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NANCY

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

Deliverable 1.4

Project Scientific/Technical Plan

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Anna Triantafyllou	UOWM	31 May 2023

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List of Acronyms

Acronym	Explanation
5G	Fifth-Generation
AAA	Authentication, Authorisation, Accounting
AI	Artificial Intelligence
API	Application Programming Interface
B5G	Beyond Fifth-Generation
B-RAN	Blockchain-Radio Access Network
BS	Base Station
CAPEX	Capital expenditures
CD	Continuous Delivery
CI	Continuous Integration
CoMP	Coordinated Multi-Point
CPRI	Common Public Radio Interface
CV	Continuous Variable
D2D	Device-to-Device
DA-RAN	Dis-Aggregated Radio Access Network
DLT	Distributed Ledger Technologies
DoF	Degree of Freedom
DPR	Distributed Phase Reference
DSA	Digitised Spectrum Assets
DV	Discrete Variable
E2E	End-to-End
FG	Forwarding Graphs
FiWi	Fiber Wireless
FLF	Federated Learning Framework
FSCD	Fast Smart Contract Deployment
ICT	Information and communications technology
IFA	Identifier for Advertisers
IMEI	International Mobile Equipment Identity
InP	Indium phosphide
KME	Key Management Entity
KPI	Key Performance Indicator
MAC	Medium Access Control
MANET	Mobile Ad-hoc Network
MCC	Mobile Cloud Computing
MDC	Mobile Device Cloud
MEC	Multi-Access Edge Computing
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MMFA	Many-to-Many File Allocation
MNO	Mobile Network Operator
MOIS	Man-to-One Important User Selection
MSP	Multi-sided Platform
MTC	Machine Type Communications
NF	Network Function
OPEX	Operating expenses
PoD	Proof of Device
PON	Passive optical network

PoW	Proof of Work
PTC	Project Technical Committee
QKD	Quantum Key Distribution
QoE	Quality of Experience
QoS	Quality of Service
RA	Random Access
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio frequency
RSU	Roadside Unit
SAE	Secure Application Entity
SDN	Software Defined Networking
SLA	Service Level Agreement
SME	Small and medium-sized enterprise
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communications
V2V	Vehicle-to-Vehicle
VCG	Vickrey Clarke Groves
VNF	Virtual network function
VR	Virtual Reality
WDM	Wavelength Division Multiplexing
WP	Work Package
XAI	Explainable Artificial Intelligence

Executive summary

The present deliverable delineates the innovation management plan of the NANCY project from a technical and scientific standpoint, in accordance with the guidelines and prerequisites of the Horizon Europe and Smart Networks and Services Joint Undertaking programme, aimed at ensuring the preservation of innovation and excellence within the project. The technical and innovative objectives are subsequently delineated, accompanied by a summary of the management strategies implemented to achieve these objectives. Within this framework, the necessity for an innovative solution, such as the one presented by the NANCY project, is supported by a concise state-of-the-art analysis of the primary subcomponents of the project, as well as the key exploitable results of the project with respect to their corresponding work packages. The report concludes by providing a measurement of innovation and a systematic approach for the ongoing evaluation of innovation over the entire duration of the project.

1. Introduction

The NANCY project is going to enable personalised, multi-tenant, and perpetual protection wireless networking by developing three complementary technologies for beyond 5G systems in an integrated and innovative way:

- NANCY will develop new radio access network (RAN) technologies using blockchain, that will boost the dynamic scalability of network capabilities by enabling the coordination of existing business and individual infrastructures, while, at the same time, will offer unprecedented high security and privacy through post-quantum cryptography (PQC) (Pilar I);
- NANCY will employ machine learning (ML) and artificial intelligence (AI) to transform beyond 5G RANs into intelligent platforms and introduce new service models to telecom/ISP and individual providers (Pilar II);
- NANCY will exploit the opportunities emerging for multi-access edge computing (MEC) in order to provide almost-zero latency and high-computational capabilities at the edge (Pilar III).

To realize this novel concept, NANCY proposed a novel RAN architecture, which combines the benefits of the blockchain, MEC, and AI, as illustrated in Figure 1, and is optimised by means of:

- An experimental-driven blockchain-RAN (B-RAN) information framework, according to which the role of each one of the network nodes can change from connectivity consumer to provider,
- B-RAN particularities and attacks types characterisation,
- AI approaches for energy and cost-efficiency optimisation as well as for supporting a wide range of applications with diverse requirements,
- Federated learning approaches for ultra-secure connectivity, optimal and adaptive radio resource management, and end-to-end (E2E) network optimisation,
- Offloading and social-aware precaching approaches to support latency-sensitive applications, and
- Smart pricing policies that open the door to new business models.

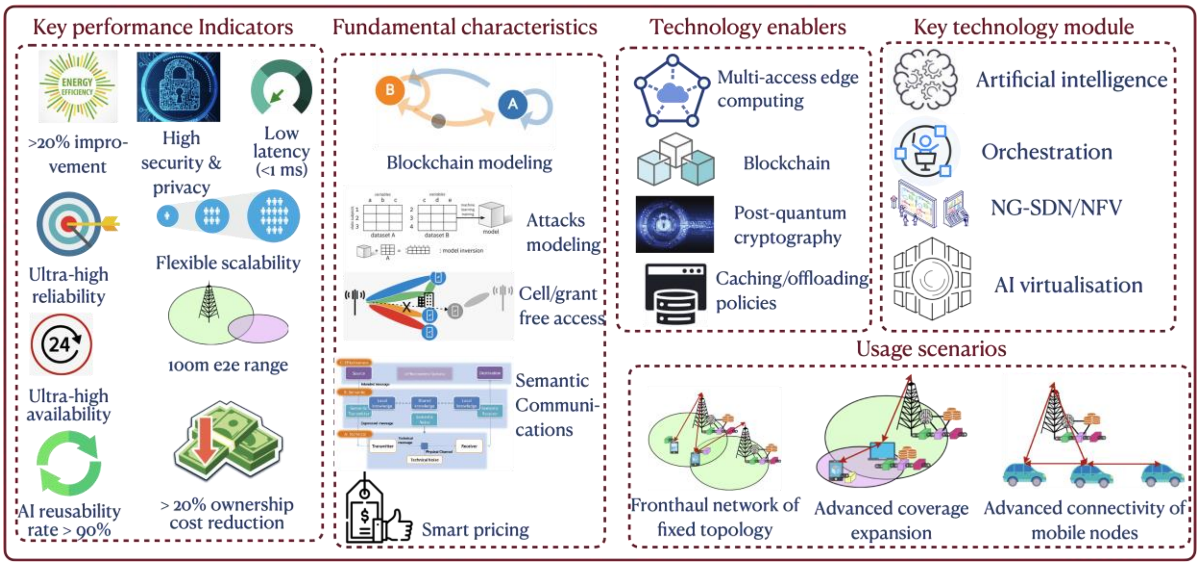

Figure 1: NANCY B5G system concept

Bringing to fruition the notion of artificial intelligence (AI)-aided blockchain wireless radio access beyond 5G networks calls for a flexible, scalable, and powerful ML-based orchestration framework, novel blockchain and attack models, a revolutionary network information theory approach, and the design of cutting-edge technology components. These include NFs for enabling common network functionalities, blockchain and cell-free radio access mechanisms, AI-based resource, and network orchestration, distributed and decentralized blockchain approaches supported by MEC, and proactive self-recovery and self-healing mechanisms, as well as devising a suitable experimental-driven performance evaluation and evaluation framework defined by the appropriately selected usage scenarios and relevant metrics. Additionally, NANCY will identify the critical technology gaps and invent, optimize, demonstrate, and assess the key enablers for the B5G RAN. In more detail, the NANCY approach is built upon three well-defined pillars:

- **Pillar I: Distributed and self-evolving B-RAN for dynamic scalability, high-security, and privacy in a heterogeneous environment**, by means of distributed and decentralized blockchain, PCQ, as well as cell-free radio access mechanisms designs, in order to significantly improve the radio resource usage by introducing novel strategies for range/service expansion, supporting novel use cases and killer apps, and exploiting the underutilized spectrum.
- **Pillar II: Towards the Pareto-optimal AI-based wireless RAN orchestration that maximises energy efficiency and trustworthiness**, supports ultra-high availability and applications with diverse requirements, optimises network topology and management, enables device collaboration as well as collaborative sensing perspective, allows system and network level AI models reproducibility and explainability, and transforms B5G RANs into intelligent platforms; thus, opening new service models to telecom/ISP and individual providers.
- **Pillar III: Distributed MEC for "almost-zero latency" and high-computational capabilities at the edge, where the data are generated,** by means of social-aware data and AI models caching and task offloading in order to transform the B5G verticals into intelligent and real-time flexible and reliable platforms.

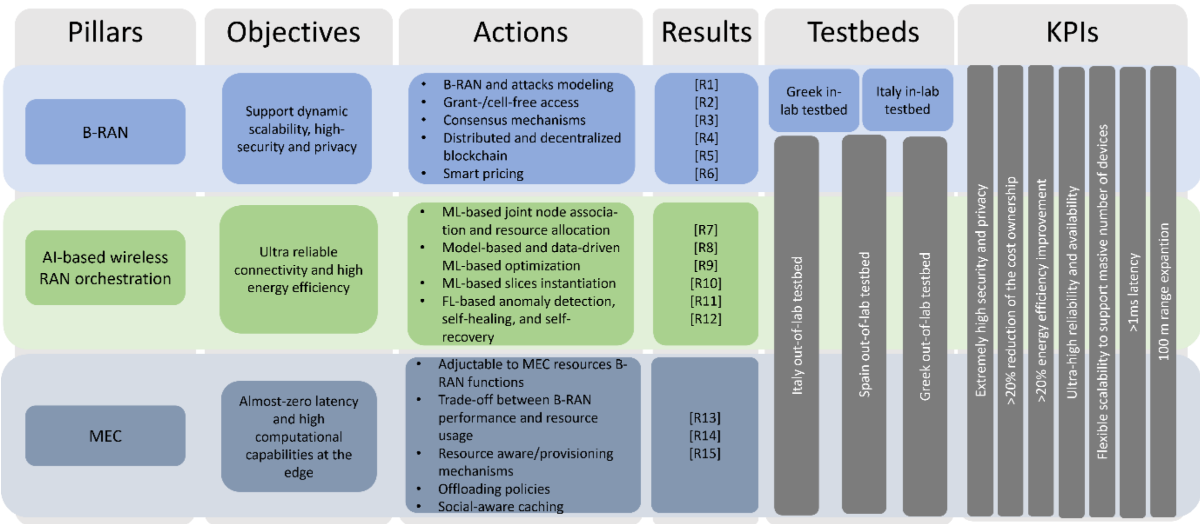

Figure 2: NANCY pillars, objectives, actions, and results

Towards realizing the three visionary pillars and achieving the corresponding objectives, NANCY will carry out a substantial number of well-planned and coordinated research & development tasks illustrated in Figure 2, engaging in analytical & fundamental studies, algorithm & signal processing, resource management strategy & network modules interface design as well as network architecture & model-based & data-driven optimisation. For each of the above objectives, the key technology breakthroughs (innovations, theoretical findings, techniques) will be demonstrated, validated & evaluated by means of:

- **Definition of a proof-of-concept software simulation and hardware demonstration platform;**
- **Implementation of the NANCY demonstration platform; and**
- **Experimental-driven modelling and evaluation of the NANCY architecture and network performance,**

in order to:

- *Experimentally validate the theoretical findings and technological developments;*
- *Qualitatively and quantitatively assess the practical limitations and obstacles of AI-aided B-RAN in a real-life operating environment;*

- *Assess the feasibility of the proposed architecture and individual components/functionalities integration; and*
- *Identify possible accelerators for the adoption of AI-aided B-RAN in the roadmaps of networks beyond 5G and potential limitations that may consist of showstoppers and ways to overcome the associated obstacles.*

1.1. Purpose of this deliverable

The present deliverable delineates the innovation management methodology of the project, which has been devised to facilitate and guarantee the efficacious utilisation of the project outcomes and to transform these outcomes into pioneering success narratives.

1.2. Relation with other deliverables and tasks

This particular deliverable pertains to all of the tasks within NANCY, as it serves as the guiding force for its comprehensive technical strategy.

1.3. Deliverable structure and notations

The present document is structured into:

- Section 2 outlines the goals of technical and innovation management, accompanied by an overview of applicable methodologies for managing innovation within the project's context.
- Section 3 provides a concise B5G market analysis for each significant domain within NANCY.
- Section 4 delineates and charts the junctures of innovation to particular work packages (WPs) of NANCY.
- In Section 5, the objectives, key performance indicators (KPIs), and approach to ensuring appropriate and timely technical, scientific and innovation management, sustaining a notable level of creativity, and promoting the project's dissemination are outlined.
- Section 6 of this report provides the final remarks and findings.

2. Overview of EU Initiatives for B5G Networks

The structure of this section is as follows: Section 2.1 presents the national, regional, and international organisations and standardisation bodies that are related to the NANCY concepts and objectives, while Section 2.2 summarizes the regulations and legislations.

2.1. Organisations and standardisation bodies

This section focuses on identifying the national, regional, and international organisations and standardisation bodies that are related to the NANCY concepts and objectives. In this direction, Table 1 presents the key standardisation organisations and open-source initiatives and documents their goals and aims alongside a short description of their relation to the NANCY objectives.

Table 1: Organizations and Standardization Bodies

Standardization and open-source initiatives	Brief description	Relation to NANCY
3GPP	The primary objective of 3GGP is to establish the Mobile Broadband Standard, which is progressively focused on facilitating the interconnection of the internet of things. This includes catering to the requirements of both ultra-reliable low latency communications and energy-efficient low-cost, low-power sensors and devices.	In the first quarter of 2022, the discussions for release 19 have begun. NANCY has a high interest in the multi-hop usage and the coordinated multi-point scenarios and the requirements that will be set in this release. Moreover, it will closely monitor the use-cases that will be defined and will map them to the NANCY usage scenarios. Finally, TECNALIA will present NANCY's B-RAN concept to 3GPP.
6G-IA	The 6G Smart Networks and Services Industry Association (6G-IA) represents the European Industry and Research community in the domain of forthcoming generation networks and services. The principal aim is to enhance Europe's dominance in the areas of 5G, 5G evolution, and SNS/6G exploration. The 6G-IA is the representative of the private sector in both the 5G Public Private Partnership (5G-PPP) and the Smart Networks and Services Joint Undertaking (SNS JU). The public side in the 5G-PPP and SNS JU is represented by the European Commission. The 6G-IA is a consortium that unites a worldwide industry community comprising telecommunications and digital entities, including operators, manufacturers, research institutions, universities, verticals, small and medium-sized enterprises, and information and communication technology associations. The 6G-IA engages in diverse undertakings in crucial domains such as	The NANCY coordinator and technical manager participate in the project coordination and technical project management working groups of 6G-IA SNS. Moreover, most of NANCY partners are members of the 6G-IA and actively participate in a number of working groups. NANCY has an interest in the following 6G-IA working groups: [WG1] Pre-standardization WG [WG2] Vision and societal challenges WG and [WG3] Security WG. In WG1, NANCY monitors the standardization roadmaps and envisions proposing its B-RAN and resource-sharing concepts for standardization. In WG2,

	standardisation, frequency spectrum, R&D initiatives, technology proficiency, partnership with significant vertical industry sectors, particularly for the experimentation of new methods, and global collaboration.	NANCY monitors the publicly available visions and major technical trends from industry, research community, and available information from other regions and explains how the NANCY technical advancements are in-line with them. In WG3, NANCY will present its security and privacy mechanisms as well as its explainable AI framework. It will advertise the project's datasets and participate in the initiatives of the working group.
AI4EU	The AI4EU platform and ecosystem, which has received backing from the European Commission through the H2020 initiative, represents the initial European foray into an on-demand artificial intelligence system. The AI4EU Platform aims to consolidate AI stakeholders and resources into a centralised location, thereby mitigating fragmentation and expediting the development of AI-based innovations, including research, products, and solutions. The AI4EU Platform is designed to function as a comprehensive resource for individuals seeking access to AI-related information, technology, services, software, and expertise. The AI4EU initiative is poised to serve as a catalyst for the European AI market, providing a significant pool of resources, fostering community networking effects, and facilitating swift development and expansion.	NANCY will monitor the AI4EU platform in order to identify trustworthy, high-quality datasets, algorithms, or even find efficient mechanisms to communicate, cooperate, and engage with other peers in an open and transparent manner. This approach will contribute to the success of NANCY by providing a mechanism that unites the paradigm of AI research application and data, while ensuring the European seal of quality, trustworthiness and explainability.
DAIRO	The acronym DAIRO represents the three fields of Data, AI, and Robotics. The adoption of this new nomenclature serves as evidence of the Association's aspiration to establish a close partnership with other communities, with the aim of collaboratively addressing the intersection of the pivotal fields of Data, AI, and Robotics. DAIRO exhibits a resolute dedication towards realising the lofty objectives of the AI, Data and Robotics Partnership, the European Data Strategy, and the EuroHPC Joint Undertaking. Furthermore, DAIRO aims to make valuable contributions towards the attainment of the European goals concerning digital and environmental transformations. Additionally, the Association will maintain its advantageous position in facilitating the creation of networks and collaborative structures between Digital Innovation Hubs and i-Spaces throughout Europe, as well as promoting the advancement of a European Data Space. The primary aim of DAIRO	The NANCY consortium will ensure the alignment of its developed components with the main lessons learnt from the task forces. NANCY will focus on the cross-sectorial task forces of DAIRO, including Data and AI Technologies, Ethical and Trustworthy Artificial and Machine Intelligence, HPC-Big Data-AI, Standards and Benchmarking, as well as the Trustworthiness of Industrial AI.

	is to enhance research, development, and innovation in AI, Data, and Robotics in Europe, with the ultimate goal of promoting value creation for businesses, citizens, and the environment.	
EOSC	The European Open Science Cloud (EOSC) is a platform designed to facilitate the storage and analysis of research data in order to bolster scientific endeavours within the European Union. The EOSC aims to furnish a federated and open multi-disciplinary milieu to European researchers, innovators, companies, and citizens. This milieu will enable them to publish, discover, and repurpose data, tools, and services for research, innovation, and educational objectives. The ultimate objective of EOSC is to establish a Web of FAIR Data and services that caters to the scientific community in Europe. This infrastructure will serve as a foundation for the development of a diverse range of value-added services. The aforementioned encompass a spectrum of activities, spanning from the utilisation of visualisation and analytics techniques to the enduring safeguarding of information or the surveillance of the adoption of open science methodologies.	NANCY will use the EOSC glossary in order to provide clear and concise definitions of key terms. The consortium will also pay attention to past, present, and future EOSC-funded projects as well as the EOSC Portal that is part of the EOSC implementation roadmap as one of the expected “federating core” services.
IEEE Standard for Blockchain Interopera-bility Data Authenti-cation and Communi-cation Protocol	Blockchain interoperability refers to the capacity of multiple blockchain systems or applications to share and utilise the information that has been exchanged between them. Interoperability is a crucial aspect that can be achieved through the effective utilisation of interfaces and protocols. Hence, there is a requirement for a benchmark of cross-chain interoperability interfaces and protocols, particularly those pertaining to data validation and communication within both homogeneous and heterogeneous blockchain systems. The aforementioned protocols facilitate the coordination of blockchains and enable the provision of diverse cross-chain models and levels to cater to business requirements, without necessitating the customization of gateways or exchanges for particular use cases. This standard presents a framework for achieving cross-chain interoperability, along with protocols and interfaces for ensuring data authentication and communication in both homogeneous and heterogeneous blockchain interoperability scenarios. The set of protocols comprises the distributed identity protocol, metadata protocol, on-chain proof transformation protocol, and cross-chain communication protocol.	NANCY will make sure to monitor the activities of the IDAC - Interoperability Data Authentication and Communication working group with a specific focus on the IEEE 3205-2023 Standard for Blockchain Interoperability Data Authentication and Communication Protocol, which falls in line with the B-RAN architecture that will be developed within NANCY.

IETF	The IETF is responsible for creating voluntary standards that are frequently embraced by Internet users, network operators, and equipment vendors. As a result, it plays a significant role in influencing the direction of the Internet's development. The IETF does not exercise any form of authority or surveillance over the Internet. The primary objective of the IETF is to enhance the functionality and performance of the Internet. The primary objective of this organisation is to generate technical and engineering documents of superior quality and relevance that exert a significant impact on the manner in which individuals conceptualise, utilise, and administer the Internet, thereby enhancing its functionality. The aforementioned records comprise a collection of protocol standards, best current practices, and informational documents of diverse nature.	NANCY will participate in selected IETF meetings in order to follow standards for automated network management as well as security and privacy. This way, NANCY will contribute towards improving existing standards and creating, implementing, and deploying new standards.
NGMN	NGMN is an organisation that facilitates collaboration among industry stakeholders, including operators, vendors, and academia, to address critical challenges. The organisation provides a platform for collective advancement towards solutions. The NGMN Alliance aims to offer effective direction towards the attainment of innovative and cost-effective mobile telecommunication services for end-users, with a specific emphasis on facilitating the complete implementation of 5G, achieving mastery of the path to disaggregation, promoting sustainability and green networks, and preparing for the advent of 6G.	Through its active involvement in the NGMN Alliance activities, NANCY aims to implement its components in line with the three major priorities for 2023 and beyond: (i) development of open, disaggregated, virtualised and cloud-native solutions with a focus on the E2E Operating Model, (ii) building sustainable & environmentally conscious solutions, and (iii) highlighting key 6G trends across technology and societal requirements as well as use cases.
NIST/PQC	NIST has commenced a procedure to request, assess, and establish one or multiple public-key cryptographic algorithms that are resistant to quantum computing. At present, public-key cryptographic algorithms are delineated in FIPS 186-4, which is the Digital Signature Standard, along with certain specialised publications. The documents SP 800-56A Revision 2 and SP 800-56B Revision 1 provide recommendations for pair-wise key establishment schemes utilising discrete logarithm cryptography and integer factorization cryptography, respectively. Notwithstanding, these algorithms are susceptible to assaults from high-capacity quantum computers, as indicated in NISTIR 8105, Report on Post Quantum Cryptography.	NANCY will closely follow the NIST's new public-key cryptography standards in order to identify additional unclassified, publicly disclosed digital signature, public-key encryption, and key-establishment algorithms that are available worldwide, and are capable of protecting sensitive government information well into the foreseeable future, including after the advent of quantum computers.
Open alliance	OPEN (One-Pair Ether-Net) Alliance is an open industry alliance comprising primarily of	NANCY's involvement in the OPEN Alliance activities is

	automotive industry and technology providers. Its objective is to promote the widespread adoption of Ethernet-based networks as the standard in automotive networking applications. The alliance operates as a non-profit organisation.	focused towards identifying (i) requirements and test specifications for harnesses, switches, ECUs, and additional functionalities, (ii) new physical layer solutions in a standards setting organization, as well as gaps related to the implementation of Ethernet-based communication.
One6G	The vision of one6G is to utilise 6G technologies and solutions to unlock the full potential of intelligent connectivity, thereby facilitating secure, resilient, and sustainable development of our society. The objective of one6G is to advance, validate, and endorse advanced cellular and wireless technology-driven communication solutions. The aim is to expedite the adoption and market penetration of 6G by endorsing worldwide research and standardisation endeavours, while simultaneously catering to the demands of connected mobility that are driven by societal and industrial factors. The objective is to expedite the progress of novel services and applications in various domains, including but not limited to advanced autonomous driving, advanced manufacturing, advanced wireless e-health, and remote education.	NANCY aims to closely follow the endeavours of one6G in order to (i) ensure its alignment with 6G technology building, promotion and early uptake, (ii) enable user engagement for requirements specification and 6G technology assessment, and (iii) ensure pre-alignment with global standardization efforts (not only 3GPP), and spectrum demands.
ONF	The Open Networking Foundation (ONF) is a non-profit consortium that is driven by operators and led by the community. Its primary objective is to promote and facilitate innovation in software-defined programmable networks while ensuring that it is accessible to all. By means of ecosystem establishment, advocacy, research, and education, the ONF is expediting the advancement of open networking and stimulating the development and acceptance of open disaggregated solutions that utilise open-source software.	By participating in the ONF standardization and communication activities, NANCY will stay on top of the state-of-the-art broadband (SEBA, VOLTHA) and programmable network (SD-FABRIC, P4, PINS, STRATUM, ONOS) projects and ensure the development of its components in line with lessons learnt.
OSM	The OSM organisation is currently in the process of creating a Management and Orchestration (MANO) stack that is open-source and conforms to the ETSI NFV Information Models. OSM, being a project led by the community, offers a MANO stack of production quality that fulfils the demands of operators for NFV deployments in the commercial sector.	NANCY will monitor the major advances of OSM-MANO in order to take advantage of all possible breakthroughs in terms of network virtualisation, orchestration, and management.
WWRF	The objective of the Wireless World Research Forum (WWRF) is to promote scholarly investigations that can lead to unrestricted	Through collaborating and monitoring the WWRF, NANCY will gain new insights on

	communication capabilities, aimed at tackling significant societal issues that lie ahead. WWRF employs the term "Wireless World" in a comprehensive manner to encompass the promotion of innovation and commerce, the integration of society, and the obstacles related to infrastructure. The objective is to develop a diverse set of technological capabilities, including but not limited to wide-area networks, short-range communications, machine-to-machine communications, sensor networks, wireless broadband access technologies, and optical networking. Additionally, the networks will be enhanced with greater intelligence and virtualization. This will facilitate the establishment of a reliable future Internet of individuals, information, and objects, as well as the advancement of a comprehensive service ecosystem.	network implementation, services, applications and value chains of the future. Also, the main focus of NANCY will reside in the 6G, Cybersecurity, Radio communication technologies, Communication architectures and technologies, and User needs & requirements, services & devices WWRF working groups.

2.2. Research and innovation actions

In this section, we present past and current national, regional, and international research and innovation actions (RIAs) that are expected to affect NANCY through outcomes exploitation and collaboration. Table 2 provides a short summary of these actions with an emphasis on the commonalities, differences, and exploitation elements within NANCY. Table 3 summarises the commonalities and differences between the identified RIAs to NANCY in terms of their technologies and usage scenarios.

Table 2: Related projects to NANCY

5G-EVE 5G European Validation platform for Extensive trials [Horizon 2020 RIA] (OTE, TEI)	
5G-EVE aspires to create the foundations for a pervasive roll-out of E2E 5G networks in Europe. 5G-EVE supports this fundamental transition by offering to vertical industries and to all 5GPPP Phase 3 projects facilities to validate their KPIs and their service. The 5G-EVE facility enables experiments with (a) heterogeneous access; (b) MEC, backhaul, core/service technologies; (c) means for site-interworking and multi-site/domain/technology slicing/orchestration.	
Similarities	**Differences**
Both 5G-EVE and NANCY will develop an orchestration platform for RANs that will utilize new wireless technologies and novel networking and computing concepts.	Compared to 5G-EVE, NANCY will leverage AI and blockchain technologies for efficient and secure RAN orchestration.
Exploitation within NANCY	
NANCY will exploit the results of 5G-EVE and extend its foundations for the pervasive roll-out of end-to-end 5G networks.	
5G-PICTURE-5G Programmable Infrastructure Converging disaggregated network and CompUte Resources [Horizon 2020 RIA] (i2CAT)	

5G-PICTURE develops and demonstrates a converged fronthaul and backhaul infrastructure integrating advanced wireless and novel optical network solutions. To address the limitations of the current D-RAN and C-RAN approaches, 5G-PICTURE exploits flexible functional splits that can be dynamically selected, to optimize resource and energy efficiency. This will result in a paradigm shift, from RAN and C-RAN to 'Dis-Aggregated RAN' (DA-RAN).	
Similarities	**Differences**
NANCY's orchestration platform will also be based on the softwarisation of the network in order to deliver a dynamic RAN.	Blockchain technologies will be leveraged by NANCY's orchestration platform to address security and privacy issues.
Exploitation within NANCY	
NANCY will tap into 5G-PICTURE's architecture to incorporate the novel concept of DA-RAN in order to perform resource disaggregation.	

5G-TRANSFORMER- Mobile Transport Platform for Verticals [Horizon 2020 RIA] (NEC)	
5G-TRANSFORMER aims to bring the network slicing paradigm into mobile transport networks by provisioning and managing slices tailored to the needs of vertical industries, including automotive, healthcare and media. The technical approach is twofold: a) enable Vertical Industries to meet their service requirements within customized slices; and b) aggregate and federate transport networking and computing fabric, from the edge up to the core and cloud, to create and manage slices throughout a federated virtualized infrastructure.	
Similarities	**Differences**
Both 5G-TRANSFORMER and NANCY leverage the Network Slicing concept for meeting the user and application requirements.	NANCY provides a 5G RAN tailored to both industrial and conventional applications. In addition, novel AI algorithms for optimally determining the network slices will be utilized.
Exploitation within NANCY	
NANCY will reuse part of the NFV orchestrator of 5G-TRANSFORMER.	

5G-AURA-Application-aware User-Centric Programmable Architectures for 5G Multi-tenant Networks [Horizon 2020 RIA] (OTE, NEC)	
The vision of future 5G networks encompasses a heterogeneous communication landscape in which existing radio access technologies (RATs) will be integrated with evolving wireless technologies and systems, software-design network architectures and cloud-enabled services. By leveraging the aforementioned concepts, 5G-AURA aims to provide a programmable multi-tenant network architectural framework for 5G networks.	
Similarities	**Differences**
NANCY will deliver a novel programmable RAN that will utilize user-centric and service-centric resource allocation schemes.	NANCY will utilize AI technologies and transfer learning methods for the optimal and fast allocation of resources.
Exploitation within NANCY	
NANCY will utilize 5G-AURA's results mainly regarding the integration of RATs in multi-tenant network architectures.	

5G-MEDIA-Programmable edge-to-cloud virtualization fabric for the 5G Media industry [Horizon 2020 RIA] (OTE, CERTH)

5G-MEDIA aims at innovating media-related applications by investigating how these applications and the underlying 5G network should be coupled and interwork to the benefit of both. In this respect, it addresses the objectives of 1) capitalising and properly extending the valuable outcomes of the running 5G PPP projects to offer agile programming, verification and orchestration platform for services; and 2) developing network functions (NFs) and applications to be demonstrated in large-scale deployments.	
Similarities	**Differences**
Similarly to 5G-MEDIA, NANCY develops an orchestration platform as well as NFs for applications with diverse requirements.	The developed orchestration platform and NFs will not be limited to media applications, but address a wide range of applications, assisted by ML.
Exploitation within NANCY	
NANCY will exploit 5G-MEDIA's results on the utilization of 5G PPP for verification and orchestration platform.	

5G-ESSENCE-Embedded Network Services for 5G Experiences [Horizon 2020 RIA] (OTE, 8BELLS, i2CAT, ITL, NEC)	
5G ESSENCE provides a highly flexible and scalable platform by creating a neutral host market and reducing operational costs. Its approach is based on a two-tier architecture: a first distributed tier for providing low latency services and a second centralized tier for providing high processing power for computing-intensive network applications. This allows decoupling the RAN's control and user planes and achieving the benefits of cloud-RAN without the enormous fronthaul latency restrictions.	
Similarities	**Differences**
Both 5G ESSENCE and NANCY will develop a novel RAN for applications with low latency requirements.	NANCY will develop a single-tier architecture that will incorporate novel computational offloading methods in order to satisfy the diverse application requirements.
Exploitation within NANCY	
NANCY integrates the know-how acquired from 5G-ESSENSE in the centralization of small cell functions for creating low latency services and high processing power for computing-intensive network applications.	

5GENESIS-5th Generation End-to-end Network, Experimentation, System Integration, and Showcasing [Horizon 2020 RIA] (TEL, OTE)	
5GENESIS validates 5G KPIs for various use cases, in both controlled setups and large-scale events. To achieve this, 5GENESIS develops an integrated E2E 5G facility, built on five diverse in terms of capabilities experimentation platforms distributed across Europe and interconnected with each other. 5GENESIS: a) implements and verifies all evolutions of the 5G standard; b) engages a wide diversity of technologies innovations; c) unifies heterogeneous physical and virtual network elements under a common coordination framework.	
Similarities	**Differences**
Both 5GENESIS and NANCY develop 5G architectures based on novel technologies such as software defined networking (SDN), NF virtualization, and network slicing.	5GENESIS consists of 5 platforms distributed across Europe, whereas NANCY will feature a single integrated 5G platform, capable of supporting a wide range of diverse applications.

Exploitation within NANCY	
NANCY exploits 5GENESIS results in the development of the E2E B5G B-RAN.	

5G-MoNArch-5G Mobile Network Architecture for diverse services, use cases, and applications in 5G and beyond [Horizon 2020 RIA] (CERTH)	
5G-MoNArch developed a flexible, adaptable, and programmable mobile network architecture for 5G. Inter-slice control and cross-domain management, experiment-driven modelling and optimization, native cloud-enabled protocol stack were the basic enablers for the sliced network. The concepts were brought into practice through prototype implementations in two testbeds instantiating slices that include the vertical use case-driven functional innovations of network reliability, resilience/security, and resource elasticity.	
Similarities	**Differences**
5G-MoNArch provides a 5G mobile network architecture using cloud technologies. NANCY aims to develop a B5G architecture, building upon the results of 5G-MoNArch.	Contrary to 5G-MoNArch, NANCY leverages Blockchain technologies for ensuring user security and privacy, as well as computational offloading techniques for enhancing the user experience.
Exploitation within NANCY	
NANCY builds upon the 5G-MoNArch principles concerning flexibility, adaptability, and low-complexity programmability in order to deliver a mobile network architecture for the B5G era.	

5GTANGO-Development and validation platform for global industry-specific network services and Apps [Horizon 2020 RIA] (UBITECH, NEC)	
5GTANGO puts forth the flexible programmability of 5G networks with i) a NFV-enabled service development kit (SDK), ii) a store with advanced validation and verification mechanisms for VNFs/network services qualification; and iii) a modular service platform in order to bridge the gap between business needs and network operational management systems. It proposes an integrated vendor-independent platform where the outcome of the development kit, that is a packaged NFV forwarding graph, is automatically tested and validated in the Store for their posterior deployment with a customizable orchestrator compatible with common existing virtual infrastructure managers (VIM) and SDN controllers in the market. This E2E ecosystem for the agile development and deployment of services realises an extended NFV DevOps model between service developers, telecom operators, and vertical industries, increasing operational efficiency, facilitating the implementation and validation of new services, and accelerating the adoption of NFV technologies.	
Similarities	**Differences**
Both 5GTANGO and NANCY propose the development of customizable orchestrators.	NANCY will use AI and blockchain technologies to leverage efficient and secure RAN orchestration.
Exploitation within NANCY	
NANCY will take into account 5GTANGO's orchestrators principle in order to devise its own AI-based B-RAN orchestrator. The efficiency of the proposed orchestrator will be evaluated against the one developed in 5GTANGO, in terms of complexity and slicing initialization latency.	

5G-PHOS-5G integrated Fiber-Wireless networks exploiting existing photonic technologies for high-density SDN-programmable network architectures [Horizon 2020 RIA] (OTE, TEI)
5G-PHOS architects and evaluates 5G broadband wireless networks for dense, ultra-dense and hot-spot area use cases drawing from recent results in the area of optical technologies towards producing and exploiting a powerful photonic integrated circuit technology toolkit. It aims to streamline

advances in multi-format and multi-bitrate optical communications, in Indium phosphide (InP) transceivers, in Triplex optical beamformers and in integrated optical add/drop multiplexers in order to migrate from CPRI-based towards integrated Fiber-Wireless (FiWi) packetized C-RAN fronthaul supporting massive mmWave MIMO communications. It will deliver: a) a set of SDN-programmable units, called FlexBox and FlexBox-Pro, that will be compatible with the emerging 25Gb/s passive optical network (PON) access networks and can deliver FiWi traffic ranging between 25-400Gb/s, b) a set of three different 64x64 MIMO Remote Radio Head configurations exploiting analog optical beamforming and producing 25Gb/s, 100Gb/s and 400Gb/s wireless data-rates, c) an integrated FiWi packetised fronthaul for supporting Medium-Transparent Dynamic Bandwidth Allocation mechanisms and cooperative radio-optical beamforming, d) a converged FiWi SDN control plane for optimally orchestrating both the optical and the wireless resources.	
Similarities	**Differences**
5G-PHOS, similar to NANCY, develops energy-efficient 5G network solutions that utilize NFV and high-density SDN-programmable FIWI 5G network technologies achieving the highest degree of RAN centralization.	The developed NANCY RAN orchestration platform will be enhanced by the utilization of AI and Blockchain technologies that leverage security issues.
Exploitation within NANCY	
NANCY will use 5G-PHOS's results in the implementation of NFV and SDN-programmable 5G networks for the development of B5G RAN platform.	

5G-TOURS-SmarT mObility, media and e-health for toURists and citizenS [Horizon 2020 RIA] (TEI, OTE)	
5G-TOURS will deploy full end-to-end trials to bring 5G to real users for thirteen representative use cases. The project will provide efficient and reliable close-to-commercial services for tourists, citizens, and patients in three different types of cities: (i) Rennes, the safe city where e-health use cases will be demonstrated; (ii) Turin, the touristic city focused on media and broadcast use cases; and (iii) Athens, the mobility-efficient city that brings 5G to users in motion as well as to transport-related service providers. These services will not only improve the quality of life for citizens and tourists but also represent an important business opportunity as they address industry segments accounting for more than 50% of the estimated revenues generated by verticals. The fundamental feature of the 5G-TOURS concept is the dynamic use of the network to seamlessly provide different types of services adapted to the specific needs of individual use cases. 5G-TOURS will enable different capabilities such as network slicing, virtualisation, orchestration, or broadcasting as well as additional features developed by the project to bring more flexibility and improved performance. The ambition is to fully demonstrate pre-commercial 5G technologies at a large scale, showing the ability of the 5G network to meet extreme and conflicting KPIs while supporting very diverse requirements on the same infrastructure. The 5G-TOURS mobile network system will integrate strategic components of the ecosystem, including the network infrastructure, terminals and end devices, the vertical solutions enabled by 5G, and the vertical customers receiving the services. 5G-TOURS has devised a thorough evaluation plan to scrutinise the viability of the use cases, addressing technical performance by analysing both network service KPIs and application-level KPIs, economic impact by analysing the estimated generated revenues, and, ultimately, the satisfaction of the vertical customers.	
Similarities	**Differences**
5G-TOURS ambition, similarly to NANCY, is to fully demonstrate pre-commercial 5G technologies at a large scale, employing novel technologies such as NFV orchestration and network slicing,	The developed orchestration platform and network functions will not be limited to media and e-health applications, but they will address a

showing the ability of the 5G network to meet extreme and conflicting KPIs while supporting very diverse requirements on the same infrastructure.	wide range of applications, assisted by the transfer learning.
Exploitation within NANCY	
NANCY will examine the KPIs defined in 5G-TOURS and adopt the ones related to the orchestration performance for the NANCY architecture evaluation.	

MATILDA-A HOLISTIC, INNOVATIVE FRAMEWORK FOR THE DESIGN, DEVELOPMENT AND ORCHESTRATION OF 5G-READY APPLICATIONS AND NETWORK SERVICES OVER SLICED PROGRAMMABLE INFRASTRUCTURE [Horizon 2020 RIA] (INTRA, OTE, UBI, ITL)	
The vision of MATILDA is to design and implement a holistic 5G end-to-end services operational framework tackling the lifecycle of design, development and orchestration of 5G-ready applications and 5G network services over programmable infrastructure, following a unified programmability model and a set of control abstractions. It aims to devise and realize a radical shift in the development of software for 5G-ready applications as well as virtual and physical network functions and network services, through the adoption of a unified programmability model, the definition of proper abstractions, and the creation of an open development environment that may be used by an application as well as network functions developers. Intelligent and unified orchestration mechanisms will be applied for the automated placement of the 5G-ready applications and the creation and maintenance of the required network slices. Deployment and runtime policies enforcement is provided through a set of optimisation mechanisms providing deployment plans based on high-level objectives and a set of mechanisms supporting the runtime adaptation of the application components and/or network functions based on policies defined on behalf of a services provider. Multi-site management of the cloud/edge computing and IoT resources is supported by a multi-site virtualized infrastructure manager, while the lifecycle management of the supported Virtual Network Functions Forwarding Graphs (VNF-FGs) as well as a set of network management activities are provided by a multi-site NFV Orchestrator (NFVO). Network and application-oriented analytics and profiling mechanisms are supported based on real-time as well as a posteriori processing of the collected data from a set of monitoring streams. The developed 5G-ready application components, applications, virtual network functions, and application-aware network services are made available for open-source or commercial purposes, re-use, and extension through a 5G marketplace.	
Similarities	**Differences**
MATILDA focuses on optimisation of orchestration functions and enforcement of runtime policies.	MATILDA does not utilise social caching and AI-powered orchestration.
Exploitation within NANCY	
MATILDA results will be exploited in NANCY WP3 & WP4, particularly when it comes to the real-time profiling mechanisms and monitoring streams.	

5G-HEART-5G HEalth AquacultuRe and Transport validation trials [Horizon 2020 RIA] (OTE)
5G-HEART focuses on vital vertical use-cases of healthcare, transport and aquaculture. In the health area, 5G-HEART will validate pillcams for automatic detection in screening of colon cancer and vital-sign patches with advanced geo-localization as well as 5G AR/VR paramedic services. In the transport area, 5G-HEART will validate autonomous/assisted/remote driving and vehicle data services. Regarding food, the focus will be on the 5G-based transformation of the aquaculture sector (worldwide importance for Norway, Greece, and Ireland). The infrastructure shared by the verticals,

will host important innovations: slicing as a service; resource orchestration in access/core and cloud/edge segments with live user environments. Novel applications and devices (e.g., underwater drones, car components, healthcare devices) will be devised. Trials will run on sites of 5G-Vinni (Oslo), 5Genesis (Surrey), 5G-EVE (Athens), as well as Oulu and Groningen, which will be integrated to form a powerful and sustainable platform where slice concurrency will be validated at scale.	
Similarities	**Differences**
Both NANCY and 5G-HEART provide a 5G E2E cloud/edge platform utilizing new network virtualisation and slicing-as-a-service technologies to support multiple 5G use cases.	NANCY will provide blockchain technologies that will leverage its orchestration platform in order to address security and privacy issues.
Exploitation within NANCY	
NANCY uses 5G-HEART network for dissemination purposes for healthcare and transport pilots.	

5GZORRO (ICT-20-2019-2020 - 5G Long Term Evolution, GA No. 871533) Zero-tOuch secuRity and tRust for ubiquitous cOmputing and connectivity in 5G networks. [i2CAT]	
5GZORRO envisions the evolution of 5G to achieve truly production-level support of diverse Vertical applications, which coexist on a highly pervasive shared network infrastructure, through automated end-to-end network slicing, across multiple operators and infrastructure/resource providers, who can share heterogeneous types of resources (spectrum, virtualized radio access, virtualized edge/core). 5GZORRO uses distributed Artificial Intelligence (AI) to implement cognitive network orchestration and management with minimal manual intervention. Distributed Ledger Technologies (DLT) are adopted to implement flexible and efficient distributed security and trust across the various parties involved in a 5G end-to-end service chain. By leveraging DLT, 5GZORRO will implement an evolved 5G Service Layer for Smart Contracts among multiple non-trusted parties, to allow Service Level Agreement monitoring, spectrum sharing, and intelligent and automated data-driven resource discovery and management.	
Similarities	**Differences**
5GZORRO utilizes Blockchain-based technologies to create smart contracts among non-trusted parties. In addition, AI techniques are used for network orchestration and management.	NANCY will utilize Blockchain technology to create a complete RAN. In addition to AI, NANCY will leverage FL approaches for optimal network orchestration and management.
Exploitation within NANCY	
NANCY evaluates 5GZORRO results on Blockchain-based technologies and AI techniques for the creation of RAN and network orchestration and management.	

Pledger (ICT-15-2019-2020 - Cloud Computing, GA No. 875316): Performance optimization and edge computing orchestration for enhanced experience and Quality of Service [INTRA, i2CAT]	
The **Pledger** project (ICT-15-2019-2020 - Cloud Computing, GA No. 875316) delivered a new architectural paradigm and a toolset that pave the way for next-generation edge computing infrastructures, tackling the modern challenges faced today and coupling the benefits of low latencies on the edge, with the robustness and resilience of cloud infrastructures.	
Similarities	**Differences**
Pledger utilises blockchain technology for smart contracts at the mobile edge.	Pledger does not take into account AI-based orchestration or social caching.
Exploitation within NANCY	

Pledger's data management on the edge can be leveraged within NANCY WP4.

TALON: Autonomous and Self-organized Artificial Intelligent Orchestrator for a Greener Industry 5.0 [Horizon 2020 RIA] (TEI, MINDS, INTRA, CERTH, 8BELLS, UBITECH, SID, INNO)	
TALON aims to deliver an autonomous programmable, adaptable, flexible, explainable and energy-efficient edge AI networking solution. Specifically, the project will develop a novel AI orchestrator that jointly optimises all edge and cloud resources found in the network entities, while also supporting end-to-end personalied and perpetual security and privacy. In this direction, TALON will leverage novel technologies such as blockchain, edge networking, and digital twins.	
Similarities	**Differences**
Both TALON and NANCY will utilize novel technologies such as cloud and edge computing, as well as blockchain and AI technologies to deliver a platform for leveraging and managing computation resources that are found in the network entities	Although similar technologies are utilized in both projects, NANCY is focused on developing a RAN architecture for B5G networks.
Exploitation within NANCY	
NANCY will closely monitor the development of TALON concerning the leverage of AI and blockchain technologies for efficiently and securely orchestrating the available computing resources.	

Table 3: NANCY related projects technologies

Project Title	Blockchain	RAN	Service orchestration	Virtualization	AI	XAI	Computational offloading	SDN/NFV	MEC-FOG	User-centric caching	AR/VR	Postquantum cryptography
5G-EVE		✓	✓					✓	✓			
5G-PICTURE		✓										
5G-TRANSFORMER		✓	✓					✓	✓			
5G-AURA		✓	✓									
5G-MEDIA			✓						✓			
5G-ESSENCE		✓	✓					✓	✓			
5GENESIS		✓	✓					✓	✓			
5G-MoNArch		✓	✓		✓			✓				
5G-TANGO		✓	✓					✓				
5G-PHOS		✓						✓				
5G-TOURS			✓					✓				
5G-ZORRO	✓	✓			✓			✓	✓			
MATILDA			✓					✓	✓			
5G-HEART			✓						✓			
Pledger	✓		✓						✓			
TALON	✓		✓		✓	✓		✓			✓	
NANCY	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

3. Overview of the envisioned B5G market

3.1. B5G market landscape and its relation to NANCY's research and technical innovations

3.1.1. B5G market landscape

Worldwide commercial deployment of mobile networks of the fifth generation (5G) is currently taking place. The momentum is still increasing as new 5G devices and services are made available by extending coverage and capacity. Beyond 5G (B5G), a second wave of technological advancements that can fulfil the entire promise of 5G, is developing concurrently with the evolution of 5G technologies. The first iteration of 3GPP Release 18, which includes cutting-edge technologies that will power future wireless upgrades and further development, will outline the technical roadmap for B5G. Meanwhile, the early vision for 6G is starting to take shape across the mobile ecosystem and more general businesses as people get ready for what will come after B5G. For a future mobile platform B5G that will be commercially available around 2030, NANCY identifies three key market drivers:

- <u>Market driver 1 - Economic growth and societal sustainability</u>: The next-generation mobile technology has a part to play in meeting goals for economic growth and societal sustainability as the influence of mobile technology is seen across more industries and areas. In order to promote peace and prosperity on a global scale, the United Nations has devised a model of 17 sustainable development goals (SDGs). 5G is already making a big contribution to the growth of the world's economy, and B5G and 6G can provide even more of a boost by bringing connected intelligence to more sectors and use cases. In more detail, social economics and inequality are affected by a lack of access to the network. One objective of B5G should be to make connectivity more accessible, regardless of financial level or region, as connecting more people tends to reduce inequality and increase the quality of life. Moreover, for sustainability, as we move towards the B5G era, the significance of green networks and devices is considerably growing. Additionally, it's important to lessen the environmental impact of billions of devices by creating them with lower carbon emissions and engineering them to use less energy.
- <u>Market driver 2 – Capitalization of technology innovations and advancements</u>: through standardization activities and especially by means of the global standardisation process, the wireless world can align on research and innovation interest areas in the core wireless and related domains, bringing them under the purview of the B5G concept. This will make it easier to conduct the targeted, team-based research and development (R&D) required to produce the next-generation platform appropriate for the demands of the coming decade. The key technology building blocks that are expected to be capitalised for the new B5G or even 6G platform include: (i) radio and baseband advancement with emphasis on the use of higher frequency bands, (ii) cross-layer and domain optimization of disaggregated networks in order to support a more diverse mix of horizontals and verticals, (iii) intelligence at the edge through virtualization, containerization and hybrid cloud architectures, (iv) network automation through distributed intelligence, and (v) introduction of passive devices and materials in order to minimize the overall network power consumption.
- <u>Market driver 3 – Enabling enhanced experience and opening the door to new use cases</u>: Smartphones entered the mainstream thanks to 4G. Wireless is entering new services and industries thanks to 5G. And with new kinds of devices, services, and deployments, B5G is expected to deliver novel user experiences at the connected intelligent edge. Fixed and mobile broadband will experience an evolution with B5G that offers greater capacity, greater throughput, and reduced latency. It will provide mission-critical services through higher dependability and availability while delivering more widespread access through ubiquitous coverage and increased connection densities. B5G will also support improved services and new use cases. Hologram telepresence, collaborative robotics, human enhancement, deeper

immersion in the digital and virtual worlds, and enhanced sensing are some of the envisaged application cases.

3.1.2. NANCY's targeted position in the B5G market

Motivated by this, NANCY will provide innovative system concepts, techniques, and technologies to address the needs and expectations of the future network B5G and it is fully in line with the new Horizon Europe Programme and EU expectations. The core contribution of NANCY is to create imaginative and concrete opportunities in order to generate competitive advantages for the European ICT market. The tight convergence of the telecommunications and IT market will be used by NANCY as the main tool for improving innovation capacity in the European mobile industry and accommodating the explosion of data traffic and the ever-increasing injection of novel applications and cutting-edge services by the service providers and OTT players. This is the key differentiator moving towards 5G technologies where the European ICT market will see the emergence of new vertical business segments and services for consumers and enterprise customers. An indicator of NANCY's ability to deliver a substantial improvement in innovation capacity is the perfect mix of multi-dimensional industrial partners coming from the telecommunications and IT sectors. In Table 4, we outline clearly how the innovation capacity and integration of new knowledge for the different stakeholders is achieved by the proposition in NANCY.

Table 4: NANCY target group related impact

Target group	Impact
Operators	The technological capabilities of NANCY provide network operators with advantageous features such as scalability, security, and efficiency. The implementation of the secure wireless access paradigm, which enables efficient resource utilisation and transforms disparate networks into a unified one, as outlined in NANCY, will have a substantial impact on network operators seeking to expand their service and coverage capabilities. The incorporation of the NANCY architecture into telecom operations will enable operators to establish efficient policies aimed at enhancing resource utilisation. Additionally, this integration will afford them greater flexibility with respect to network resilience and reliability. The practical implementation and validation of network sharing concepts can potentially lead to a reduction in both CAPEX and OPEX for operators, particularly during the initial stages of 5G deployment. The scope of the NANCY project includes additional services that are expected to provide network operators with advantageous outcomes in the realm of critical communications.
Infrastructure providers	The advent of 5G presents a distinctive opportunity for infrastructure providers. Undoubtedly, MNOs have to construct the forthcoming 5G networks. However, possessing the necessary licenses for this purpose does not suffice. The utilisation of elevated frequencies in 5G infrastructures necessitates a more concentrated network to compensate for the reduced coverage area and diminished propagation. To clarify, MNOs require a significantly greater number of sites, which directly affects their level of competitiveness within the market. While a few MNOs may consider mergers and acquisitions as a means to achieve economies of scale, the majority of them are inclined towards collaborating with infrastructure companies. The proposed secure shared network, in conjunction with enhanced scalability, will render the role of infrastructure providers increasingly pivotal. This is where the NANCY project adds value.

Telecom providers	The primary expenditure associated with the installation of fibre optic cabling pertains to the procedural aspects, as opposed to the physical constituents of the fibre optic cable. It can be inferred that Fixed Telecom Providers have a tendency to overprovision their fibre optic cabling infrastructure. The current scenario is characterised by a significant amount of untapped bandwidth, represented by unused dark fibre. The utilisation of dark fibre will be advantageous for 5G technology as it necessitates increased backhaul capacity in numerous locations to facilitate network densification, owing to the implementation of higher-speed yet shorter-range radios. The deployment and usage patterns of 5G technology have created a level of uncertainty that necessitates greater flexibility in backhaul. Without network sharing approaches, the cost of backhaul may become prohibitively expensive. The NANCY project aims to investigate such approaches.
Manufacturers	By implementing the NANCY approach, manufacturers can assume a crucial role in driving innovation, expanding their product portfolio, and creating new products related to RAN, orchestration, and intelligent devices for network edge applications. The integration of blockchain capabilities and intelligent algorithms into NANCY solutions enables vendors to establish themselves as significant contributors in the domains of security, edge computing, and intelligent devices. These domains are crucial for the implementation of Next Generation mobile networks. The implementation of NANCY architecture is anticipated to facilitate the attainment of optimal performance and scalability, which are deemed necessary by 5G stakeholders while minimising power consumption.
ICT Providers & Integrators	NANCY is expected to provide significant advantages to system integrators and technology/platform providers, enabling them to engage in partnerships with prominent industrial players and manufacturers. This collaborative effort will enhance their strategic positioning and enable them to attain an early-mover advantage in the industry, while also taking into account the swift evolution of the 5G market. The ICT industry can establish itself as a leading proponent in delivering integrated solutions and be at the forefront of the Next Generation of mobile networks by participating in the design and prototyping of ML, AI, blockchain/security, and other related technologies. This will provide the industry with a clear roadmap and opportunities for exploitation. The objective of approaching the network edge, implementing virtualisation, and enabling cloud-based architectures will lead to a significant overhaul of the network sector, generating a substantial need for IT, cloud, and edge computing proficiency.
Vertical Industries	Vertical industries in Europe are striving to improve their technical capabilities to distinguish themselves on a global scale and bolster their brand recognition. The accessibility of the NANCY accomplishments will enable various vertical sectors to establish and authenticate diverse utilisation scenarios. The implementation of 5G technology can provide vertical industries with improved features and capabilities, enabling them to integrate novel processes or enhance their current ones. This can lead to increased efficiency and profitability. The NANCY architecture is designed to be open and universal, with the capability to accommodate use cases from various vertical industries.

SMEs	The utilisation of SDN and NFV technologies to separate software and hardware, coupled with the implementation of effective, publicly accessible software stacks for networks, has resulted in the emergence of open network ecosystems that are not restricted to major manufacturers and their clientele in the telecommunications industry. NANCY has proposed the utilisation of blockchain, AI, ML-based slice instantiation, and edge computing technologies to enable the seamless reconfiguration and scalability of advanced functionalities. The advent of 5G technology is expected to have a significant impact on SMEs that specialise in network service development. This is because they will have the opportunity to introduce novel applications that take advantage of the enhanced capabilities offered by 5G. Within the NANCY ecosystem, small and medium-sized enterprises have the opportunity to assume the responsibilities of both network application developers and maintainers. Reducing the obstacle for novel market participants is an acknowledged advantage of software network technologies, and holds significant significance for the telecommunications industry, which has historically been controlled by a limited number of prominent entities.
Academia and the Research Community	The NANCY project aims to focus on publishing in esteemed conferences and open-access journals of superior quality. Additionally, the project will utilise enhanced cooperation between academia and industry to explore the potential of 5G multi-carrier network sharing, along with network slicing and mobile-edge computing services and deployments. In addition, NANCY places significant importance on its contribution towards the development of novel industry standards and the initiatives of open-source communities. The project has demonstrated a resolute commitment to making available as open-source tools, the specific solutions that have been developed. This approach is expected to yield substantial benefits to the scientific and research community in Europe. The assimilated knowledge will facilitate the formulation and appropriate structuring of novel courses pertaining to 5G networking, alongside the incorporation and assimilation of technological advancements, perspectives, and outcomes from NANCY into the curriculum and advanced-level projects and research at the master's and PhD levels. This approach will serve to familiarise forthcoming cohorts of Engineers and Computer Scientists in the European community with avant-garde research and development.

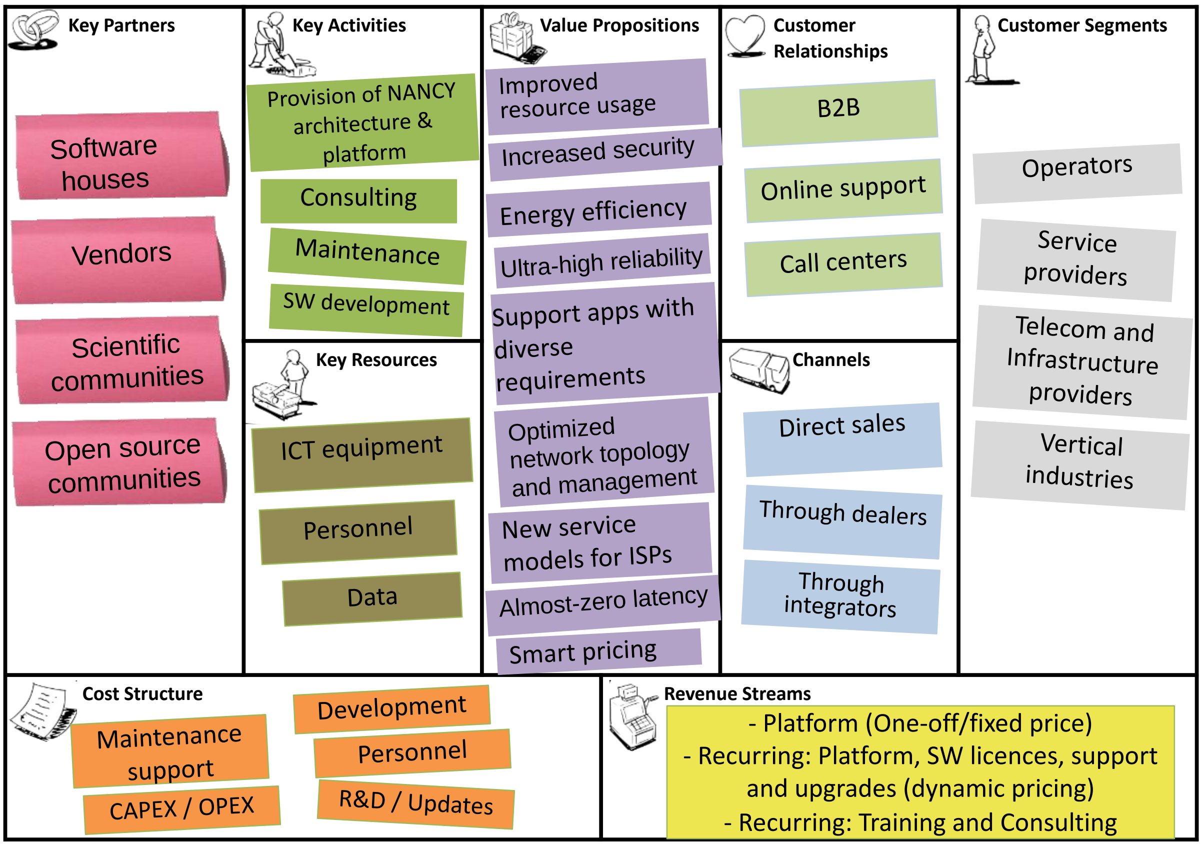

Figure 3: Business Model Canvas of the NANCY platform

The NANCY partners have distinct exploitation interests according to their core activities. Motivated by this and as illustrated in Figure 3, NANCY partners have already formulated an initial business plan. A large set of innovative tools and results are expected to be produced in the NANCY project. The aforementioned results will create a rich landscape of joint and individual exploitation opportunities. **Exploitation leads** who will coordinate the business development aspects of the key exploitation results (KERs) with the support of other partners are:

- KER 1 - NANCY architecture and approach: UOWM, MINDS, UBITECH, TECNALIA, i2CAT, ITL, INTRA, 8BELLS, TDIS, DRAXIS, OTE, VOS, IJS, CRAT, Bi2S, INNO, CERTH, SID, UMU, SSS
- KER 2 – Novel trustworthy grant/cell-free cooperative access mechanisms: 8BELLS, VOS, IJS, INNO, SID, UMU
- KER 3 - A novel security and privacy toolbox: UoWM, MINDS, UBITECH, TECNALIA, NEC, ITL, TDIS, DRAXIS, CRAT, TEI, INNO, SID, UMU, SSS
- KER 4 – Realistic blockchain and attacks models: UOWM, MINDS, UBITECH, NEC, INTRA, 8BELLS, TDIS, OTE, IJS, CRAT, TEI, Bi2S, INNO, CERTH, SID, UMU, SSS
- KER 5 – A novel quantum key distribution mechanism: UOWM, MINDS, UBITECH, NEC, ITL, TDIS, INNO
- KER 6 – AI-based B-RAN orchestration with slicer instantiator: i2CAT, ITL, INTRA, 8BELLS, IJS, CRAT, Bi2S, INNO, CERTH, SID, UMU, SSS
- KER 7 – A novel AI virtualiser for underutilized computational & communication resource exploitation: i2CAT, INTRA, 8BELLS, VOS, IJS, TEI, INNO, CERTH, SID, UMU, SSS
- KER 8 – Novel self-evolving AI model repository: i2CAT, ITL, INTRA, 8BELLS, IJS, CRAT, Bi2S, INNO, CERTH, SID, UMU, SSS
- KER 9 – Semantic & goal-oriented communication schemes for beyond Shannon performance: UOWM, MINDS, 8BELLS, INNO, SID, UMU
- KER 10 – An explainable AI framework: MINDS, UBITECH, TECNALIA, NEC, INNO, SID, UMU

- KER 11 – Next-generation SDN-enabled MEC for autonomous anomaly detection, self-healing and self-recovery: MINDS, TECNALIA, NEC, i2CAT, DRAXIS, CRAT, INNO, SID, UMU, SSS
- KER 12 – A computational offloading mechanism with novel resource-aware/provision scaling mechanisms and novel battery as well as computational-capabilities aware offloading policies: i2CAT, 8BELLS, OTE, VOS, IJS, CRAT, Bi2S, INNO, SID, UMU, SSS.
- KER 13 – User-centric caching mechanisms: 8BELLS, VOS, IJS, Bi2S, INNO, SID, UMU, SSS

With these KERs, in terms of exploitation, the NANCY universities and research organizations/companies will:

- **Increase research portfolios**. / Enlarge their **solutions portfolios**.
- Improve **research results**. / Improve **existing offerings**.
- Enhance **knowledge basis** and create new **teaching opportunities**. / Build **capacity and skills** of workers.
- Enhance participation in **research projects**. / Initiate **new business collaborations**.
- Enter new **scientific communities**. / Enter new **markets**.

The preliminary KER-specific exploitation plans are presented below in **the NANCY BMC**. It will be regularly assessed, refined, and improved to ensure high impact. D1.8 will include a result ownership list as well as business and sustainability plans by which all partners will ensure the longevity of the NANCY results.

3.2. Key research and technical advancement of NANCY

Table 5: NANCY technical advancements and innovations

ID	NANCY Technical Advances and Innovations	NANCY Pillars		
		I	II	III
R1	B-RAN architecture	✓	✓	✓
R2	Novel trustworthy grant/cell-free cooperative access mechanisms	✓	✓	✓
R3	A novel security and privacy toolbox that contains lightweight consensus mechanisms, and decentralized blockchain components	✓		✓
R4	Realistic blockchain and attacks models and an experimental validated B-RAN theoretical framework	✓		
R5	A novel quantum key distribution mechanism to boost end-user privacy	✓		
R6	Smart-pricing policies	✓	✓	
R7	AI-based B-RAN orchestration with slicer instantiator	✓	✓	✓
R8	A novel AI Virtualiser for underutilized computational and communication resource exploitation	✓	✓	✓
R9	Novel self-evolving AI model repository	✓	✓	✓
R10	Experimentally-driven reinforcement learning optimization of B-RAN		✓	✓
R11	Semantic & goal-oriented communications	✓	✓	✓
R12	An explainable AI framework			
R13	Next-generation SDN-enabled MEC for autonomous anomaly detection, self-healing and self-recovery		✓	✓
R14	A computational offloading mechanism with novel resource-aware/provision scaling mechanisms and novel battery as well as computational-capabilities aware offloading policies	✓	✓	✓
R15	User-centric caching mechanisms		✓	✓

The advances and innovations presented in Table 5 are further elaborated in Table 6.

Table 6: NANCY technical advancements and innovations state-of-the-art

R1: B-RAN architecture
Motivation and current limitations: Novel architectural transformations for the RAN are proposed through global initiatives like open-RAN (O-RAN) [1], which aims to introduce virtualized network elements, openness, and intelligence to RAN management to leverage the potential of AI and network virtualization in next-generation communications. O-RAN has been hailed as a key enabler for RAN sharing since it enables multi-vendor deployments by dynamically managing and coordinating both radio and cloud resources [2], all while incorporating AI capabilities. O-innovative RAN's design opens up new possibilities for other operators in terms of delivering, distributing, and executing VNFs. To fulfil user equipment (UE) requests, stakeholders may swiftly contract and install VNFs via catalogues (i.e., marketplaces). Operators with resources on their site can freely expose their service conditions and rates, allowing any other participant to choose the best deal. With this strategy, competition is unrestricted, but prices are static, as they are not tailored to the needs of specific RAN users. Furthermore, given the openness of O-RAN sharing contexts, unique techniques are necessary to enable safe and reliable dynamic and real-time competitive resource trading.
Challenges and progress beyond SOTA: To help promote and build confidence in these new open markets, NANCY will incorporate blockchain and smart contract technologies into O-RAN medium access control (MAC) layer, which provides immutable and permanent records that can be audited by interested parties. The smart contract is used to explain the radio access network (RAN) user's needs and to enforce the service level agreement (SLA). In addition to the automation and network management efficiency offered by next-generation self-organizing networks (NG-SON) and O-RAN, blockchain eliminates the need for expensive intermediaries (e.g., banks, credit rating agencies) and provides unprecedented levels of transparency and trustworthiness, with the potential for significant cost savings. Furthermore, blockchain minimises the time it takes to reach agreements, allowing for true fluidity in RAN sharing. Operators dynamically sublease their resources to leverage existing infrastructure and allow other operators to enhance coverage and capacity using blockchain-enabled RAN sharing for 5G and beyond, where O-RAN is the basic architecture. Each operator is free to choose the best balance of capital investment and resource use at any time, not just when signing a RAN sharing contract or deploying a network. The democratisation and decentralisation of the telecom sector are enabled through dynamic resource trading, which allows for the creation of new competitive marketplaces with new players.

R2: Novel trustworthy grant/cell-free cooperative access mechanisms
Motivation and current limitations: Most existing random access (RA) protocols are designed for the scenario, where all devices either belong to or are authenticated by a common operator such that all devices can trust each other [3], [4]. In order to achieve higher overall efficiency, each node is supposed to strictly follow the protocol at the expense of some individual performance. For example, random backoff in the ALOHA protocol can reduce a network's collision probability but would increase the initial access latency for individual nodes. However, B5G networks are expected to include a massive number of devices with low-latency requirements that belong to multiple parties. This implies that B5G networks and devices are inherently trustless. Therefore, the existing structure based on a dominant operator and trusty devices is too restrictive. Moreover, most network resources are still used in an isolated manner by their owners (i.e., network operators). Higher resource utilisation efficiency can be achieved by integrating the subnetworks separated by operators into a larger inter-operative multi-operator network. Additionally, a network structure that arises from the integration of multi-operator trustless networks poses many new challenges. In particular, from the network's point of view, for resource sharing across operators, it is difficult to quantify the contributions of each node (or network operator) and provide appropriate economic payout and incentives. For this very reason, several well-known resource-sharing concepts, such as cognitive radio (CR) and mobile ad hoc network (MANET), have failed to achieve widespread commercial success since their inception [5]. Furthermore, authentication, authorization, and accounting (AAA) control becomes highly complex and nearly intractable, due to the lack of trust.

Once an AP reboots due to a system crash or power failure, the device registration will take a long time for a large number of devices. From the individual device's perspective, a dishonest or rogue device may not strictly follow a given networking protocol but instead could try to acquire more than its fair share of resources for self-interest. Rogue devices could even ignore control packets from the AP for selfish reasons.
Challenges and progress beyond SOTA: Currently, most research efforts on blockchain-enabled networks and wireless applications remain at the conceptual level. Despite the fact that several such ideas have been discussed, there has been a general lack of in-depth understanding of technical details. In fact, adopting blockchain to support RANs requires comprehensive considerations to identify important challenges. First, blockchain has the shortcoming of long latency due to confirmation delays. Its applicability to delay-sensitive use cases, such as lower-layer communication protocols, can be questionable, since, in general, blockchain-enabled networks exhibit longer delay over centralized networks. Second, the maintenance of a public blockchain requires powerful computation and substantial energy consumption, while mobile devices generally have limited power and computation capability. Furthermore, additional limitations of blockchain such as scalability and privacy will remain in blockchain-enabled networks. To countermeasure the aforementioned limitations, NANCY will present novel access protocols, which are enabled by the underlying B-RAN architecture. In more detail, a possible solution to combat the selfish behaviours of rogue devices is to compel mobile devices to follow the RA protocol and meanwhile provide traffic control with mechanisms. To avoid long delays for confirmations in blockchain, a novel physical (PHY) layer safeguard mechanism will be designed, which will leverage the inherent nature of wireless links. To build more efficient networks, NANCY exploits the B-RAN architecture to integrate cross-network resources including infrastructures and spectra. Additionally, to provide appropriate economic incentives in shared networks, the blockchain will play the role of a multi-sided platform (MSP) to match and create value for multiple parties. NANCY will also support advanced interactive and cooperative relationships between different types of nodes in the B5G network by exploiting smart contacts, which can lead to an agreement among multiple trustless clients. For example, if a UE is within the range of several APs, these APs can cooperatively provide common data service in the same spectrum band such that the UE service is enhanced by leveraging spatial channel diversity. Moreover, if a UE is not within the range of any AP, then it can use an intermediate UE in order to access the network.
R3: A novel security and privacy toolbox that contains lightweight consensus mechanisms, and decentralized blockchain components
Motivation and current limitations: Alternative history attack is one major security loophole in most distributed systems. The attacker privately mines an alternative blockchain fork in which a fraudulent double-spending transaction is included. After waiting for several confirmations for the network to accept the current main chain, the attacker releases the fraudulent fork. If the fraudulent fork is longer than the benign one, the attacker can successfully alter a confirmed history, which can be catastrophic for the whole blockchain. In B-RAN, altering a confirmed chain may result in two UEs using the same spectral asset at the same time, causing serious interferences. This security issue is due to the inconsistency of an asynchronous distributed network. The blockchain is designed to produce a history of transactions that is computationally impractical to modify. The consensus mechanisms, such as proof of work (PoW), guarantee an eventual convergence instead of an immediate convergence. The cost is to wait for several confirmations until the B-RAN "almost" converges. Clearly, more confirmations can reduce the risk of fraud, but, at the same time, they significantly increase latency. Usually, in cryptocurrency systems, six confirmations (almost 60 minutes in Bitcoin) may be desirable. This delay, however, may be too long for radio access services. As a protocol of wireless access, it is possible to use a smaller number of confirmations for security in B-RAN than that in cryptocurrencies. Fewer confirmations for a new block result in a shorter delay, although it might increase the risk of alternative history attack. Also, the radio access services in this

work are not just packet-level connection requests but connections from minutes to hours. Thus, the delay in tens of seconds to register a new service is acceptable.
Challenges and progress beyond SOTA: Consensus mechanism: B-RAN, as a decentralized system, requires proper consensus mechanisms for consistency. PoW has been widely used in practice and proven to be secure in cryptocurrencies such as Bitcoin. In PoW, network maintainers, also known as miners, need to obtain a hash value below a given target by repeatedly guessing a random variable named nonce. However, PoW-based consensus mechanisms consume a tremendous amount of energy, which is likely unbearable for energy-limited mobile devices. Consequently, PoD is proposed as a promising alternative by utilizing the fact that wireless access usually depends on a hardware device associated with a unique identifier (ID). PoD deploys unique tamper-proof IDs, such as the international mobile equipment identity (IMEI) and Identifier for Advertisers (IFA), in order to distinguish different network entities. Also, due to variations during manufacture, every device has multiple hardware-dependent features, which could constitute a unique RF fingerprinting for each device and can be identified from the transmitted RF signal. In the real world, forging an identity of a device is often costly, whereas creating multiple identities is almost costless in cryptocurrencies. Therefore, PoD can safeguard the security of B-RAN without expending immense computing power and is thus suitable for wireless networks. Motivated by this, NANCY will develop new PoD-based low-latency and computational complexity mechanisms and assess their alternative history attack risk. Moreover, it will investigate the use of MEC approaches, in order to enable PoW-based as well as Byzantine and reconfigurable byzantine fault-tolerant consensus mechanisms. Penalty mechanism: As a further secure step, blacklisting can be introduced to recognize double spending and identify the tainted credits in B-RAN. The victim should monitor these credits and track their flow. Other APs might not be willing to accept tainted credits, since they are likely associated with fraud. Particularly, if a PoD-based consensus algorithm PoD is adopted, it may not prevent malicious users from mining several forks simultaneously since the mining cost is much lower compared to PoW. Hence, an extra penalty needs to be introduced to discourage miners from trying to create a new branch by increasing the opportunity cost of mining. Moreover, interference control in B-RAN can be conveniently realised among participating nodes. Through pre-payment (credit) or deposit, an AP can be fined a penalty if it is found to have caused interference to other contracted services, or to be transmitting at very high radio power that degrades other participants' QoS. TDIS PQC Signature Token: it consists of a smart card integrating a quantum-resistant digital signature algorithm. This feature can be used to ensure the integrity and authentication of data files. For this purpose, asymmetric key pairs will be used: the private keys are stored in the token and will be used to sign. The signature is internally processed and will be based on the digest of the data file. On the other hand, the associated public keys, certified by a certification authority to allow the receiver to check the signature and, thus, to verify the authenticity and integrity of the file. The certificates may be stored in the token or present on a server in the cloud

R4: Realistic blockchain and attacks models and an experimental validated B-RAN theoretical framework
Motivation and current limitations: Accurate blockchain modelling is the basis in developing a secure, energy and spectral efficient wireless network, as well as performing network optimisations. In other words, it is a key element in developing a decentralised and self-managed B-RAN architecture. In this direction, in [6], the authors identified and discussed a set of trade-offs, including the optimal selection of the block size subject to throughput and the balance between numerous confirmations to increase security and latency. However, although the optimization problems were formulated, no analytical solution was presented, due to the lack of an appropriate blockchain theoretical model. Finally, the experimental results in [6] highlighted the importance of taking into account parameters such as UE power consumption limitations and the bottleneck of blockchain scalability. Motivated by the aforementioned challenges, in [7], the authors presented an initial queuing-based model in order to analytically evaluate the trade-off between latency and security. The disadvantage of this model is that it neglects the effect of decentralization on RANs, as

well as a number of other key parameters, such as the block length, the energy consumption, bandwidth availability, etc. as well as several important mechanisms, like the different type of consensus mechanisms that can be used in B-RANs. Finally, no-analytical models have been developed for alternative more practical approaches, such as the one provided in [8], where the B-RAN employed Fast Smart Contract Deployment (FSCD) and Digitized Spectrum Assets (DSA) to reduce the access delay and improve the spectral management. To sum up, it is clear that existing contributions are unable to quantify: (i) the impact of decentralization on RANs, after introducing blockchain; (ii) the trade-off between level of decentralisation and latency, throughput, energy consumption, and other key performance indicators (KPIs); (iii) the different consensus mechanisms, (iv) the alternative history attack risk; and (v) inherent limitations of blockchain.
Challenges and progress beyond SOTA: Motivated by the above, NANCY focuses on progressing beyond SOTA by developing a new experimentally-verified generalised theoretical model that accommodates the impact of decentralisation in B-RANs, by leveraging the Markov theory as well as random matrix theory, stochastic geometry and ML tools. This model will also take into account different types of consensus mechanisms, sources of security risks and attackers as well as the fundamental limitations of blockchain. In this direction, the potential factors that influence security will be determined and their impact will be evaluated. Building upon this model, the theoretical framework for the performance characterization, in terms of throughput, energy consumption, computational cost, latency, and security as a function of the network parameters and the decentralization level will be delivered. Moreover, blockchain-specific KPIs that will quantify the B-RAN transparency, immutability, and availability will be defined and analytically evaluated. In other words, the theoretical framework is expected to reveal inherent trade-offs between the networks and blockchain-specific KPIs, which will be exploited in order to optimize the B-RANs performance.

R5: A novel quantum key distribution mechanisms to boost end-user privacy
Motivation and current limitations: Quantum communication is a field of quantum physics that studies the transmission of quantum states or quantum information along one or more parties for some purposes. Quantum communication links and nodes (quantum repeaters, routers, etc.) build up a so-called quantum network. Quantum networks can consist of simple photonic devices capable of preparing and measuring only one quantum bit (qubit) at a time, to all the way distributed large-scale quantum computers. Thus, Quantum networks are the building blocks of the future quantum internet. A major difference between a quantum network and a classical network is that information exchange cannot be modelled by extrapolating the classical model. In a quantum network, any readout would involve a measurement, and the laws of quantum mechanics dictate that once a qubit is measured, it collapses into a state, and thus, superposition and entanglement are destroyed. In other words, once a qubit is processed, it cannot be read out until a suitable point in the computation, determined by the protocol handling the qubit, has been reached. All these challenges have made the most widely accepted applications for quantum communication fall in the field of cryptography, where the laws of quantum mechanics are exploited to secure data and specifically to share a secret key between symmetric parties, a technique named Quantum Key Distribution (QKD). In quantum cryptography or QKD, the secret key is sent over a quantum channel, using quantum particles such as photons. Once the key is shared, the transmission of information is done on the classical channel. Quantum key distribution protocols can be divided into different categories depending on the detection technique required to recover the key information. Discrete-variable (DV) protocols and distributed phase reference (DPR) protocols rely on information encoded on single photons: polarization for the DV and phase or arrival times of the photons for DPR and thus, both rely on single photon detection techniques. Continuous variable (CV) protocols encode information on the quadrature of the quantized electromagnetic field using coherent states and thus, homodyne or heterodyne detection techniques are used in this case.
Challenges and progress beyond SOTA: QKD has already a small market, which is expected to exponentially grow in the coming years. The biggest challenges to-date for commercial QKD

deployments are the complexity of building modular, reliable and long-haul devices and, at the same time, the lack of quantum repeaters (currently under development). The latter is one of the reasons why it is recommended to keep the connection length below 100Km. This shorter stretch allows to avoid using conventional secure repeaters in between the peers to store and relay the keys. This would in fact be not only a complication but also the weakest link of the chain in terms of security.

The fronthaul is the best candidate for this trial, as it has all the required characteristics and architectural pervasiveness to maximise the gain in terms of costs, power consumption and reliability. It works on relatively short distances, requires traffic encryption, works over C/D-WDM optical transport (so allowing high density of logical channels on the same fibre) and does not have many active components (e.g., optical amplifiers) over the physical link, which would jeopardize the quantum signal.

R6: Smart pricing policies
Motivation and current limitations: It is evident that lately we are witnessing a tremendous growth in mobile traffic which is expected to grow even faster in the context of next-generation cell networks (5G and B5G). In order to enable cooperative solutions, which allow offloading traffic to mobile peer devices while extending the radio access network coverage (particularly required for high-frequency communications), suitable incentives need to be found and optimally applied to participating mobile users. In more detail, the cell-free paradigm which is envisioned for 5G and beyond cell networks relies on the utilization of mobile relaying nodes. It is noted that the concept of relaying nodes was first introduced in 3GPP Release 10, but it was never really implemented, mainly due to practical reasons. Specifically, in a cooperative cell network scheme, apart from the related technology enablers, monetary incentives comprise a driving force that can substantially reform the mobile connectivity marketplace, especially in the context of 5G and beyond systems, which allow the application of new business models, for instance through tenanting schemes. The possibility of data content peer-to-peer trading is studied in [9]. According to the considered scenario, mobile users predict their traffic demands to perform pre-caching in order to minimize their expected payments. On the other hand, the operator deploys dynamic pricing policies and receives a commission from each trade. Game theory is applied to find the respective equilibrium point. Any such peer-to-peer cooperative scheme requires efficient decentralized spectrum management, given that radio resources are highly valuable and scarce. The application of blockchain for such a purpose is investigated in [10], where the high potential of this technology is examined, and [11], where the adoption of an auction scheme is also introduced. In general, the decentralised resource management, the cooperative relaying scheme based on momentary incentives, as well as the necessity for advanced security features within a distributed network lead to a promising combination of blockchain technologies with optimal pricing mechanisms, as described in [12].
Challenges and progress beyond SOTA: The organization and management of a massive number of mobile users towards collaborating for effective resource sharing and data relaying, while ensuring economic sustainability and feasibility is challenging. Widely used game-theory-based pricing schemes (e.g., Stackelberg games) observe the strategy and choices of each player to find the equilibrium. However, due to a large number of players (i.e., a massive number of users), the determination of such an equilibrium is challenging. Furthermore, as the users move among APs the availability of spectrum changes. Therefore, pricing policies have to take into account the mobility of users. In NANCY, by integrating Blockchain technologies into the RAN, smart policies can be developed, which leverage AI techniques in order to adapt and provide monetary user incentives and regulate resource sharing while retaining an optimal profit model for the MNO. In addition, pricing policies will focus on providing computational offloading incentives. These incentives will assist in realizing an efficient MEC framework in the B-RAN.

R7: AI-based B-RAN orchestration with slicer instantiator
Motivation and current limitations: Since B-RAN enables untrusted nodes to interact with each other in a secure manner, it provides a promising way to device-to-device (D2D) communication and

caching, relaying, and cooperation, and enables the utilisation of mesh topologies. It is apparent that the topology of the B-RAN can dynamically change, due to the different roles that each network node can play as well as the existence of mobile nodes; thus, the communication system becomes extremely complex to design. This originates from the large number of parameters to be optimized based on the contextual information that is gathered and made available to the network controllers. In an era where AI is considered to be a pervasive and effective solution for addressing several complex problems, it is legitimate to investigate its role in the context of B-RAN. This is especially true, in particular, in light of the recently approved "ITU-T Y.3172 architectural framework for machine learning in future networks including IMT-2020" [13]. In principle, AI methods are powerful approaches for optimizing B-RAN. Reinforcement learning approaches, in particular, implement the learning and decision-making procedures by interacting with the environment by taking actions and receiving feedback on the result of the actions that are taken. Therefore, they can automatically perceive complicated wireless networks, diverse requirements of emerging services, and time-variant states of available resources. Moreover, they can accurately analyse the topology, channel assignment, and interference of the current wireless network and then select the most appropriate operation mode for each node as well as enable cooperation between different nodes. However, supervised AI approaches require massive amounts of data that is difficult to gather in resource-constrained systems, or that is just not available in many application fields [14]. Thinking of applying, on the other hand, AI methods, it may take a very long time before the system converges to a stable and optimal operating point. In wireless networks, which are highly dynamic in nature, the system may not converge within the coherence time of the environment because of the well-known exploitation-exploration dilemma of AI methods. As a consequence, there is a compelling need of developing AI algorithms that can be optimized and designed by using a small amount of data and that can optimally converge in a time much shorter than the coherence time of the wireless environment.
Challenges and progress beyond SOTA: By exploiting blockchain and AI, NANCY can perform optimal user association, routing, and resource allocation policies in a secure environment. Additionally, to overcome the aforementioned limitations of conventional AI approaches, NANCY will examine the emerging concept of transfer learning as the enabling tool for reducing the amount of data for system optimisation and making AI effective in the proposed scenario. Transfer learning is a method that allows us to transfer the knowledge that is used in a given context to execute a given task, into a different but related context to execute another task [15]. The approach that we propose consists of combining together model-based and data-driven optimization methods. The idea is to exploit prior knowledge of the system based on mathematical models as the initialization point from which AI methods start interacting with the environment for system optimisation. The rationale of the approach lies in the fact that the initial network status obtained from a model embeds many of the most important features of the actual system, and, therefore, it will take less time and data for AI methods to converge towards the optimal operating point. Finally, the AI-based B-RAN orchestrator will enable network slicing in a flexible and elastic manner. In more detail, following the developments of 5GPPP Phase 2 projects, NANCY devices a B-RAN orchestrator capable of decomposing and allocating NFS. As a consequence, services are decomposed into function groups, which can then be autonomously allocated anywhere in the network (including infrastructure in the cloud, edge, and user plane). The location of NFs is chosen based on the slice's requirements. For example, for latency-critical applications, NFs may be located in individual infrastructure at the edge, while for computationally demanding tasks, they may be moved to the edge or even in the cloud plane. Additionally, the B-RAN orchestrator takes into account the different characteristics of the usage scenarios, e.g., in the CoMP scenario, synchronization NFs should be placed in a central location, while in the range expansion scenario, they can be placed in the intermediate node in order to reduce the consumption of x-haul resources.

R8: A novel AI Virtualiser for underutilized computational and communication resource exploitation

Motivation and current limitations: The introduction of sophisticated applications, as well as the exponential growth of data, has resulted in higher communication, processing, and storage requirements, as well as stringent reaction time and network bandwidth requirements. Complex data processing and storing are required for new applications such as VR/AR methods, autonomous driving, and robotics, which necessitate a greater degree of data exchange, computation, and storage. These applications provide significant hurdles to conventional networks, notably in terms of communication and computing. In this context, mobile cloud computing (MCC) is recognized as a viable alternative for fulfilling the growing need for connectivity and processing capacity [16]. Because MCC employs the client-server communication architecture, it may provide rich computational resources to mobile users, but it is costly and time-consuming when uploading real-time data. Despite its benefits, the distance of cloud servers from consumers results in excessive transmission latency and the rise of mobile data will put significant strain on backhaul networks. As a result, multi-access edge computing (MEC) was introduced in order to address such difficulties by relocating processing resources closer to the devices, and reducing energy usage and latency [17]. However, in mobile situations, distant compute resources may not be immediately available due to intermittent connectivity and non-seamless wireless coverage. In a number of situations, ad-hoc unloading is necessary. Offloading computation to adjacent mobile devices, and forming a mobile device cloud (MDC) as a result, is a potential solution [18]. MDC offloading takes advantage of the fact that mobile devices routinely contact other devices that can provide processing resources as part of their inherent mobility pattern. These encounters, however, are few, short-lived, and opportunistic. As a result, the efficiency of offloading mechanisms is determined by the mobility patterns of how frequently devices with different computing capacities communicate with one another.
Challenges and progress beyond SOTA: The MDC paradigm enables the utilisation of underutilised processing capabilities in mobile nodes. However, due to the heterogeneity and mobility of devices, orchestrating such resources is difficult. Furthermore, because these devices' connectivity is sporadic, determining how long the computational resources will be accessible poses another challenge. NANCY provides the AI Virtualiser, which is capable of identifying the computing resources required by a certain task and making suitable offloading decisions. Such decisions include whether the entire job will be offloaded or only a portion of it, as well as how many and which nodes will engage in the computation in order to maximise the overall system utilisation within certain limits, such as node capabilities and energy reserves. Additionally, technologies like NFV, SDN, and slicing will be used to increase the resource manager's flexibility. In order to reduce the time of the offloaded work, AI techniques will be used to recognise the availability patterns of mobile nodes. Finally, if a node leaves the MDC, D2D communications will be used to transfer data between nodes with the least amount of delay and influence on calculation performance.
R9: Novel self-evolving AI model repository
Motivation and current limitations: The length and difficulty of AI research generated a new field that aims to automate the development of AI algorithms by utilising machine computing instead of human research [19]. One popular candidate is architecture search, which employs expert-designed layers as building blocks to constrain the space by respecting the rules of backpropagation. Other models investigated ways to limit their search by taking into account specific algorithmic aspects, such as data augmentation [20], objective functions in reinforcement learning [21], or learning rules used during backpropagation [22]. However, some algorithmic aspects remain hand-designed which may save compute time, but has two major drawbacks. Firstly, it creates a new burden on researchers to hand-design such search spaces and undermines the purported objective of reducing human effort [23]. Secondly, the human factor can impose biases in the search results in favour of human-designed algorithms and, therefore, reduce the innovation potential [24].
Challenges and progress beyond SOTA: To address this, the NANCY self-evolving AI model repository is responsible for storing and searching for AI models by using simple mathematical operations as building blocks. It simultaneously searches based on the model, optimization

procedure, and initialization parameters, thus limiting the human-design factor and highlighting automated discovery of non-NN algorithms. This framework, as proposed in NANCY, represents every AI model as a computer algorithm with 3 component functions, *setup, predict, and learn.* These functions perform the model initialization, prediction & learning, respectively. To achieve this, NANCY will deploy a highly-optimized open-source infrastructure capable of searching through 10,000 models/second/CPU core.

R10: Experimentally-driven reinforcement learning optimization of B-RAN
Motivation and current limitations: As presented in Table 5, a couple of research and innovation projects, such as 5G-ZORRO, and Pledger, have attempted to include blockchain functionalities in mobile network architectures. In these projects, blockchain has been characterised through a simplified model with fixed computational and storage resources, which does not take into account the particularities of the consensus mechanism that has been employed. Similarly, prior studies have considered that the computational and storage resources in the B-RAN are fixed [7] and neglected the performance differentiations that different blockchain-specific mechanisms can provide.
Challenges and progress beyond SOTA: In realistic usage scenarios, e.g., in usage scenario 3, the computational and storage resources may constantly change. Moreover, different consensus and attack avoidance mechanisms can be employed based on the use case requirements. This is expected to change the characteristics of B-RAN, rendering the aforementioned models unable to accurately accommodate the network's particularities. Since an accurate B-RAN model is the basis of optimizing B-RAN architectures, in this direction, NANCY will leverage its experimental platforms (in-lab testbeds) to derive more accurate models, which will be verified in realistic environments by means of outdoor testbeds, and will aid at optimally parametrizing the NANCY overall architecture. Specifically, in each cycle, the output of the experimentally-driven RL optimisation of NANCY's B-RAN (state and reward) is forwarded to the experimental controller that computes the updated state (weights) and the required actions. Then, the appropriate AI models and their respective data are assigned to services, which are assigned to optimally-selected network nodes to complete them. Throughout this procedure, communication and computing resource requirements are received from the NANCY AI Virtualiser and the AI models from the NANCY self-evolving AI model repository. This novel optimisation framework meets the needs of modern and future applications, as well as offers higher throughput, minimizes energy consumption, and provides higher stability on a system level.

R11: Semantic & goal-oriented communication schemes for beyond Shannon performance
Motivation and current limitations: Up to now, generations of wireless systems have been designed to accommodate the exponential growth of downlink traffic. Nevertheless, starting from 4G, we experience a reduction and sometimes inversion of the asymmetry between uplink and downlink traffic [25]. In 5G, the increasing support of machine learning algorithms is causing a further explosion of uplink traffic. 5G uplink capacity has not been sized to meet such exploding demand for the next decade. With 6G, this trend will be further intensified through the introduction of an increasing number of distributed intelligent nodes collecting, processing, and storing data. Some identified use cases, such as Industrial IoT or virtual reality, already impose new KPIs requirements such as stringent latency bounds, packet delivery jitter, reliability, or achievable throughput, but also regarding the systems dependability [26]. For instance, holographic communications employing multiple-view cameras are expected to require several terabits per second (Tb/s) per link in both uplink and downlink (a requirement not supported by 5G) and a stringent end-to-end (E2E) latency to ensure real-enough virtual and seamless remote experience [27, 28].
Challenges and progress beyond SOTA: The new vision of 6G networks that incorporates semantics and effectiveness aspects takes inspiration from, Nikola Tesla, who stated, in 1926: ''When wireless is perfectly applied, the whole Earth will be converted into a huge brain'' [29]. Following this idea, NANCY's approach towards 6G networks takes semantics and effectiveness aspects as central aspects of network design. In this context, focusing on semantics and clearly identifying the goal of communication, helps us to distil the data that are strictly relevant to conveying the information

intended by the source or to fulfilling a predefined goal. Disregarding irrelevant data becomes then a key strategy to significantly reduce the amount of data to be transmitted and recovered, thus saving in bandwidth, delay and energy. According to this view, goal-oriented and semantic communications will be a keystone for exploring the meaning behind the bits and enabling brain-like cognition and effective task execution among distributed network nodes. This change of perspective represents a fundamental paradigm shift where the success of task execution at the destination (effectiveness problem) is the core concern rather than achieving error-free communications at the symbol level (technical problem). Specifically, the NANCY semantic encoder is responsible to detect and extract semantic content (e.g., meaning) of the source signal and compress or remove irrelevant information. Moreover, the NANCY semantic decoder interprets the information sent by the source and recovers the received signal into a form that is understandable by the destination user. It also needs to evaluate the satisfaction of the destination user and decide whether or not the receipt of the semantic information is successful. Finally, NANCY will mitigate the semantic noise, which is introduced during the communication process and causes misunderstanding and incorrect reception of the semantic information.

R12: An explainable AI framework
Motivation and current limitations: Deep models are characterized as opaque, or black-box AI systems, due to the difficulty of tracing the model's internal decision-making procedures, which yield a particular prediction. To tackle such limitations, a lot of effort has been conducted in current literature to provide the explanations needed to boost the understandability of black-box AI systems; to this end, XAI techniques have appeared. As such technologies have not matured yet, a lot of issues are noted in XAI, such as the difficulties humans face when trying to interpret the in-depth explanations of a model's purpose, while notably, post-hox explanations are still characterised as too imprecise [30]. Finally, the mostly-utilized XAI techniques face challenges, as perturbation-based methods are considered to be broad, while decision-set methods do not take into account the frequency of the features' values [31]. As such, a lot of research has been conducted to aid in evolving XAI.
Challenges and progress beyond SOTA: Undoubtedly, significant steps have been made in the effort to shed light on the black-box model's inner decision-making mechanisms. NANCY aims in building on past efforts and improving the suggested techniques by proposing a model-agnostic algorithm for making opaque models' decisions explainable and understandable. The NANCY XAI engine comprises 4 stages and will utilise two key technologies, namely SHAP and LIME. The former provides global insights on the importance of specific features by estimating the average marginal contribution of a feature value over all possible coalitions, while the latter will explain how the model works in a local vicinity by building sparse linear models around selected predictions. Because of this exhaustive approach, the NANCY XAI Engine guarantees properties like consistency and local accuracy. Through the creation of such innovative solutions, NANCY certainly boosts XAI efforts while making AI models understandable to humans, thus enhancing the trustworthiness of the proposed AI system.

R13: Next-generation SDN-enabled MEC for autonomous anomaly detection, self-healing and self-recovery
Motivation and current limitations: As the complexity and density of distributed network architectures increase, the need of developing new technologies, which enable flexible system management and devices' self-configuration as well as improved reliability by providing means of self-healing and self-recovery in case of failures, becomes of much importance. In this sense, software-defined networking (SDN) and network function virtualisation (NFV) have been recognized as promising features, since they can provide almost-instance network adaptivity to dynamic events; thus, they can support self-healing and self-configuration functionalities and optimize the network performance [32]. However, self-healing comes with several challenges. One of the most important is to guarantee the network quality of service (QoS) and experience (QoE) demands during the self-healing process. In more detail, it is widely recognized that self-healing processes have a negative

effect on the network's latency, which, may increase to approximately 50 ms [33]. Notice that, in several B5G applications, such latency is unacceptable. To surpass this limitation, proactive self-healing mechanisms that predict and prevent problems in advance have been reported [34]. The key idea behind this approach is to gather data and build proper models that quantify the probability and impact of different failures as well as the corresponding healing actions. Depending on the data that is available and fed, different AI-based models and techniques can be applied in order to minimize the probability of network failure [35]. Such approaches demand the exchange of a large amount of raw data between edge and central nodes, which results in wireless channel pollution. To counterbalance this, ML-based proactive failure mechanisms on the edge nodes have attracted the attention of both the academy and industry [36], due to their simple integration in several frameworks, such as Docker, OpenStack, OPNFN, and MANO. The disadvantage of such mechanisms is that in most cases they demand that end-node to have high computational and storage capabilities as well as practically no power limitations. In other words, they are not suitable approaches for mobile UEs.
Challenges and progress beyond SOTA: In order to surpass the aforementioned limitations, NANCY develops a distributed federated learning framework (FLF), in which the model training is distributed across a number of UE that are selected as a solution of a well-defined optimisation problem with constraints the energy autonomy of each UE and its computational capabilities. Within the FLF the UEs employ their local data to train advanced ML that are required by the core AI machine, located at the edge plane. The UEs then communicate only the model updates to the AI machine for aggregation instead of the raw data. This will significantly reduce network pollution. The updated AI machine executes proactive self-healing mechanisms and feeds its outcomes/predictions to the UEs.

R14: A computational offloading mechanism with novel resource-aware/provision scaling mechanisms and novel battery as well as computational-capabilities aware offloading policies
Motivation and current limitations: Blockchain can be considered as an application deployed on mobile devices. As a consequence, each mobile device needs to be equipped with a mining-based blockchain. To support this, mobile devices have to utilise a consensus mechanism. However, the processes that need to be carried out are computation-intensive and energy-consuming; hence, they cannot be supported by resource and energy-constrained devices. The MEC concept aims to realise computing and network services closer to the end-users [37]. MEC aims to enable the massive number of connected devices to cooperatively execute real-time compute-intensive tasks [38]. In a MEC framework, mobile devices can offload these tasks to nearby APs and utilize the distributed computing enabled by the APs. Then, APs compute and provide results, (i.e., block and hash pointer about the transactions) to mobile devices. A crucial decision in computation offloading is whether to offload or not. In the former case, the UE should also decide the offloading amount [39]. Therefore, a decision on computation offloading may result in a) local execution, where the whole computation is done locally at the mobile device, b) full offloading, where the whole computation is offloaded and processed by the MEC, and c) partial offloading, where a part of the computation is processed locally while the rest is offloaded to the MEC. Computation offloading, and partial offloading in particular is a very complex process affected by different factors, such as user preferences, radio, and backhaul connection quality, UE capabilities, as well as cloud capabilities and availability [40]. Several approaches for determining the optimal task scheduling policy have been proposed, including Markov decision [41], [42] and constrained Markov decision [43], [44], [45] ones that take into account the energy and computational constraints of the offloading device. However, most of the presented solutions require either a centralized offloading policy or a predetermined selection caching provider. As a consequence, they significantly constrain the RANs flexibility.

Challenges and progress beyond SOTA: To countermeasure the aforementioned limitations and to enable adaptive computation offloading in B-RANs, NANCY will provide a novel blockchain-specific offloading mechanism that takes into account the availability and computation capabilities of the APs and caching providers within range. For example, in D2D caching, mobile devices can choose their role, i.e., caching providers or requesters, according to their current caching resource availability state and future plans. Mobile devices with surplus caching resources can become caching providers for caching requesters. Caching requesters send the amount of caching resources and expect service time to the nearest AP. The AP broadcasts all received caching requests from the local caching providers. Caching provides a response with the amount of caching resources and their future plans to the APs, which by formulating and solving an optimization problem that maximizes system utility, decides which caching requester will use each one of the caching providers. This optimisation problem is usually of high complexity and for each solution, sophisticated optimization mechanisms need to be developed. In this direction, NANCY will identify and formulate a number of offloading problems and provide low-complexity realistic solutions.
R15: User-centric caching mechanisms
Motivation and current limitations: The wireless capacity demands are expected to increase by at least 1000 times by 2030. As a result, network operators will aggressively densify their network infrastructure to reuse the spectrum as much as possible. Small cell densification enables spatial reuse by deploying multiple small cells. However, traffic served by an access point (AP) is limited by the backhaul's link capacity. Caching on the edge has been recognized as an effective solution to tackle the backhaul constraint of network densification. Caching the popular files in mobile terminal equipment and transferring those files via device-to-device (D2D) or cooperative D2D communication technology can improve the traffic offload rate from the base station (BS) over edge computing wireless network. This method improves the transmission efficiency and transmission stability of communication by reducing latency and decreasing backhaul link. Moreover, it is considered an effective way to offload traffic from the core segment of the network, where contents are usually stored in data centres. D2D or cooperative D2D communication links may drop at any instant. UE is mobile and is carried by people with social attributes. On the other hand, in D2D or cooperative D2D, the success of the user requesting content is closely related to the social relationship between users, due to the social selfishness of D2D users. Consequently, to improve the performance of D2D content sharing, social-and-mobility-aware caching strategy for D2D scenarios [46] exploit user interest similarity and mobility. D2D caching content deployment strategies such as, community discovery mechanism [47], caching nodes selection algorithm and file caching probability determination algorithm, aim at reducing the probability of requesting files from BS, improving caching efficiency. Furthermore, other approaches [48], [49], [50] efficiently select important users (IUs) and methods to allocate files to the storage of the IUs by modelling a many-to-one IU selection (MOIS) matching algorithm and a many-to-many file allocation (MMFA) matching algorithm, in order to maximize the social-welfare and minimize the download latency respectively.
Challenges and progress beyond SOTA: Motivated by the above, NANCY proposes a social-aware caching mechanism that by profiling the connected users, it can predict and prefetch content closer to the users in a network. Content can be cached either on the small cell APs or on the users' devices where D2D communication is used to share cached content. In NANCY, we focus on i) cache placement, ii) content delivery, and iii) the development of profiling and prefetching mechanisms. In order to improve the cache hit rate, NANCY uses a social-aware D2D cooperation cache strategy that is based on social attributes and content spread range. Furthermore, to ensure QoE at the lowest cost, a noncooperative game-based D2D user allocation scheme will be utilised. However, this allocation scheme does not take into account the conflicts of interest between users because the allocated D2D cooperative users may meet the service requirement of multiple users at the same time. Accordingly, NANCY will develop a Vickrey-Clarke-Groves (VCG) trustworthy auction mechanism that will be responsible for handling the conflicts of interest among D2D users. In VCG,

the interest of the bidder is related to the losses of other users which are caused by the bidder. One important application of the NANCY B-RAN architecture is B5G connected vehicular systems in which vehicles exchange information via mobile edge nodes such as themselves and roadside units. The information obtained from the knowledge layer (e.g., the trustworthiness between devices) could be used to facilitate communications among devices and realize trustworthy and reliable data transmission.

4. NANCY research and technical innovative advancements per WP

In Table 7, the corresponding NANCY research and technical objectives are presented, along with the challenges that are expected to be addressed, the technological means to achieve them, as well as the goals and measurable criteria of success.

Table 7: Objectives/challenges and means to achieve/address them.

VISION (3 Pillars)	Objective/Challenges	Means to Achieve/Address them
	O-1: "To design a novel RAN that supports dynamic scalability, high security and privacy"	
"Distributed and self-evolving B-RAN for dynamic scalability, high-security and privacy in a heterogeneous environment"	• To support cell-expansion • To support multi-tenant connectivity • To develop low-latency consensus mechanisms • To develop decentralized authentication and anonymization mechanisms • To ensure unprecedented levels of security and privacy • To develop an experimentally verified information theoretical framework for modelling and optimizing B-RAN • To support dynamic and flexible scalability • To develop smart pricing policies	• B-RAN-enabled advance cooperative and multi-hop relaying access schemes will be designed • Novel proof of device (PoD) consensus mechanisms will be developed. • Distributed and decentralized blockchain components will be designed. • Develop a novel a PQC digital signature to ensure the security of the blockchain • Identify B-RAN particularities, new types of security and privacy gaps as well as attacks • Model B-RAN and attacks using Markov and stochastic theory as well as ML-based approaches • Develop two in-lab testbeds to verify the accuracy of B-RAN model. • Develop three out-of-lab demonstrators for real-time B-RAN evaluation and optimization. • Design grant-/cell-free access mechanisms that enable the exploitation of individual and business underutilized resources • Develop smart pricing policies that enable individual infrastructures to be transformed from service consumers to providers.
	Means to verify:	

Result	Verification
[R1]	First White Paper (M12), Newsletters (M12), D3.1 NANCY Architecture Design (M12), White Paper (M12)
[R2]	D4.3 Trustworthy grant/cell-free Cooperative Access Mechanisms (M25), Newsletters (M26), Second White Paper (M26)
[R3]	D5.2 NANCY Security and Privacy Distributed Blockchain-based Mechanisms (M26), Newsletters (M26), Second White Paper (M26)
[R4]	Newsletters (M22), Second White Paper (M26), D2.2 NANCY Experimental-Driven Modelling (M28), Newsletters (M28), D2.3 NANCY Network Information Framework (M30), Newsletters (M30), Third White Paper (M36)
[R5]	D5.1 Quantum Key Distribution Mechanisms (M22), Newsletters (M22), Second White Paper (M26)
[R6]	D4.5 Smart Pricing Policies (M27), Newsletters (M28), Third White Paper (M36)

Goals/Measurable Criteria -Targeted KPIs:

Technology-related KPIs		
KPI	**SotA KVI**	**Targeted KVI**
Availability	99%	99.9999%
Block throughput	6-12 operations/node/sec	10-20 operations/node/sec
Key generation	10ms	<1ms
Signing	100ms	<10ms
Verification	10ms	<1ms
Data loss events	(AS specific)	-10%
Communication chatter	(AS specific)	-30%
Data and access security	90%	99.99%
Probability of successful attack	10^{-4}	10^{-5}
Detection rate	70-80%	80-90%
EE improvement	4-18% (conventional AI approaches)	37-41% (AI service orchestration)
Data efficiency (DE) improvement	~10%	>20%
Network offloading latency	~0.3-0.5 sec/GB	~0.1-0.3 sec/GB
Resource utilization rate	>85%	>99.99%
Theoretical framework accuracy	-	>95%
Operation cost reduction	20-40%	70%

O-2: “To transform networks beyond 5G to intelligent platforms integrating ultra-reliable connectivity and high-energy efficiency”

“Towards the Pareto-optimal AI-based wireless RAN orchestration that maximizes energy efficiency and trustworthiness”

- Support hyper dense ambient networks with dynamically changing topologies
- Complexity increasing drastically, due to large scale networks and large data volumes
- Maximize the network’s energy efficiency
- Support ultra-high availability
- Support applications with diverse requirements
- Optimize network topology and management
- Enable device collaboration
- Enable anomaly detection and provision in network level and creation of self-healing and self-recovery mechanisms

- ML to support dynamic cells by means of performing joint node association/pairing and resource allocation with minimum complexity and side-information requirements
- Model-based optimization with ML to improve known analytical models of limited accuracy
- Data-driven real-time optimization with ML to improve network deployment, management and resource reusage
- ML-based slices instantiation to support applications with diverse requirements
- Design federated-learning (FL) aided proacting mechanism for anomaly detection, self-healing and self-recovering

Means to verify:

Result	Verification
[R7]	D3.3 NANCY AI-based B-RAN Orchestration (M24), Newsletter (M24), Second White Paper (M26)
[R8]	D3.4 NANCY AI virtualiser (M24), Newsletter (M28), Third White Paper (M36)
[R9]	D3.3 NANCY AI-based B-RAN Orchestration (M24), Newsletter (M24), Second White Paper (M26)

[R10]	D4.2 Resource Elasticity Techniques (M23), Newsletter (M24), Second White Paper (M26)
[R11]	D4.4 Semantic & goal-oriented communication schemes for beyond Shannon performance (M26), Newsletter (M28), Third White Paper (M36)
[R12]	D5.4 NANCY Explainable AI Toolbox (M29), Newsletter (M30), Third White Paper (M36)

Goals/Measurable Criteria:

Technology-related KPIs		
KPI	**SotA KVI**	**Targeted KVI**
Reliability	99.999%	99.99999%
Prediction accuracy	75%	90%
Explainability	1-3 Likert	2-5 Likert
SHAP/LIME Explanations	Few insights	Multiple insights
FAIRness Maturity Indicators	-	Success
RXD (reproducibility) metrics	25%	50%
Reusability score	55%	80%
OTCE Score (Transferability)	80%	90%
E2C EE improvement	4-18% (conventional AI approaches)	37-41% (AI service orchestration)
Data efficiency (DE) improvement	~10%	>20%
Interoperability maturity	Level 2-3	Level 4-5
Transfer accuracy	40-50%	60-70%
FL testing accuracy	60-70%	70-90%
FL training loss	4-5	2-3
En/Decryption training accuracy	70-80%	80-90%

O-3: “To provide «almost-zero latency” and high-computational capabilities at the edge”

“ Distributed MEC for “ almost-zero latency” and high-computational capabilities at the edge, where the data are

- Support delay-sensitive applications that demands application latency lower than 50 ms, such as AR/VR
- Support high-complexity B-RAN functionalities
- Deal with the computing and battery capacity limitations of end nodes
- Support RANs with variable number of resources, such as vehicular RANs.

- Identification of the B-RAN functions whose operation should be adjusted to the available computational/MEC resources
- Characterization of the trade-off between the identified B-RAN functions performance and the computational resources usage,
- Development of novel resource-aware/provision scaling mechanisms
- Design novel battery and computational-capabilities aware offloading policies that exploit the increased degree of freedom (DoF) provided by B-RAN
- Develop social-aware precaching mechanisms to decisively reduce the application latency

Means to verify:

Result	Verification
[R13]	D5.3 Self-healing and Self-recovery Mechanisms (M29), Newsletter (M30), Third White Paper (M36)
[R14]	D4.1 Computational Offloading and User-centric Caching (M21), Newsletter (M22), Second White Paper (M26)
[R15]	D4.1 Computational Offloading and User-centric Caching (M21), Newsletter (M22), Second White Paper (M26)

	Goals/Measurable Criteria:

Technology-related KPIs		
KPI	**SotA value**	**Targeted value**
Network offloading latency	~0.3-0.5 sec/GB	~0.1-0.3 sec/GB
Resource utilization rate	>85%	>99.99%
Operation cost reduction	20-40%	70%
E2C EE improvement	4-18% (conventional AI approaches)	37-41% (AI service orchestration)
Data efficiency (DE) improvement	~10%	>20%

In this direction and as depicted in Table 8, the work of NANCY has been organized into six (6) WPs. WP1 deals with the administration, dissemination and exploitation work of the project, while WP2-WP6 provide the innovation of the project. In what follows, the technical WPs are described and their relation to the innovative results of the NANCY project is revealed. Finally, the technical work of each partner in each WP is documented.

Table 8: NANCY work package structure.

WP	Work Package Title
1	Project, Innovation & Data Management
2	Usage Scenario and B-RAN Modelling, Network Requirements, and Research Framework
3	NANCY Architecture & Orchestration
4	Dynamic Resource Management and Smart Pricing
5	Security, Privacy & Trust Mechanisms
6	NANCY System Integration, Validation & Demonstration

4.1. WP2 – Usage scenario and B-RAN modelling, network requirements, and performance assessment

WP2 will identify the user and stakeholder requirements and define the NANCY KPIs based on the user expectations and vision, and possible constraints and boundaries of B5G realms. Moreover, this WP will conduct experimental-driven B-RAN modelling. To sum up, the objectives of this WP are:

- To define the use cases and user/system/network and stakeholder requirements;
- Synthesize all the requirements and derive integrated system functional and technical specifications;
- To perform experimental-driven B-RAN modelling;
- To identify and describe the NANCY concept technology enables and evaluate their performance bounds through respective simulations;
- To identify possible types of attacks and assess the security and privacy risks; and
- To derive analytical models for theoretically estimating the performance bounds of B-RAN.

4.1.1. Work-organization and outcomes

Task 2.1 will identify and define the NANCY use cases, address the emerging needs and requirements of the demonstrators, and describe the initial implementation scenarios of the mechanisms that will be developed within the project demonstrators. To this end, this task will design the pilot technical details and the role of each participant, especially that of the end users (precision agriculture – farmers, smart grid – technicians in the energy domain, healthcare – doctors and nurses, supply chain – factory workers and technicians). By providing early descriptions of the NANCY use-cases, all partners will have a clear understanding of the requirements and needs for NANCY, while these use-cases will be used as a starting point for the research/technical and demonstration/business-oriented WPs. In addition to the description of the NANCY use cases, the definition of the suitable acceptance criteria per mechanism/component will be realised. The set of acceptance criteria for the concepts, models and mechanisms to be developed will be further elaborated in WP6 towards the definition of the demonstrators' evaluation strategy that will allow the validation and evaluation of the deployed mechanisms in the pilot testbeds in the project.

The challenge of understanding the particularities of B-RAN and the types of attacks that it may experience is crucial for the theoretical assessment as well as the optimization of the network performance and is addressed in Task 2.2. Towards this direction, we exploit experimental measurements and simulation results. In more detail, in this task, a Markov-based model is used to accommodate the fundamental characteristics of B-RAN, namely born and death of requests and blockchains. Stochastic geometry and random matrix theory will be exploited to model the changing resource and storage capabilities of the network as well as the physical characteristics of the end-nodes, e.g., the number of end-nodes, their position, each node's available resources, and capabilities to serve as a connectivity provider. Moreover, in this task, the different types of attacks are identified and mathematically modelled. To provide a tractable model that can deliver useful design and B-RAN optimization guidelines and reveal the B-RAN security and privacy risks, a ML-based approach will be used. In the first phase of the project simulation results will be used to train the ML-algorithm. After the development of the in-lab testbeds, experimental data will replace the simulated ones in order to increase the accuracy of the model. At the end of the project, data from the outdoor testbeds will be used to make the final adjustments to the models and verify their accuracy.

Building upon the newly developed B-RAN and attack models, a novel network information framework is developed in Task 2.3 that quantifies the achievable performance of networks in different environments. For example, coverage probability and outage probability are evaluated in an urban environment for the range expansion and CoMP scenarios. Moreover, the network latency will be assessed for different consensus mechanisms and the trade-off between latency, computational complexity (power consumption), and security will be quantified. The analysis will exploit tools from point processes and random shape theory and related ML algorithms are developed. Tools from reinforcement learning, transfer learning, and deep unfolding to optimise B-RAN performance when employing the AI-based B-RAN orchestrator will be employed. We consider the performance feasible with a certain number of DoF, indicating the need for adjustable rooting. Finally, network-level performance evaluation will be done and verified through simulation and experimental results.

The newly developed models will be used by Task 2.4 to quantify the achievable performance of the B-RAN in different environments. For example, coverage probability and outage probability will be evaluated in an urban environment using a simulator and outdoor testbeds. Network-level performance evaluation will be done and final simulation and experimental results from NANCY will be presented and compared against the developed theoretical framework.

4.1.2. Partners' Role

INNO will be the WP leader and will coordinate the work. All others will participate and elaborate on use cases/system requirements definition. INNO, MINDS, and UBITECH will participate in performance assessment studies. OTE will focus on B-RAN and attack modelling approaches. 8BELLS will contribute to the development of the network information framework. INNO and MINDS will focus on simulations and evaluation of performance metrics. UBITECH and INNO will contribute to system-level performance evaluations. All partners will present a summary of their final relevant simulation results from all work packages.

4.2. WP3 – NANCY architecture and orchestration

The key objective of WP3 is to provide the overall design of the NANCY architecture based on three pillars (B-RAN, AI-based orchestration, and MEC) for the incorporation of O-RAN and prior 5GPPP project architectural design findings, the development of NANCY enabling innovations, and their integration into the architecture. Thus, WP2 will build on knowledge from previous projects, design the reference NANCY architecture, and define how tailor-cut extensions, which are required by specific use cases, can be integrated into the architecture. WP3 will feed its results to WPs 5 and 6 and it will take into consideration the use case and KPIs definitions of WP2. The real-world measurements performed in WP6 will be fed back to WP3.

In order to achieve the main goal of WP3, the following objectives will be pursued:

- Identify the architectural gaps in current research projects and SOTA solutions;
- Identify the key outcomes and the architecture commonalities from O-RAN solution;
- Specify the required architectural components to support B-RAN;
- Define in detail the overall NANCY reference architecture, including the software framework, tools, schemes, and algorithms by taking into account the identified requirement in WP1, along with the current SOTA technology axes, models and O-RAN open architecture requirements;
- Design novel (AI-based) algorithms, functionalities and solutions following the experimental-driven modelling and optimization approach; and
- Identify and specify orchestration functions that will be used to manage the overall orchestration framework and support the dynamic nature of NANCY.

4.2.1. Work-organization and outcomes

In Task 3.1, the involved partners will specify the overall NANCY architecture, in collaboration with WP2, WP4, WP5 and WP6. In more detail, a baseline B5G architecture based on O-RAN is identified and a gap analysis with respect to the B5G/6G objectives will be reported. Moreover, this task will provide a gap analysis and full specifications of the B5G architecture ensuring a consistent output with the rest of 5G-PPP activities. Additionally, it will monitor and take into account the related outcomes of other 5G-PPP projects in order to guarantee that NANCY will have an important impact on the road towards B5G. To achieve its goals this task consists of the following activities:

- collect information from other 5GPPP and non-5GPPP projects in order to identify common architectural blocks and ensure that major innovations are also considered by NANCY;
- create the overall roadmap for the specification of the architecture and guarantee that the results of the other WPs/Tasks will fill in the identified demands of the overall system;
- specify the overall architecture; and
- provide the schematics of the main functionalities at a level of detail that can be used by Tasks 6.2 and 6.4 in order to develop the in-lab testbeds.

The outcomes of Task 3.1 are as follows:

- a gap analysis identifying the architecture functions and characteristics that O-RAN does not sufficiently address, but are required by NANCY architectures;
- full specification of NANCY (and B5G) network architecture; and
- ensure a consistent output with the rest of the 5G-PPP activities.

Task 3.2 focuses on the design of the novel enabling common NFs for the NANCY. These are related to the realisation of a MEC-enabled protocol stack as well as to slice control, resource and cross-domain management. Moreover, in the context of this task, we will follow an experiment-driven optimization process by incorporating the models developed in WP2 into architectural functionalities and algorithms and experimentally optimise their operational behaviour. The aforementioned functionalities will form the common network functionality that will be always present in all supported usage scenarios. The new functions devised in this task will be fed to WP5 in order to be integrated into the NANCY platform. Their effectiveness will be assessed through simulations in WP2 and demonstrated in WP6. The planned activities Task 3.2 are:

- devise new solutions for the MEC-enabled protocol stack and test them against selected use cases that are going to be implemented in WP6; and
- identify and specify the required functions by means of experimental-driven optimisation based on in-lab and real-life measurements.

Task 3.3 focuses on the functions needed to orchestrate the B-RAN deployment and instantiation of slices. It will exploit AI approaches to optimise the practically infinite DoF of B-RANs. The methods devised will be applied to the three real-life usage scenarios by WP6 and will be enhanced by dynamic resource allocation algorithms that will be designed in WP4. However, Task 3.3 will not limit its contribution to the three identified usage scenarios. On the contrary, the work of Task 3.3 will go beyond these three usage scenarios, and it will provide a general methodology for the instantiation and parametrisation of slices in B-RANs. The planned activities of this Task are:

- design new resource discovery approaches that will boost the B-RAN DoFs;
- provide AI-based algorithms for user/device association that makes the most of the infinity DoFs provided by the B-RAN;
- investigate how specific MEC requirements and network resources as well as deployment topologies and options will affect the selection and deployment of specific NFs; and
- define an appropriate framework to seamlessly integrate specialised functions, such as the ones designed in WP4 and WP5.

Task 3.4 delivers the NANCY AI virtualiser. In more detail, the AI virtualiser is responsible for identifying the computational resources required by a specific task and making the appropriate offloading decisions. It enables the exploitation of unutilized computational resources found throughout the NANCY edge-to-cloud continuum. NANCY takes advantage of technologies like slicing, NG-SDN, and NFV, and combines them intelligently with ML techniques able to detect the availability patterns of edge and mobile nodes to increase the flexibility of the resource manager. Finally, MDC and D2D communications will be utilized in order to migrate data between nodes with minimal latency and impact on the computation performance.

4.2.2. Partners' Role

IJS will act as WP Leader and will coordinate the work. INNO will be responsible for the design of the overall architecture design. IJS will explore novel network common functionalities and will contribute to the AI-based orchestration and AI model repository functionalities. Finally, i2CAT will lead the research on the AI virtualiser for resource exploitation.

4.3. WP4 – Dynamic resource management and smart pricing

The main objective of WP4 is to develop the NFs that provide flexible resource management and allows individuals to become connectivity providers by developing well-defined smart pricing policies. The resulting NFs will be utilised to foster the corresponding functional innovations that will be integrated in the NANCY platform in WP6. The following specific objectives will be pursued:

- design low-complexity computational offloading and social-aware caching mechanisms;
- identify the B-RAN functions whose operation should be adjusted to the available computational/MEC resources;
- characterize the trade-off between NFs performance and resource usage;
- develop low-complexity proactive scaling mechanisms;

- develop ultra-reliable and low-latency cooperative and multi-hopping access schemes tailored for delay, security and resilience critical applications; hence, addressing the requirement for reliable communication with latency limitations; and
- develop smart pricing policies that will significantly reduce the ownership cost.

4.3.1. Work-organization and outcomes

Through the implementation of B-RAN, Task 4.1 enables each one of the network devices to be used for computation and storage offloading, since it guarantees the privacy of the data that are stored in other-than-the-owner-devices. However, the resources in a B-RAN may not be fixed; especially in the case of movable nodes. Therefore, the challenge of guaranteeing the data availability to their owner arises. To address this, this task devices mechanisms novel offloading policies that exploit increased DoF provided by the B-RAN as well as the human-centric nature of the B5G networks, and takes into account the nature of the offloading and offloaded devices. Another, important objective that NANCY aims at achieving is to ensure that the latency requirement of critical-latency applications can be met. In this direction, this task designs social-aware caching functionalities that predict and precache to the edge the content that the serving-nodes may request. This task provides inputs to WP5 and WP6, where the effectiveness of the proposed policies and mechanisms will be demonstrated, and receives as inputs the use cases requirements from WP2 and the overall NANCY architecture from WP3.

Resource management is one of the most basic and important aspects in the design of a wireless system and it is responsible for the efficient utilization of resources and to guarantee user/device QoS and QoE and overall system performance. Having obtained the values of the fundamental, large-scale network parameters based on the analytical modelling studies conducted in WP2, the next step towards an optimal resource allocation mechanism is the development of online algorithms for dynamically and efficiently allocating spectral, spatial and computational resources to users/devices in various time-scales to guarantee differentiated QoS/QoE across multiple served users/devices. Each mechanism can be viewed as a solution to an optimisation problem aiming at maximizing one or multiple key performance indicators without violating system operation assumptions. In particular, this task will leverage the latest developments in optimisation theory and propose a highly adaptable framework for optimal resource management, combining various redesigned resource allocation techniques. Another objective of this task is to improve the utilisation efficiency of computational resources by:

- adjusting the resource poll to the B-RAN workflow with the goal of providing sufficient resources to all functions; and
- providing a graceful degradation in NF performance when resources are insufficient.

In this direction, the elasticity framework is based on computational elasticity; and MEC elasticity. The main activities in Task 4.2 are:

- the identification of the B-RAN functions whose operation should be adjusted to the available computational/MEC resources;
- the characterisation of the trade-off between the identified functions' performance and the usage of the computational resources; and
- the development of novel scaling mechanisms.

This task rethinks and transforms the conventional notion of the hexagonal cell into dynamic cells that can provide grant/cell-free cooperative access to a massive number of end-devices. In this direction, novel access protocols that are supported by the B-RAN will be developed. Furthermore, efficient solutions for resource allocation and resource management through network slicing will be designed. These solutions will take into consideration a massive number of UE with a diverse range of QoS requirements. To achieve accurate user detection and satisfy the required QoS, Task 4.3 will develop novel multiuser detection algorithms based on joint channel estimation and compressive sensing techniques. Finally, smart contracts will be leveraged to enhance the trustworthiness of the B-RAN. These smart contracts will enable the secure relay of data among users while limiting data access only to the authorized user(s). This task receives as inputs the use case requirements from WP2, the NANCY architecture from WP3, and the trust mechanisms from WP5 and provides inputs to WP5 and WP6, regarding the integration and the evaluation of NANCY, respectively.

Task 4.4 focuses on developing the communication schemes that will be utilised in this project. In particular, semantic communications will be leveraged for assisting in the correct information transmission and interpretation. To this end, semantics and knowledge representation systems will be investigated and adapted to the requirements of the B5G network. Furthermore, the communication semantics will be integrated into goal-oriented communications where the particular constraints and specifications of each communication type and link among the devices will be defined in detail. Using goal-oriented communications only the required information for the fulfilment of the goal is transmitted, thus minimising the communication overhead, while also increasing the energy efficiency of the system.

The main objective of Task 4.5 is to design smart policing policies for the use of individual and business infrastructure in B-RAN. In this task, a new smart pricing framework will be developed, where the role of the UE will be able to change from communication service consumer to provider. AI techniques will be used in order to provide monetary incentives to users. This state-of-the-art pricing framework will enhance the value-creation potential of the users while retaining the MNO profits. Auction theory techniques will also be leveraged in order to design novel pricing models. Since a user does not know the values of bidders (i.e., other users), auctions provide an efficient mechanism for the user to get higher revenue than is obtainable via static pricing. In addition, game-theoretic methods will be utilised in designing efficient resource-sharing schemes, as they can effectively model conflicts and cooperation among B-RAN users. This task receives as inputs the use case requirements from WP2, the NANCY architecture from WP3, and the decentralized Blockchain from WP5 and provides inputs to WP5 and WP6, regarding the integration and the evaluation of NANCY, respectively.

4.3.2. Partners' Role

UMU will be the WP leader. UMU will be responsible for the successful development of the offloading and caching mechanisms, while IJS will lead the resource elasticity techniques and UMU will coordinate the trustworthy grant/cell-free cooperative access mechanisms. INNO will be responsible for the semantic & goal-oriented beyond Shannon communications framework. Finally, the smart pricing policies will be developed under the leadership of 8BELLS.

4.4. WP5 – Security, privacy, and trust mechanisms

The main objectives of WP5 are:

- to develop ultra-reliable and low-latency cooperative and multi-hopping access schemes tailored for delay, security and resilience critical applications; hence, addressing the requirement for reliable communication with latency limitations;
- to introduce trust zones for preventing the propagation of security gaps;
- to attain security and privacy in case of shared infrastructure and resources, including areas such as MEC data privacy and MEC security;
- to design the blockchain toolbox;
- to exploit light-weight consensus mechanisms tailored to address the needs for low-rate low-cost massive connectivity; and
- to develop proactive self-healing and self-recovery mechanisms.

4.4.1. Work-organization and outcomes

Task 5.1 is focused on the development of the mechanisms that leverage the laws of quantum and post-quantum theory in order to share a secret key between symmetric parties in the B-RAN with information-theoretic security as well as offer excellence in terms of information-sharing security through post-quantum cryptography. In particular, novel quantum key generators will be developed able to generate and exchange the quantum keys through the fronthaul interface. To this end, a REST-based API will be designed, which will be used by the SAEs to request quantum keys from the KMEs. Coarse and dense WDM techniques will be leveraged in order to enable the efficient exchange of post-quantum encrypted data and quantum keys. The respective transport channels for the data and the keys will be multiplexed and transmitted through the same fibre link. This task receives as inputs the use case requirements from WP2 and the overall NANCY architecture from WP3, and provides inputs to WP5 and WP6, regarding the integration and the evaluation of NANCY, respectively.

Task 5.2 is focused on the design and development of blockchain-based mechanisms for ensuring the security and privacy of the users and the devices. Distributed trust and security and privacy will be the core components of the envisioned blockchain-based mechanisms. To this end, digital signatures will be developed, which will establish the validity of the data by using cryptographic algorithms (e.g., the elliptic curve digital signatures, ring signatures, etc.). In this task, a peer-to-peer secure blockchain-based network will be built, with the ability to verify and monitor the transactions for better transparency, security, and privacy. As massive numbers of users are expected to be deployed in the B-RAN, the scalability of the developed algorithms is challenging. Therefore, novel algorithms will be designed and developed that can ensure user privacy and security in near real-time constraints, by exploiting the distributed processing capabilities of the edge computing concept. Task 5.2 receives as inputs the overall NANCY architecture from WP3, and provides inputs to WP5 and WP6, regarding the integration and the evaluation of NANCY, respectively.

Task 5.3 is focused on the development of the decentralized Blockchain components, utilized throughout the NANCY solution. In particular, this task will design and develop the identity management tools along with sharing techniques and the inner functions (e.g., Ricardian Smart Contracts) for the generation and management of smart contracts. Moreover, the Blockchain infrastructure will provide support for peer-to-peer interactions between users and IoT devices through contractual agreements. This will provide the opportunity for embedded business terms for automating interactions of autonomous connected devices. Furthermore, task 5.3 will focus on developing several Blockchain-enabled functionalities, such as the tokenisation of digital assets, implementation of data integrity mechanisms, and security through a Practical Byzantine Fault Tolerance (PBFT) consensus. To sum up, the main activities of this task are the following:

- the identification of the blockchain mechanisms that can be developed in order to enhance the security and privacy of NANCY;
- the identification, and evaluation of different consensus mechanisms and the design of novel consensus mechanisms;
- present and assess anonymisation and device identification mechanisms; and
- development of the unified blockchain toolbox.

This task receives as inputs the overall NANCY architecture from WP3, and provides inputs to WP5 and WP6, regarding the integration and the evaluation of NANCY, respectively.

Task 5.4 is focused on the development of federal learning-aided proactive mechanisms for anomaly detection, self-healing, and recovery mechanisms. In this direction, possible threats will be identified and their impact on the network performance will be assessed. Task 5.4 will design and implement effective and efficient learning mechanisms based on Big Data analytics. The learning algorithms will learn by co-relating existing network data with newly acquired data and identifying patterns across collected data for a certain period of time. Streaming techniques will be utilized in order to transform the collected raw data into streams appropriate for the anomaly detection process. The anomaly detection process will consider various metrics, such as the network functions and resources availability and performance, as well as multiple detection levels, such as user-level, cell-level, and core network-level. Finally, Task 5.4 will leverage multiple state-of-the-art technologies, such as SDN, NFV, Self-Organizing Networks (SON), AI, and ML to design and develop appropriate counter-measures. Furthermore, T5.4 will implement the necessary big data management mechanisms to allow NANCY to scale up to extreme data volumes. INTRA will provide a multiple-broker Kafka-based big data platform (and associated management tools) that will able to replicate data and provide necessary fault-tolerance (i.e., a data-wise self-healing and self-recovery mechanism) while serving data on the analytics components and securing them with the addition of encryption, authentication and authorization mechanisms (SASL, Kerberos, TLS etc.).

Task 5.5 is focused on the development of Explainable AI functionalities. In this direction, the main principles of explainable AI will be utilised for simplifying and making more understandable to network operators the AI-enabled self-healing and self-recovery processes. In more detail, the concepts of Familiarity, Knowledgeability, and Fairness will be explored using semantics. Familiarity is concerned with whether the users are familiar with an AI algorithm, while Knowledgeability defines how to use a particular AI algorithm. Moreover, Fairness refers to whether the AI processing outcomes are reliable for various groups. In this direction, various methods and relevant programming libraries will be explored and utilised, such as LIME, Dalex, ELI5, SHapley Additive exPlanations (SHAP), and Explainable Boosting Machines (EBM). This task will ensure the trustworthiness and transparency of the resource orchestration processes, effectively mitigating data privacy issues. In this direction, state-of-art techniques will be employed, including EBMs, DTs, and interoperable model-agnostic approaches.

4.4.2. Partners' Role

NEC will be the WP leader contributing to security, privacy, and trust mechanisms, TDIS will mainly contribute to the quantum-key distribution mechanisms, and NEC will contribute to the security and privacy mechanism as well as the decentralised blockchain toolbox. CRAT in cooperation with TEI and SID will work on self-healing and self-recovery mechanisms, while MINDS will lead the explainable AI functionalities.

4.5. WP6 – NANCY System Integration, Validation & Demonstration

WP6 aims to:

- Provide an integration plan to drive the end-to-end integration process of the NANCY platform,
- Setup a continuous integration/development (CI/CD) environment to ease the development, testing, and integration processes and achieve higher quality software that complies with the defined requirements and specifications.
- Deploy and test the NANCY facilities and components at different levels and verify the correct system-level operation and functionality, ensuring the quality of the produced integrated B-RAN.
- Integrate all software components developed in WP3 and WP4 and release the NANCY platform in two major releases.
- Perform interoperability check and experimental-driven joint-optimization, and verify the theoretical framework presented in WP2 in real-environment conditions.

Moreover, throughout the duration of this WP feedback could be given from the integration of the NANCY solutions to the pilot demonstration phase, i.e., if modification or configuration is necessary before beginning the pilot running. In addition, WP6 aims at planning, demonstrating and evaluating the three realistic, proof-of-concept NANCY use usage scenarios. Finally, this WP aims at developing in-lab testbeds and producing experimental data that are fed in WP2 in order to derive the theoretical framework and verify it. The specific objectives within the scope of WP6 include:

- Validate the architecture and design concepts related to O-RAN by testing a prototype in a lab deployment with selected applications;
- Analyse the technical feasibility of B-RAN, identify potential implementation challenges and provide the findings to other WPs (WP2-WP6) in order to develop the corresponding improvements in the architecture design and functionalities;
- Determine the most suitable/optimum allocation of NF functions to locations in running networks;
- Analyse the effort of setting up and operating a B-RAN infrastructure, gain experience in the integration of a B5G network platform in legacy networks and on possible migration strategies from legacy to B5G networks;
- Obtain feedback from tenants and end-customers on usability, benefits, and drawbacks of B-RAN from a user perspective; and
- Provide real-time measurements to WP2, and WP3 for the experimental-driven modelling and optimization.

4.5.1. Work-organization and outcomes

To guide the NANCY Platform development, a suitable development environment will be set up and maintained, allowing ongoing automation and continuous monitoring of the development, testing and integration processes. The setup, installation and appropriate configuration of a CI/CD environment will be the main objective of Task 6.1 to ease the development workflows. A set of collaborative workflow tools to facilitate the integration process will be set up (issue tracking, artifacts repository, software building, testing and verification, etc.). Well-known open-source tools will be used such as Git for source code management, Jenkins for automated building and testing, Artifactory for managing, storing and distributing the produced binary files and others, while de-facto standards (e.g., Docker) will be used for bundling the software components. The setup of the supporting infrastructure (cloud or on-premise) for the development, deployment and testing of the platform will also be part of this task. The use of automation and configuration management tools will be considered (e.g., Ansible, Terraform), as well as advanced containerization frameworks (e.g., Docker Swarm, Kubernetes) for the deployment of the NANCY components. Guidelines for the usage of the respective CI/CD tools and infrastructure will be formulated and provided by INTRA. Procedures and practices that assist in the automation of the data management workflows (collection, storage, monitoring, processing and analysis of data) will be also considered in this task. Task 6.1 will also undertake the development of a solid continuous integration plan to guide the integration of the developed software components. This integration plan will analyse all software resources (e.g., mechanisms, modules, components, services) available, and identify, specify and document the integration points amongst these resources.

Task 6.2 aims at unifying the outcomes of the developed components and services in WP3, WP4, WP4 & T6.1 in order to release the integrated NANCY platform in the first major release. Preliminary unit tests and inter-module and inter-component integration will be included, to synthesize the basic NANCY functionalities. The NANCY components and services will be continuously integrated, in accordance with the integration plan, along with the defined interfaces and communication protocols as set in the NANCY architecture specification. The final version will incorporate improvements based on the development refinement performed in WP3, WP4, WP5, WP6, and pilots' validation results. The intention is to achieve a fully functional platform resulting from the integration of all these software components and provide a prototype suitable for the pilots' experimentation. The integration will be carried out on a step-by-step basis under a planned procedure, running local interoperability tests after each step. Training for the deployment of the individual components to the pilot sites will also be carried out within this task. Static code analysis methods will be considered to exclude errors at an early stage of development, possibly extending to security errors and bugs.

Task T6.3 will perform the remaining unit, integration and system tests to achieve seamless coordination and interoperation among the NANCY components and services in a controlled environment before actual deployment and use by the end users in an operational context. It will use as input the software components created within WP3, WP4, WP5, and will test them using established software testing methods. Further to the work in T6.2, all functionalities will be included in the final release, end-to-end scenarios will be tested and the performance of the platform will be assessed. The steps that will be followed are:

- remaining unit & inter-module tests,
- integration tests in a larger end-to-end scale,
- system tests and technical assessment of the outcome,
- recommendations for the final platform refinements, and
- fine-tuning and overall optimisation.

Software testing will verify the proper system functioning of the integrated NANCY platform. The steps of the testing will be per unit, then bilateral integration and at the end end-to-end workflow integration tests. Testing proceeds through the following cycle: a subset of tests is executed to validate that the initial prototype is stable enough for detailed test and evaluation effort to commence, intensive tests are implemented, executed & evaluated, test results are evaluated against testing objectives (additional testing is done as necessary) and test methods are improved as needed to support the next cycle of testing (final prototype). The test results will provide feedback for the implementation and integration of the initial and final platform releases, indicating necessary modifications and ensuring correct system-wise operation.

Task 6.4 outputs the initial and the final detailed planning reports for the six NANCY pilots and an evaluation methodology, including the description of the desired KPIs. Task 6.4 incorporates the required preparation procedures for the pilot demonstration. It will specify the desired characteristics of implementation and experiment sites, based on the parameters outlined, will map these needs to the profiles of end users participating in the NANCY community and will ensure that the evaluation is conducted with an adequate spectrum of end users, in terms of devices, nodes, edge nodes, platforms, cloud services, and security and privacy aspects; thus, that the project final products can be of benefit of the EU and 5GPPP wide B5G ecosystem communities with varying device and interfaces requirements. The final outcome of this task will be a detailed experimental plan that will be used for scheduling and monitoring the implementation of all five testbeds and an evaluation methodology, including the description of the desired KPIs.

Tasks 6.5 through 6.9 will develop the NANCY in-lab (T6.5 and T6.7) and outdoor (T6.6, T6.8, and T6.9) testbeds of the NANCY project. Specifically:

- Task 6.5 will implement selected algorithms from WPs 3, 4, and 5 with a focus on the ones that are required for the range expansion usage scenario.
- Task 6.6 will develop a testbed in the Athens tourist centre that utilizes the overall architecture and several of the NFs and policies developed in WP3-WP5, with a focus on orchestration, computational and storage offloading, social-aware caching, as well as security and privacy in order to demonstrate their effectiveness in supporting latency-critical broadband applications, such as AR/VR.
- Task 6.7 will create an in-lab testbed at ITL, which will provide the required experimental data for the development of the B-RAN and attack models. The testbed will implement selected algorithms from WPs 3, 4, and 5 with a focus on the ones that are required for usage scenario 2.

- Task 6.8 will build the Italian outdoor testbed that will implement the overall NANCY architecture and selected algorithms from WP3-WP5 with a focus on orchestration, resilience/security, and privacy.
- Task 6.9 will build a testbed in Spain. The testbed will implement the overall NANCY architecture and selected algorithms from WP3-WP5 with a focus on mobility management, orchestration, resilience/security, and privacy.

4.5.2. Partners' Role

ITL is the WP leader and will coordinate the work. ITL will also participate and elaborate on the demonstration scenarios and evaluation of the demonstration outcomes. Furthermore, OTE will coordinate the Greek in-lab and outdoor demonstrators' preparation. Moreover, ITL will be responsible for the Italian in-lab and outdoor demonstrators, while TECNALIA will realise the Spain outdoor demonstrator. INTRA and UBITECH will contribute to the initial and continuous integration plan, while INTRA and ITL will lead the demonstration planning, evaluation methodology and KPIs definition, and the interoperability checks and joint-optimization, respectively.

5. Technical, scientific and innovation management

This section outlines the primary objectives of the technical, scientific, and innovation management process, encompassing the essential performance metrics designated for categorising the specific innovations targeted, as well as the comprehensive monitoring mechanism for identifying, cataloguing, and revising the innovations generated within NANCY.

5.1. Objectives

The objective undertaken by NANCY is characterised by a correlation between each technical goal and a corresponding objective index. Table 9 illustrates the methodology that the consortium will employ to measure the advancement of each objective over time. During the course of the project, a set of three technical objectives will be monitored:

- Design of a novel RAN that supports dynamic scalability, high security and privacy;
- Transformation of beyond 5G networks to intelligent platforms integrating ultra-reliable connectivity and high-energy efficiency; and
- Provisioning of "almost-zero latency" and high-computational capabilities at the edge.

Table 9: NANCY results progress plan.

Objective	Result	Year 1	Year 2	Year 3
O-1: " To design a novel RAN that supports dynamic scalability, high-security and privacy"	**[R1]** B-RAN architecture	**[100%]** use cases and KPIs definition **[100%]** specification definition completed **[100%]** technological enablers identification completed **[50%]** reference architecture definition	**[100%]** reference architecture definition **[70%]** NANCY architecture integration and verification by in-lab experiments	**[100%]** NANCY architecture integrated **[100%]** NANCY architecture optimized and verified by real-life experiments
	[R2] Novel trustworthy grant/cell-free cooperative access mechanisms	**[100%]** required functions identified **[10%]** novel mechanisms designed and developed	**[90%]** Novel mechanisms designed and developed **[100%]** required functions implemented **[60%]** required NFs tested in the simulator and optimized	**[100%]** required functions integrated **[100%]** required NFs tested in in-lab testbeds and optimized **[100%]** required functions demonstrated
	[R3] A novel security and privacy toolbox that contains lightweight consensus mechanisms, and decentralized blockchain components	**[100%]** requirements identified **[50%]** mechanism designed and tested in the simulator	**[80%]** mechanism design and tested in the simulator **[100%]** components designed **[100%]** components validated in in-lab testbeds	**[100%]** designed consensus mechanism assessment in in-lab and outdoor demonstrators **[100%]** real-life assessment

	[R4] Realistic blockchain and attacks models and an experimental validated B-RAN theoretical framework	**[100%]** B-RAN particularities identified **[100%]** security and privacy gaps listed **[100%]** B-RAN Markov based model de-fined and simulated **[100%]** Stochastic characteristics included **[100%]** Theoretical investigated KPIs defined **[50%]** Theoretical framework developed	**[100%]** B-RAN particularities and security/privacy gaps verified in in-lab testbeds **[100%]** ML-based modelling approach defined **[100%]** In-lab data-driven model created **[100%]** Theoretical framework verified by in-lab experiments	**[100%]** B-RAN particularities security/ privacy gaps verified in real-life testbeds **[100%]** In-lab and real-life data-driven model created **[100%]** Theoretical framework real-life verification
	[R5] A novel quantum key distribution mechanisms to boost end-user privacy	**[100%]** requirements identified **[100%]** design	**[100%]** Development **[100%]** Simulation-based evaluation	**[100%]** In-lab and real-life validation, assessment and demonstration
	[R6] Smart pricing policies	**[10%]** Smart pricing policies designed	**[90%]** Smart pricing policies designed **[100%]** Smart pricing policies integrated	**[100%]** Smart pricing policies tested in real-life demonstrators
O-2: " To transform networks beyond 5G to intelligent platforms integrating ultra-reliable connectivity and high-energy efficiency"	**[R7]** AI-based B-RAN orchestration with slicer instantiator	**[100%]** orchestrator specifications definition **[100%]** NF for association and recourse allocation of B-RAN identified. **[100%]** NF functions for association and recourse allocation of O-RAN specified. [100%] Required for development NFs defined **[30%]** Association and recourse allocation strategies designs	**[70%]** Association and recourse allocation strategies designed **[100%]** Association and recourse allocation required NFs implemented and integrated in NANCY platform **[50%]** Association and recourse allocation NFs tested and assessed in in-lab experiments **[100%]** mechanism development	**[100%]** Association and recourse allocation NFs tested and assessed in in-lab experiments. **[100%]** Association and recourse allocation NFs real-life assessment. **[100%]** B-RAN in-lab evaluation, optimization and demonstration **[100%]** mechanism validation and evaluation

	[R8] A novel AI virtualiser for underutilized computational & communication resource exploitation	**[100%]** specifications definition [**20%**] development	[**80%**] development [**100%**] simulation-based assessment [**50%**] in-lab assessment	[**100%**] in-lab assessment [**100%**] demonstration
	[R9] Novel self-evolving AI model repository	**[100%]** specifications definition	**[100%]** repository development	**[100%]** functionalities validation
	[R10] Experimentally-driven reinforcement learning optimization of B-RAN		**[90%]** B-RAN in-lab evaluation, optimization and demonstration **[80%]** Architecture optimized based on in-lab data	**[100%]** Architecture optimized based on in-lab data **[100%]** Architecture optimized based on real-life data
	[R11] Semantic & goal-oriented communication schemes for beyond Shannon excellence	**[100%]** specifications and semantic communications schemes definition	**[100%]** semantic communications schemes development [**50%**] simulation-based assessment	[**100%**] simulation-based assessment [**100%**] In-lab demonstration
	[R12] An explainable AI framework	**[80%]** framework design	**[100%]** framework design **[70%]** framework development	**[100%]** framework development **[100%]** framework simulation, in-lab, and real-life assessment
O-3: " To provide «almost-zero latency" and high-computational capabilities at the edge"	**[R13]** Next-generation SDN-enabled MEC for autonomous anomaly detection, self-healing and self-recovery	[**100%**] types of anomalies identification	[**80%**] mechanism development	[**100%**] mechanism development [**100%**] mechanism validation, evaluation and optimization
	[R14] A computational offloading mechanism with novel resource-aware/provision scaling mechanisms and novel battery as well as computational-	**[100%]** specifications definition **[10%]** design	**[90%]** design **[100%]** development and integration **[100%]** simulation-based assessment	**[100%]** in-lab and real-life validation

	capabilities aware offloading policies			
	[R15] User-centric caching mechanisms	**[100%]** specifications definition **[10%]** design	**[90%]** design **[100%]** development and integration	**[100%]** in-lab and real-life validation

5.2. Inter-disciplinary approach

As described above, the key pillars of NANCY are i) distributed and self-evolving B-RAN, ii) Pareto-optimal AI-based wireless RAN orchestration and iii) Distributed MEC. Those are then mapped to research and technical objectives, which focus on dynamic scalability, security, privacy, reliability, energy efficiency, low-latency and high-computational capabilities at the edge. For each objective, the NANCY consortium has identified distinctive and well-defined innovative results. The methodology applied in the NANCY project combines Markov chain and game theory-based mathematical modelling of the B-RAN and possible threats, information theory-enabled theoretical analysis, in-lab and real-world theoretical framework verification, design and development of novel network functions and architectures that bring intelligence near the end-device, formulation, and solution of new optimization framework, which guarantees the overall system excellence in terms of energy efficiency, reliability, security, latency, the creation of a real-time adaptation framework based on reinforcement learning and few-shot learning, as well as the development of an innovative semantic/task-oriented communication framework.

The B-RAN and attack models of NANCY are built upon stochastic geometry, which will be used as a tool to define the nodes' initial position, and motion theory in order to create realistic motion patterns; thus, a dynamic network topology, random matrix theory in order to define the communication and computational resources of each node at the user, edge and cloud plane, as well as possible attacks. To model message generation, NANCY will employ stochastic theory tools, whereas to model block generation, Markov chain approaches will be exploited. Leveraging the aforementioned tools, NANCY will create a novel system-level simulator capable of capturing the key characteristics of NANCY's RAN. In this direction, software design principles that will allow simulation complexity minimisation and as a result acceptable simulation delay will be employed. The accuracy of this simulator will be initially verified by a set of in-lab experiments, built upon USRP-based SDNs, as well as derived data analysis. This experiment will allow us to optimise the simulator in terms of accuracy by following an agile production procedure. In other words, for creating the B-RAN and attack models, NANCY will follow an interdisciplinary approach that combines mathematical tools, software development, and experimental verification.

The theoretical and optimisation frameworks of NANCY build on information and communications as well as game theory. NANCY recognises that Shannon's information theoretical framework cannot be directly applied to B-RAN, due to the discontinuous block birth process. As a result, we need to rethink and redesign basic principles in order to "recreate" the Shannon theory by starting again for the correct definition of the system's entropy. This process will give birth to new insightful KPIs and will catalyse the extraction of novel analytical expressions for the quantification of the system's performance. Again, this framework will be experimentally verified through the USRP-based prototype. Additionally, to define the performance envelope of the B-RAN, NANCY will exploit communications theory tools. In more detail, we are going to use linear algebra, probability theory and integral calculus in order to extract ideally closed-form expressions and/or insightful approximations for the fundamental KPIs, namely energy efficiency, reliability (outage probability, error rate), availability (coverage probability), etc. The theory is applicable and relevant for the design and optimization of B-RAN connecting a base station or an access point with intermediate nodes and the end user. Also, the theoretical framework gives guidelines and design criteria for the B-RAN design, performance evaluation, and KPI benchmarking, which is important when assessing the final performance of the practical solutions in the demonstrations and performance verification studies.

The design of B-RAN is fuelled by distributed blockchain and virtualization principles. To allow low-computational capabilities users to participate in the network under a security and privacy umbrella, new low-complexity consensus mechanisms will be developed for the distributed blockchain as well as a novel hardware abstraction layer and a quantum-based key exchanging framework. This will require the exploitation of the computer and network architecture as well as the cryptography design expertise of several partners. The orchestration framework of NANCY is based on novel AI tools. In more detail, it uses reinforcement learning in combination with federated learning for real-time adaptation. It also maximizes the systems DE by implementing few-shot learning approaches. Finally, explainable AI mechanisms are used, not only to provide transparency and trustworthiness but to identify the key factors that affect the system's local and overall performance and take the appropriate steps for real-time experimental driven system optimization and adaptation to ever-changing conditions. In other words, AI is another domain that NANCY is going to exploit.

To develop the first fully integrated semantic & goal-oriented communications prototype, the NANCY consortium will follow a series of steps including: i) theoretical analysis, ii) algorithms selection and design, iii) in-lab verification, and iv) out-of-lab demonstration. In particular, since semantic goal-oriented communications allow transferring of the conceptual nature of the message, new KPIs for quantifying systems reliability based on the success or failure of the requested tasks should be defined. Based on these KPIs, the suitable ML algorithms for each will be selected and/or designed and their performance will be assessed in the lab. In other words, semantic & goal-oriented communications, and communication theory tools in combination with AI and experimental verification approaches will be employed.

Finally, NANCY will conduct a business and market landscape analysis in order to provide SMEs/start-ups and other initiatives of the project to closely monitor and identify opportunities for exploitation.

To sum up, NANCY synergistically combines multiple disciplines to create breakthrough scientific innovations with practical value for 6G system technologies and development. Different work packages will focus on some core technologies being methodologically coherent while still inter-disciplinary. The demonstrations will bring all the research methods and their products together in the validation and performance verification.

5.3. Methodology

The primary objective of NANCY is to introduce a new reference architecture for B-RAN that utilises advanced technologies to improve the effectiveness of current 5G systems. The results of NANCY will be made available and accessible to a diverse range of audiences with varying needs and goals. In order to stimulate interest, it is imperative to incorporate outcome-driven and participatory exercises, as well as focus on targeting the global market. Furthermore, corporate-sponsored communication activities, such as marketing initiatives, will serve to promote the framework of NANCY. To this end, NANCY has identified certain communication indices with the aim of augmenting public awareness and interest.

NANCY’s technical, scientific, and innovation management encompasses:

- The consistent monitoring of the project's progress in relation to the established objectives;
- The surveillance of activities pertaining to potential development and dissemination, encompassing novel innovations propelled by market demands; and
- The propensity to generate novel innovation pathways that may surpass the predetermined project objectives.

As previously stated, a primary aim of NANCY is to effectively facilitate the dissemination and utilisation of the outcomes derived from the research and developmental activities carried out throughout the duration of the project. The scope of this activity encompasses not only the distribution of innovative methodologies generated within the project, but also the influence that NANCY has on fostering innovation within the pertinent industry. This objective is not solely focused on the widespread distribution of findings, but also on their utilisation. In order to enhance the likelihood of the project's emergence as a successful innovation with commercial viability, the participating organisations must undertake specific preparatory measures. The project team must possess the necessary readiness to tackle concerns pertaining to the requisite undertakings for the commercialization of the proposed solution.

The implemented methodology is predicated on the intimate partnership between the technical and scientific, and innovation managers and the technical development partners of the project, aimed at leveraging the project's innovative capabilities and furnishing direction on the project's technological selections, grounded in both current and forthcoming market trends. The Scientific and Technical Committee (STC) bears the responsibility of overseeing the project's technical planning, monitoring, and implementation in relation to scientific and technical affairs. The STC assumes responsibility for monitoring the advancement of the project and rendering judgments on all pertinent technical and administrative issues, encompassing technological and technical selections, redirection of work within a WP, significant allocation of partners or WPs resources, modifications to the time plan, the inclusion of a new partner, replacement or exclusion of an existing partner, and resolution of conflicts between WPs. Furthermore, the STC is responsible for managing equipment allocation, procurement processes, technical specifications, and the integration of new partners. Task leaders are required to provide details regarding any technological decisions or innovative solutions that have emerged within their respective tasks. The present data will include the following:

- Descriptions of the chosen innovation or technology paths;
- Rationalization and justification regarding the specific result as an innovation or technological selection; and
- Examination of various alternative options and an assessment of market trends as perceived by technical experts.

The sharing of knowledge and skills is facilitated through collaborative efforts between projects, where technologies or components developed in other projects may be effectively utilised within the framework of NANCY. To enhance the legitimacy of the proposed methodology, it is imperative for the project to partake in academic conferences, as well as the most prominent European workshops. This way, NANCY is expected to facilitate the engagement and attraction of prospective stakeholders and consumers, while simultaneously serving as a gateway for the introduction of ICT solutions to the market. Finally, maintaining ongoing alignment with current trends and technological advancements will yield a superior outcome and an innovative product with heightened commercial appeal.

Furthermore, apart from the aforementioned measures, two supplementary approaches will be employed to guarantee the promotion of novelty throughout the project. The initial approach entails the identification of KERs within the components of the projects. KERs refer to distinct subcomponents of a project that have the potential to enhance the value generated. The identification of three distinct categories of KERs has been documented, namely methodologies, technological bricks, and standards.

The result of this approach will yield a comprehensive Value Creation map for the NANCY initiative, irrespective of the intricacy of its individual sub-components. The subsequent approach will be implemented in conjunction with the identified KERs and activities to facilitate the exchange of information among the involved stakeholders. This approach is rooted in Lean Engineering and constitutes a fundamental methodology. The A3 Knowledge Briefs will document essential knowledge elements and pertinent details regarding the value proposition and business context that it supports. The creators of KER will bear the responsibility of disseminating the KER to the relevant contributors and business partners. The objective of these reports is to facilitate discourse and align the interests of the partners.

5.4. Software engineering lifecycle

The software engineering lifecycle model has undergone significant expansion since its inception as the initial and most ancient "waterfall" model. The diversity of such models is determined by the wide range of product types, ranging from basic algorithms to intricate neural networks within NANCY. Therefore, it is imperative that the chosen model is selected on a per-component basis to accommodate its unique characteristics. To this end, NANCY will adopt key elements from various software engineering lifecycle models, such as Iterative, Spiral, Agile, and V-shaped. The latter, as depicted in Figure 4, sufficiently reflects the overall system engineering approach to be followed by NANCY.

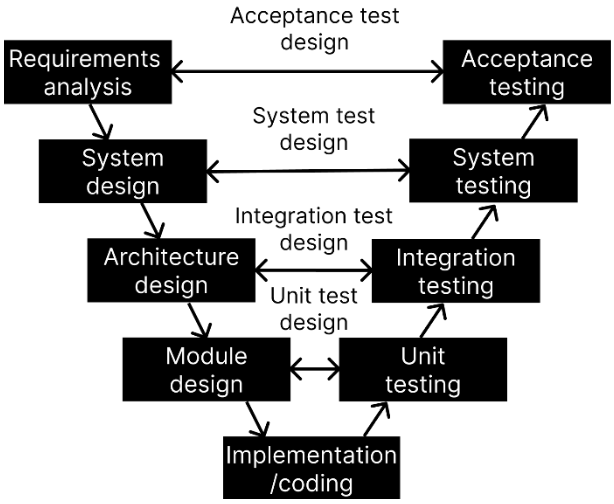

Figure 4: V-shaped software engineering lifecycle model

Irrespective of the chosen individual model, all of them comprise the following fundamental stages:

- The initiation of every software engineering life cycle model commences with the **analysis** phase, during which the stakeholders involved in the process engage in discussions pertaining to the requirements of the ultimate product. The objective of this phase is to provide a comprehensive specification of the system requirements. Moreover, it is imperative to ensure that all stakeholders involved in the process possess a comprehensive understanding of the assigned tasks and the precise methodology for implementing each requirement.
- During the second phase of the software engineering life cycle, the developers engage in the process of **designing** the software architecture. All potential technical inquiries that may arise during this phase are deliberated upon by all relevant parties. The component encompasses a comprehensive delineation of the utilised technologies, team allocation, constraints, temporal parameters, and financial resources. Optimal component decisions are determined based on the specified requirements.
- Upon approval of the requirements, the subsequent stage in the **development** process commences, which involves the actual implementation of the component. The programming

process commences with the composition of source code, while taking into consideration pre-established specifications.

- The phase of **testing** encompasses the process of debugging. The process of identifying and documenting code flaws that were overlooked during software engineering is conducted in this stage, with the intention of relaying the information to the developers for remediation. The iterative testing procedure continues until all significant concerns have been addressed and the software's operational processes have achieved a state of stability.
- Upon completion of the programme and resolution of any critical issues, the next step is to initiate its **release** to the end users. The team in question offers user feedback and provides consultation and support to the users during the period of utilisation.

5.5. Assessment framework

The NANCY project's research, scientific, and innovation may be of significant interest to communication and network experts and other affiliated parties with pertinent technologies. Each dissemination activity attended corresponds to a relevant index. The participants of NANCY will thoroughly scrutinise and deliberate upon all essential domains in relation to defining the KPIs.

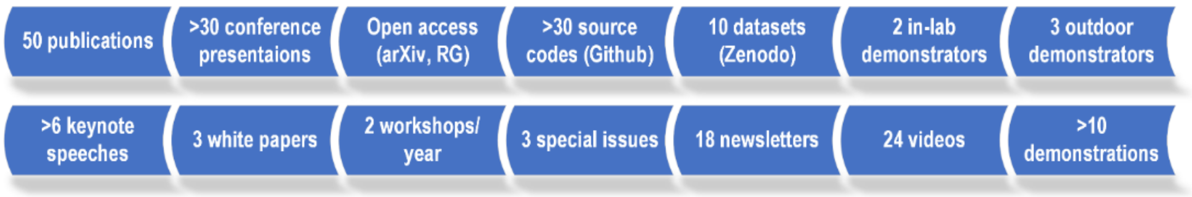

Figure 5: NANCY open science practices

As illustrated in Figure 5, NANCY focuses on enriching the corresponding research area, by adhering to Open Science practices. For this purpose:

- NANCY will make certain to produce open-access research; specifically, the project aims in specifying the research plans to be followed as early as possible and making the aforementioned plans publicly available through preregistration. To secure high-quality research outputs, scientific publications under development will be subjected to peer-reviews prior to the data collection process, as registered reports.
- Upon the completion of the research, all **50 manuscripts** demonstrating the results will be made publicly available on the arXiv as well as the TechRxiv open-access archive and on open research communities (i.e., ResearchGate, Academia.edu) as pre-prints, before they are officially peer-reviewed. By publicising research outcomes at the earliest possible moment, NANCY accelerates the pace at which science progresses.
- Scientific publications demonstrating research outputs and conclusions, when necessary, will be accompanied by the corresponding source code, including algorithms, tools, machine learning models, and will be inclusive, if required, of the datasets utilised, to ensure the reproducibility of the results, and support the verification of the proposed methodologies. Such data and publications will be made available and will be openly accessible, through deposition in trusted repositories, well-known to the scientific community. Indicative repositories that the NANCY consortium is going to use are: github, codeport, zenodo, etc. Taking into account NANCY's research and technical advances and innovations, it is estimated that more than **30 source codes** and ML models will become available by the end of the NANCY project.
- The developed research algorithms' source code will be made available freely in the project's repository.
- The datasets of the research will be managed according to the FAIR principles, as highlighted in the Open Research Data and Publications section. Moreover, these datasets will be

published in the IEEE Data Portal, the EU Data Portal, the Zenodo, as well as the NANCY's repository, with the corresponding links being available on NANCY's webpage. The project is expected to output more than **10 datasets**.

- NANCY will post detailed information concerning its 5 demonstrators on the project's website. Moreover, the results from the 2 in-lab demonstrators will be presented in main events and conferences, including EuCNC, IEEE Globecom, IEEE ICC, and others, while the 3 outdoor demonstrators will be presented to the research communities (i.e., universities, research centres, etc.) in national events. Till the end of the projects, more than **10 demonstrations** are expected to be performed.
- NANCY's results will be presented to national and international world-class conferences. More than **30 presentations** in prestigious conferences and workshops are expected to be conducted.
- NANCY's partners will participate as Keynote speakers in multiple dissemination actions throughout the EU and the rest of the world. More than **6 keynote speeches** are expected to be conducted.
- NANCY will publish **3 white papers**, one for each pillar, alongside the scientific publications, while being inviting to a larger reviewing community.
- NANCY will organise multiple workshops in order to demonstrate its technological innovation to the scientific community and incentivise their transition from research to innovation and, finally, the industrial world. At least **2 workshops/year** are expected to be organized.
- NANCY will initialise **3 special issues**, each of which will be focused on promoting novel research ideas with regard to one of the NANCY pillars. Notice that several of NANCY's key researchers have successfully organized a number of special issues in several IEEE and non-IEEE venues.
- NANCY will publish **18 newsletters** throughout its duration that will explain the scientific and technological innovations and advances accomplished by the NANCY consortium to the public.
- NANCY will post **24 videos** on social media that include: (i) 1 video by the project coordinator's organisation that will briefly describe the project, (ii) 1 video by the project technical coordinator's organisation that will explain NANCY's technical advances, (iii) 21 videos, one by each partner, that will detail their role and expertise in the project, and (iv) 1 final video in which NANCY's outcomes will be presented.
- NANCY aims to thoroughly involve relevant actors, from the conceptualisation of the idea, to the development of the content, in order to provide valuable research outcomes, able to benefit society. By adopting OS practices, NANCY aims in enriching public knowledge and support scientific evolution, through open access to insightful research results and technological advancements.

Preliminary work has already been undertaken to ascertain the suitable KPIs as a mechanism for assessing the outcomes and achievements of NANCY. Specifically,

- The project's research operations were evaluated based on their scientific quality with regard to the number of publications produced by the partners of the Consortium as well as the number of participations in external events and presentations.
- The effective coordination among the partners of the Consortium is crucial for achieving the desired outcomes of the project and it will be assessed based on the quantity of published works produced by multiple partners, as well as the quantity of collaborative efforts necessitating the participation of various stakeholders, conducted through both virtual and physical means.
- The project's visibility and reach at both the European and global levels will be quantified by the average number of monthly visits to the project's website and the quantity of reports featured in various media outlets such as radio, news publications, magazines, and blogs.

To ensure efficient monitoring, it is imperative to initially identify the essential performance indicators associated with NANCY. Subsequently, a monitoring mechanism should be established in tandem with the innovation system to evaluate the corresponding progress and ascertain potential opportunities. Table 10 outlines the KPIs applicable to Innovation solutions and establishes a correlation between them and the anticipated results of the NANCY advancements.

Table 10: NANCY innovation KPIs.

KPI	Description
Timing	The timing aspect denotes the placement of the innovative solution in relation to the demands of the market, and notably, the projected duration for achieving market saturation. The extraction process occurs subsequent to the market analysis and exploitation plan for each innovation, in accordance with the investigations conducted.
TRL level	This denotes the level of technological readiness achieved at the conclusion of the project, and may also be associated with the post-project exploitation strategies. The metric has a direct impact on the decision-making process regarding the time required to bring a product to market.
Possible IPR	This offers a glimpse into the anticipated intellectual property rights that may ensue from innovative activities. The aforementioned can be correlated with the strategic initiatives of partner exploitation and the TRL stages.
Number of competitors	The aforementioned excerpt is derived from the market analysis and delineates the comprehensive competitive landscape within the particular targeted industry. The proposed innovations' position in relation to competition is evaluated through a combination of market share and SWOT analysis.
Expected market size	The aforementioned outcome is in line with the anticipated results of the market analysis and entails a forecast of the market's dimensions for the year of intended release.
Opportunities and barriers	The present statement pertains to a segment of the SWOT analysis, which aims to assess the potential for market penetration of the proposed innovations.

6. Conclusion

The objective of this particular submission is to provide an exposition of the technical, scientific, and innovation management approach employed in NANCY. Upon examining the state-of-the-art of each primary subcomponent of the project, it becomes apparent that there exists a significant demand and ample opportunity for the implementation of NANCY's innovative solutions. Furthermore, the study provides a comparative analysis of analogous ongoing or completed research initiatives in the European Union, in conjunction with innovative aspects for each work package, thereby reinforcing the aforementioned assertion.

In order to ensure the achievement of the goals and objectives outlined within the NANCY project, it is imperative that the technical, scientific, and innovation plan be executed in tandem with the project's development and persist until its conclusion. The adequate execution of the proposed plan will guarantee that the project adheres to the demands of the pertinent market and that the outcomes sustain a notable degree of novelty and economic importance.

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