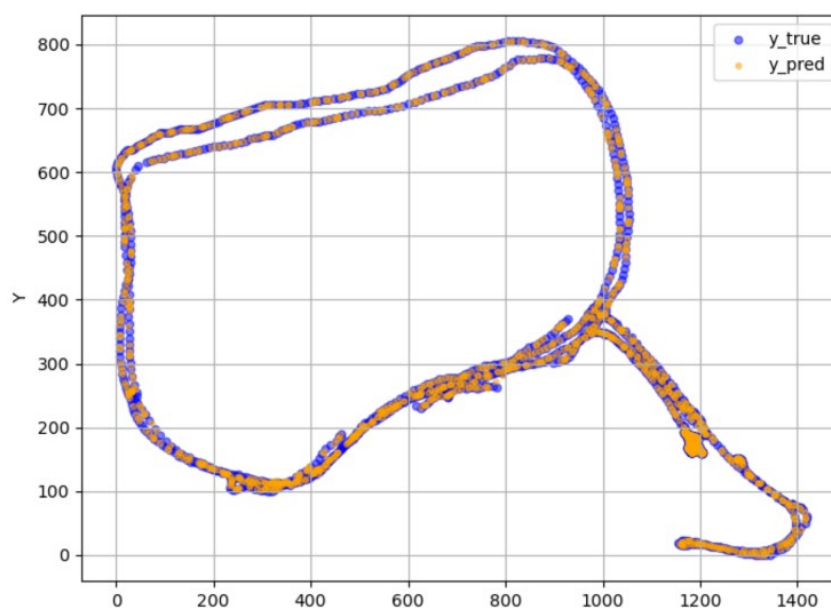


Figure 32: Example of localization experiment with ~2m average error. Horizontal and vertical axis represent longitude and latitude, and  $y_{true}$  and  $y_{pred}$  are the location vectors containing x and y coordinate.

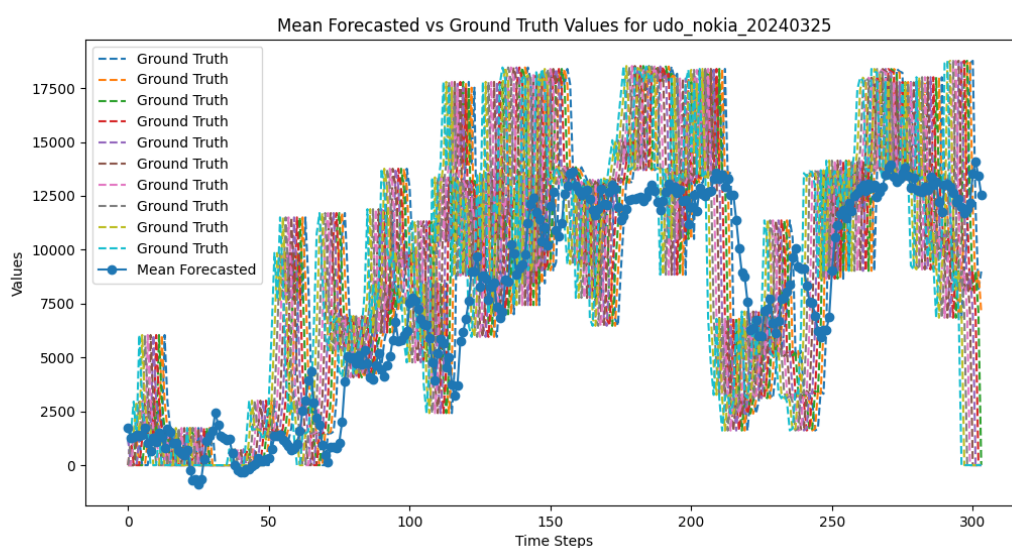


Figure 33: Graph derived from retrained TFS model for UDP protocol, tested with Nokia operator data; Ground Truth lines stem from separate forecasting horizon steps (step=1 to 10)

#### 4.2.4. ID Management & Wallet (ID-Mngnt – Wallet)

Table 34 summarizes the ID-Mngnt - Wallet integration tests.

Table 34: ID-Mngnt - Wallet integration tests summary

| Integration Test ID         | Objective                                            | Status    |
|-----------------------------|------------------------------------------------------|-----------|
| <b>ID Mngnt_Wallet_I001</b> | Test configuration of the wallet with ID credentials | Completed |

|                                       |                                                                                                                                                                                                                                                                                                     |                     |                                                                           |          |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|---------------------------------------------------------------------------|----------|
| ID Mngnt_Wallet_I002                  | Test verification of credentials provided by a wallet                                                                                                                                                                                                                                               | Completed           |                                                                           |          |
| ID Mngnt_Wallet_I003                  | Generation of privacy preserving attributes                                                                                                                                                                                                                                                         | Completed           |                                                                           |          |
| ID Mngnt_Wallet_I004                  | Verification of privacy preserving attributes                                                                                                                                                                                                                                                       | Completed           |                                                                           |          |
| ID Mngnt_Wallet_I005                  | PSK key derivation from 5G root key                                                                                                                                                                                                                                                                 | On going            |                                                                           |          |
| ID Mngnt_Wallet_I006                  | Credential generation and issuance based on subscriber capabilities                                                                                                                                                                                                                                 | Partially completed |                                                                           |          |
| ID Mngnt_Wallet_I007                  | Issuer's pK retrieval from blockchain                                                                                                                                                                                                                                                               | On going            |                                                                           |          |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                                     |                     |                                                                           |          |
| Test type                             | Integration                                                                                                                                                                                                                                                                                         |                     |                                                                           |          |
| Identifier                            | ID Mngnt_Wallet_I001, ID Mngnt_Wallet_I002, ID Mngnt_Wallet_I003, ID Mngnt_Wallet_I004, ID Mngnt_Wallet_I005, ID Mngnt_Wallet_I006, ID Mngnt_Wallet_I007                                                                                                                                            |                     |                                                                           |          |
| Testers                               | UMU, NEC                                                                                                                                                                                                                                                                                            |                     |                                                                           |          |
| Test Purpose                          | Use the wallet for ID management purposes such as Authentication and Authorisation.                                                                                                                                                                                                                 |                     |                                                                           |          |
| References                            | [5], [6]                                                                                                                                                                                                                                                                                            |                     |                                                                           |          |
| Configuration                         | Cohda MK6, Raspberry Pi 5 and LattePanda                                                                                                                                                                                                                                                            |                     |                                                                           |          |
|                                       |                                                                                                                                                                                                                                                                                                     |                     |                                                                           |          |
| Pre-test conditions                   | 5G key user<br>The remote UE and the MRAT-NCP have correctly configured their own p-abc wallet (both of them) and blockchain wallet (only the MRAT-NCP)                                                                                                                                             |                     |                                                                           |          |
|                                       |                                                                                                                                                                                                                                                                                                     |                     |                                                                           |          |
| Test Sequence                         | Step                                                                                                                                                                                                                                                                                                | Type                | Description                                                               | Result   |
| 1                                     | 1                                                                                                                                                                                                                                                                                                   | Stimulus            | Consumer and Issuer derives key from 5G key to establish a secure channel | On going |
|                                       | 2                                                                                                                                                                                                                                                                                                   | Check               | Consumer request Verifiable Credential to issuer                          | On going |
|                                       | 3                                                                                                                                                                                                                                                                                                   | Check               | Issuer generates and sends credential to Consumer                         | Pass     |
|                                       | 4                                                                                                                                                                                                                                                                                                   | Check               | Consumer stores credential on its wallet                                  | Pass     |
| 2                                     | 1                                                                                                                                                                                                                                                                                                   | Stimulus            | Consumer receives proximity service notification                          | Pass     |
|                                       | 2                                                                                                                                                                                                                                                                                                   | Check               | Consumer sends VC with required information to Provider                   | Pass     |
|                                       | 3                                                                                                                                                                                                                                                                                                   | Check               | Provider retrieves Issuer’s pK from blockchain                            | On going |
|                                       | 4                                                                                                                                                                                                                                                                                                   | Check               | Provider verifies the VC                                                  | Pass     |
| Test Verdict                          | The flow is proper and secure, as it establishes a protected channel through 5G key derivation, enables the consumer to reliably receive and store the credential, and ensures that the provider can verify its authenticity and validity using the issuer’s public key recorded on the blockchain. |                     |                                                                           | Pass     |

#### 4.2.5. ID Management & VoSysMonitor (ID-Mngnt – VoSysMonitor)

Table 35 summarizes the ID-Mngnt - VoSysMonitor integration tests.

Table 35: ID-Mngnt - VoSysMonitor integration tests summary

| Integration Test ID                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Objective                                                      | Status                                                                                                                                               |        |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|--------|
| ID<br>Mngnt_VoSySMonitor_I001         |                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Test read and write access of ID system on OP-TEE-based cache. | Completed                                                                                                                                            |        |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                                                                                                                                                      |        |
| Test type                             | Integration                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                |                                                                                                                                                      |        |
| Identifier                            | ID Mngnt_VoSySMonitor_I001                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                |                                                                                                                                                      |        |
| Testers                               | UMU, VOS                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                |                                                                                                                                                      |        |
| Test Purpose                          | Instantiate Open Trusted Execution Environment (OPTEE) solution for caching mechanisms on ARM-based far-edge device included in the MRAT-NCP.                                                                                                                                                                                                                                                                                                                 |                                                                |                                                                                                                                                      |        |
| References                            | [12]                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                |                                                                                                                                                      |        |
| Configuration                         | For this scenario we need an ARMv8 board with Trustzone capabilities (eg. AM69SK) with VOSySmonitor firmware installed. This board will act as the “relay node” in the V2X scenario and will be deployed at the network edge. The board will feature a fully-fledged Linux OS in the main non-secure partition, while in the Secure partition the OP-TEE OS will be installed.                                                                                |                                                                |                                                                                                                                                      |        |
|                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                                                                                                                                                      |        |
| Pre-test conditions                   | Regarding the workflow, a Client Application on the Non-Secure OS is the starting point to invoke Secure Storage Operations towards the Trusted Application on the Secure OS. Each operation always passes through the secure firmware (VOSySmonitor), ensuring the security of the operations.<br>For this test, the Client Application will request secure storage operations from the TEE related to user pseudonyms and their capabilities in the system. |                                                                |                                                                                                                                                      |        |
|                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                |                                                                                                                                                      |        |
| Test Sequence                         | Step                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Type                                                           | Description                                                                                                                                          | Result |
|                                       | 1                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Stimulus                                                       | V2X relay node request to securely store a user with pseudonym “abc” that associates with NANCY services “A,B,C” to the OP-TEE REE_FS secure storage | Pass   |
|                                       | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Check                                                          | Client application opens a trusted session and offloads the “store” request to the Trusted Application through VOSySmonitor                          | Pass   |
|                                       | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Check                                                          | Information successfully stored into the secure data store in an encrypted format                                                                    | Pass   |
|                                       | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Stimulus                                                       | V2X relay node request to quickly retrieve the capabilities of the user with pseudonym “abc” from the relay node                                     | Pass   |
|                                       | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Check                                                          | Client application opens a trusted session and offloads the “load” request to the Trusted Application through VOSySmonitor                           | Pass   |
|                                       | 6                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Check                                                          | Response is ready at the V2X relay node that associates the user with pseudonym “abc” with the NANCY services “A,B,C”                                | Pass   |
| Test Verdict                          | The REE_FS Secure Storage service of OP-TEE is validated to successfully handle operations in the V2X relay node that quickly associates users based on their pseudonyms with associated NANCY services, acting as a secure data cache at the network edge.                                                                                                                                                                                                   |                                                                |                                                                                                                                                      | Pass   |

#### 4.2.6. Digital Agreement Creator & Marketplace (DAC – Marketplace)

Table 36 summarizes the ID-Mngnt - VoSySMonitor integration tests.

Table 36: ID-Mngnt - VoSySMonitor integration tests summary

| Integration Test ID                   |                                                                                                                 | Objective                                                                                                       |                                                                                                                             | Status    |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|-----------|
| DAC_Marketplace_I001                  |                                                                                                                 | Test the correct generation and reception of a digital agreement based on the information from the marketplace. |                                                                                                                             | Completed |
| Analytic Integration Test Description |                                                                                                                 |                                                                                                                 |                                                                                                                             |           |
| Test type                             | Integration                                                                                                     |                                                                                                                 |                                                                                                                             |           |
| Identifier                            | DAC_Marketplace_I001                                                                                            |                                                                                                                 |                                                                                                                             |           |
| Testers                               | TECNALIA, DRAXIS                                                                                                |                                                                                                                 |                                                                                                                             |           |
| Test Purpose                          | Test the correct generation and reception of a digital agreement based on the information from the marketplace. |                                                                                                                 |                                                                                                                             |           |
| References                            | [4]                                                                                                             |                                                                                                                 |                                                                                                                             |           |
| Configuration                         | Not needed                                                                                                      |                                                                                                                 |                                                                                                                             |           |
|                                       |                                                                                                                 |                                                                                                                 |                                                                                                                             |           |
| Pre-test conditions                   |                                                                                                                 |                                                                                                                 |                                                                                                                             |           |
|                                       |                                                                                                                 |                                                                                                                 |                                                                                                                             |           |
| Test Sequence                         | Step                                                                                                            | Type                                                                                                            | Description                                                                                                                 | Result    |
|                                       | 1                                                                                                               | Stimulus                                                                                                        | The marketplace makes a request to the DAC for the suitable agreement creation:<br>http://188.245.61.44:8090/DAC/createSLA. | Pass      |
|                                       | 2                                                                                                               | Check                                                                                                           | The DAC creates and returns the agreement to the marketplace                                                                | Pass      |
| Test Verdict                          |                                                                                                                 |                                                                                                                 |                                                                                                                             | Pass      |

#### 4.2.7. Blockchain Component & Wallet (BC – Wallet)

Table 37 summarizes the Blockchain and Wallet integration tests.

Table 37: BC - Wallet integration tests summary

| Integration Test ID                   |                                                                                                | Objective                                                                                          | Status    |
|---------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-----------|
| BC_Wallet_I001                        |                                                                                                | Test correct user connection to the Fabric network using a connection profile (YAML or JSON file). | Completed |
| BC_Wallet_I002                        |                                                                                                | Test correct submission of transactions or queries to the ledger through the smart contract API.   | Completed |
| Analytic Integration Test Description |                                                                                                |                                                                                                    |           |
| Test type                             | Integration                                                                                    |                                                                                                    |           |
| Identifier                            | BC_Wallet_I001, BC_Wallet_I002                                                                 |                                                                                                    |           |
| Testers                               | NEC                                                                                            |                                                                                                    |           |
| Test Purpose                          | Test if the wallet can communicate with the blockchain.                                        |                                                                                                    |           |
| References                            | Architecture and components description can be found in [4].                                   |                                                                                                    |           |
| Configuration                         | Blockchain is up and running, connection profile of the blockchain is available to the wallet. |                                                                                                    |           |
|                                       |                                                                                                |                                                                                                    |           |

|                            |                               |             |                                                               |               |
|----------------------------|-------------------------------|-------------|---------------------------------------------------------------|---------------|
| <b>Pre-test conditions</b> | Blockchain is up and running. |             |                                                               |               |
| <b>Test Sequence</b>       | <b>Step</b>                   | <b>Type</b> | <b>Description</b>                                            | <b>Result</b> |
|                            | 1                             | Stimulus    | Start the wallet service providing the connection profile.    |               |
|                            | 2                             | Check       | Wallet returns no error and listening on the designated port. | <b>Pass</b>   |
| <b>Test Verdict</b>        |                               |             |                                                               | <b>Pass</b>   |

#### 4.2.8. Blockchain Component & Marketplace (BC – Marketplace)

Table 38 summarizes the Blockchain and Marketplace integration tests.

Table 38: BC - Marketplace integration tests summary

| Integration Test ID                   |                                                                               | Objective                                                                     |                                                                         | Status    |
|---------------------------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------|-----------|
| BC_Marketplace_I001                   |                                                                               | Test the correct deployment of the smart contracts on the Blockchain network. |                                                                         | Completed |
| Analytic Integration Test Description |                                                                               |                                                                               |                                                                         |           |
| Test type                             | Integration                                                                   |                                                                               |                                                                         |           |
| Identifier                            | BC_Marketplace_I001                                                           |                                                                               |                                                                         |           |
| Testers                               | TECNALIA, NEC                                                                 |                                                                               |                                                                         |           |
| Test Purpose                          | Test the correct deployment of the smart contracts on the Blockchain network. |                                                                               |                                                                         |           |
| References                            | [4]                                                                           |                                                                               |                                                                         |           |
| Configuration                         | The Hyperledger Fabric Blockchain network configuration is described in [4].  |                                                                               |                                                                         |           |
|                                       |                                                                               |                                                                               |                                                                         |           |
| Pre-test conditions                   | Not applicable                                                                |                                                                               |                                                                         |           |
|                                       |                                                                               |                                                                               |                                                                         |           |
| Test Sequence                         | Step                                                                          | Type                                                                          | Description                                                             | Result    |
|                                       | 1                                                                             | Stimulus                                                                      | Deployment of the marketplace smart contracts in the Blockchain network | Pass      |
|                                       | 2                                                                             | Check                                                                         | The marketplace API is accessible                                       | Pass      |
| Test Verdict                          |                                                                               |                                                                               |                                                                         | Pass      |

#### 4.2.9. Wallet – Marketplace

Table 39 summarizes the Wallet - Marketplace integration tests.

Table 39 Wallet - Marketplace integration tests summary

| Integration Test ID            |  | Objective                                                                                                                    | Status    |
|--------------------------------|--|------------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>Wallet_Marketplace_I001</b> |  | Test the correct execution of functions in the marketplace from the wallet.                                                  | Completed |
| <b>Wallet_Marketplace_I002</b> |  | Integration with the smart contract marketplace:<br>(Provided Wallet_F001) Test all wallet interfaces related to marketplace | Completed |

|                                              |                                                                                                                                                                                                                                                                                                     |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
|                                              |                                                                                                                                                                                                                                                                                                     |                                | operations to manage providers, services and searches.                                                                                                                                                                                                                                                                                                    |             |
|                                              |                                                                                                                                                                                                                                                                                                     | <b>Wallet_Marketplace_I003</b> | Integration with PQC signing:<br>(Provided Wallet_F001) Unit test for the correctness of the wallet PQC signing function and the verification function on SLARegistry chaincode.                                                                                                                                                                          | Completed   |
|                                              |                                                                                                                                                                                                                                                                                                     | <b>Wallet_Marketplace_I004</b> | Integration with the smart contract SLA:<br>(Provided Wallet_F001 and Wallet_F005) Test wallet <i>signSLA</i> interface to see if the SLA is correctly signed and updated (also with PQC signature) and if the subscribers for SLASigning events get notified. Test wallet <i>getSLA</i> and <i>getSLAByConsumerId</i> to look up SLAs in the blockchain. | Completed   |
|                                              |                                                                                                                                                                                                                                                                                                     | <b>Wallet_Marketplace_I005</b> | Integration with the oracle:<br>(Provided Wallet_F001, Wallet_F004 and Wallet_F006) Test wallet <i>createSearch</i> interface to see if the oracle triggers SLA creation correctly and if the subscriber for SLASigning events get notified.                                                                                                              | Completed   |
| <b>Analytic Integration Test Description</b> |                                                                                                                                                                                                                                                                                                     |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
| <b>Test type</b>                             | <b>Integration</b>                                                                                                                                                                                                                                                                                  |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
| <b>Identifier</b>                            | <b>Wallet_Marketplace_I001, Wallet_Marketplace_I002<br/>Wallet_Marketplace_I003, Wallet_Marketplace_I004,<br/>Wallet_Marketplace_I005</b>                                                                                                                                                           |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
| <b>Testers</b>                               | <b>TECNALIA, NEC</b>                                                                                                                                                                                                                                                                                |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
| <b>Test Purpose</b>                          | Test the correct execution of functions in the marketplace from the wallet.                                                                                                                                                                                                                         |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
| <b>References</b>                            | The marketplace workflow and corresponding wallet API calls are described in <b>[4]</b>                                                                                                                                                                                                             |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
| <b>Configuration</b>                         | The marketplace and the SLARegistry smart contracts are deployed. The smart pricing service and the DAC service are up and running. The oracle services are up and running with the correct configuration to communicate with the blockchain network as well as the smart pricing and DAC services. |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
| <b>Pre-test conditions</b>                   | Unit tests for the deployed smart contracts are passed successfully. Oracle services are all registered and enrolled successfully in the blockchain. Start the wallet gateway service on a given port.                                                                                              |                                |                                                                                                                                                                                                                                                                                                                                                           |             |
| 1                                            | 1                                                                                                                                                                                                                                                                                                   | Stimulus                       | Invoke wallet API call to create a sample provider.                                                                                                                                                                                                                                                                                                       |             |
|                                              | 2                                                                                                                                                                                                                                                                                                   | Check                          | If provided malformed call parameters, call fails, and wallet returns corresponding error message.                                                                                                                                                                                                                                                        | <b>Pass</b> |
|                                              | 3                                                                                                                                                                                                                                                                                                   | Check                          | If the 'id' attribute in the call parameters is present and there is no DID in the called wallet that matches this value, call fails, and wallet returns corresponding error message.                                                                                                                                                                     | <b>Pass</b> |
|                                              | 4                                                                                                                                                                                                                                                                                                   | Check                          | If call parameter are well formatted, further checks refer to the test of createProvider call on the marketplace smart contract. If successful, the wallet returns the newly created provider information. If failed, the wallet returns the corresponding error message from the blockchain.                                                             | <b>Pass</b> |

|   |   |          |                                                                                                                                                                                                                                                                                             |      |
|---|---|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
|   | 5 | Check    | When the creation in step 1.4 is successful, call listProviders from the wallet and returns the just created provider.                                                                                                                                                                      | Pass |
| 2 | 1 | Stimulus | Test to update and delete a provider similar to test 1.                                                                                                                                                                                                                                     |      |
| 3 | 1 | Stimulus | Invoke wallet API call to create a sample service.                                                                                                                                                                                                                                          |      |
|   | 2 | Check    | If provided malformed call parameters, call fails, and wallet returns corresponding error message.                                                                                                                                                                                          | Pass |
|   | 2 | Check    | If the 'provider_id' attribute in the call parameters is present and there is no DID in the called wallet that matches this value, call fails, and wallet returns corresponding error message.                                                                                              | Pass |
|   | 3 | Check    | If call parameter are well formatted, further checks refer to the test of createService call on the marketplace smart contract. If successful, the wallet returns the newly created service information. If failed, the wallet returns the corresponding error message from the blockchain. | Pass |
| 4 | 1 | Stimulus | Test to update and delete a service similar to test 3.                                                                                                                                                                                                                                      |      |
| 5 | 1 | Stimulus | Invoke wallet API call to create a sample search.                                                                                                                                                                                                                                           |      |
|   | 2 | Check    | If provided malformed call parameters, call fails, and wallet returns corresponding error message.                                                                                                                                                                                          | Pass |
|   | 3 | Check    | If the 'consumer_id' attribute in the call parameters is present and there is no DID in the called wallet that matches this value, call fails, and wallet returns corresponding error message.                                                                                              | Pass |
|   | 4 | Check    | If call parameter are well formatted, further checks refer to the test of createSearch call on the marketplace smart contract. If successful, the wallet returns the search result. If failed, the wallet returns the corresponding error message from the blockchain.                      | Pass |
| 6 | 1 | Stimulus | Call the wallet service to subscribe the SLAInit event.                                                                                                                                                                                                                                     |      |
|   | 2 | Check    | Invoke the createSearch call with valid parameters. The wallet returns an SLAInit event with the matched consumer_id as in the createSearch call                                                                                                                                            | Pass |
| 7 | 1 | Stimulus | Call the wallet service to subscribe the SLASigning event. Invoke the signSLA call to the wallet.                                                                                                                                                                                           |      |
|   | 2 | Check    | If provided malformed call parameters, call fails, and wallet returns corresponding error message.                                                                                                                                                                                          | Pass |
|   | 3 | Check    | If the 'slald' in the signSLA call parameters does not exist in the SLARegistry, call fails and wallet returns error message.                                                                                                                                                               | Pass |
|   | 4 | Check    | If the 'uid' in the signSLA call parameters cannot be found in the wallet, call fails and wallet returns error message.                                                                                                                                                                     | Pass |
|   | 5 | Check    | If the corresponding DID of the 'uid' call parameter does not match either the 'provider_id' or the 'consumer_id' in the SLA of the provided "slald", call fails and wallet returns corresponding error message.                                                                            | Pass |
|   | 6 | Check    | When 'uid' matches either provider_id or consumer_id of the corresponding SLA, if the DID                                                                                                                                                                                                   | Pass |

|                     |   |       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |             |
|---------------------|---|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
|                     |   |       | corresponds to the 'uid' parameter uses PQC signature scheme as the verification method, when the PQC signature produced by the wallet is successfully verified and stored by the blockchain, the wallet returns empty. Meanwhile, wallet that subscribed to the SLASigning event receives a notification of the signed SLA, in which either the producer signature or consumer signature field is now a PQC signature.                                                                                                                                           |             |
|                     | 7 | Check | When 'uid' matches either provider_id or consumer_id of the corresponding SLA, if the DID corresponds to the 'uid' parameter uses non-PQC signature scheme as the verification method, when the signSLA call from the wallet is successfully validated and stored by the blockchain, the wallet returns empty. Meanwhile, wallet that subscribed to the SLASigning event receives a notification of the signed SLA, in which either the producer signature or consumer signature field is the transaction ID of the corresponding successful signSLA transaction. |             |
|                     | 8 | Check | If check 7.6 and 7.7 fails, the wallet returns the error message from the blockchain and receives no corresponding notification.                                                                                                                                                                                                                                                                                                                                                                                                                                  | Pass        |
| <b>Test Verdict</b> |   |       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <b>Pass</b> |

#### 4.2.10. AI Virtualiser & VoSysMonitor (AIVirt– VoSysMonitor)

Table 40 summarizes the AIVirt– VoSysMonitor integration tests.

Table 40: AI Virt - VoSysMonitor integration tests summary

| Integration Test ID                   |                                                                                                                                                                                                                                                                                                          | Objective                                                                                                                                                                                                     | Status    |
|---------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>AIVirt_VoSysMonitor_I001</b>       |                                                                                                                                                                                                                                                                                                          | Test response of VoSysMonitor to Libvirt commands (virsh define, virsh start, virsh create, virsh shutdown, virsh destroy, virsh reboot, virsh suspend, virsh resume) triggered from AIVirt through OpenStack | Completed |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                               |           |
| <b>Test type</b>                      | <b>Integration</b>                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                               |           |
| <b>Identifier</b>                     | <b>AIVirt_VoSysMonitor_I001</b>                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                               |           |
| <b>Testers</b>                        | <b>I2CAT, VOS</b>                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                               |           |
| <b>Test Purpose</b>                   | The purpose of this test is to validate the operations on vManager's partitions initiated from the Libvirt tool, as integration point with the AI Virtualiser.                                                                                                                                           |                                                                                                                                                                                                               |           |
| <b>References</b>                     | <b>[8]</b>                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                               |           |
| <b>Configuration</b>                  | For this scenario we need an ARMv8 board with VOSysmonitor firmware deployed and one management partition (a Linux OS) booted.                                                                                                                                                                           |                                                                                                                                                                                                               |           |
| <b>Pre-test conditions</b>            | To start the testing, we load the vManager driver on the management partition (making /dev/vmanager available).<br><br>Also, the Libvirt "virtmand" service must be ready and accessible through the "vman:///system" URI. The vManager user-space daemon "vmand" should be also available in the system |                                                                                                                                                                                                               |           |

| Test Sequence       | Step                                                                                                                                                       | Type     | Description                                                                                                                     | Result      |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------------------------------------------------------------------------------------------------------------------|-------------|
|                     | 1                                                                                                                                                          | Stimulus | ./vmmand<br>Spawning the vManager daemon as the first step                                                                      | Pass        |
|                     | 2                                                                                                                                                          | Stimulus | virsh -c vman:///system define <xml_file><br><br>Libvirt xml_file points to <kernel> image, <disk> image and <device tree> file | Pass        |
|                     | 3                                                                                                                                                          | Check    | Domain <domain> defined from <xml_file><br><br>(Libvirt output)                                                                 | Pass        |
|                     | 4                                                                                                                                                          | Check    | Partition #X created<br><br>(vManager daemon output)                                                                            | Pass        |
|                     | 5                                                                                                                                                          | Check    | ls /dev/vmanX<br><br>Partition device is available at Linux management partition                                                | Pass        |
|                     | 6                                                                                                                                                          | Stimulus | virsh -c vman:///system list -all<br><br>Check available partitions through Libvirt                                             | Pass        |
|                     | 7                                                                                                                                                          | Check    | List shows partition with ID #X, Name <domain> and State "shut off"                                                             | Pass        |
|                     | 8                                                                                                                                                          | Stimulus | virsh -c vman:///system start <domain><br><br>Libvirt command to start the partition execution                                  | Pass        |
|                     | 9                                                                                                                                                          | Check    | Domain <domain> started<br><br>(Libvirt output)                                                                                 | Pass        |
|                     | 10                                                                                                                                                         | Check    | vManager daemon shown messages that DTB and Kernel images were loaded successfully                                              | Pass        |
|                     | 11                                                                                                                                                         | Check    | Partition boot-up messages appear on the partition's serial console                                                             | Pass        |
| <b>Test Verdict</b> | <b>The successful creation and startup of a vManager partition is tested through Libvirt commands, simulated as being instructed by the AI Virtualiser</b> |          |                                                                                                                                 | <b>Pass</b> |

#### 4.2.11. AI Virtualiser & Self-Evolving Model Repository (AIVirt –SEMR)

The autoscaling benchmark was designed to evaluate the performance and responsiveness of the inference service under varying concurrency levels. The test sequentially launched batches of HTTP POST requests to the QoE endpoint deployed through Ray Serve, sending a fixed inference payload while progressively increasing the number of concurrent requests from 1 up to 1024. Each batch was executed in parallel using a thread pool, measuring the round-trip time (RTT) of each individual request. The resulting latencies were stored for statistical analysis and aggregated into mean, percentile, and standard deviation metrics. Between experiments, a cooldown period of 160 seconds was introduced to allow the underlying autoscaler to adjust the number of replicas and stabilize. The collected data, exported to inference\_all.csv, was later processed using a custom plotting script that visualizes the mean latency and percentile bands across concurrency levels, along with boxplots and jittered scatter distributions. This methodology enables a clear assessment of how the inference

system scales under load and how effectively autoscaling mechanisms maintain latency within acceptable bounds. Table 41 summarizes the AI Virt - SEMR integration tests.

Table 41: AI Virt - SEMR integration tests summary

| Integration Test ID                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Objective                                                                                                                     | Status                                                                      |        |
|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|--------|
| AIVirt_SEMR_I001                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Test connectivity between the AI Virt and JSI SEMR cluster                                                                    | Completed                                                                   |        |
| AIVirt_SEMR_I002                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Test triggering the AI Virt (through the Slice Manager API end point) after provisioning it with the JSI SEMR kubeconfig file | Completed                                                                   |        |
| AIVirt_SEMR_I003                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Test capacity threshold for latency                                                                                           | New and Completed                                                           |        |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                               |                                                                             |        |
| Test type                             | Integration                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                               |                                                                             |        |
| Identifier                            | AIVirt_SEMR_I003                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                               |                                                                             |        |
| Testers                               | i2CAT, IJS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                               |                                                                             |        |
| Test Purpose                          | Test how the capacity increments affect the latency and how this could help us reach a threshold value depending on the final use case.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                               |                                                                             |        |
| References                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                               |                                                                             |        |
| Configuration                         | The benchmark was conducted on a NAOMI-deployed Ray Serve cluster running on Kubernetes, with the QoE inference endpoint exposed at http://<cluster-ip>/ray-api/qoe/. The client used Python 3.10 in a virtual environment with requests, pandas, and matplotlib, sending concurrent POST requests to measure latency. Prometheus and Grafana were configured for observability, and autoscaling was enabled with a 160-second cooldown between tests to allow the system to stabilize before the next concurrency level.                                                                                                                                                                                                                                                                                                                                                |                                                                                                                               |                                                                             |        |
|                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                               |                                                                             |        |
| Pre-test conditions                   | <p>The NAOMI Ray Serve cluster was fully deployed and operational, with the QoE endpoint accessible via the API gateway.</p> <ul style="list-style-type: none"><li>All Ray head and worker pods were in a <i>Running</i> state and the autoscaler was active.</li><li>The client machine had network connectivity to the cluster and sufficient system limits (ulimit -n ≥ 65535) for concurrent HTTP connections.</li><li>Required Python dependencies (requests, pandas, numpy, matplotlib) were installed and the benchmark_autoscaling.py script was executable.</li><li>Monitoring services (Prometheus, Grafana, and MLflow) were running to observe resource usage, scaling activity, and log experiment metrics.</li><li>The inference payload was validated through a single manual request to confirm model readiness before starting the load test.</li></ul> |                                                                                                                               |                                                                             |        |
|                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                               |                                                                             |        |
| Test Sequence                         | Step                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Type                                                                                                                          | Description                                                                 | Result |
|                                       | 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Stimulus                                                                                                                      | Environment checking                                                        | Pass   |
|                                       | 2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Check                                                                                                                         | Client setup and initial warmup                                             | Pass   |
|                                       | 3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Check                                                                                                                         | Benchmark execution                                                         | Pass   |
|                                       | 4                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Check                                                                                                                         | Latency recording and results aggregation                                   | Pass   |
|                                       | 5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Check                                                                                                                         | Confirm the threshold to increase the CPU capacity and minimize the latency | Pass   |
| Test Verdict                          | We managed to run the plotting script to generate summary figures showing latency trends and variability across loads.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                               |                                                                             | Pass   |

Figure 34 illustrates the individual response times observed when sending increasing numbers of concurrent requests to the QoE inference endpoint. Each dot represents the latency of a single request. As the level of concurrency grows, the dispersion of latency values also increases, indicating higher variability and occasional performance degradation at higher loads. The trend highlights the system's scaling behavior and the impact of concurrent demand on end-to-end response times. With this test we obtain the threshold in which to activate more processing in order to reduce the CPU, depending on the final use case needs.

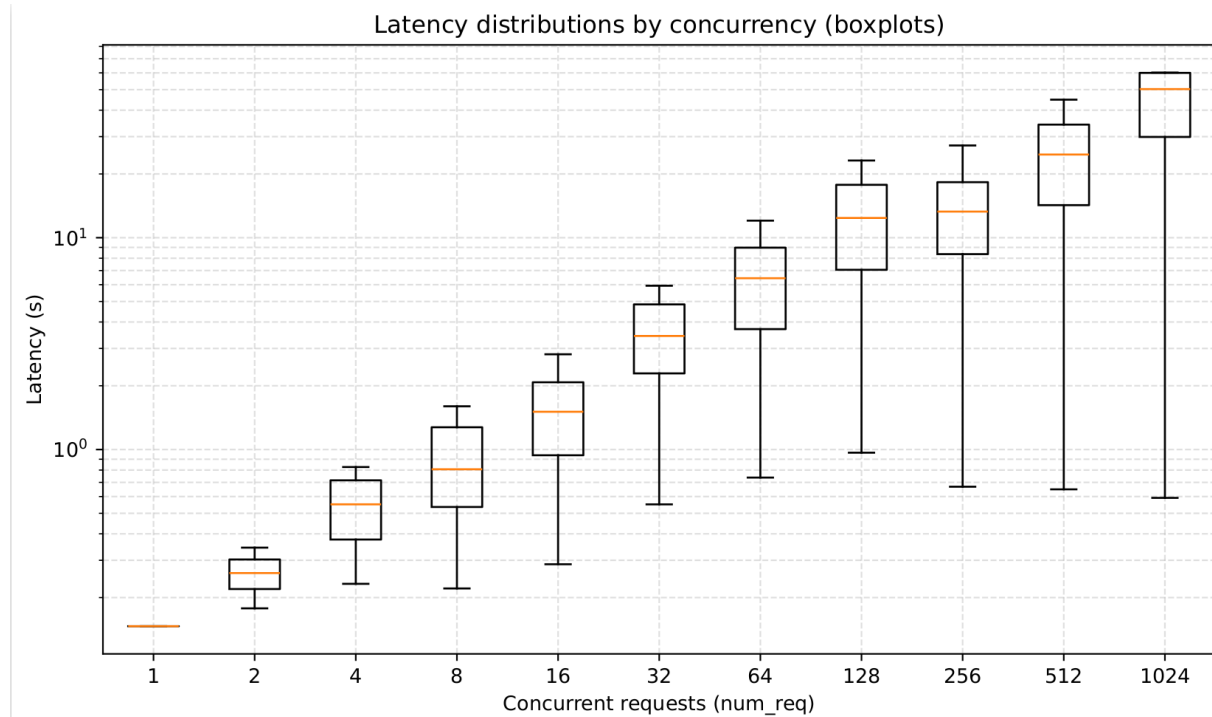


Figure 34: Concurrent requests vs latency in seconds

#### 4.2.12. Marketplace & Smart Pricing Policies (Marketplace – SPP)

Table 42 summarizes the Marketplace – SSP integration tests.

Table 42: Marketplace - SPP integration tests summary

| Integration Test ID                   |                                                                                                                                             | Objective                                                                                                                  | Status    |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>Marketplace_SPP_I001</b>           |                                                                                                                                             | Test the correct reception of the most suitable price of the most suitable service from those available in the marketplace | Completed |
| Analytic Integration Test Description |                                                                                                                                             |                                                                                                                            |           |
| <b>Test type</b>                      | Integration                                                                                                                                 |                                                                                                                            |           |
| <b>Identifier</b>                     | <b>Marketplace_SPP_I001</b>                                                                                                                 |                                                                                                                            |           |
| <b>Testers</b>                        | TECNALIA, 8BELLS                                                                                                                            |                                                                                                                            |           |
| <b>Test Purpose</b>                   | Test the correct reception of the most suitable price of the most suitable service from those available in the marketplace                  |                                                                                                                            |           |
| <b>References</b>                     | [13], [4]                                                                                                                                   |                                                                                                                            |           |
| <b>Configuration</b>                  | Not applicable                                                                                                                              |                                                                                                                            |           |
| <b>Pre-test conditions</b>            | A service request should have been received in the marketplace which should have selected suitable services in terms of request definition. |                                                                                                                            |           |

| Test Sequence       | Step | Type     | Description                                                                                                                                                                                                                                   | Result      |
|---------------------|------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
|                     | 1    | Stimulus | The marketplace makes a request to the SP for the most suitable service in terms of price:<br><a href="https://nancy-smart-pricing.8bellsresearch.com/price_calculation">https://nancy-smart-pricing.8bellsresearch.com/price_calculation</a> | Pass        |
|                     | 2    | Check    | The smart pricing provides the most suitable service and the most suitable price.                                                                                                                                                             | Pass        |
|                     | n    | Check    |                                                                                                                                                                                                                                               |             |
| <b>Test Verdict</b> |      |          |                                                                                                                                                                                                                                               | <b>Pass</b> |

#### 4.2.13. Models – Self Evolving Model Repository (SEMR)

Self-Evolving Model Repository (SEMR) is a modular platform that manages the full lifecycle of AI/ML models—from training and storage to serving and monitoring. This test validates its integration capabilities and performance under realistic workflow orchestration scenarios. Table 43 summarizes the Models – SEMR integration tests.

Table 43: Models - SEMR integration tests summary

| Integration Test ID                   |      | Objective                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                             | Status    |
|---------------------------------------|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|-----------|
| Models_SEMR_I001                      |      | Testing the speed and latency of model serving                                                                                                                                                                                                                                                                                                                                                                                                                 |                             | Completed |
| Analytic Integration Test Description |      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                             |           |
| Test type                             |      | Integration                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                             |           |
| Identifier                            |      | Models_SEMR_I001                                                                                                                                                                                                                                                                                                                                                                                                                                               |                             |           |
| Testers                               |      | IJS                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                             |           |
| Test Purpose                          |      | The integration will evaluate the performance of the orchestration of the lifecycle of AI-based models and their serving.                                                                                                                                                                                                                                                                                                                                      |                             |           |
| References                            |      | Detailed description in [18]                                                                                                                                                                                                                                                                                                                                                                                                                                   |                             |           |
| Configuration                         |      | All configurations are set as helm values. Documentation and all configurations can be found in SEMR/helm_charts/values.yaml<br>Project is modular with 5 main components: <ul style="list-style-type: none"><li>• AI/ML model store with MLflow</li><li>• Distributed computing and AI/ML training with Ray</li><li>• Workflow orchestration with Flyte</li><li>• Data storage with MinIO</li><li>• System monitoring with Prometheus &amp; Grafana</li></ul> |                             |           |
| Pre-test conditions                   |      | Minimal requirements <ul style="list-style-type: none"><li>• 12 CPU cores</li><li>• 32GB RAM</li><li>• 100GB Available disk space</li></ul>                                                                                                                                                                                                                                                                                                                    |                             |           |
| Test Sequence                         | Step | Type                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Description                 | Result    |
|                                       | 1    | Stimulus                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Register, Trigger workflows |           |
|                                       | 2    | Check                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Monitor, collect metrics    | Pass      |
|                                       | 3    | Check                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Run training jobs           | Pass      |
|                                       | 4    | Check                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Deploy models               | Pass      |

|                     |                                                                   |       |                     |                                     |
|---------------------|-------------------------------------------------------------------|-------|---------------------|-------------------------------------|
|                     | 5                                                                 | Check | Store, fetch models | Pass                                |
|                     | 6                                                                 | Check | Save, load data     | Pass                                |
| <b>Test Verdict</b> | <b>Check inference latency, mean latency and execution length</b> |       |                     | <b>Manual inspection/monitoring</b> |

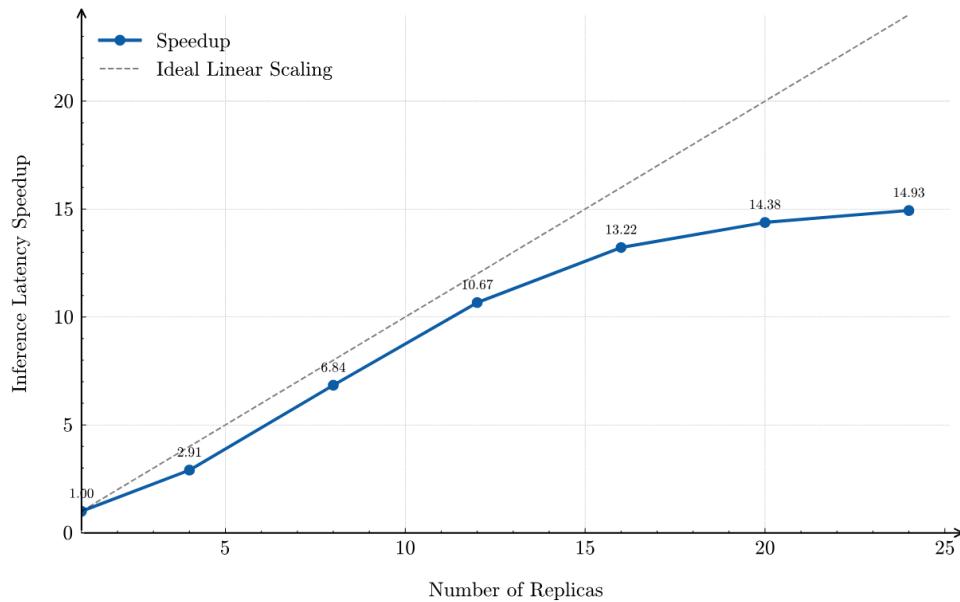


Figure 35: Inference speedup vs number of replicas

Figure 35 depicts mean inference latency speedup compared to the increasing number of model replicas when running 500 concurrent requests on a deployed QoE model. By increasing the number of replicas a linear latency reduction is expected. The ideal linear speedup is plotted on the graph for comparison.

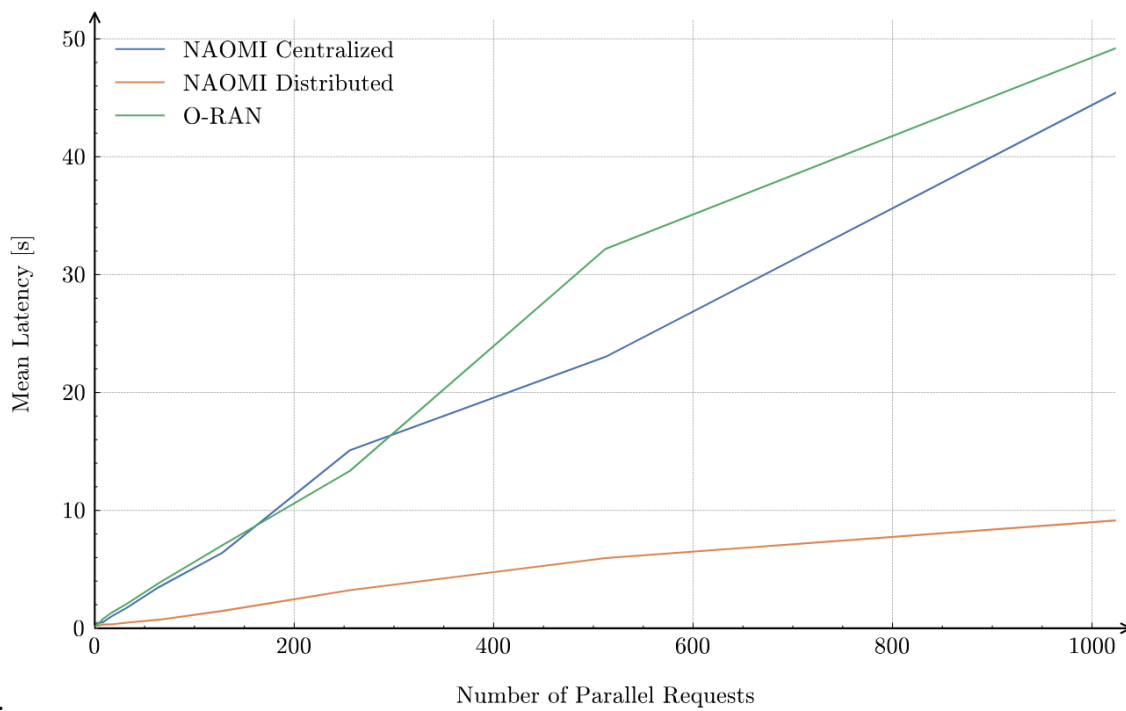


Figure 36: Mean latency vs. Number of parallel Requests

Figure 36 presents mean end-to-end latencies for concurrent inference requests on the deployed QoE prediction model. By increasing the number of concurrent requests ((x) axis) sent to the API endpoint, the mean latency increases (measured in seconds on (y) axis). The mean latencies for the O-RAN solution as well as both NAOMI solutions, centralised and when deployed on a distributed infrastructure, are plotted on the graph.

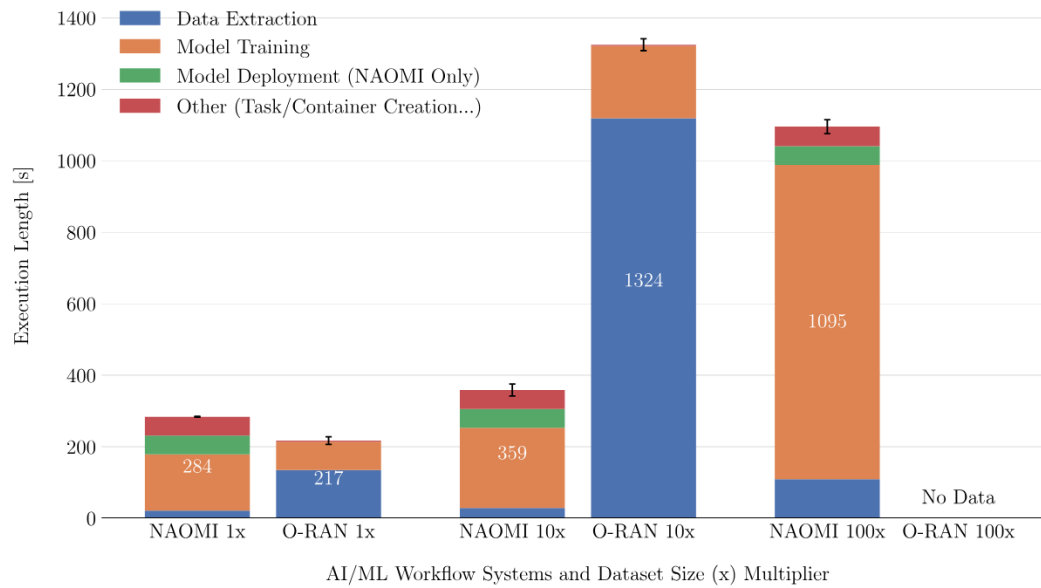


Figure 37: Execution time of different AI/ML workflow systems and dataset size

Figure 37 presents the execution times of the QoE prediction workflow on both solutions for a reference dataset ( 1 x ), a dataset with 10 times the size of the reference dataset ( 10 x ) and a dataset 100 times the size of the reference one ( 100 x ). Different dataset sizes and solutions are plotted on the (x) axis and execution time in seconds on the (y) axis for each of the experiments.

#### 4.2.14. Self-Evolving Model Repository & Federated Learning Intrusion Detection System (SEMR – FL-IDS)

Table 44 summarizes the SEMR – FL-IDS integration tests.

Table 44: SEMR – FL-IDS integration tests summary

| Integration Test ID                   |                                                                                                                                                                        | Objective                                                                                                                        | Status (Completed, Dropped, New and completed) |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| SEMR_FL-IDS_I001                      |                                                                                                                                                                        | Validation of NAOMI full integration (MLflow model storage, Ray Serve, endpoint prediction functionality using mocked services). | Completed                                      |
| SEMR_FL-IDS_I002                      |                                                                                                                                                                        | Validation of MLflow model storage integration (run directories, artifacts, MLmodel).                                            | Completed                                      |
| SEMR_FL-IDS_I003                      |                                                                                                                                                                        | Validation of Ray Serve deployment functionality (mock predictor, async predictions).                                            | Completed                                      |
| Analytic Integration Test Description |                                                                                                                                                                        |                                                                                                                                  |                                                |
| Test type                             | Integration                                                                                                                                                            |                                                                                                                                  |                                                |
| Identifier                            | SEMR_FL-IDS_I001                                                                                                                                                       |                                                                                                                                  |                                                |
| Testers                               | MINDS                                                                                                                                                                  |                                                                                                                                  |                                                |
| Test Purpose                          | Verify that the system integrates correctly with NAOMI by validating MLflow model storage, Ray Serve deployment, and REST API endpoint response with mock predictions. |                                                                                                                                  |                                                |
| References                            | <ul style="list-style-type: none"> <li>The module deploy_model and test_endpoint test.</li> <li>NAOMI documentation.</li> </ul>                                        |                                                                                                                                  |                                                |

|                                       |                                                                                                                                                                                                                                                                                                                                                           |          |                                                                                                     |                                                               |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------|
| Configuration                         | <ul style="list-style-type: none"><li>Test environment with unittest framework.</li><li>Installed packages: mlflow, ray[serve], requests, numpy.</li><li>Mocked dependencies: mlflow.set_tracking_uri, mlflow.pyfunc.load_model, ray.init, ray.serve.run, requests.post.</li></ul>                                                                        |          |                                                                                                     |                                                               |
| Pre-test conditions                   | <ul style="list-style-type: none"><li>mlruns directory exists (MLflow default storage)</li><li>deploy_model.py script present in workspace</li><li>test_endpoint.py script present in workspace</li><li>Mock MLflow model object prepared with predict method</li><li>Mock REST API response set to status_code=200 with JSON prediction output</li></ul> |          |                                                                                                     |                                                               |
| Test Sequence                         | Step                                                                                                                                                                                                                                                                                                                                                      | Type     | Description                                                                                         | Result                                                        |
|                                       | 1                                                                                                                                                                                                                                                                                                                                                         | Check    | Verify mlruns directory exists.                                                                     |                                                               |
|                                       | 2                                                                                                                                                                                                                                                                                                                                                         | Check    | Verify deploy_model.py script exists.                                                               |                                                               |
|                                       | 3                                                                                                                                                                                                                                                                                                                                                         | Check    | Verify test_endpoint.py script exists.                                                              |                                                               |
|                                       | 4                                                                                                                                                                                                                                                                                                                                                         | Stimulus | Send POST request to “http://localhost/ray-api/nancy/” with sample test data.                       | Mocked API endpoint returned sample predictions successfully. |
|                                       | 5                                                                                                                                                                                                                                                                                                                                                         | Check    | Verify response status code = 200.                                                                  | Pass                                                          |
|                                       | 6                                                                                                                                                                                                                                                                                                                                                         | Check    | Verify response JSON contains "predictions" key.                                                    | Pass                                                          |
|                                       | 7                                                                                                                                                                                                                                                                                                                                                         | Check    | Verify returned predictions match expected shape (3x7).                                             | Pass                                                          |
| Test Verdict                          |                                                                                                                                                                                                                                                                                                                                                           |          |                                                                                                     | Pass                                                          |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                                                                                           |          |                                                                                                     |                                                               |
| Test type                             | Integration                                                                                                                                                                                                                                                                                                                                               |          |                                                                                                     |                                                               |
| Identifier                            | SEMR_FL-IDS_I002                                                                                                                                                                                                                                                                                                                                          |          |                                                                                                     |                                                               |
| Testers                               | MINDS                                                                                                                                                                                                                                                                                                                                                     |          |                                                                                                     |                                                               |
| Test Purpose                          | Verify that a trained model has been correctly saved to MLflow by checking the existence of the mlruns directory, run subdirectories, and model artifacts (model/ or MLmodel file).                                                                                                                                                                       |          |                                                                                                     |                                                               |
| References                            | <ul style="list-style-type: none"><li>mlruns/ directory (default MLflow tracking storage).</li><li>Training pipeline output.</li><li>MLflow documentation.</li></ul>                                                                                                                                                                                      |          |                                                                                                     |                                                               |
| Configuration                         | <ul style="list-style-type: none"><li>Test environment with unittest framework.</li><li>Required packages: mlflow, glob, os.</li><li>MLflow local tracking backend (file-based in mlruns/).</li></ul>                                                                                                                                                     |          |                                                                                                     |                                                               |
| Pre-test conditions                   | <ul style="list-style-type: none"><li>At least one MLflow run has been executed before this test.</li><li>“mlruns” directory exists and contains a subdirectory “mlruns/0”.</li><li>Run directory should contain either “artifacts/model/” with saved model files, or “MLmodel” file with run metadata.</li></ul>                                         |          |                                                                                                     |                                                               |
| Test Sequence                         | Step                                                                                                                                                                                                                                                                                                                                                      | Type     | Description                                                                                         | Result                                                        |
|                                       | 1                                                                                                                                                                                                                                                                                                                                                         | Check    | Verify mlruns directory exists.                                                                     | Pass                                                          |
|                                       | 2                                                                                                                                                                                                                                                                                                                                                         | Check    | Verify mlruns/0 directory exists.                                                                   | Pass                                                          |
|                                       | 3                                                                                                                                                                                                                                                                                                                                                         | Check    | Collect run directories under mlruns/0 and ensure there is at least one (so the latest run exists). | Pass                                                          |
|                                       | 4                                                                                                                                                                                                                                                                                                                                                         | Check    | If artifacts/model/ exists, verify it contains model files.                                         | Pass (files found)                                            |

|                                       |                                                                                                                                                                                                                                                      |          |                                                                                                         |                                       |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|---------------------------------------------------------------------------------------------------------|---------------------------------------|
|                                       | 5                                                                                                                                                                                                                                                    | Check    | If artifacts/model/ does not exist, then, if MLmodel file exists in run directory, verify its presence. | Pass (if files exists)                |
|                                       | 6                                                                                                                                                                                                                                                    | Check    | Else, if “artifacts/model/” and “MLmodel” do not exist, verify run directory contains metadata files.   | Pass                                  |
| Test Verdict                          |                                                                                                                                                                                                                                                      |          |                                                                                                         | Pass                                  |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                      |          |                                                                                                         |                                       |
| Test type                             | Integration                                                                                                                                                                                                                                          |          |                                                                                                         |                                       |
| Identifier                            | SEMR_FL-IDS_I003                                                                                                                                                                                                                                     |          |                                                                                                         |                                       |
| Testers                               | MINDS                                                                                                                                                                                                                                                |          |                                                                                                         |                                       |
| Test Purpose                          | Verify that the model can be loaded from MLflow, a Ray Serve predictor can be instantiated, and predictions can be returned in the expected format.                                                                                                  |          |                                                                                                         |                                       |
| References                            | <ul style="list-style-type: none"><li>The deploy_model module.</li><li>MLflow and Ray Serve API documentation.</li></ul>                                                                                                                             |          |                                                                                                         |                                       |
| Configuration                         | <ul style="list-style-type: none"><li>Test environment with unittest framework.</li><li>Required packages: mlflow, ray, numpy, fastapi, asyncio.</li></ul>                                                                                           |          |                                                                                                         |                                       |
|                                       |                                                                                                                                                                                                                                                      |          |                                                                                                         |                                       |
| Pre-test conditions                   | <ul style="list-style-type: none"><li>mlflow.pyfunc.load_model is patched to return a mock model.</li><li>ray.init and ray.serve.run are patched to avoid starting real Ray processes.</li><li>deploy_model.py exists in the project root.</li></ul> |          |                                                                                                         |                                       |
|                                       |                                                                                                                                                                                                                                                      |          |                                                                                                         |                                       |
| Test Sequence                         | Step                                                                                                                                                                                                                                                 | Type     | Description                                                                                             | Result                                |
|                                       | 1                                                                                                                                                                                                                                                    | Check    | Verify that deploy_model.py exists in the project root.                                                 | Pass                                  |
|                                       | 2                                                                                                                                                                                                                                                    | Stimulus | Initialize mocked predictor object (MockPredictor).                                                     | Creates and returns predictor object. |
|                                       | 3                                                                                                                                                                                                                                                    | Stimulus | Generate predictions with test data through predictor’s predict method (async).                         | Returns predictions JSON.             |
|                                       | 4                                                                                                                                                                                                                                                    | Check    | Verify predictions include "predictions" key.                                                           | Pass                                  |
|                                       | 5                                                                                                                                                                                                                                                    | Check    | Verify predictions item of JSON has length 1 (list).                                                    | Pass                                  |
|                                       | 6                                                                                                                                                                                                                                                    | Check    | Verify predictions list contains 7 items (length=7).                                                    | Pass                                  |
| Test Verdict                          |                                                                                                                                                                                                                                                      |          |                                                                                                         | Pass                                  |

#### 4.2.15. Post Quantum Cryptography Sign & Secure Communications (PQCSign – PQCSecCom)

Table 45 summarizes the PQC Sign – PQC SecCom integration tests.

Table 45: PQC Sign – PQC SecCom integration tests summary

| Integration Test ID                          | Objective                                                                                                                           | Status    |
|----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>PQCSign_PQCSecCom_I001</b>                | Test the integration of the PQC Signature Token and the PQC secure communication component for Dilithium algorithm sign in hardware | Completed |
| <b>Analytic Integration Test Description</b> |                                                                                                                                     |           |
| <b>Test type</b>                             | <b>Integration</b>                                                                                                                  |           |
| <b>Identifier</b>                            | <b>PQCSign_PQCSecCom_I001</b>                                                                                                       |           |
| <b>Testers</b>                               | <b>TEI</b>                                                                                                                          |           |

|                            |                                                                                                                                                                      |             |                                                                                                                     |               |
|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|---------------------------------------------------------------------------------------------------------------------|---------------|
| <b>Test Purpose</b>        | Evaluate the integration of the PQC Signature Token with the PQC secure communication component, with the Dilithium algorithm using hardware-based digital signing.  |             |                                                                                                                     |               |
| <b>References</b>          | <b>[11]</b>                                                                                                                                                          |             |                                                                                                                     |               |
| <b>Configuration</b>       | Raspberry PI 4 with Raspberry Pi OS (Bookworm version) with installed libclassicclient_8.1.0-b01.00_raspberrypi.aarch64.deb library for interact with TDIS HW token. |             |                                                                                                                     |               |
| <b>Pre-test conditions</b> | Physical smart card reader with TDIS token insert.                                                                                                                   |             |                                                                                                                     |               |
| <b>Test Sequence</b>       | <b>Step</b>                                                                                                                                                          | <b>Type</b> | <b>Description</b>                                                                                                  | <b>Result</b> |
|                            | 1                                                                                                                                                                    | Stimulus    | Run NancyTest app provided by TDIS with pkcs11 option and a proper string content to be signed in hardware          | Pass          |
|                            | 2                                                                                                                                                                    | Check       | The app successfully signs the content checking the results and the logs.                                           | Pass          |
|                            | 3                                                                                                                                                                    | Stimulus    | Run the PQC Secure Communication (PQC-SC) component with pkcs11 HW configuration to enable the signing in hardware. | Pass          |
|                            | 4                                                                                                                                                                    | Check       | The PQC-SC successfully sign the content, using TDIS token, checking the results and the logs.                      | Pass          |
| <b>Test Verdict</b>        |                                                                                                                                                                      |             |                                                                                                                     | Pass          |

#### 4.2.16. AI Network Quality Module & Network Information Framework (AINQM – NIF)

Table 46 summarizes the AINQM – NIF integration tests.

Table 46: AINQM - NIF integration tests summary

| Integration Test ID                   |                                                                                                    | Objective                                                        | Status                                        |           |
|---------------------------------------|----------------------------------------------------------------------------------------------------|------------------------------------------------------------------|-----------------------------------------------|-----------|
| AINQM_NIF_I001                        |                                                                                                    | Test the correct format for the input and output of the AI model | Completed                                     |           |
| Analytic Integration Test Description |                                                                                                    |                                                                  |                                               |           |
| Test type                             | Integration                                                                                        |                                                                  |                                               |           |
| Identifier                            | AINQM_NIF_I001                                                                                     |                                                                  |                                               |           |
| Testers                               | 8BELLS                                                                                             |                                                                  |                                               |           |
| Test Purpose                          | Test the correct format for the input and output of the Outage Probability Prediction AI model.    |                                                                  |                                               |           |
| References                            | [20], Chapter 4                                                                                    |                                                                  |                                               |           |
| Configuration                         | Test input files prepared in JSON format<br>Output expected in structured JSON with defined schema |                                                                  |                                               |           |
|                                       |                                                                                                    |                                                                  |                                               |           |
| Pre-test conditions                   | -                                                                                                  |                                                                  |                                               |           |
|                                       |                                                                                                    |                                                                  |                                               |           |
| Test Sequence                         | Step                                                                                               | Type                                                             | Description                                   | Result    |
|                                       | 1                                                                                                  | Stimulus                                                         | Provide valid input JSON to AI model's input. | Completed |

|                     |   |          |                                                                         |             |
|---------------------|---|----------|-------------------------------------------------------------------------|-------------|
|                     | 2 | Check    | Model returns output JSON in correct schema (fields present and typed). | Pass        |
|                     | 3 | Stimulus | Send malformed input JSON (e.g., missing field).                        | Completed   |
|                     | 4 | Check    | Model returns error message with proper format.                         | Pass        |
|                     | 5 | Stimulus | Send input with extra/unexpected fields.                                | Completed   |
|                     | 6 | Check    | Model ignores extra fields or returns warning without failure.          | Pass        |
| <b>Test Verdict</b> |   |          |                                                                         | <b>Pass</b> |

#### 4.2.17. AI Network Quality Module (AINQM) – XAI

Table 47 summarizes the AINQM - XAI integration tests.

Table 47: AINQM - XAI integration tests summary

| Integration Test ID                   |                                                                                                                                                                             | Objective                                                                                                                 | Status    |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|-----------|
| AINQM_XAI_I001                        |                                                                                                                                                                             | Validation of connection to AINQM prediction component.                                                                   | Completed |
| AINQM_XAI_I002                        |                                                                                                                                                                             | Validation of outage prediction workflow by ensuring PredictionClient returns correct outage probability and time index.  | Completed |
| AINQM_XAI_I003                        |                                                                                                                                                                             | Validation of XAI integration by checking IntegratedExplainer uses PredictionClient for predictions and enriches results. | Completed |
| AINQM_XAI_I004                        |                                                                                                                                                                             | Validation of SHAP global explanations, ensuring proper output directory and success status.                              | Completed |
| AINQM_XAI_I005                        |                                                                                                                                                                             | Validation of LIME local explanations, confirming access status and correct handling of output directory.                 | Completed |
| Analytic Integration Test Description |                                                                                                                                                                             |                                                                                                                           |           |
| <b>Test type</b>                      | Integration                                                                                                                                                                 |                                                                                                                           |           |
| <b>Identifier</b>                     | AINQM_XAI_I001                                                                                                                                                              |                                                                                                                           |           |
| <b>Testers</b>                        | MINDS                                                                                                                                                                       |                                                                                                                           |           |
| <b>Test Purpose</b>                   | Verify that the system can successfully establish a connection to the AINQM prediction component and detect its availability.                                               |                                                                                                                           |           |
| <b>References</b>                     | From prediction_client module the PredictionClient class.                                                                                                                   |                                                                                                                           |           |
| <b>Configuration</b>                  | <ul style="list-style-type: none"> <li>Test environment with unittest and requests package installed.</li> <li>The requests.get method patched to return 200 OK.</li> </ul> |                                                                                                                           |           |

|                                       |      |                                                                                                                                                                                                                                                                    |                                                                     |                                  |
|---------------------------------------|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|----------------------------------|
| Pre-test conditions                   |      | <ul style="list-style-type: none"><li>• Mocked requests.get simulates service availability at http://localhost:5000.</li><li>• No real service required.</li></ul>                                                                                                 |                                                                     |                                  |
|                                       |      |                                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Test Sequence                         | Step | Type                                                                                                                                                                                                                                                               | Description                                                         | Result                           |
|                                       | 1    | Stimulus                                                                                                                                                                                                                                                           | Call PredictionClient.is_available() to check service availability. | Returns True                     |
|                                       | 2    | Check                                                                                                                                                                                                                                                              | Verify is_available() result equals True.                           | Pass                             |
| Test Verdict                          |      |                                                                                                                                                                                                                                                                    |                                                                     | Pass                             |
| Analytic Integration Test Description |      |                                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Test type                             |      | Integration                                                                                                                                                                                                                                                        |                                                                     |                                  |
| Identifier                            |      | AINIQM_XAI_I002                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Testers                               |      | MINDS                                                                                                                                                                                                                                                              |                                                                     |                                  |
| Test Purpose                          |      | Validate that outage predictions can be retrieved correctly from AINQM and contain expected fields.                                                                                                                                                                |                                                                     |                                  |
| References                            |      | From prediction_client module the PredictionClient class.                                                                                                                                                                                                          |                                                                     |                                  |
| Configuration                         |      | <ul style="list-style-type: none"><li>• Test environment with unittest and requests, pandas packages installed.</li><li>• The requests.post method patched to return mock outage prediction.</li></ul>                                                             |                                                                     |                                  |
|                                       |      |                                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Pre-test conditions                   |      | <ul style="list-style-type: none"><li>• Sample DataFrame (test_df) with required network features written to temporary CSV.</li><li>• Mock requests.post configured to return outage probability 0.75, Binary_Outage=1 and Classification="Outage_Risk".</li></ul> |                                                                     |                                  |
|                                       |      |                                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Test Sequence                         | Step | Type                                                                                                                                                                                                                                                               | Description                                                         | Result                           |
|                                       | 1    | Stimulus                                                                                                                                                                                                                                                           | Call PredictionClient.predict with test_df and time_index=2.        | Returns mock prediction dict     |
|                                       | 2    | Check                                                                                                                                                                                                                                                              | Verify time_index matches input (2).                                | Pass                             |
|                                       | 3    | Check                                                                                                                                                                                                                                                              | Verify "Outage Probability" is equal to 0.75.                       | Pass                             |
| Test Verdict                          |      |                                                                                                                                                                                                                                                                    |                                                                     | Pass                             |
| Analytic Integration Test Description |      |                                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Test type                             |      | Integration                                                                                                                                                                                                                                                        |                                                                     |                                  |
| Identifier                            |      | AINIQM_XAI_I003                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Testers                               |      | MINDS                                                                                                                                                                                                                                                              |                                                                     |                                  |
| Test Purpose                          |      | Ensures that the IntegratedExplainer component correctly calls the PredictionClient to obtain outage predictions (via the mocked HTTP response) and then applies its own post-processing logic to enrich the raw prediction with additional fields.                |                                                                     |                                  |
| References                            |      | From integrated_explainer module the IntegratedExplainer class.                                                                                                                                                                                                    |                                                                     |                                  |
| Configuration                         |      | <ul style="list-style-type: none"><li>• Test environment with unittest and requests, pandas packages installed.</li><li>• Patched requests.post for prediction.</li></ul>                                                                                          |                                                                     |                                  |
|                                       |      |                                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Pre-test conditions                   |      | <ul style="list-style-type: none"><li>• Mock PredictionClient service returns outage probability and classification fields.</li><li>• IntegratedExplainer initialized with prediction URL http://localhost:5000.</li></ul>                                         |                                                                     |                                  |
|                                       |      |                                                                                                                                                                                                                                                                    |                                                                     |                                  |
| Test Sequence                         | Step | Type                                                                                                                                                                                                                                                               | Description                                                         | Result                           |
|                                       | 1    | Stimulus                                                                                                                                                                                                                                                           | Call IntegratedExplainer.predict with test_df and time_index=2.     | Returns enriched prediction dict |
|                                       | 2    | Check                                                                                                                                                                                                                                                              | Verify "Outage Probability" present in result.                      | Pass                             |
|                                       | 3    | Check                                                                                                                                                                                                                                                              | Verifv "Binary_Outage" present in result.                           | Pass                             |

|                                       |                                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|--------------------------------------------------------------------------------------------|---------------------------------|
|                                       | 4                                                                                                                                                                                                                                                      | Check    | Verify "Classification" present in result.                                                 | Pass                            |
| Test Verdict                          |                                                                                                                                                                                                                                                        |          |                                                                                            | Pass                            |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
| Test type                             | Integration                                                                                                                                                                                                                                            |          |                                                                                            |                                 |
| Identifier                            | AINIQM_XAI_I004                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
| Testers                               | MINDS                                                                                                                                                                                                                                                  |          |                                                                                            |                                 |
| Test Purpose                          | Validate that SHAP-based global feature importance explanations can be generated for outage prediction.                                                                                                                                                |          |                                                                                            |                                 |
| References                            | From integrated_explainer module the IntegratedExplainer class.                                                                                                                                                                                        |          |                                                                                            |                                 |
| Configuration                         | <ul style="list-style-type: none"><li>Test environment with unittest and pandas, scikit-learn, xgboost packages installed.</li><li>Patched preprocess_data_robust, outage_prediction_explainer.global_explain and IntegratedExplainer.model.</li></ul> |          |                                                                                            |                                 |
|                                       |                                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
| Pre-test conditions                   | <ul style="list-style-type: none"><li>Synthetic dataset generated via sklearn.make_classification.</li><li>XGBoost model trained on sample data.</li><li>Patches simulate data preprocessing and SHAP explanation generation.</li></ul>                |          |                                                                                            |                                 |
|                                       |                                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
| Test Sequence                         | Step                                                                                                                                                                                                                                                   | Type     | Description                                                                                | Result                          |
|                                       | 1                                                                                                                                                                                                                                                      | Stimulus | Call IntegratedExplainer.explain_global with mock_df and output_dir arguments.             | Returns explanation result dict |
|                                       | 2                                                                                                                                                                                                                                                      | Check    | Verify status in explanation results equals to "success".                                  | Pass                            |
|                                       | 3                                                                                                                                                                                                                                                      | Check    | Verify output_directory in explanation results matches the input path.                     | Pass                            |
| Test Verdict                          |                                                                                                                                                                                                                                                        |          |                                                                                            | Pass                            |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
| Test type                             | Integration                                                                                                                                                                                                                                            |          |                                                                                            |                                 |
| Identifier                            | AINIQM_XAI_I005                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
| Testers                               | MINDS                                                                                                                                                                                                                                                  |          |                                                                                            |                                 |
| Test Purpose                          | Validate that LIME-based local explanations are generated correctly for a specific prediction instance.                                                                                                                                                |          |                                                                                            |                                 |
| References                            | From integrated_explainer module the IntegratedExplainer class.                                                                                                                                                                                        |          |                                                                                            |                                 |
| Configuration                         | <ul style="list-style-type: none"><li>Test environment with unittest and pandas, scikit-learn, xgboost packages installed.</li><li>Patched preprocess_data_robust, outage_prediction_explainer.local_explain and IntegratedExplainer.model.</li></ul>  |          |                                                                                            |                                 |
|                                       |                                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
| Pre-test conditions                   | <ul style="list-style-type: none"><li>Synthetic dataset generated via sklearn.make_classification.</li><li>XGBoost model trained on sample data.</li><li>Patches simulate preprocessing and LIME explanation function.</li></ul>                       |          |                                                                                            |                                 |
|                                       |                                                                                                                                                                                                                                                        |          |                                                                                            |                                 |
| Test Sequence                         | Step                                                                                                                                                                                                                                                   | Type     | Description                                                                                | Result                          |
|                                       | 1                                                                                                                                                                                                                                                      | Stimulus | Call IntegratedExplainer.explain_local with mock_df, sample_id=2 and output_dir arguments. | Returns explanation result dict |
|                                       | 2                                                                                                                                                                                                                                                      | Check    | Verify status in explanations dict equal to "success".                                     | Pass                            |
|                                       | 3                                                                                                                                                                                                                                                      | Check    | Verify output_directory in explanations dict matches input path.                           | Pass                            |

|                     |  |             |
|---------------------|--|-------------|
| <b>Test Verdict</b> |  | <b>Pass</b> |
|---------------------|--|-------------|

#### 4.2.18. Explainable AI & Federated Learning Intrusion Detection System (XAI – FL-IDS)

Table 48 summarizes the XAI – FL-IDS integration tests.

Table 48: XAI – FL-IDS integration tests summary

| Integration Test ID                   |                                                                                                                                                                                                                                                                                       | Objective                                                        |                                                      | Status              |
|---------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------|---------------------|
| XAI_FL-IDS_I001                       |                                                                                                                                                                                                                                                                                       | Validation of model transfer and loading into the XAI component. |                                                      | Completed           |
| XAI_FL-IDS_I002                       |                                                                                                                                                                                                                                                                                       | Validation of expected explanations generation and storage.      |                                                      | Completed           |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                       |                                                                  |                                                      |                     |
| Test type                             | Integration                                                                                                                                                                                                                                                                           |                                                                  |                                                      |                     |
| Identifier                            | XAI_FL-IDS_I001                                                                                                                                                                                                                                                                       |                                                                  |                                                      |                     |
| Testers                               | MINDS                                                                                                                                                                                                                                                                                 |                                                                  |                                                      |                     |
| Test Purpose                          | Validate that a federated learning model (mock trained) is correctly transferred from the FL component to the XAI component and can be loaded successfully.                                                                                                                           |                                                                  |                                                      |                     |
| References                            | From anomaly_detection_explainer.py module the load_model method.                                                                                                                                                                                                                     |                                                                  |                                                      |                     |
| Configuration                         | <ul style="list-style-type: none"><li>Test environment with unittest and sklearn, pandas, pickle, shutil packages installed.</li><li>Trained RandomForestClassifier on sample random data.</li><li>Mocked filesystem operations (os.makedirs, shutil.copy) and pickle.load.</li></ul> |                                                                  |                                                      |                     |
|                                       |                                                                                                                                                                                                                                                                                       |                                                                  |                                                      |                     |
| Pre-test conditions                   | <ul style="list-style-type: none"><li>Mock trained FL model serialized as .pkl.</li><li>Mock destination directories in XAI component.</li></ul>                                                                                                                                      |                                                                  |                                                      |                     |
|                                       |                                                                                                                                                                                                                                                                                       |                                                                  |                                                      |                     |
| Test Sequence                         | Step                                                                                                                                                                                                                                                                                  | Type                                                             | Description                                          | Result              |
|                                       | 1                                                                                                                                                                                                                                                                                     | Stimulus                                                         | Call function to transfer FL model to XAI directory. | Mocked copy invoked |
|                                       | 2                                                                                                                                                                                                                                                                                     | Check                                                            | Verify XAI model path exists.                        | Pass                |
|                                       | 3                                                                                                                                                                                                                                                                                     | Stimulus                                                         | Load model using mocked pickle.load.                 | Model loaded        |
|                                       | 4                                                                                                                                                                                                                                                                                     | Check                                                            | Verify loaded object has the expected methods.       | Pass                |
| Test Verdict                          |                                                                                                                                                                                                                                                                                       |                                                                  |                                                      | Pass                |
| Analytic Integration Test Description |                                                                                                                                                                                                                                                                                       |                                                                  |                                                      |                     |
| Test type                             | Integration                                                                                                                                                                                                                                                                           |                                                                  |                                                      |                     |
| Identifier                            | XAI_FL-IDS_I002                                                                                                                                                                                                                                                                       |                                                                  |                                                      |                     |
| Testers                               | MINDS                                                                                                                                                                                                                                                                                 |                                                                  |                                                      |                     |
| Test Purpose                          | Validate that the XAI component can generate global and local explanations using the transferred FL model.                                                                                                                                                                            |                                                                  |                                                      |                     |
| References                            | From anomaly_detection_explainer.py module the load_model, global_explain and local_explain methods.                                                                                                                                                                                  |                                                                  |                                                      |                     |
| Configuration                         | <ul style="list-style-type: none"><li>Test environment with unittest and sklearn, pandas, shap, LIME packages installed.</li><li>Mocked FL model (RandomForestClassifier).</li><li>Mocked file I/O (os.makedirs, plt.savefig, json.dump).</li></ul>                                   |                                                                  |                                                      |                     |
|                                       |                                                                                                                                                                                                                                                                                       |                                                                  |                                                      |                     |
| Pre-test conditions                   | <ul style="list-style-type: none"><li>Synthetic random dataset for test purposes created.</li><li>XAI model directory contains mock FL model.</li></ul>                                                                                                                               |                                                                  |                                                      |                     |

| Test Sequence       | Step | Type     | Description                                             | Result                                                     |
|---------------------|------|----------|---------------------------------------------------------|------------------------------------------------------------|
|                     | 1    | Stimulus | Load the mock model from file using load_model.         | Returns the trained model object                           |
|                     | 2    | Stimulus | Call global_explain with sample dataset.                | Generates PNG plots and JSON files in the output directory |
|                     | 3    | Check    | Verify the global explanation results are the expected. | Pass                                                       |
|                     | 4    | Stimulus | Call local_explain with a sample flow ID.               | Generates PNG plots and JSON files in the output directory |
|                     | 5    | Check    | Verify the local explanation results are the expected.  | Pass                                                       |
| <b>Test Verdict</b> |      |          |                                                         | <i>Pass</i>                                                |

### 4.3. Integration Monitoring

In the context of the integration activities, regular monitoring of the progress updates, issues reporting and planning for their resolution was performed. Specifically, as described in D6.2, the integration aspects were discussed during the weekly WP6 meetings and ad-hoc meetings were organized among the involved partners to deal with specific technical issues. To streamline the integration monitoring process and facilitate communication among the technical teams, a central management project based on GitHub was used for issue tracking and reporting on the progress of the integration activities. Through this tool, regular feedback was provided from the technical teams for all functional and integration testing activities (Figure 38 and Figure 39).

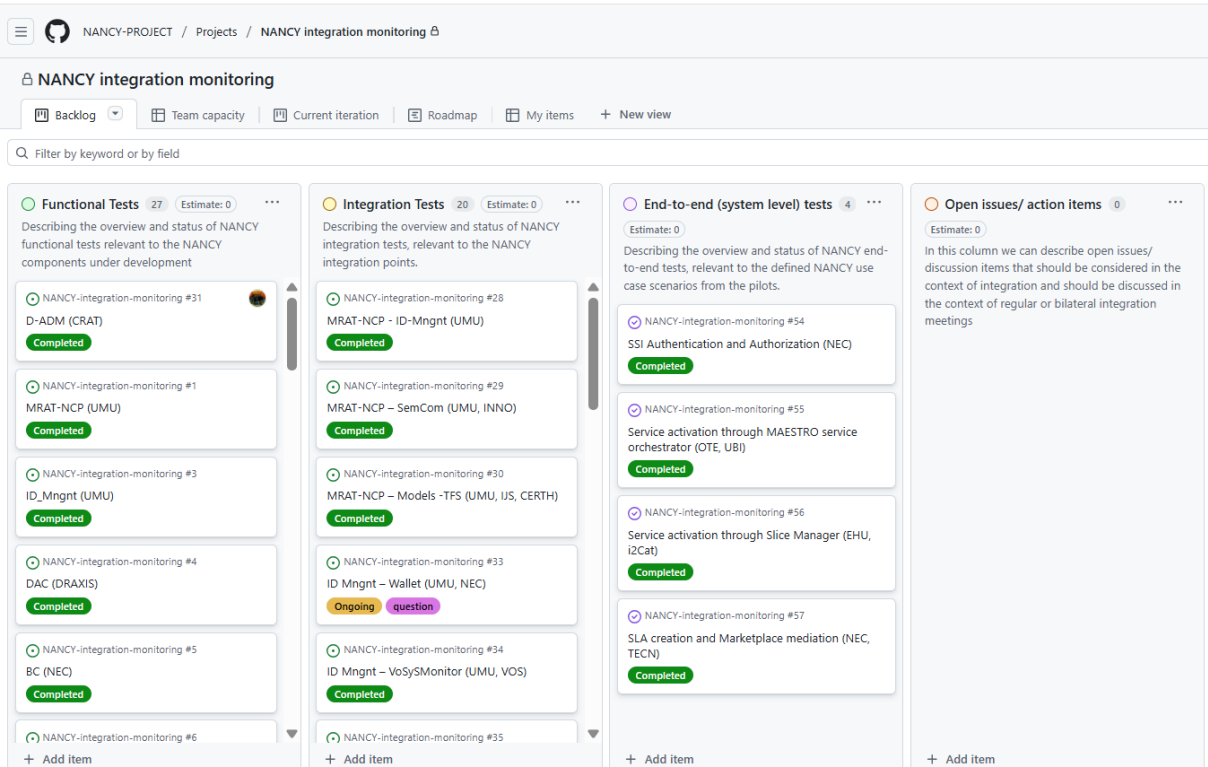
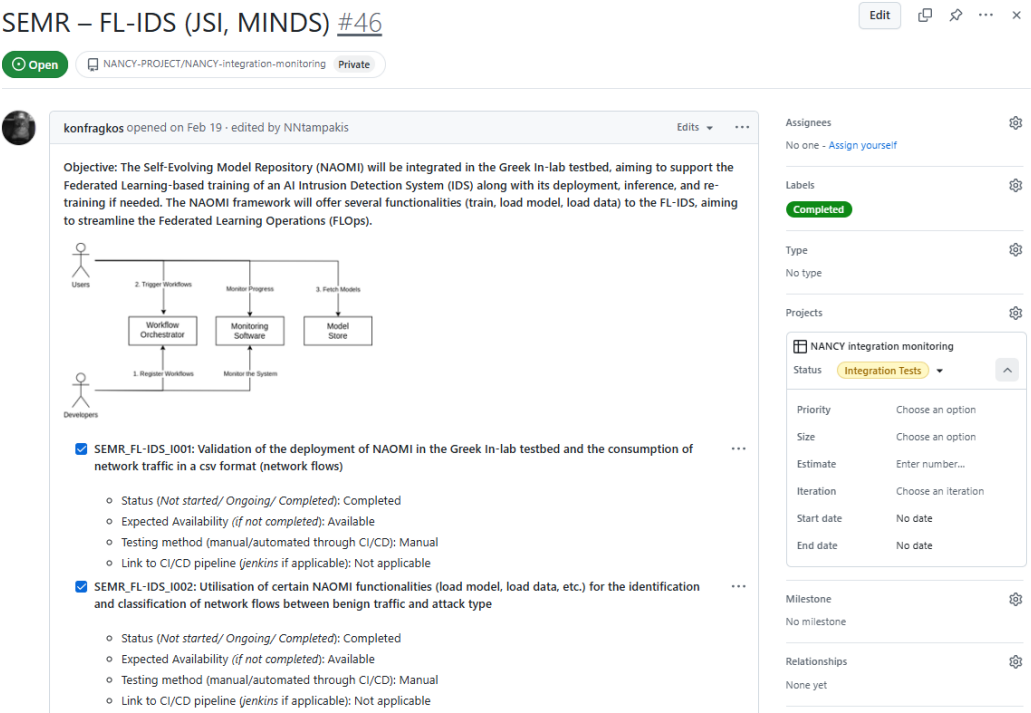


Figure 38: High-level view of dedicated Github project for NANCY integration monitoring



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NANCY-PROJECT/NANCY-integration-monitoring

Integration tests could be found here in 3 files:

```
test_full_naomi_integration.py | Add integration with NAOMI
test_mlflow_storage.py
test_ray_deployment.py
```

Also screenshots:

```
C:\Users\30697\Desktop\NANCY\GitHub\nancy_federated_learning_framework\venv\Lib\site-packages\pydantic\fields.py:1011: Py
danticDeprecatedSince20: 'min_items' is deprecated and will be removed, use 'min_length' instead. Deprecated in Pydantic
V2.0 to be removed in V3.0. See Pydantic V2 Migration Guide at https://errors.pydantic.dev/2.10/migration/
  warn('min_items' is deprecated and will be removed, use 'min_length' instead', DeprecationWarning)
✓ MLflow integration confirmed
✓ Deployment script exists
✓ Endpoint test script exists
✓ Endpoint test simulation succeeded

NAOMI Integration Test Results:
=====
✓ MLflow model storage verified
✓ Ray Serve deployment script verified
✓ API endpoint test script verified

All components of the NAOMI integration are ready.
When connecting to a real NAOMI deployment, update the IP addresses in:
1. src/server/server.py (for MLflow tracking URI)
2. deploy_model.py (for NAOMI_IP)
3. test_endpoint.py (for NAOMI_IP)
.
-----
Ran 1 test in 0.813s
OK

Found latest run: mlruns/0\1e8476dda2484e3183c59bb7d0434195\
Model artifacts found at: mlruns/0\1e8476dda2484e3183c59bb7d0434195\artifacts\model
Model files: ['conda.yaml', 'data', 'MLmodel', 'python_env.yaml', 'requirements.txt']
✓ MLflow run was created successfully
✓ Run directory: mlruns/0\1e8476dda2484e3183c59bb7d0434195\
✓ MLflow integration test passed
.
-----
Ran 1 test in 0.002s
OK
```

Figure 39: Example of integration point-specific reporting view

## 5. NANCY Platform – System-Level Validation Workflows

This section provides a detailed description of the end-to-end verification workflows designed to validate various aspects of the NANCY platform at a system level from an integration perspective. These workflows encompass operations across the central management, inter-operator, and testbed/demonstrator domains.

The selected workflows are largely horizontal, spanning multiple testbed and demonstrator use cases, and aim to assess the readiness of the corresponding procedures before their execution at the different demonstrations (T6.5–T6.9), following the integration plan presented in [2]. Accordingly, these system-level testing activities serve as a preliminary step to the more detailed test activities being conducted at the individual testbeds and demonstrators as per the approach outlined in [3] for evaluating and validating the expected results of the NANCY project. The analytical evaluation results of these test activities will be reported in D6.10.

### 5.1. Self Sovereign Identity (SSI) Authentication and Authorization

SSI (Self-Sovereign Identity) is a standardized distributed identity management approach to allow users to have full control of their own identities and credentials while authentication and authorization are processed in an anonymous way.

The objective of the *SSI Authentication and Authorization* workflow, horizontal to various NANCY test beds, is to provide the platform and its users with a distributed infrastructure for privacy management<sup>4</sup> in service provisioning. This infrastructure allows users to authenticate themselves and be authorized to certain NANCY services using decentralized identities and verifiable credentials.

In other words, we provide a means for:

- A user to build and manage its own decentralized identity; what we call *Decentralized Identifiers (DIDs)*.
- A user to provide a valid signature based on its decentralized identity (authentication)
- An issuer – not necessarily the service provider – to issue a credential to a given user, stating that such user should have access to service X. The user keeps the credential for itself (no centralized credentials) and when needed provides a verifiable presentation of said credential to a verifier entity in order to be authorised to service X (authorisation).
- Equip the system with a decentralized ledger on top of which the former procedures can be realised.

#### Prerequisites for the workflow:

To understand the prerequisites for this workflow to function, it is important to revisit what is indicated in [4]: “W3C has proposed corresponding standards for SSI systems<sup>5</sup>, namely, the Decentralized Identifiers (DIDs) and the Verifiable Credentials (VCs). DID provides a standardized approach to uniquely identifying users or subjects in decentralized systems, and VC describes a way to manage credentials, i.e., digitally signed attestations regarding a subject's attributes or affiliations, by leveraging DIDs for trust and interoperability. The standards propose an architecture where a user

---

<sup>4</sup> See NANCY D5.2 and ETSI GR PDL 019

([https://www.etsi.org/deliver/etsi\\_gr/PDL/001\\_099/019/01.01.01\\_60/gr\\_PDL019v010101p.pdf](https://www.etsi.org/deliver/etsi_gr/PDL/001_099/019/01.01.01_60/gr_PDL019v010101p.pdf))

<sup>5</sup> <https://www.w3.org/TR/did-1.0/>

holds DIDs and VCs in their own digital wallet, requests issuers to acquire VCs, and interacts with verifiers to get authenticated by presenting Verifiable Presentations (VPs) derived from his VCs without disclosing his credentials. Meanwhile, all parties upload the public part of their identifiers and schemas in a verifiable data registry for other parties to look up information.

Thus, the key prerequisites are:

- To deploy the NANCY blockchain as the verifiable data registry. This includes registering the DIDs and associated public keys of all parties in the blockchain. Also, revoked verifiable credentials – if any – should be listed in the blockchain too.
  - From [4]: “As a verifiable data registry, the NANCY blockchain manages DID registration and VC revocation through two smart contracts. In NANCY, the DID registration is handled by smart contract DIDRegistry, which records DIDs and public keys associated with the DIDs. Meanwhile, another smart contract, VCRegistry, keeps a list of all revoked VCs for verifiers to look up during authentication.”
- To equip all parties with the NANCY wallet: issuer/s, user/s, verifier/s and application service. The NANCY Wallet `WALLETGATEWAY` creates and holds the DIDs and credentials for said parties. In addition, the wallet runs a gRPC service to communicate with the blockchain. As explained in [4], the NANCY wallet gateway has defined specific gRPC methods to interact with the marketplace and the DID registry smart contracts. Also, as a gateway to the blockchain, the wallet serves as a registrar of the NANCY Certification Authority, and it registers as well as enrolls each user to the blockchain.

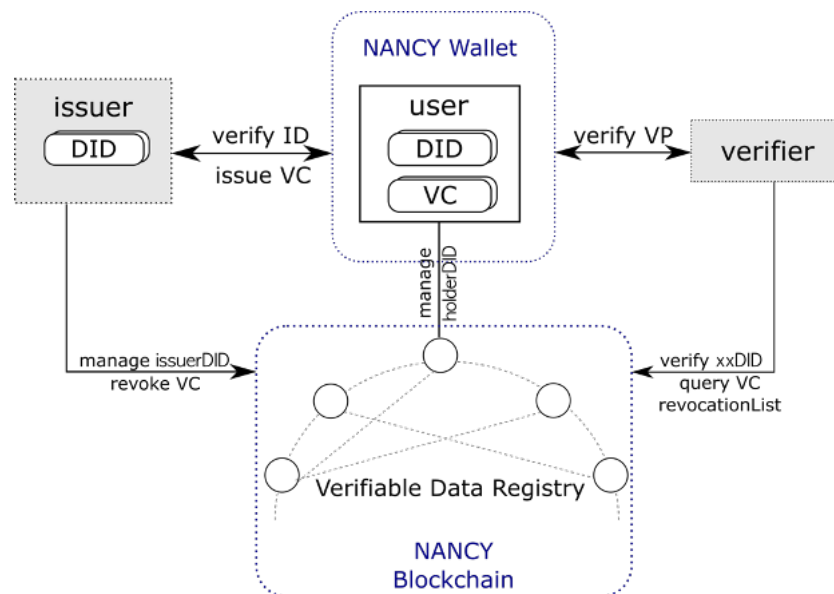


Figure 40: SSI Architecture with NANCY wallet and NANCY blockchain

The sequence diagram of the authentication & service authorization procedures is provided in Figure 41 and described analytically in the following.

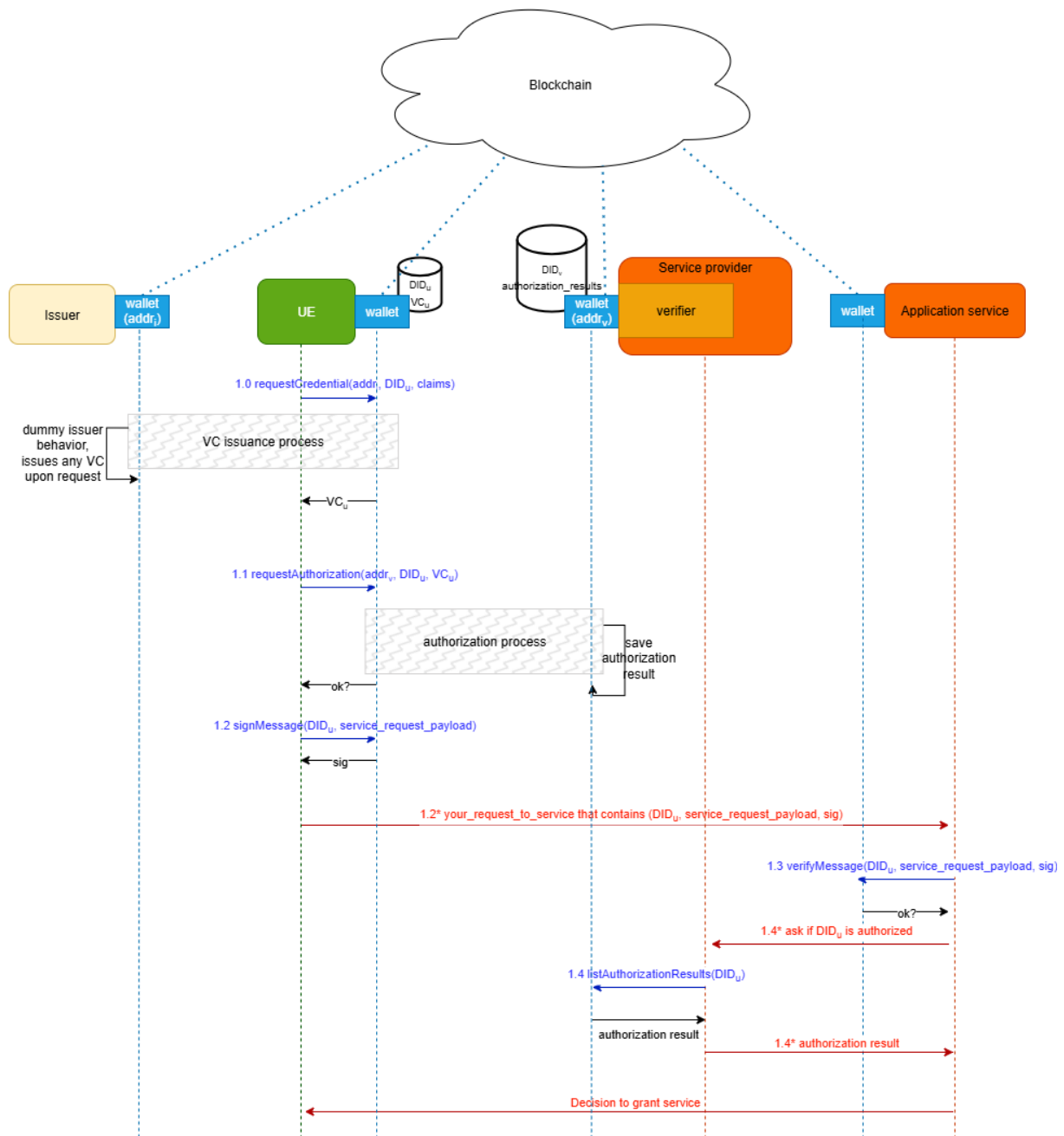


Figure 41: SSI authentication and authorization procedures

**Setup:** All entities, i.e., issuer, UE, service provider verifier, and the application service, start a wallet gateway service (Figure 42) that is connected to the NANCY blockchain, alongside their applications.

Note that upon the start of a wallet gateway service, at least one DID is created/retrieved for the wallet derived from the provided “uid”. This DID is registered in the NANCY blockchain and its verification method (i.e., public key) can be looked up by all entities in the blockchain.

```

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 75 ..... 14:29:54
GATEWAY_PORT=5000 GATEWAY_UID=UE docker-compose -f docker-compose-wallet.yaml run --service-ports --name UE wallet-service
[+] Creating 1/0
[+] Container docker-mongo-1 Running
Wallet service of NonUE starts listening on port 5000...
mongouri: mongodb://admin:adminpw@mongo:27017/
[main] INFO org.mongodb.driver.client - MongoClient with metadata {"driver": {"name": "mongo-java-driver|sync|kmongo", "version": "5.5.0"},
"os": {"type": "Linux", "name": "Linux", "architecture": "amd64", "version": "6.10.14-linuxkit"}, "platform": "Java/Ubuntu/21.0.7+6-Ubuntu-0
ubuntu12.04|Kotlin/2.0.0", "env": {"runtime": "docker"}} created with settings MongoClientSettings{readPreference=primary, w
riteConcern=WriteConcern{w=null, wTimeout=null ms, journal=null}, retryWrites=true, retryReads=true, readConcern=ReadConcern{level=null}, cr
edential=MongoCredential{mechanism=null, username='admin', source='admin', password=<hidden>, mechanismProperties=<hidden>}, transportSettin
gs=null, commandListeners=[], codecRegistry=ProvidersCodecRegistry{codecProviders=[ProvidersCodecRegistry{codecProviders=[ValueCodecProvider
{}, BsonValueCodecProvider{}, DBRefCodecProvider{}, DBObjectCodecProvider{}, DocumentCodecProvider{}, IterableCodecProvider{}, MapCodecProvi
der{}, GeoJsonCodecProvider{}, GridFSFileCodecProvider{}, Js310CodecProvider{}, JsonObjectCodecProvider{}, BsonCodecProvider{}]}, org.litote
e.kmongo.service.CustomCodecProvider@24959ca4, ProvidersCodecRegistry{codecProviders=[org.litote.kmongo.jackson.JacksonCodecProvider@1028988
6]}], loggerSettings=LoggerSettings{maxDocumentLength=1000}, clusterSettings={hosts=[mongo:27017], srvServiceName=mongodb, mode=SINGLE, req
uiredClusterType=UNKNOWN, requiredReplicaSetName='null', serverSelector='null', clusterListeners=[]}, serverSelectionTimeout='30000 ms', loca
lThreshold='15 ms'}, socketSettings=SocketSettings{connectTimeoutMS=10000, readTimeoutMS=0, receiveBufferSize=0, proxySettings=ProxySettin
gs{host=null, port=null, username=null, password=null}}, heartbeatSocketSettings=SocketSettings{connectTimeoutMS=10000, readTimeoutMS=10000,
receiveBufferSize=0, proxySettings=ProxySettings{host=null, port=null, username=null, password=null}}, connectionPoolSettings=ConnectionPoo
lSettings{maxSize=100, minSize=0, maxWaitTimeMS=120000, maxConnectionLifeTimeMS=0, maxConnectionIdleTimeMS=0, maintenanceInitialDelayMS=0, m
aintenanceFrequencyMS=60000, connectionPoolListeners=[], maxConnecting=2}, serverSettings=ServerSettings{heartbeatFrequencyMS=10000, minHear
tbeatFrequencyMS=500, serverMonitoringMode=AUTO, serverListeners=[]}, serverMonitorListeners=[], sslSettings=SslSettings{enabled=false,
invalidHostNameAllowed=false, context=null}, applicationName='null', compressorList=[], uuidRepresentation=UNSPECIFIED, serverApi=null, auto
EncryptionSettings=null, dnsClient=null, inetAddressResolver=null, contextProvider=null, timeoutMS=null}
[cluster-ClusterId{value='68d535d52561e8b5dac3d47d', description='null'}-mongo:27017] INFO org.mongodb.driver.cluster - Monitor thread succe
ssfully connected to server with description ServerDescription{address=mongo:27017, type=STANDALONE, cryptd=false, state=CONNECTED, ok=true,
minWireVersion=0, maxWireVersion=25, maxDocumentSize=16777216, logicalSessionTimeoutMinutes=30, roundTripTimeNanos=25761333, minRoundTripTi
meNanos=0}
>>>> Non-UE Wallet <<<<
Create new user in the wallet:
>> Enrollment ID: 'nancy-UE-B9PQdE7zFi6yFZDUuASFy9'
>> DID: 'did:nancy:UE-B9PQdE7zFi6yFZDUuASFy9'
WARNING: Runtime environment or build system does not support multi-release JARs. This will impact location-based features.
Successfully enrolled user admin and imported it into the wallet
Successfully enrolled user 'nancy-UE-B9PQdE7zFi6yFZDUuASFy9' with role 'non-UE' and imported it into the wallet
Server started, listening on port 5000...

```

Figure 42: Start a UE wallet gateway service at address 'localhost:5000' with uid='UE' and corresponding DID='did:nancy:UE-7kb29s3ukveUdfkuGZeg9J'

Note that all wallet calls are defined as gRPC calls, which are described in [4]. The examples in the snapshots below use `grpcurl` as the gRPC client to invoke the wallet calls.

#### Step 1.0: The UE acquires a verifiable credential (VC) from the issuer.

As preparation for the authorization process, the UE must first acquire a Verifiable Certificate (VC) from an issuer, who is known to/trusted by the (service provider) verifier. And here we describe how an UE acquire a VC from an issuer.

First the UE application invokes the *RequestCredential* gRPC call of the UE wallet service, providing its holder DID  $DID_u$ , the list of `claims` of the holder (e.g., attributes that the UE wants the issuer to acknowledge in the VC), and the address of the issuer wallet service (Figure 43). And then the UE wallet acquires the VC from the issuer wallet if the request is approved.

```

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 75 ..... INT x 14:34:07
grpcurl -plaintext -d '{"issuerAddress": "195.37.154.23:8881", "credParam": {"holderDID": "did:nancy:UE-B9PQdE7zFi6yFZDUuASFy9", "claims": {"age": 20}}}' localhost:5000 dlt.DltGatewayService/RequestCredential
{
  "credential": "{@context\": [\"https://www.w3.org/2018/credentials/v1\", \"https://www.w3.org/2018/credentials/examples/v1\"], \"type\": [\"VerifiableCredential\", \"NancyCredential\"], \"id\": \"did:nancy:vc-71dfa9b9-8a30-477e-8b50-5fd47f837bbd\", \"issuer\": \"did:nancy:wallet-external-test-3EtvHYvKEDF4JAWPpr9Lv5\", \"issuanceDate\": \"2025-09-25T12:30:31Z\", \"expirationDate\": \"2029-06-17T18:56:59Z\", \"credentialSubject\": {\"id\": \"did:nancy:UE-B9PQdE7zFi6yFZDUuASFy9\", \"age\": 20, \"proof\": {\"type\": \"EcdsaSecp256k1Signature2019\", \"created\": \"2025-09-25T12:30:31Z\", \"domain\": \"nancy.example.com\", \"nonce\": \"knWSNHGRKj7aN6\", \"proofPurpose\": \"assertionMethod\", \"verificationMethod\": \"did:nancy:wallet-external-test-3EtvHYvKEDF4JAWPpr9Lv5#key-1\", \"jws\": \"eyJJNj0iOi0mZhbHLLCjcm0IjpbImI2NCJdLCJhbGciOiJFbGUzIiwiaWF0Ijoi2025-09-25T12:30:31Z\", \"vwyRumPagGKYy_arkTlLb7HHQGIqLMIXtRaq-0GmHzmJZRUBewqZDWzGly_FRPAB8oLcj87yA\"}}}"
}

```

Figure 43: Invoke RequestCredential call to UE wallet with a claim of 'age:20' to issuer wallet service at '195.37.154.23:8881'.

#### Step 1.1: The UE triggers the authorization process to the verifier.

The UE application invokes the gRPC call *RequestAuthorization* to the UE wallet service., providing its holder DID  $DID_u$ , the credential VC ID used to acquire authorization, and the address of the verifier wallet service (Figure 44), and receives the authorization result from the verifier. In the authorization process, the UE wallet actually first asks the verifier wallet for a challenge nonce, then generates a

verifiable proof (VP) based on the challenge nonce and the VC, and the verifier wallet finally verifies the VP (Figure 45). After that, the verifier saves upon each authorization request, the validation results for later reference in its local database.

```
~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 14:34:15
grpcurl -plaintext -d '{"verifierAddress": "195.37.154.23:8881", "authParam": {"vcId": "did:nancy:vc-71dfa9b9-8a30-477e-8b50-5fd47f837bbd", "holderDID": "did:nancy:UE-B9PQdE7zFi6yFZDUuASfy9"}}' localhost:5000 dlt.DltGatewayService/RequestAuthorization
{
  "result": true
}
```

Figure 44: Invoke RequestAuthorization call to UE wallet with the acquired VC to verifier wallet service at '195.37.154.23:8881'

```
[2025-09-25T12:35:12.218279968] >>> getNonce request from 'did:nancy:UE-B9PQdE7zFi6yFZDUuASfy9'
[2025-09-25T12:35:12.419452716] >>> VP validation request from 'did:nancy:UE-B9PQdE7zFi6yFZDUuASfy9':*** Verification SUCCEED ***
```

Figure 45: Verifier wallet received and processed the authorization request from UE.

**Step 1.2:** The UE signs its service request messages and attaches its signature to all its future service requests (the service requests is UC specific outside of SSI scope).

Once the authorization is successful, meaning that the UE has proved to the verifier of the service provider that it possesses a valid credential, the UE can further request access to services from the service provider.

More specifically, if the UE wants to access an application service, the UE application first calls the UE wallet to sign its service request via gRPC call *SignMessage* using the credential of the  $DID_u$  (Figure 46), and the signature is sent along the service request to the application service.

```
~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 14:38:56
grpcurl -plaintext -d '{"did": "did:nancy:UE-B9PQdE7zFi6yFZDUuASfy9", "payload": "service_request_message_digest_example"}' localhost:5000
dlt.DltGatewayService/SignMessage
{
  "vmId": "did:nancy:UE-B9PQdE7zFi6yFZDUuASfy9#key-1",
  "signature": "MEYCIQWYmhkBRNUvyaTyLjhlklsS70wS0R85GccRBhi/BnRQIhAN2TdZfgGX+tF4HT8zpqUN32xo7w6BFc0jDZzLWUSRgT"
}
```

Figure 46: UE application requests UE wallet to sign a request payload digest.

**Step 1.3:** The application service processes the request and verifies the signature sent from the UE.

The application service first authenticates the UE if the request sender is really  $DID_u$  as claimed in the request. To achieve this, the application invokes the gRPC call *VerifyMessage* on his wallet service, which looks up in the blockchain to retrieve the public key of the  $DID_u$  and verify the signature (Figure 47).

```
~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 14:48:42
grpcurl -plaintext -d '{"did": "did:nancy:UE-B9PQdE7zFi6yFZDUuASfy9", "vmId": "did:nancy:UE-B9PQdE7zFi6yFZDUuASfy9#key-1", "payload": "service_request_message_digest_example", "signature": "MEYCIQWYmhkBRNUvyaTyLjhlklsS70wS0R85GccRBhi/BnRQIhAN2TdZfgGX+tF4HT8zpqUN32xo7w6BFc0jDZzLWUSRgT"}' localhost:5000
dlt.DltGatewayService/VerifyMessage
{
  "result": true
}
```

Figure 47: Verifier wallet verifies the request payload signature.

**Step 1.4:** The service provider queries the verifier about the authorization result of the UE.

When the signature validation is successful, the application service further queries the verifier application who authorizes all UEs in Step 1.2 for the authorization results. This call from the application service to the verifier application is use-case specific and out of scope. Then the verifier

application requests the verifier wallet to look up the authorization results of  $DID_u$  with call *ListAuthorizationRequests* or *FindLatestAuthorizationResult* and finally informs the result to the application service (Figure 48).

```
~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 75 ..... INT x < 14:52:45
grpcurl -plaintext -d '{"value": {"holderDID": "did:nancy:UE-B9PQdE7zFi6yFZDUuASfY9"}' 195.37.154.23:8881 dlt.DltGatewayService/Li
stAuthorizationResults
{
  "value": "[VpVerificationResult(timestamp=2025-09-25T12:35:12.495Z, holderDID=did:nancy:UE-B9PQdE7zFi6yFZDUuASfY9, vp={\"@context\":[\"http
ps://www.w3.org/2018/credentials/v1\"],\"type\":\"VerifiablePresentation\"},\"verifiableCredential\":{\"@context\":[\"https://www.w3.org/20
18/credentials/v1\"],\"https://www.w3.org/2018/credentials/examples/v1\"},\"type\":\"VerifiableCredential\",\"NancyCredential\":\"\",\"id\":\"di
d:nancy:vc-71dfa9b9-8a30-477e-8b50-5fd4f7837bbd\",\"issuer\":{\"did:nancy:wallet-external-3EtVHYvKEDF4JAWpp9LvS\",\"issuanceDate\":\"20
25-09-25T12:30:38:31Z\",\"expirationDate\":\"2029-06-17T18:56:59Z\",\"credentialSubject\":{\"id\":\"did:nancy:UE-B9PQdE7zFi6yFZDUuASfY9\",\"age
\":20},\"proof\":{\"type\":\"EdcScaSecp256k1Signature2019\",\"created\":\"2025-09-25T12:30:38:31Z\",\"domain\":\"nancy.example.com\",\"nonce\":\"
knwSN8hGqJ7aNe6\",\"proofPurpose\":\"assertionMethod\",\"verificationMethod\":\"did:nancy:wallet-external-3EtVHYvKEDF4JAWpp9LvS#key-1
\",\"jws\":\"eyJjbnJ0bmZhbHN1LCJcm10jpbm12NCJkLCJhbGciOiJFbUZlbnksif0..0gae1LzR6tIiVMyvRumpAgGKYy_arKtIlb7hHG0q1MxIRaq-oGmH2mjZRbuewZDw
zGly_FRPAB80ic8jB7YA\"},\"proof\":{\"type\":\"EdcScaSecp256k1Signature2019\",\"created\":\"2025-09-25T12:38:56Z\",\"domain\":\"nancy.example.
com\",\"nonce\":\"DPSWfTaaatA0i\",\"proofPurpose\":\"assertionMethod\",\"verificationMethod\":\"did:nancy:UE-B9PQdE7zFi6yFZDUuASfY9#key-1\"},
\"jws\":\"eyJjbnJ0bmZhbHN1LCJcm10jpbm12NCJkLCJhbGciOiJFbUZlbnksif0..0naRZJ9DoykCU2R_KT20NHA4ragsAv0FYvzb-b-LEo1qBbL4tDLI2McpSCdQmdxjEbzEAE
FcaL-38iCtUwHIA\"}], valid=true, errorMsg=)"]
```

Figure 48: Look up authorization results of the UE DID on the verifier wallet service.

## 5.2. Service Activation through BSS and Maestro Service Orchestrator

### 5.2.1.Prerequisites to the Workflow

- **UE Connectivity:** The User Equipment (UE) is registered and connected to the 5G network, with the capability to initiate data sessions through the operator's access domain. This ensures that the UE can communicate with the BSS and subsequently access the instantiated AR/VR service.
- **SLA Definition and Mapping:** The Service Level Agreement (SLA) template for the AR/VR service is predefined, deployed within Maestro, and linked to the corresponding configuration file in the BSS that describes the AR/VR service parameters. The BSS utilizes this configuration to generate and issue service orders for the requested AR/VR service. An example of a preconfigured service order within the BSS with the predefined service specification is shown in Figure 49.

```

{
  "id": "mindsapp with Blockchain",
  "name": "Minds App with Blockchain",
  "formData": {
    "@type": "ServiceOrder",
    "description": "Minds App with Blockchain",
    "requestedStartDate": "2024-07-15T10:00:00Z",
    "expectedCompletionDate": "2026-08-16T10:00:00Z",
    "requestedCompletionDate": "2026-08-17T10:00:00Z",
    "state": "INITIAL",
    "orderDate": "2024-07-14T12:00:00Z",
    "serviceOrderItem": [
      {
        "action": "add",
        "state": "ACKNOWLEDGED",
        "service": {
          "serviceSpecification": {
            "name": "service-spec-end-user-cfs",
            "id": "bb4f3d66-5350-49ea-8b31-ff325f149200",
            "@type": "ServiceSpecification"
          },
          "name": "Minds App with Blockchain",
          "serviceCharacteristic": [
            { "name": "Service name", "valueType": "TEXT", "value": "Minds App with Blockchain" },
            { "name": "Service package manager", "valueType": "ENUM", "value": "helm" },
            { "name": "Base service registry/repository URL", "valueType": "TEXT", "value": "oci://harbor.nancy.rid-intrasoft.eu/sidroco/" },
            { "name": "Service artifact identifier in service registry/repository", "valueType": "TEXT", "value": "nancy-vr-video-streamer" },
            { "name": "Cluster Manager", "valueType": "ENUM", "value": "Kubernetes" },
            { "name": "Kubernetes Service Id", "valueType": "TEXT", "value": "59dc20f8-0c54-43f0-b415-3b2c216afc4a" }
          ]
        }
      ]
    ],
    "relatedParty": [
      {
        "name": "UBITECH",
        "role": "REQUESTER",
        "id": "2c034f2b-4ecc-44cc-9af3-6633aa96b217",
        "@type": "RelatedParty"
      }
    ]
  }
}

```

Figure 49: An example of a preconfigured service inside the BSS featuring all the necessary fields for a service order to Maestro.

### 5.2.2. Workflow Description

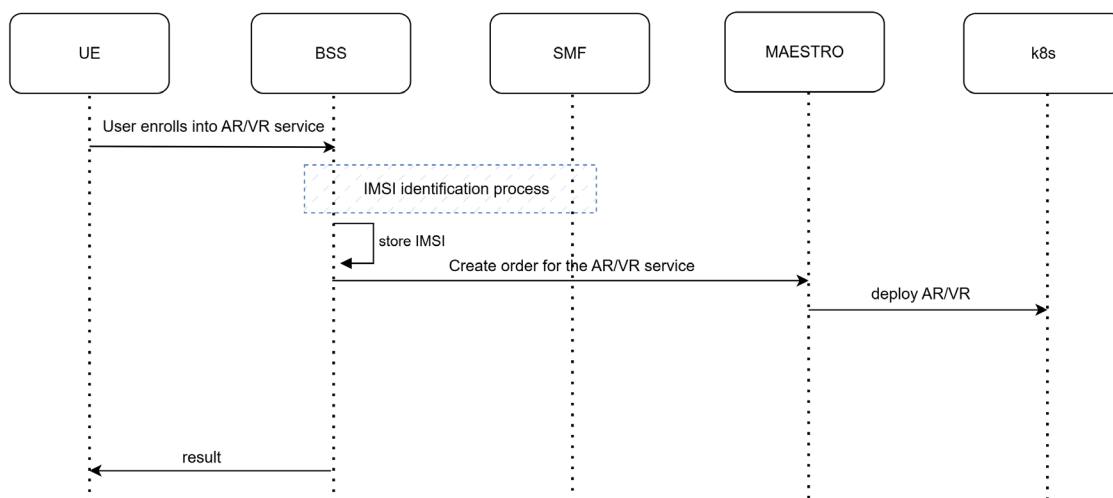


Figure 50: Service activation workflow

The workflow, that is shown in Figure 50, begins when the UE initiates a request to enroll in the AR/VR service through the Operator's BSS, by visiting a dedicated web page and selecting the desired service, as illustrated in Figure 51. This page displays the available preconfigured AR/VR services and includes information about the user's IP address and IMSI, which the BSS obtains through its interaction with the 5G SMF API of the 5G Core.

## Register for a Service

Your IP Address:

10.10.10.1

Your IMSI:

imsi-202031001111111

| Service Name              | Status    | Action                    |
|---------------------------|-----------|---------------------------|
| NGINX Deployment          | Available | <button>Register</button> |
| Minds App                 | Available | <button>Register</button> |
| Minds App with Blockchain | Available | <button>Register</button> |

Figure 51: BSS user enrollment dedicated web page

Once the user selects a service, the BSS creates and stores a persistent association between the user's IMSI and the selected service, which will later be used as part of the authentication process of the AR/VR application server.

Subsequently, the BSS forwards the corresponding service order to Maestro via its northbound interface. Maestro receives and processes the order, instantiates the required AR/VR service components, and deploys them within the Kubernetes (K8s) cluster operated by OTE. Figure 52 shows the logs during a user service registration, including IMSI lookup and Mastro service deployment.

Figure 52: BSS logs for user service registration

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OTE BSS System

Service Orders

Back to Home

Refresh

Minds App with Blockchain

COMPLETED

Delete

ID: c53465bc-3bb7-46ce-b17a-84291027b484

Order Date: 2025-10-14 12:23

Requested Start: 2024-07-15 10:00

Start Date: N/A

Expected Completion: 2026-08-16 10:00

Priority: N/A

Completion Date: N/A

Category: N/A

External ID: N/A

Service Order Items

| ID                                   | Action | State     | Service                                                                                  | Details   |
|--------------------------------------|--------|-----------|------------------------------------------------------------------------------------------|-----------|
| fbdb84c5-f0d6-4e6b-965c-a1bbc25b611d | add    | COMPLETED | Minds App with Blockchain<br>3af38451-36a6-48fe-bc9b-55c46c810275<br>FEASIBILITY_CHECKED | Show JSON |

Figure 53: Service orders and their status as seen in the BSS.

5.3. Service Activation through BSS and Slice Manager

The goal of this workflow (Figure 54) is to enable the instantiation of services provided by the EHU operator using the Slice Manager orchestrator. Upon a service request, EHU’s service manager is responsible for building an SLA that captures the service requirements and sends it to the Slice Manager to enforce it. According to this SLA, the Slice Manager configures compute and RAN resources through k8s and RIC Manager, respectively. Through this workflow, the EHU operator is able to provide services to requesting users, meeting the requested requirements and KPIs.

**Prerequisites/Assumptions for the workflow:** This workflow assumes that all the components necessary for the EHU operator to provide its services are operational, including the O-RAN 5G network and the MEC. In addition, the multi-hop network of vehicles is also deployed, with one of them being able to request a service. Lastly, SSI components are also running in order to carry out the authentication and authorization workflow.

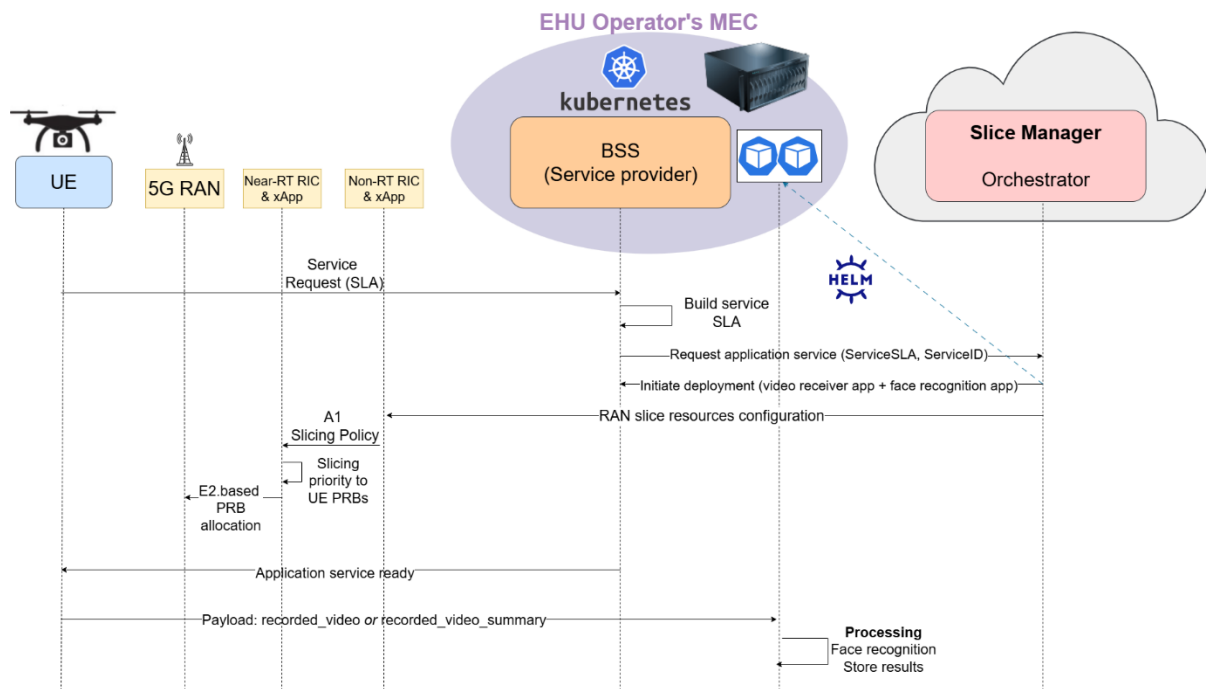


Figure 54: Service activation through BSS and Slice Manager workflow

**Workflow description:**

EHU's service provider uses Slice Manager's REST API for the lifecycle management of application services in the MEC. When the service provider receives a valid request, first it constructs the SLA to determine how that request will be relayed to the Slice Manager. Based on the SLA, the service provider determines the compute resources (CPU, RAM), slice priority in the RAN, and the functional characteristics of the application to deploy (i.e. whether the application processes a video stream or a summary of the video in text format).

In regards to compute, the artifacts of the application are uploaded using the `/network_service/post/` endpoint, whereas the `/network_service_instance/post/` request is used to instantiate an onboarded application. The content of this POST request depends on the SLA, as it impacts the kind of application to deploy and the compute resources to allocate to it. This results in the deployment of the corresponding helm chart in the Kubernetes cluster of EHU's MEC.

```
ubuntu@sm-131:~$ kubectl get all -n demo-nancy-5g
```

| NAME                                   | READY | STATUS  | RESTARTS | AGE |
|----------------------------------------|-------|---------|----------|-----|
| pod/video-server-face-7f4b78c59c-zkcnh | 1/1   | Running | 0        | 9d  |
| pod/video-server-file-7f67478c49-l4wwk | 1/1   | Running | 0        | 9d  |

| NAME                               | TYPE      | CLUSTER-IP    | EXTERNAL-IP | PORT(S)        | AGE |
|------------------------------------|-----------|---------------|-------------|----------------|-----|
| service/udp-face-detection-service | NodePort  | 10.120.109.29 | <none>      | 5000:30500/UDP | 9d  |
| service/udp-listener-service       | ClusterIP | 10.115.142.43 | <none>      | 6000/UDP       | 9d  |

| NAME                              | READY | UP-TO-DATE | AVAILABLE | AGE |
|-----------------------------------|-------|------------|-----------|-----|
| deployment.apps/video-server-face | 1/1   | 1          | 1         | 9d  |
| deployment.apps/video-server-file | 1/1   | 1          | 1         | 9d  |

| NAME                                         | DESIRED | CURRENT | READY | AGE |
|----------------------------------------------|---------|---------|-------|-----|
| replicaset.apps/video-server-face-7f4b78c59c | 1       | 1       | 1     | 9d  |
| replicaset.apps/video-server-file-7f67478c49 | 1       | 1       | 1     | 9d  |

Figure 55: Deployment of target application's helm chart in Kubernetes cluster of EHU's MEC based on SLA specification

The dynamic modification of RAN resources is triggered by the reception of a slicing policy update from the Slicing rApp running in the RIC Manager. This update is received through a REST API request (PUT or POST), which identifies the target slice, either by a friendly name or by specifying its SST, SD,

MCC, MNC parameters (i.e., S-NSSAI and PLMNID), and a slice priority. The slice priority is an integer between 1 (highest) and 100 (lowest), representing the relative share of Physical Resource Blocks (PRBs) among active slices. For instance, with two slices, priorities of 10–10 result in an even 50%-50% PRB split, while 1–2 leads to a 66%-33% distribution. Examples of REST API calls are shown below:

```
curl -X PUT http://ric-manager-service:8104/policyupdate -H "Content-Type: application/json" -d '{"sst": "1", "sd": "000001", "mcc": "001", "mnc": "02", "slice_prio": "2"}'
```

```
curl -X PUT http://ric-manager-service:8104/policyupdate -H "Content-Type: application/json" -d '{"sst": "1", "sd": "000002", "mcc": "001", "mnc": "02", "slice_prio": "1"}'
```

```
curl -X DELETE http://ric-manager-service:8104/policyupdate -H "Content-Type: application/json" -d '{"sst": "1", "sd": "000002", "mcc": "001", "mnc": "02"}'
```

Policies can be updated or deleted (resetting the priority to its default value of 10) via the PUT/POST and DELETE methods, respectively. Once a request is received, the rApp generates a valid A1 SLA Slicing policy and forwards it to the Near-RT RIC. The Near-RT RIC validates the policy instance against the corresponding policy type schema (see Section 3.18) and then delivers it to the relevant xApp. The SLA Slicing xApp continuously monitors the number of slices and the UEs associated with each one, applying the received configuration by sending appropriate E2-RC messages to the srsRAN DU. These messages dynamically control PRB allocation per UE for each slice. The correct enforcement of PRB distribution can be verified through available Key Performance Metrics (KPMs) in srsRAN, such as DRB.UETpDL. Once both the compute and networking resources are ready and configured, the user is notified and can begin using the service by interacting with the indicated IP address and port.

#### 5.4. Service Level Agreement (SLA) Creation and Marketplace Mediation (Inter-Operator Domain)

The objective of the *SLA creation and Marketplace mediation* workflow, potentially horizontal to various NANCY test beds but currently being used in the Greek In-lab scenario, is to provide the platform with a business-layer chaincode where operators can engage in the secure exchange of resources to keep their quality of service for their customers. Here, we deliver to NANCY's interdomain a tool for operators to register (through their BSS) their available resources as well as to consume and offload available resources from other operators when needed. The reader should note that the initial assets to exchange (as described in [4]) were *services*, but after further discussions, it was decided that *resources* were more flexible and closer to the reality of service provisioning in a B5G system.

In other words, we provide a means for:

- Operators to provide information about themselves (as Provider Endpoints) and their resources (Resource Endpoints), and to make requests for searching for other available resources (Search Endpoints) from other operators.
- Oracles to allow automatic interaction with the Smart Pricing for the most suitable service selection in terms of price, as well as with the Digital Agreement Creator for the generation of the SLA between operators.
- Creating, signing, and registering SLAs between operators and end-users.

- Equip the system with a decentralized ledger containing the necessary chaincode so that the former procedures can be realised securely, accountably and with privacy guarantees.

**Prerequisites for the workflow:**

The key prerequisites are:

- To have at least two providers listed in the marketplace, including their available resources.
- To equip all relevant parties with the NANCY wallet: operators and end-users. As mentioned in Section 5.1, the NANCY Wallet `WALLETGATEWAY` creates and holds the DIDs and credentials for said parties. In addition, the wallet runs a gRPC service to communicate with the blockchain. As explained in [4], the NANCY wallet gateway has defined specific gRPC methods to interact with the marketplace (e.g., for listing or searching for resources) and the SLA Registry (e.g. for signing an SLA).
- To equip the oracles with a wallet so that they can interact with the NANCY blockchain and subscribe to events.
- For all parties to be subscribed - through their wallets - to the relevant events. See [4] for more details:
  - Oracles:
    - `initPricing` event
    - `initSLACreation` event
    - `initSLASignature` event
  - Others:
    - `SLAInit` event
    - `SLASigning` event

The sequence diagram of the workflow is shown in Figure 56 and will be described analytically in the following.

Figure 56: SLA creation and Marketplace mediation workflow

Step 0 (preparation): Both providers and consumers run their wallet service that connects them to the blockchain which hosts the marketplace smart contract (Figure 57, Figure 58).

```

~/w/E/N/r/dlt-component/g/docker > feature/impl-ssi-client +1 *1 !4 ?5
GATEWAY_PORT=5000 GATEWAY_UID=provider docker-compose -f docker-compose-wallet.yaml run --service-ports --name provider wal
let-service
[+] Creating 1/0
✓ Container docker-mongo-1 Running 0.0s
Wallet service of NonUE starts listening on port 5000...
mongouri: mongodb://admin:adminpw@mongo:27017/
[main] INFO org.mongodb.driver.client - MongoClient with metadata {"driver": {"name": "mongo-java-driver|sync|kmongo", "versio
n": "5.5.0"}, "os": {"type": "Linux", "name": "Linux", "architecture": "amd64", "version": "6.10.14-linuxkit"}, "platform": "J
ava/Ubuntu/21.0.7+6-Ubuntu-0ubuntu122.04|Kotlin/2.0.0", "env": {"container": {"runtime": "docker"}}} created with settings Mon
goClientSettings{readPreference=primary, writeConcern=WriteConcern{w=null, wTimeout=null ms, journal=null}, retryWrites=true,
retryReads=true, readConcern=ReadConcern{level=null}, credential=MongoCredential{mechanism=null, username='admin', source='adm
in', password=<hidden>, mechanismProperties=<hidden>}, transportSettings=null, commandListeners=[], codecRegistry=ProvidersCod
ecRegistry{providers=[ProvidersCodecRegistry{codecProviders=[ValueCodecProvider(), BsonValueCodecProvider(), DBRefCodecPr
ovider(), DBObjectCodecProvider(), DocumentCodecProvider(), IterableCodecProvider(), MapCodecProvider(), GeoJsonCodecProvider(
), GridFSFileCodecProvider(), Js310CodecProvider(), JsonObjectCodecProvider(), BsonCodecProvider()], org.litote.kmongo.servi
ce.CustomCodecProvider@5038d0b5, ProvidersCodecRegistry{codecProviders=[org.litote.kmongo.jackson.JacksonCodecProvider@32115b2
8]}}, loggerSettings=LoggerSettings{maxDocumentLength=1000}, clusterSettings={hosts=[mongo:27017], srvServiceName=mongoddb, mo
de=SINGLE, requiredClusterType=UNKNOWN, requiredReplicaSetName='null', serverSelector='null', clusterListeners='[]', serverSel
ectionTimeout='30000 ms', localThreshold='15 ms'}, socketSettings=SocketSettings{connectTimeoutMS=10000, readTimeoutMS=0, rece
iveBufferSize=0, proxySettings=ProxySettings{host=null, port=null, username=null, password=null}}, heartbeatSocketSettings=Soc
ketSettings{connectTimeoutMS=10000, readTimeoutMS=10000, receiveBufferSize=0, proxySettings=ProxySettings{host=null, port=null
, username=null, password=null}}, connectionPoolSettings=ConnectionPoolSettings{maxSize=100, minSize=0, maxWaitTimeMS=120000,
maxConnectionLifetimeMS=0, maxConnectionIdleTimeMS=0, maintenanceInitialDelayMS=0, maintenanceFrequencyMS=60000, connectionPoo
lListeners=[], maxConnecting=2}, serverSettings=ServerSettings{heartbeatFrequencyMS=10000, minHeartbeatFrequencyMS=500, server
MonitoringMode=AUTO, serverListeners='[]', serverMonitorListeners='[]', sslSettings=SslSettings{enabled=false, invalidHostNam
eAllowed=false, context=null}, applicationName='null', compressorList=[], uuidRepresentation=UNSPECIFIED, serverApi=null, auto
EncryptionSettings=null, dnsClient=null, inetAddressResolver=null, contextProvider=null, timeoutMS=null}
[cluster-ClusterId{value='68db945110bcac0fec900adc', description='null'}-mongo:27017] INFO org.mongodb.driver.cluster - Monito
r thread successfully connected to server with description ServerDescription{address=mongo:27017, type=STANDALONE, cryptd=fals
e, state=CONNECTED, ok=true, minWireVersion=0, maxWireVersion=25, maxDocumentSize=16777216, logicalSessionTimeoutMinutes=30, r
oundTripTimeNanos=25812375, minRoundTripTimeNanos=0}
>>>> Non-UE Wallet <<<<
Create new user in the wallet:
>> Enrollment ID: 'nancy-provider-LAqUYpNi4zwj8VwUjA36N1'
>> DID: 'did:nancy:provider-LAqUYpNi4zwj8VwUjA36N1'
WARNING: Runtime environment or build system does not support multi-release JARs. This will impact location-based features.
An identity for the admin user 'admin' already exists in the wallet
Successfully enrolled user 'nancy-provider-LAqUYpNi4zwj8VwUjA36N1' with role 'non-UE' and imported it into the wallet
Server started, listening on port 5000...

```

Figure 57: Start provider wallet service at port 5000 and created DID 'did:nancy:provider-LAqUYpNi4zwj8VwUjA36N1'

```

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ... ✓ < 10:29:32
GATEWAY_PORT=6000 GATEWAY_UID=consumer docker-compose -f docker-compose-wallet.yaml run --service-ports --name consumer wallet-servi
ce
[+] Creating 1/0
✓ Container docker-mongo-1 Running 0.0s
Wallet service of NonUE starts listening on port 6000...
mongouri: mongodb://admin:adminpw@mongo:27017/
[main] INFO org.mongodb.driver.client - MongoClient with metadata {"driver": {"name": "mongo-java-driver|sync|kmongo", "version": "5.5.
0"}, "os": {"type": "Linux", "name": "Linux", "architecture": "amd64", "version": "6.10.14-linuxkit"}, "platform": "Java/Ubuntu/21.0.7+
6-Ubuntu-0ubuntu122.04|Kotlin/2.0.0", "env": {"container": {"runtime": "docker"}}} created with settings MongoClientSettings{readPrefe
rence=primary, writeConcern=WriteConcern{w=null, wTimeout=null ms, journal=null}, retryWrites=true, retryReads=true, readConcern=ReadCon
cern{level=null}, credential=MongoCredential{mechanism=null, username='admin', source='admin', password=<hidden>, mechanismProperties=<
hidden>}, transportSettings=null, commandListeners=[], codecRegistry=ProvidersCodecRegistry{providers=[ProvidersCodecRegistry{code
cProviders=[ValueCodecProvider(), BsonValueCodecProvider(), DBRefCodecProvider(), DBObjectCodecProvider(), DocumentCodecProvider(), Ite
rableCodecProvider(), MapCodecProvider(), GeoJsonCodecProvider(), GridFSFileCodecProvider(), Js310CodecProvider(), JsonObjectCodecProv
ider(), BsonCodecProvider()], org.litote.kmongo.service.CustomCodecProvider@24959ca4, ProvidersCodecRegistry{codecProviders=[org.litote
.kmongo.jackson.JacksonCodecProvider@10289886]}}, loggerSettings=LoggerSettings{maxDocumentLength=1000}, clusterSettings={hosts=[mong
o:27017], srvServiceName=mongoddb, mode=SINGLE, requiredClusterType=UNKNOWN, requiredReplicaSetName='null', serverSelector='null', clust
erListeners='[]', serverSelectionTimeout='30000 ms', localThreshold='15 ms'}, socketSettings=SocketSettings{connectTimeoutMS=10000, rea
dTimeoutMS=0, receiveBufferSize=0, proxySettings=ProxySettings{host=null, port=null, username=null, password=null}}, heartbeatSocketSet
tings=SocketSettings{connectTimeoutMS=10000, readTimeoutMS=10000, receiveBufferSize=0, proxySettings=ProxySettings{host=null, port=null
, username=null, password=null}}, connectionPoolSettings=ConnectionPoolSettings{maxSize=100, minSize=0, maxWaitTimeMS=120000, maxConnec
tionLifetimeMS=0, maxConnectionIdleTimeMS=0, maintenanceInitialDelayMS=0, maintenanceFrequencyMS=60000, connectionPoolListeners=[], max
Connecting=2}, serverSettings=ServerSettings{heartbeatFrequencyMS=10000, minHeartbeatFrequencyMS=500, serverMonitoringMode=AUTO, server
Listeners='[]', serverMonitorListeners='[]', sslSettings=SslSettings{enabled=false, invalidHostNameAllowed=false, context=null}, appli
cationName='null', compressorList=[], uuidRepresentation=UNSPECIFIED, serverApi=null, autoEncryptionSettings=null, dnsClient=null, inet
AddressResolver=null, contextProvider=null, timeoutMS=null}
[cluster-ClusterId{value='68db95442ac7411a1073284d', description='null'}-mongo:27017] INFO org.mongodb.driver.cluster - Monitor
thread successfully connected to server with description ServerDescription{address=mongo:27017, type=STANDALONE, cryptd=false, state=CONNECTED
, ok=true, minWireVersion=0, maxWireVersion=25, maxDocumentSize=16777216, logicalSessionTimeoutMinutes=30, roundTripTimeNanos=23464541,
minRoundTripTimeNanos=0}
>>>> Non-UE Wallet <<<<
Create new user in the wallet:
>> Enrollment ID: 'nancy-consumer-55pHm6at6WuwDKHN5BMK7F'
>> DID: 'did:nancy:consumer-55pHm6at6WuwDKHN5BMK7F'
WARNING: Runtime environment or build system does not support multi-release JARs. This will impact location-based features.
An identity for the admin user 'admin' already exists in the wallet
Successfully enrolled user 'nancy-consumer-55pHm6at6WuwDKHN5BMK7F' with role 'non-UE' and imported it into the wallet
Server started, listening on port 6000...

```

Figure 58: Start consumer wallet service at port 6000 and created DID 'did:nancy:consumer-55pHm6at6WuwDKHN5BMK7F'

**Step 1:** Both provider application and consumer application call the wallet APIs to subscribe to all SLA events relevant to the user.

The wallet gateway provides subscription to two SLA events: *SLAInit* and *SLASigning*. A user can invoke his wallet gateway with gRPC method *SubscribeToSLAInit* and *SubscribeToSLASigning* to subscribe these two events respectively (Figure 59).

```

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 10:33:43
grpcurl -plaintext localhost:5000 dlt.DltGatewayService/SubscribeToSLAInit

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 10:33:55
grpcurl -plaintext localhost:5000 dlt.DltGatewayService/SubscribeToSLASigning

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 10:34:29
grpcurl -plaintext localhost:6000 dlt.DltGatewayService/SubscribeToSLAInit

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 10:34:37
grpcurl -plaintext localhost:6000 dlt.DltGatewayService/SubscribeToSLASigning

```

Figure 59: Call both provider and consumer wallet to subscribe to SLA events

**Step 2:** Provider application calls its wallet to create a new provider profile (CreateProvider) on the marketplace in blockchain (Figure 60). The provider ID must be an existing DID in the wallet.

```

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 14:53:18
grpcurl -plaintext -d '{"value": {"id": "did:nancy:provider-LAqUYpNi4zwj8VwUjA36N1", "name": "orange", "type": "publisher", "available_resources": 60}}' localhost:5000 dlt.DltGatewayService/CreateProvider
{
  "value": {
    "id": "did:nancy:provider-LAqUYpNi4zwj8VwUjA36N1",
    "model_type": "nancy_provider",
    "model_version": "0.2.0",
    "owner": "795eb927e23fdf913f55f0f93b97aef843c9badf0503fd5bd14",
    "mspi_id": "Org1MSP",
    "timestamp": "1759222889",
    "name": "orange",
    "type": "publisher",
    "available_resources": 60
  }
}

```

Figure 60: Provider creates a provider profile on marketplace

**Step 3:** Provider application calls its wallet to create a new service profile under the previous created provider profile in the blockchain (Figure 61). The provider ID of the new service must match an existing provider ID.

```

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 ?5 ..... ✓ < 4s < 11:01:33
grpcurl -plaintext -d '{"value": {"provider_id": "did:nancy:provider-LAqUYpNi4zwj8VwUjA36N1", "cpu": 4, "ram": 6, "location": "madrid", "storage": 60, "maximumULthroughput": 34, "maximumDLthroughput": 56, "minPrice": 40, "maxPrice": 120}}' localhost:5000 dlt.DltGatewayService/CreateService
{
  "value": {
    "id": "be9d9b15968946718c4d6920de03c991551cbcf4bcd3c9a6cc76a886b4f87a5e",
    "model_type": "nancy_service",
    "model_version": "0.2.0",
    "owner": "795eb927e23fdf913f55f0f93b97aef843c9badf0503fd5bd14",
    "mspi_id": "Org1MSP",
    "timestamp": "1759223071",
    "provider_id": "did:nancy:provider-LAqUYpNi4zwj8VwUjA36N1",
    "cpu": 4,
    "ram": 6,
    "location": "madrid",
    "storage": 60,
    "maximumULthroughput": 34,
    "maximumDLthroughput": 56,
    "minPrice": 40,
    "maxPrice": 120
  }
}

```

Figure 61: Provider application creates a new service profile through its wallet

**Step 4:** Consumer application calls its wallet to create a new search in the marketplace given the search criteria (Figure 62).

When the marketplace finds multiple services that match the search criteria, the smart pricing service is triggered to find the winner service with a suggested price, then the DAC service is triggered to

create an initial SLA with the corresponding service for the consumer. The created SLA triggers an SLAInit event that will be received by all subscribers, and in this case, both the provider and consumer wallet service (Figure 63).

```
~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 75 ..... 3s < 11:04:35
grpcurl -plaintext -d '{"value": {"consumer_id": "did:nancy:consumer-55pHm6at6WuWdKH5BMK7F", "service_query": {"cpu": {"$gt": 1}, "provider_query": {"available_resources": {"$gt": 40}}}}' localhost:5000 dlt.DltGatewayService/CreateSearch
{
  "value": {
    "id": "e80bf2e8afadab78308625e84011f6c7c6ea6cbb19a1b651fa923db1fbd5f68a", "model_type": "nancy_search", "model_version": "0.1.2", "owner": "795eb927e23fd913f55f0f93b9dbd2c6c71036b97aef843c9badf0503fd5bd14", "mspi_id": "OrgIMSP", "timestamp": 1759223466, "status": "PRICE", "services": [
      {
        "id": "10646f5179386ae4f996d04ba6547d277b3d086393d4d956ad05cd57ffbf912d", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "c6bc09c8e1de8c297f8a7a3ac6ef9afb0da2c24dda54246dbdd2599acb429211", "mspi_id": "OrgIMSP", "timestamp": 1753263791, "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEDF4JAWPpr9LVs", "cpu": 10, "ram": 10, "location": "kozani", "storage": 100, "maximumULthroughput": 100, "maximumDLthroughput": 100, "minPrice": 100, "maxPrice": 1000, "id": "35c8f3d473cd73e729fe4a16ba15c44508351e83d1ab48faef749e926437e93c", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1753271057, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 123, "ram": 123, "location": "ithaca", "storage": 10, "maximumULthroughput": 10, "maximumDLthroughput": 10, "minPrice": 10, "maxPrice": 10, "id": "434f203282d3d12c55e76ec685947d4965059077eddb290e83405135be8d20118", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1758715228, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 15, "ram": 15, "location": "kozani", "storage": 15, "maximumULthroughput": 15, "maximumDLthroughput": 15, "minPrice": 5, "maxPrice": 50, "id": "4a17e4d771ae2aa9cdd463bb81b38e2c2c2b01323ea0622bb4276daa7223b8", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1758715453, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 5, "ram": 5, "location": "kozani", "storage": 5, "maximumULthroughput": 5, "maximumDLthroughput": 5, "minPrice": 1, "maxPrice": 5, "id": "513407ab62497630a7ce9d256c44dc5f71d9af3a20ccd1aa1087211cec1ba1c", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1758716528, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 20, "ram": 20, "location": "kozani", "storage": 20, "maximumULthroughput": 20, "maximumDLthroughput": 20, "minPrice": 5, "maxPrice": 6, "id": "6dcb4c1878241e15fe8cabca69851b218ce98f0dd38399da1c01bedb6c5455b", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "c6bc09c8e1de8c297f8a7a3ac6ef9afb0da2c24dda54246dbdd2599acb429211", "mspi_id": "OrgIMSP", "timestamp": 1753262780, "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEDF4JAWPpr9LVs", "cpu": 10, "ram": 10, "location": "kozani", "storage": 100, "maximumULthroughput": 100, "maximumDLthroughput": 100, "minPrice": 100, "maxPrice": 1000, "id": "74d78531df2959edf09baabdf2683d087444b3f50ceb3b8531dc6b876f69a", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "d01820e9b4c86f9255d402559ee4f5088eaa083db471703d361347844e6f7", "mspi_id": "OrgIMSP", "timestamp": 1751538155, "provider_id": "did:nancy:holder-ArXJUtftuNHAKmBe8pLBq", "cpu": 4, "ram": 6, "location": "madrid", "storage": 60, "maximumULthroughput": 34, "maximumDLthroughput": 56, "minPrice": 120, "maxPrice": 120, "id": "7b8893e97cf72182a794ea3f96545d4dbb8ab5b8517c3c637ecf65c046197", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1758715479, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 10, "ram": 10, "location": "kozani", "storage": 10, "maximumULthroughput": 10, "maximumDLthroughput": 10, "minPrice": 8, "maxPrice": 10, "id": "967028ce57e25d5f6ae97d4e0870bdcff0645d5f773705e04b768c234112b3", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1758716642, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 20, "ram": 20, "location": "kozani", "storage": 20, "maximumULthroughput": 20, "maximumDLthroughput": 20, "minPrice": 89, "maxPrice": 95, "id": "9cf2e3cfb662670f4c51f0fc24af18f48fa0b39c4542b6e35fe03bb912493ad", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1758715446, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 5, "ram": 5, "location": "kozani", "storage": 5, "maximumULthroughput": 5, "maximumDLthroughput": 5, "minPrice": 1, "maxPrice": 5, "id": "be1293660b7121e18801bd3796f53993e1d16deb96a9ba069a4492cd9852b91", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1758715817, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 20, "ram": 20, "location": "kozani", "storage": 20, "maximumULthroughput": 20, "maximumDLthroughput": 20, "minPrice": 5, "maxPrice": 50, "id": "be9d9b15968946718c4d6920de03c991551cbcf4bcd3ba6cc76a886b4f87a5e", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "795eb927e23fd913f55f0f93b9dbd2c6c71036b97aef843c9badf0503fd5bd14", "mspi_id": "OrgIMSP", "timestamp": 1759223071, "provider_id": "did:nancy:provider-LAQYpNi4zj8VwUjA36N1", "cpu": 4, "ram": 6, "location": "madrid", "storage": 60, "maximumULthroughput": 34, "maximumDLthroughput": 56, "minPrice": 40, "maxPrice": 120, "id": "d1cb03426c283a7c127b4ccbc3183babdd412e1d1c85930a99289f02b911bc5", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "c6bc09c8e1de8c297f8a7a3ac6ef9afb0da2c24dda54246dbdd2599acb429211", "mspi_id": "OrgIMSP", "timestamp": 1753263645, "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEDF4JAWPpr9LVs", "cpu": 10, "ram": 10, "location": "kozani", "storage": 100, "maximumULthroughput": 100, "maximumDLthroughput": 100, "minPrice": 100, "maxPrice": 1000, "id": "e234f8e1c3bda7a24242626485f4e50042492f95b35210067ce44a40fb538c7", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "a792978cc2b1f227fb1ada98976b60e9fc572ec53744f74f93e429f8df00f84f", "mspi_id": "OrgIMSP", "timestamp": 1753352099, "provider_id": "did:nancy:holder-XqBYPmMmBH4u7Pyd3puFCG", "cpu": 10, "ram": 10, "location": "myservice", "storage": 10, "maximumULthroughput": 10, "maximumDLthroughput": 10, "minPrice": 10, "maxPrice": 10, "id": "e48a586318fff14c65287cb871b83ec17c19f94549de132dea3d480d1dd4f6c7", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "f6e71a82a72827dd13b286e22b649c69fd2016576ebb393e89c9a9f9603ef17", "mspi_id": "OrgIMSP", "timestamp": 1758716409, "provider_id": "did:nancy:holder-YSEHR2XoakJ3iqbYKZu8iz", "cpu": 20, "ram": 20, "location": "kozani", "storage": 20, "maximumULthroughput": 20, "maximumDLthroughput": 20, "minPrice": 1, "maxPrice": 15, "id": "f1adf07a9631b590a630ae0ba4875466de6d6643e95add9ef4c971f432f89839", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "c6bc09c8e1de8c297f8a7a3ac6ef9afb0da2c24dda54246dbdd2599acb429211", "mspi_id": "OrgIMSP", "timestamp": 1751879113, "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEDF4JAWPpr9LVs", "cpu": 4, "ram": 6, "location": "madrid", "storage": 60, "maximumULthroughput": 34, "maximumDLthroughput": 56, "minPrice": 40, "maxPrice": 120, "id": "ff652685c245d97661890770a09ed0e06cbb0684c2cc5ca1ddf4c51fd58be199", "model_type": "nancy_service", "model_version": "0.2.0", "owner": "b102d1528b3ef005346bb186b2fe35b93cd6bacecaca94a8f24d02f299d8524", "mspi_id": "OrgIMSP", "timestamp": 1752227569, "provider_id": "did:nancy:test2-MfwTb2r9RnCj918k6BxtFJ", "cpu": 4, "ram": 6, "location": "madrid", "storage": 60, "maximumULthroughput": 34, "maximumDLthroughput": 56, "minPrice": 40, "maxPrice": 120, "consumer_id": "did:nancy:consumer-55pHm6at6WuWdKH5BMK7F", "pricing": null, "sla": null}
}
```

Figure 62: Consumer creates a search on the marketplace which returns matched services

```

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client #1 #1 !4 ?5 ..... ✓ < 10:33:43
grpcurl -plaintext localhost:5000 dlt.DltGatewayService/SubscribeToSLAInit
{
  "name": "InitSLA",
  "payload": "{\n  \"id\": \"292\", \"value\": \"{\n    \"service_id\": \"f1adf07a9631b590a630ae0ba4875466de6d6643e95add9ef4c971f432f89839\", \"pro\n    vider_id\": \"did:nancy:wallet-external-test-3EtvHYvkEDF4JAWPpr9LvS\", \"price\": 74.12, \"id\": \"292\", \"consumer_id\": \"\n    did:nancy:consumer-55pHm6at6WuwDKHN5BMK7F\", \"hash_smartcontract\": \"0x2424353\", \"service_description\": {\n    \"id\": \"\", \"\n    \"model_type\": \"\", \"model_version\": \"\", \"owner\": \"\", \"mspi_id\": \"\", \"timestamp\": 0, \"provider_id\": \"\n    \"\", \"did:nancy:wallet-external-test-3EtvHYvkEDF4JAWPpr9LvS\", \"cpu\": 0, \"ram\": 0, \"location\": \"\", \"storage\": 0, \"\n    maximumULthroughput\": 0, \"maximumDLthroughput\": 0, \"minprice\": 40, \"maxprice\": 120}}\", \"provider_id\": \"did:nancy:wallet-exte\n    nal-test-3EtvHYvkEDF4JAWPpr9LvS\", \"consumer_id\": \"did:nancy:consumer-55pHm6at6WuwDKHN5BMK7F\", \"provider_sig\": \"\", \"consumer_sig\": \"\n  }\"
}"

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client #1 #1 !4 ?5 ..... ✓ < 10:33:55
grpcurl -plaintext localhost:5000 dlt.DltGatewayService/SubscribeToSLASigning

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client #1 #1 !4 ?5 ..... ✓ < 10:34:29
grpcurl -plaintext localhost:6000 dlt.DltGatewayService/SubscribeToSLAInit
{
  "name": "InitSLA",
  "payload": "{\n  \"id\": \"292\", \"value\": \"{\n    \"service_id\": \"f1adf07a9631b590a630ae0ba4875466de6d6643e95add9ef4c971f432f89839\", \"pro\n    vider_id\": \"did:nancy:wallet-external-test-3EtvHYvkEDF4JAWPpr9LvS\", \"price\": 74.12, \"id\": \"292\", \"consumer_id\": \"\n    did:nancy:consumer-55pHm6at6WuwDKHN5BMK7F\", \"hash_smartcontract\": \"0x2424353\", \"service_description\": {\n    \"id\": \"\", \"\n    \"model_type\": \"\", \"model_version\": \"\", \"owner\": \"\", \"mspi_id\": \"\", \"timestamp\": 0, \"provider_id\": \"\n    \"\", \"did:nancy:wallet-external-test-3EtvHYvkEDF4JAWPpr9LvS\", \"cpu\": 0, \"ram\": 0, \"location\": \"\", \"storage\": 0, \"\n    maximumULthroughput\": 0, \"maximumDLthroughput\": 0, \"minprice\": 40, \"maxprice\": 120}}\", \"provider_id\": \"did:nancy:wallet-exte\n    nal-test-3EtvHYvkEDF4JAWPpr9LvS\", \"consumer_id\": \"did:nancy:consumer-55pHm6at6WuwDKHN5BMK7F\", \"provider_sig\": \"\", \"consumer_sig\": \"\n  }\"
}"

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client #1 #1 !4 ?5 ..... ✓ < 10:34:37
grpcurl -plaintext localhost:6000 dlt.DltGatewayService/SubscribeToSLASigning

```

Figure 63: Both provider and consumer received notification of new SLAInit event with SLA\_ID=292

**Step 5:** After the reception of the SLAInit event, the provider or consumer application checks the SLA content, and if they agree on the contents of the SLA, it calls the wallet service to sign the SLA (slaSign) providing the slald and their DIDs (Figure 64).

The wallet signs the SLA and provides the signature to the SLARegistry smart contract. If the signature validation is successful, an SLASigning event is emitted to subscribers who can review the signed SLA (Figure 65).

```
~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 75 ..... ✓ < 11:20:53
grpcurl -plaintext -d '{"value": {"$id": "292", "uid": "did:nancy:consumer-55pHm6at6WuWdKHNSBMK7F\\\\"}}' localhost:6000 dlt.DltGatewayService/SLASign
{}
```

Figure 64: Consumer signs the SLA ID=292

```
~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 75 ..... ✓ < 10:33:43
grpcurl -plaintext localhost:5000 dlt.DltGatewayService/SubscribeToSLAInit
{
  "name": "InitSLA",
  "payload": {
    "id": "292",
    "value": {
      "service_id": "f1adf07a9631b590a630ae0ba4875466de6d6643e95add9ef4c971f432f89839",
      "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
      "price": 74.12,
      "id": "292",
      "consumer_id": "did:nancy:consumer-55pHm6at6WuWdKHNSBMK7F",
      "hash_smartcontract": "0x2424353",
      "service_description": {
        "id": "292",
        "model_type": "wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
        "model_version": "1",
        "owner": "mspi_id",
        "timestamp": 0,
        "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
        "cpu": 0,
        "ram": 0,
        "location": "storage",
        "maximumULthroughput": 0,
        "maximumDLthroughput": 0,
        "minprice": 40,
        "maxprice": 120
      },
      "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
      "consumer_id": "did:nancy:consumer-55pHm6at6WuWdKHNSBMK7F",
      "provider_sig": "",
      "consumer_sig": ""
    }
  }
}

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 75 ..... ✓ < 10:34:29
grpcurl -plaintext localhost:6000 dlt.DltGatewayService/SubscribeToSLAInit
{
  "name": "InitSLA",
  "payload": {
    "id": "292",
    "value": {
      "service_id": "f1adf07a9631b590a630ae0ba4875466de6d6643e95add9ef4c971f432f89839",
      "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
      "price": 74.12,
      "id": "292",
      "consumer_id": "did:nancy:consumer-55pHm6at6WuWdKHNSBMK7F",
      "hash_smartcontract": "0x2424353",
      "service_description": {
        "id": "292",
        "model_type": "wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
        "model_version": "1",
        "owner": "mspi_id",
        "timestamp": 0,
        "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
        "cpu": 0,
        "ram": 0,
        "location": "storage",
        "maximumULthroughput": 0,
        "maximumDLthroughput": 0,
        "minprice": 40,
        "maxprice": 120
      },
      "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
      "consumer_id": "did:nancy:consumer-55pHm6at6WuWdKHNSBMK7F",
      "provider_sig": "",
      "consumer_sig": ""
    }
  }
}

~/work/EU_Projects/NANCY/repo/dlt-component/gateway/docker > feature/impl-ssi-client +1 *1 !4 75 ..... ✓ < 10:34:37
grpcurl -plaintext localhost:6000 dlt.DltGatewayService/SubscribeToSLASign
{
  "name": "SigningSLA",
  "payload": {
    "id": "292",
    "value": {
      "service_id": "f1adf07a9631b590a630ae0ba4875466de6d6643e95add9ef4c971f432f89839",
      "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
      "price": 74.12,
      "id": "292",
      "consumer_id": "did:nancy:consumer-55pHm6at6WuWdKHNSBMK7F",
      "hash_smartcontract": "0x2424353",
      "service_description": {
        "id": "292",
        "model_type": "wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
        "model_version": "1",
        "owner": "mspi_id",
        "timestamp": 0,
        "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
        "cpu": 0,
        "ram": 0,
        "location": "storage",
        "maximumULthroughput": 0,
        "maximumDLthroughput": 0,
        "minprice": 40,
        "maxprice": 120
      },
      "provider_id": "did:nancy:wallet-external-test-3EtvHYvKEdF4JAWPpr9LvS",
      "consumer_id": "did:nancy:consumer-55pHm6at6WuWdKHNSBMK7F",
      "provider_sig": "",
      "consumer_sig": "152ed9856ea730faf3e81e4a70cfc7482c8db1c0fe71569fb9a062b1d5995b8"
    }
  }
}
```

Figure 65: Both parties receive the SigningSLA event and SLA id=292 now has the consumer signature.

Inside the marketplace, two different kinds of operations take place:

- The first one is related to the registration of operators and services, which should be done as a starting point for the interdomain flow. The marketplace receives the CreateProvider or CreateService requests from the operators' wallets to register the details of the available operators and services.
- The second one is related to the new service search in an offloading process. The marketplace receives the CreateSearch request from the operator wallet to search for a suitable available service to offload its current service to. Internally, there are the following different steps:
  - The NANCY marketplace first searches among the registered services and operators to find those whose features fulfill the requirements defined in the request.
  - Once the suitable services are identified, the marketplace makes a price request to the Smart Pricing. The Smart Pricing calculates the most suitable service in terms of

price as well as the suitable price. More details are gathered in [13]. This information is sent as response to the marketplace.

- The service identified by the Smart Pricing is the one to be considered for the offloading process. At this point, the marketplace obtains all the details about the selected service and sends them to the Digital Agreement Creator in an SLA creation request. Besides, the requester operator details are also sent in the request.
- The Digital Agreement Creator generates the SLA and sends it back to the marketplace.
- The marketplace receives the SLA and sends it to the SLA Signature smart contract for the signature management by the two involved operators: the requester and the one operating the identified service.

## 6. Conclusions

NANCY develops a secure and cutting-edge framework for Beyond 5G (B5G) wireless networks by integrating advanced technologies such as Artificial Intelligence, Blockchain, Quantum-safe technologies, MEC, and Orchestration. Its goal is to enable intelligent and secure resource management, adaptive networking, and enhanced orchestration performance.

This deliverable builds upon the results reported in [1] and [2] to provide the final version of the NANCY integrated system. It presents the specifics of the interconnection among NANCY operational domains and the testbeds/demonstrators, emphasizing the flexible instantiation of relevant NANCY components for different demonstration use cases. Detailed descriptions of the functional and integration test execution specifications and results for the final set of NANCY bilateral integration points are also provided. Finally, selected end-to-end validation workflows are described, including their specifications and corresponding results. These workflows serve to validate the readiness of the corresponding operations taking place among the different NANCY operational domains: Central Management, Inter-operator and testbeds/demonstrators. As described in section 5, these workflows are largely horizontal (i.e., replicated) across the different testbeds/demonstrators. D6.10 will extend this work by providing a comprehensive description of the NANCY final Pilots, namely the Italian Massive IoT, Spain Outdoor, and Greek Outdoor, together with the final validation and evaluation results. The latter will also build upon the defined evaluation methodology and the detailed planning of the final demonstrations, as outlined in [3].

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