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TrialsNet: Trials supported by Smart Networks beyond 5G

Deliverable D2.1

Preliminary design aspects for Platforms and Networks solutions

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List of Acronyms and Abbreviations

Acronym	Description
3GPP	3rd Generation Partnership Project
4G	Fourth Generation of mobile communications
5G	Fifth Generation of mobile communications
5GC	5G Core
5GCN	5G Core Network
5G-PPP	5G Infrastructure Public Private Partnership
5GQI	5G Quality indicator
A5G	Advanced 5G Technology
6G	Sixth Generation of mobile communications
AAA	Authorization, Authentication, and Accounting
AI	Artificial Intelligence
AIaaS	AI as a Service
AMF	Access and Mobility Management Function
APC	Authentication and Policy Control
API	Application Programming Interface
APN	Access Point Name
APP	Application
AR	Augmented Reality
AUSF	Authentication Server Function
B5G	Beyond 5G mobile network
BB	Baseband Unit
BFP	Berkeley Packet Filters
BGP	Border Gateway Protocol
BIPT	Belgisch Instituut voor postdiensten en telecommunicatie
BMS	complete Building Management System
CCAM	Connected and Automated Mobility
CDN	Content Delivery Network
CI/CD	Continuous Integration and Continuous Deployment
CM	Configuration Management
CMG	Cloud Mobile Gateway
CMM	Cloud Mobility Manager
CMU	Compact Mobility Unit
CN	Core Network
CNIT	Consorzio Nazionale Interuniversitario per le Telecomunicazioni
COTS	Commercial-Off-The-Shelf
CP	Control Plane
CPE	Customer-Premises Equipment
CPS	Cyber-Physical System
CPU	Central Processing Unit
CU	Central Unit
CUPS	Control User Plane Separation
DBSCAN	Depth-based spatial clustering of applications with noise
DC	Data Center
DL	Download Link
DNN	Data Network Name
DQN	Deep Q-network
DRL	Deep Reinforcement Learning
DT	Digital Twin
DU	Distributed Unit
E2E	End-to-end
eNB	Evolved Node B
ENI	Experiential Networked Intelligence
ERC	Ericsson España SA
EVPN	Ethernet Virtual Private Network
ETSI	European Telecommunications Standards Institute
FTTH	Fiber-to-the-Home
GAM	Galleria d'Arte Moderna
GDPR	General Data Protection Regulation
GM	Group Management
gNB	gNodeB
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPU	Graphics Processing Unit
GTP	Gateway Tunneling Protocol
GUI	Graphical User Interface
HD	High-Definition
HEVC	High efficiency video coding
HMD	Head-Mounted Display
HPE	Hewlett Packard Enterprise
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
IM	Identity Management
IP	Internet Protocol
IPSEC	Internet Protocol Security
IoT	Internet of Things
IRU	Indoor Radio Unit
ISG	Internal Steering Group
KPI	Key Performance Indicator
LAN	Local Area Network
LCM	Life Cycle Management
LM	Location Management
LTE	Long Term Evolution
MANO	Management and Orchestration
MCI	Mass Casualty Incident
MEC	Mobile Edge Computing
MIMO	Multiple Input Multiple Output
ML	Machine Learning
MNOs	Mobile Network Operators
MPLS	Multi-Protocol Label Switching
MQTT	MQ Telemetry Transport
MR	Mixed Reality
MTLF	Model Training Logical Function
NEF	Network Exposure Function
NETCONF	Network Configuration Protocol

NF	Network Function
NFV	Network Function Virtualization
NI	Network Intelligence
NIC	Network Interface Controller
NPN	Non-Public Network
NR	New Radio
NRF	Network Repository Function
NRM	Network Resource Management
NSA	Non-Standalone Architecture
NSSAI	Network Slice Selection Assistance Information
NSSF	Network Slice Selection Function
NWDAF	Network Data Analytics Function
OAI	Open Air Interface
OBU	Onboard Unit
OODA	Observe-Orient-Decide-Act
OS	Operating System
OSM	Open-Source MANO
PAI	Pervasive Artificial Intelligence
PCF	Policy Control Function
PDR	Packet Delivery Ratio
PDU	Protocol Data Unit
PKI	Public Key Infrastructure
PNF	Physical Network Function
PNI-NPN	Public Network Integrated Non Public Network
PPDR	Public Protection and Disaster Relief
QoE	Quality of Experience
QoS	Quality of Service
RAM	Random Access Memory
RAN	Radio Access Network
RAT	Radio Access Technology
RD	Radio Dot
RDI	Radio Dot Interface
REST	Representational State Transfer
RIC	Radio access network Intelligent Controller
RL	Reinforcement Learning
RRM	Radio Resource Management
RSU	Roadside Unit
RTT	Roundtrip Time
RU	Radio Unit
Rx	Receiver
SA	Standalone Architecture
SaaS	Software as a service
SBA	Software-Based Architecture
SDK	Software Development Kit
SDN	Software Defined Networking
SDO	Standards Development Organization
SDR	Software-Defined Radio
SDU	Service Data Unit
SEAL	Service Enabler Architecture Layer
SIM	Subscriber Identity Module
SMF	Session Management Function
SNPN	Stand-alone Non-Public Network
SOM	Self-Organizing Maps
SUT	Session Under Test
TAP	Test Access Point
TDD	Time-Division Duplex
TIM	Telecom Italia SPA
TUN	network TUNnel
Tx	Transmitter
UAV	Unmanned Vehicle
UC	Use Case
UDM	Unified Data Management
UDR	User Data Repository
UE	User Equipment
UL	Upload Link
UP	User Plane
UPB	Polytechnic University from Bucharest
UPF	User Plane Function
URLLC	Ultra-reliable low latency communication
USB	Universal Serial Bus
Uu	The Radio interface between UT-RAN and the User Equipment.
TAC	Tracking Area Code
V2X	Vehicle-to-Everything
VAL	Vertical Application Layer
vEPC	Virtual Evolved Packet Core
VIM	Virtual Infrastructure Manager
vLAN	Virtual Local Area Network
VM	Virtual Machine
VNF	Virtual Network Function
VPN	Virtual Private Network
VR	Virtual Reality
VRU	Vulnerable Road User
VXLAN	Virtual Extensible LAN
WP	World Package
Wi-Fi	Wireless Fidelity
XR	Extended Reality
YANG	Yet Another Next Generation
ZSM	Zero-touch network and Service Management

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Executive Summary

The TrialsNet project aims to implement large-scale trials of innovative Beyond 5G mobile network (B5G) applications to assess how this technology improves people's quality of life in inclusive, safe, resilient, and sustainable cities. As of nowadays, more than half of the world's population lives in cities. TrialsNet's use cases (UCs) are focused on three relevant domains of the urban European ecosystem, identified as i) Infrastructure, Transportation, Safety & Security, ii) eHealth and Emergency, and iii) Culture, Tourism, and Entertainment.

In WP2, the main objective is the development of the platforms and network solutions. This Work Package (WP) performs its work in strict collaboration with WP3, WP4, and WP5, which will develop the UCs in the context of the three domains. Based on the requirements coming from the UCs, WP2 will design and deploy the complete infrastructure to conduct the related trials. In this context, this public deliverable D2.1 describes the preliminary design aspects for the platforms and network solutions in the four clusters of the project, located in Italy, Spain, Romania, and Greece, which are summarized below.

Italian cluster: This cluster is organized into two different sites located in Turin and Pisa, respectively. In Turin, the main objective is to perform large-scale trials by leveraging the TIM commercial network deployment, which includes the integration of existing platforms, infrastructures, and network solutions provided by previous projects. In Pisa, an ad-hoc network infrastructure will be deployed to experiment with advanced End-to-End (E2E) orchestration functionalities, integrating different UCs that will also involve a remote hospital located in Massa.

Spanish cluster: This cluster consists of a Fifth Generation of mobile communications (5G) infrastructure located in Leganés, Madrid, that will be used to perform the initial tests of the UC applications. Afterward, it will be installed at the venue where the trials of the UCs will be conducted in a real-life environment. For this purpose, Ericsson has developed a flight rack that provides a portable on-site radio and core user plane (UP) infrastructure, while the core control plane (CP) remains installed in Leganés.

Romanian cluster: This cluster is based in Iasi, with an indoor 5G Standalone Architecture (SA) Rel-16 infrastructure from the Iasi Orange 5G Lab, and the outdoor 5G Non-Standalone Architecture (NSA) commercial network provided by Orange Romania. The Orange 5G Lab located in Bucharest could also be used to test the UC applications before the actual trial phase. The cluster is complemented by the facilities provided by IMEC, located in Antwerp and Ghent, Belgium. These facilities offer an extensive experimentation setup based on real-life testbeds such as CityLab Smart City, Smart Highway, 5GOpen, and a portable 5G testbed. Consequently, the overall setup will be extensively utilized as a supporting trial infrastructure for the Romanian cluster, where IMEC will provide both network and virtualized infrastructure resources for building and testing the 5G and beyond enablers.

Greek cluster: This cluster is based on a public 5G network, for leveraging its high-speed connectivity, low latency, and wide coverage. Specifically, the network uses NSA architecture and operates at a frequency of 3.5 GHz. In addition, a private network infrastructure provided by WINGS will be utilized to conduct testing activities, validation, and demonstration, prior to the UCs trials deployment on field.

This deliverable also provides details of the TrialsNet methodology, which is based on an iterative approach. Starting with the assessment of current 5G capabilities, the methodology will iteratively progress through four main phases: deployment, trial executions, results evaluation, and network optimization. This approach, combined with the introduction of TrialsNet's innovations and the collection of Key Performance Indicators (KPIs) and user feedback from the trials, will lead to the definition of requirements for the next generation mobile network. It is important to highlight that different technologies and functionalities will be available depending on the cluster, thus providing a comprehensive and heterogeneous set of capabilities and features.

The deliverable also describes the main TrialsNet innovations, which will be part of the research-oriented activities of the project. These innovations will be experimented with to evaluate the enhancements that can be achieved in comparison to the current network solutions. The TrialsNet innovations can be categorized into horizontal innovations, which are related to transversal B5G/Sixth Generation of mobile communications (6G) functionalities such as zero-touch management, and vertical innovations, which are related to specific UCs, for example, automatic orchestration of network slice resources.

1 Introduction

WP2 will work on the deployment of the B5G infrastructures that will be used to perform the large-scale trials of the project's 6G applications which require very demanding performances in terms of ultra-low latencies, very high throughputs, and solid reliability. On such basis, WP2 primary objective will be to collect the requirements coming from WP3, WP4, and WP5 (as defined in their respective deliverables D3.1 [1], D4.1 [2], and D5.1 [3]) and use them to design, integrate and deploy the platforms and network solutions in support to the successful implementation of the proposed UCs. The UCs defined by WP3, WP4, and WP5 and belonging to the three domains are summarized hereafter:

- **Infrastructure, Transportation, Security & Safety**
    - Use Case 1 "Smart Crowd Monitoring" (Madrid)
    - Use Case 1 "Smart Crowd Monitoring" (Iasi)
    - Use Case 2 "Public Infrastructure Assets Management" (Athens)
    - Use Case 3 "Autonomous APRON" (Athens)
    - Use Case 4 "Smart Traffic Management" (Iasi)
    - Use Case 5 "Control Room in Metaverse" (Turin)
- **eHealth and Emergency**
    - Use Case 6 "Mass Casualty Incident (MCI) and Emergency Rescue in Populated Area" (Athens/Madrid)
    - Use Case 7 "Remote Proctoring" (Pisa)
    - Use Case 8 "Smart Ambulance" (Pisa)
    - Use Case 9 "Adaptive Control of Hannes Prosthetic Device" (Pisa)
- **Culture, Tourism, and Entertainment**
    - Use Case 10 "Immersive Fan Engagement" (Madrid)
    - Use Case 11 "Service Robots for Enhanced Passenger's Experience" (Athens)
    - Use Case 12"City Parks in Metaverse" (Turin)
    - Use Case 13 "Extended Reality (XR) Museum Experience" (Turin)
    - Use Case 14 "Extended Reality (XR) Museum Experience" (Athens)

WP2 will also work to support the introduction of new functionalities, encompassing both experimental and commercial equipment that will be deployed in the different sites. From this perspective, the expected outcome from the activities performed by WP2 is twofold. On one side, the interplay between the applications and the network deployments will provide insights into the limitations of the current technology and will permit to identify the areas requiring enhancements in terms of B5G/6G functionalities. On the other side, the introduction of novel functionalities, including the latest advancements within 3rd Generation Partnership Project (3GPP) Rel-16 and Rel-17 prototypes, will foster an elastic and flexible set of infrastructures where innovation can flourish providing the means to improve the implementation of the UCs.

In this document, Section 2 describes the TrialsNet methodology following an iterative approach based on the four main phases of deployment, trials execution, results evaluation and network optimization. It also defines the TrialsNet technologies in terms of 3GPP releases and functionalities starting from which B5G additional features can be introduced.

Section 3 describes for each cluster the related infrastructure in terms of technology, hardware (HW), standard releases, architecture, and functionalities, how these will enable the implementation of the related UCs (UCs) based on their requirements, and how the infrastructure could be enhanced in terms of components and functionalities to improve their performances and benefit the UCs.

Section 4 reports the research-oriented activities in terms of the network innovations that will be introduced by TrialsNet and that will be categorized in horizontal innovations (related to transversal B5G/6G functionalities) and vertical innovations (related to particular UCs).

Finally, the conclusions section provides the main outcomes of the deliverable D2.1 and introduces the next steps related to WP2 activities.

2 TrialsNet framework

This section describes the TrialsNet methodology that will be followed to achieve the objectives of i) understanding where current networks are not sufficient to fulfil the performances required by the UCs, and ii) deriving the new requirements for next generation mobile networks. In addition, this section also defines the technologies on top of which TrialsNet will introduce its B5G functionalities.

2.1 TrialsNet methodology

The TrialsNet methodology reported in Figure 1 is based on an iterative approach that, starting from the assessment of the capabilities of the current mobile network solutions, will iteratively perform the four main phases of Deployment, Trials, Evaluation and Optimize described in the following:

- **Deployment:** This initial phase is based on WP3, WP4, and WP5 input that defines the UCs (in certain cases also with the users involvement) and the related network requirements (see D3.1 [1], D4.1 [2], and D5.1 [3]) that need to be fulfilled to support their implementation. Based on such requirements and on the capabilities offered by the platform and network solutions of the different clusters detailed in Section 3, the network infrastructures can be deployed as the base for the following phase related to the trials execution.
- **Execution:** During the trials execution phase, some UCs are expected to challenge the capabilities provided by the infrastructures of the related cluster. In order to evaluate in which measure the capabilities and the actual resources available in each cluster may differentiate, during the execution phase, proper KPIs as well as feedbacks from the users involved in the trials in terms of questionnaires aimed at assessing the perceived Quality of Experience (QoE), will be collected.
- **Evaluation:** In this phase, the data collected during the trials execution will be analysed with the objective to understand where the baseline platform and network solutions could be enhanced. Through the evaluation phase, it will therefore be possible to identify strengths, weaknesses, and potential areas of improvement.
- **Optimization:** Based on the outcomes of the evaluation phase, the platform and network solutions can be accordingly optimized by different means such as the enablement of new network functions (NF)s, the addition of spectrum resources (i.e., radio bands), the tuning of proper parameters, etc. Additionally, the optimization phase can take advantage of the TrialsNet research-oriented activities through which innovative functionalities can be provided and integrated in the current setup. Thanks to this approach, TrialsNet will provide an updated and optimized infrastructure deployments with increased performances, reliability, and efficiency.

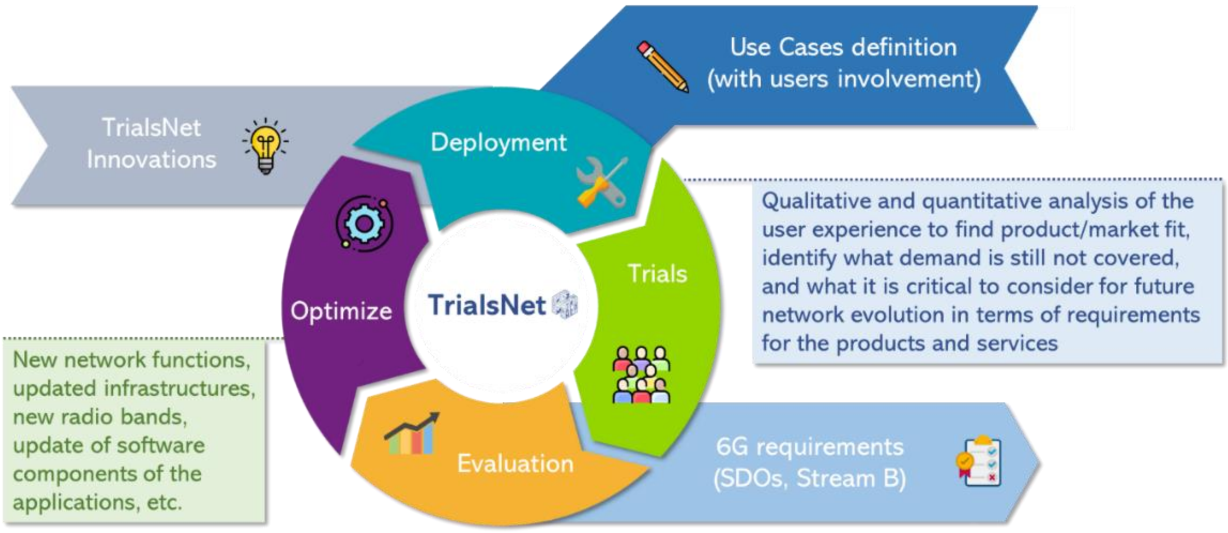


Figure 1. TrialsNet methodology.

TrialsNet aims to complete at least one full iteration of these four phases. However, the possibility of conducting multiple iterations during the project's lifespan remains open and it will strictly depend on the progress of the activities for each single UC. This iterative approach allows for continuous improvement and optimization, enabling TrialsNet to stay at the forefront of innovation throughout its duration. It has to be highlighted that the insights gained through this methodology will be not only limited to TrialsNet but they will also contribute as input in terms of new 6G requirements to the other ongoing Stream B projects [4], as well as the main Standards Development Organizations (SDOs), thus fostering a broader understanding of the subject matter related to the definition of the next generation of mobile networks.

2.2 TrialsNet technologies

The TrialsNet will develop large-scale trials through the implementation of 13 representative UCs in 4 different clusters located in Italy, Spain, Romania, and Greece. In this context, it is important to note that the development and implementation of these UCs will be based on the progression of technology following the different releases of the 5G standard. In addition, the development of such technologies and related functionalities will be diversified on cluster basis, thus providing a comprehensive and heterogeneous set of capabilities and features at project level.

In order to ensure the successful deployment and operation of the UCs, it is crucial to align the availability of advanced technologies with the corresponding 5G standards. This synchronization allows for the integration of cutting-edge features and functionalities within the UCs, maximizing their performance and capabilities.

Despite the overall progress of 5G technology, certain advancements might be limited to specific clusters or sites due to various factors such as research and development focus, infrastructure availability, or regulatory considerations. This means that while the majority of UCs will benefit from a shared set of technologies, there may be specific instances where certain UCs will have access to additional or unique technologies that are specific to their respective clusters.

These specialized technologies can offer specific advantages and opportunities to the UCs that have access to them. They may include features like ultra-low latency communication, advanced network slicing capabilities, or specific solutions tailored to a particular UC. By leveraging these technologies, the UCs can explore new opportunities, conduct in-depth experiments, and facilitate innovative applications that are not possible with standard technologies alone.

As the TrialsNet project progresses, ongoing collaboration and knowledge sharing between the different UCs and their respective clusters will be crucial. This will enable cross-pollination of ideas and experiences, fostering a dynamic environment where the benefits of unique technologies can be shared and replicated, contributing to the overall advancement of the TrialsNet project.

Therefore, TrialsNet established a comprehensive terminology to effectively differentiate and categorize the various phases of network development throughout the lifetime of the project. This terminology serves the purpose of clearly distinguishing between the TrialsNet technology deployments and the work conducted by (SDOs, which have already designated all technology emerging from Release 18 as 5G Advanced [5].

One of the key motivations behind defining this terminology is to ensure a distinct separation between TrialsNet technology deployments and the broader developments within SDO framework. The TrialsNet project necessitates careful consideration of specific HW and software components, which are crucial for the successful implementation of its platform and network solutions. By creating this distinction, TrialsNet can take advantage of focusing on the specific aspects of its solutions and innovations while maintaining a clear view on the broader advancements of 5G technology.

The TrialsNet technology deployments encompass the implementation of cutting-edge HW and software components tailored to the specific objectives and goals of the project. These deployments are integral to the network's functionality and performance, as they are designed to leverage the latest advancements in 5G technology. By clearly defining this framework, TrialsNet technology will remain aligned with the objectives of the project and utilizes the most appropriate technologies available.

On the other hand, the work performed by SDOs encompasses the broader landscape of 5G technology advancements. These organizations play a vital role in shaping the future of telecommunications by establishing standards and guidelines for the industry. With the advent of Release 18, SDOs have defined the related technologies as 5G Advanced, in terms of enhanced capabilities and features. By acknowledging this distinction, TrialsNet can recognize the contributions of SDOs to the overall development of 5G technology while focusing specifically on the TrialsNet project's unique requirements and deployments.

In conclusion, the establishment of this terminology allows TrialsNet to effectively navigate the complexities of network development within the TrialsNet project. By delineating between TrialsNet technology deployments and the broader advancements in 5G technology by SDOs, TrialsNet can ensure clarity, focus, and alignment with its specific objectives. This separation enables a streamlined approach to the project's implementation, while also recognizing and benefiting from the advancements made by the wider telecommunications industry.

TrialsNet defined the following two distinct sets of technologies as reference for its platform and network solutions development activities:

- **TrialsNet Baseline 5G Technology (Bs5G):** This technology represents the initial set of capabilities and functionalities available at the beginning of the project and provides the basis for the development phase of the UCs. Through this baseline technology, TrialsNet establishes a reference point for measuring the initial KPIs achieved during the execution of different UCs. Therefore, the TrialsNet Baseline 5G Technology provides a starting point for the project and sets the initial performance expectations.
- **TrialsNet Advanced 5G Technology (A5G):** This technology represents the set of enhanced capabilities and functionalities that will be available across the various clusters by the end of the project. The improvement work for TrialsNet A5G encompasses two primary aspects. Firstly, it involves the planned enhancements of the existing technology within each cluster. Secondly, and more importantly, it involves the incorporation of the results evaluation coming from the initial deployments of UCs in each cluster. By closely monitoring and analysing the results and outcomes of the initial UC implementations, TrialsNet will identify areas for improvement and optimize the technology to achieve more advanced capabilities and improve performances.

In other words, the TrialsNet A5G represents the collective knowledge and advancements gained throughout the different implementation phases of the UCs aiming to refine and enhance the network capabilities beyond the baseline technology. By leveraging the specific requirements and experiences gained from deploying UCs in various clusters, TrialsNet can drive meaningful enhancements to the technology. Based on the iterative approach described in the previous sub-section, this ensures that the TrialsNet A5G is not only going to be provided by the initial plans but also by the UC's on-field implementation and results coming from each cluster.

In summary, the distinction between TrialsNet Baseline 5G Technology and TrialsNet A5G provides a clear framework for the development of UCs in the project. The baseline technology sets the initial reference point for performance evaluation, while the advanced technology represents the progressive improvements based on planned enhancements and the results obtained from the initial UC deployments. This approach allows for continuous refinement and optimization, ultimately leading to more advanced and capable 5G technology within the TrialsNet's platform and network solutions.

In Section 3, a detailed overview of the available technology in terms of components and functionalities of the infrastructures across the different clusters is provided, which are summarized in Figure 2. To ensure comprehensive coverage, TrialsNet categorizes the technology in two main groups: those coming from SDOs and those specifically required to support the certain applications of the UCs. Some of these application-specific technologies are discussed in Section 4.

With this categorization, the TrialsNet Baseline 5G Technology encompasses the combination of Rel-15/Rel-16 network solutions (Rel-15 solutions are based on commercial deployments, that are planned to be upgraded to the following release of the standard: the detailed timeline of this process will be confirmed at a later stage of the project), edge and orchestration functionalities. These provide the baseline components for the initial development phase of the UCs. The TrialsNet Baseline 5G Technology serves as a starting point and reference for measuring the initial KPIs achieved when running different UCs and from which the network can evolve and improve.

On the other hand, the TrialsNet A5G goes beyond the baseline and incorporates additional elements to further enhance the capabilities and performance of the network. This advanced technology includes features such as Artificial Intelligence (AI) based orchestration and the support of AI as a Service (AIaaS) for UCs that require it. AI based orchestration ensures efficient management and coordination of resources throughout the network, enabling optimal performance and flexibility. The integration of AIaaS empowers UCs with advanced AI capabilities, enabling them to leverage AI algorithms and models to enhance their operations and applications. Other additional functionalities provided by the project include Digital Twinning and Time Sensitive Networking (TSN). Research in these fields holds immense potential for revolutionizing network management and ensuring efficient, reliable, and time-critical communication. Digital Twins (DT)s, virtual replicas of physical systems or processes, are increasingly being explored to create accurate and dynamic models of network infrastructures, as we discuss in Section 4.1.3. Additionally, the integration of TSN into DTs empowers the synchronization and deterministic communication of time-critical data in industrial and real-time applications, which promise to reshape the landscape of network management and accelerate the realization of the next-generation Internet of Things (IoT) ecosystems. Both these solutions will be developed in the context of the Spanish cluster.

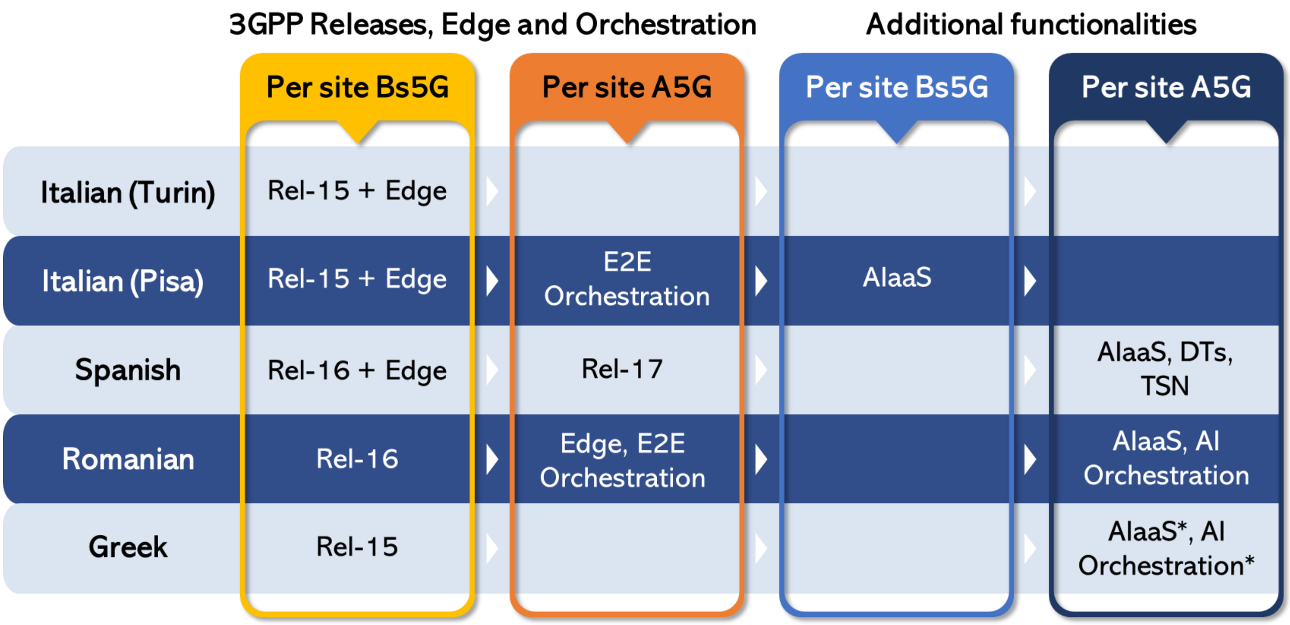


Figure 2. TrialsNet components and functionalities in the different sites (* means at service level only).

By incorporating these advanced functionalities into the TrialsNet network solutions, TrialsNet can enhance its capabilities and enable new implementation possibilities for the UCs. The TrialsNet A5G represents the culmination of planned improvements as well as the valuable insights gained from the initial deployments of UCs across different clusters. It takes into account the specific requirements and results coming from the trials that will be performed to ensure that the network evolves and adapts to meet the unique needs of each UC and cluster. As reported in the previous subsection, in case it will not be possible to satisfy completely the implementation of the UCs, this will be used by the TrialsNet to contribute towards the definition of the requirements of the next generation mobile networks.

3 TrialsNet clusters infrastructures description

This section provides an overview of the TrialsNet's platform and network solutions that will be designed, deployed, and integrated for the implementation of the trials in the four clusters located in Italy, Spain, Romania and Greece. More in detail, the Italian cluster will consist of two different sites located in Turin (see sub-section 3.1) and Pisa (see sub-section 3.2), while the Spanish, Romanian and Greek clusters (described in sub-sections 3.3, 3.4 and 3.5, respectively) will consist of one site each. It should be highlighted that the Romanian cluster will also relay on an ad-hoc experimental infrastructure that will be initially deployed in IMEC premises in Belgium and then moved to the trial site in Romania. Overall, the cluster framework provided by TrialsNet will address both commercial and experimental domains providing a complete package of trials activities for which results will be evaluated to validate further the benefits of B5G system and/or deriving new requirements towards 6G.

3.1 Italian cluster (Turin site)

This section describes the main infrastructure components in terms of platform and network solutions for the Turin site of the Italian cluster in which UC5 "Control Room in Metaverse" [1], UC12 "City Parks in Metaverse" and UC13 "Extended Reality (XR) Museum Experience" [3] will be implemented. The Turin site in the Italian cluster includes a very extensive set of technologies, that will leverage on the previously gathered experience in the 5G EVE and 5G-TOURS projects (0 and 3.1.1.5 respectively). Also, other available software component are the XR infrastructure provided by TIM (Section 0) and the Symphony IoT platform (Section 3.1.1.5).

3.1.1 Infrastructure components and functionalities

The following sub-sections provide a comprehensive description of the Turin site infrastructure that will deliver mobile connectivity through the 5G commercial network and the different platforms that will be utilized for the implementation of the UCs. Figure 3 depicts the general infrastructure scheme for the Turin site.

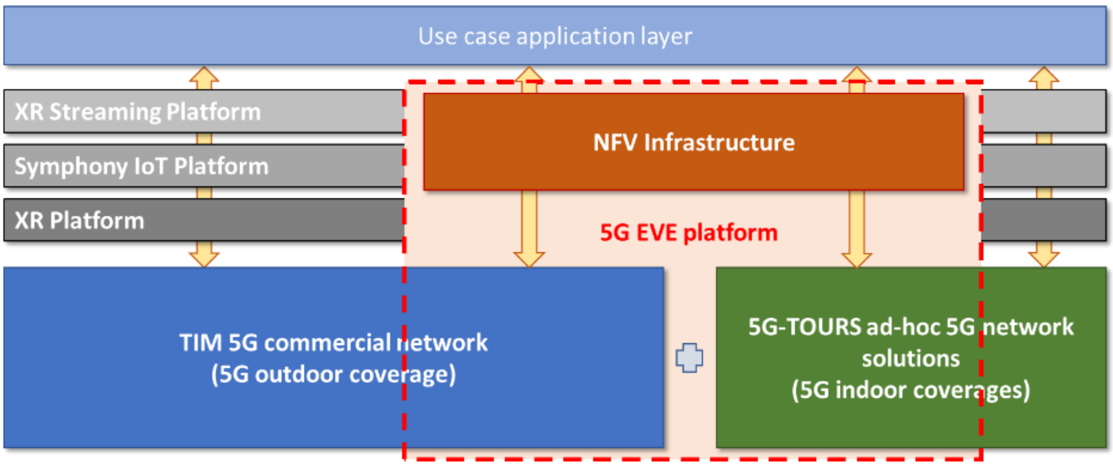


Figure 3. Turin site general infrastructure scheme.

3.1.1.1 5G network infrastructure

The mobile connectivity in the Turin site will be essentially provided by the 5G commercial network deployment of TIM. Taking advantage of the different products releases that will become available during the project's lifetime, the development of large-scale trials covering very extended areas and reaching a multitude of end-users with 5G enabled devices (phones, tablets, Virtual Reality (VR) visors, etc.) will be therefore possible. Starting from around 40 5G sites deployed in 2021, the TIM commercial network in the Turin area is continuously growing, thus extending the possibility to implement the UCs in different areas of the city. In terms of network infrastructure equipment, the Turin site is deployed on commercial products from Ericsson. The current network deployment is based on the 5G NSA (Non-Standalone) architecture implemented with Option 3 as per 3GPP Rel-15 using the 3.7 GHz band in which TIM owns 80 MHz. During the lifetime of the project, the TIM commercial network will evolve to the 5G Standalone (SA) architecture based on Rel-16 products. At the time of writing this document, the deployment roadmap of the commercial network is currently under definition so that updates on the 5G coverage based on Rel-16 will be provided in the next deliverable.

Based on the requirements (both in terms of functionalities and performance) that will come from the UCs, the TIM 5G commercial network will be extended with the platform and network solutions described in the following sub-sections.

3.1.1.2 5G EVE platform

5G EVE, "5G European Validation platform for Extensive trials" has been a project of ICT17 with the scope to support the transition to 5G by offering to vertical industries and to all 5G Infrastructure Public Private Partnership (5G-PPP) Phase3 projects facilities to validate their network KPIs and their services. The 5G EVE E2E facility consists of the interconnection of four 5G-site-facilities (France, Spain, Italy, Greece), which had been selected considering their work with vertical industries and standardization bodies, on top of their 5G technology competences. The Italian site facility was deployed with contribution of Italian partners, and coordinated by TIM, it supported UCs from ICT19 founded projects. Most of those facilities are still up and running, and available to be used and extended to support developing new activities, including TrialsNet UCs implementation.

The 5G EVE Italian platform [5] offers different radio environments for testing with dedicated CNs, including commercial 5G network (the current 3GPP release is Rel-15 NSA), that can be used with commercial Access Point Name (APN) for internet access and/or via private APN (with the APN name, 5geve.tim.it, available with enabled Subscriber Identity Module (SIM) cards) to access the 5G EVE facilities. Radio and CN are based on Ericsson equipment. The facility is multi-location, interconnected by high performance links (via TIM transport network or dark fiber), see Figure 4.

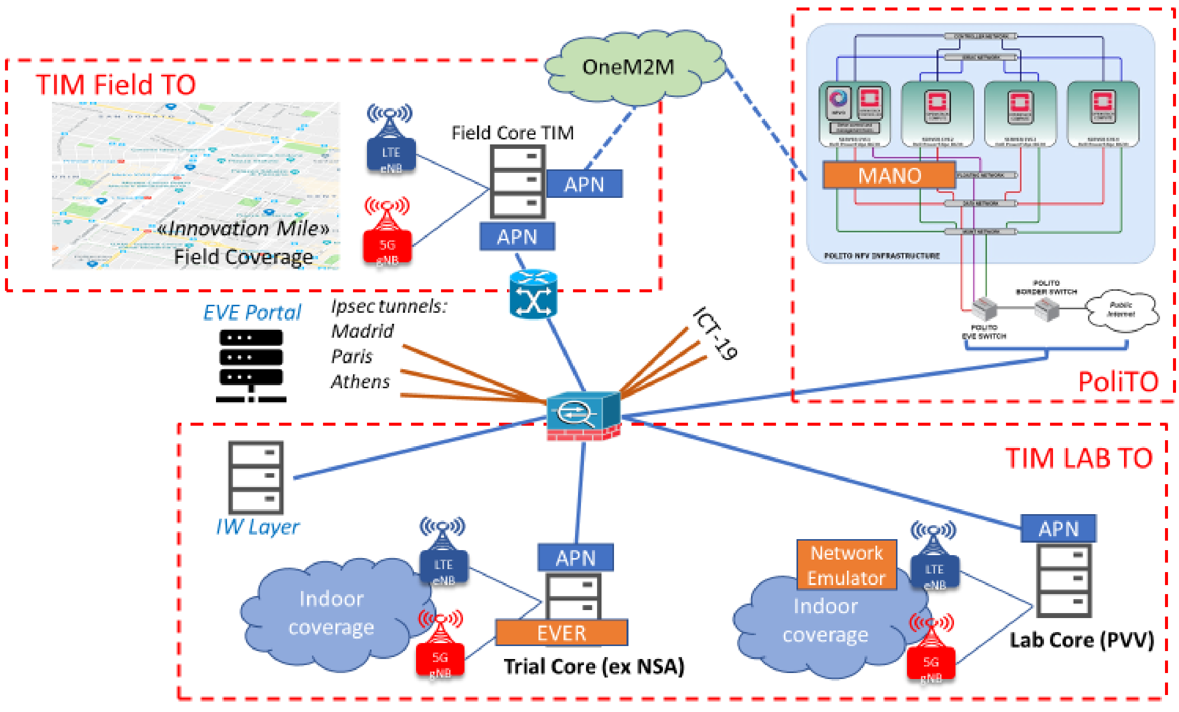


Figure 4. 5G EVE Turin site architecture.

Between the several functionalities that the 5G EVE platform can provide, TrialsNet will mostly make use of the service cloud infrastructure hosted by Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT) at Politecnico di Torino premises. This infrastructure is based on Openstack and it can onboard both Virtual Network Functions (VNFs) and Physical Network Functions (PNFs) and consists of three physical servers. The first one is acting as service server container, where all the services related to the 5G EVE infrastructure are instantiated. The other two servers are configured as OpenStack Compute nodes, where the VNFs are executed based on a Management and Orchestration (MANO) operating at service/ Virtual Machines (VMs) layer. In addition, TrialsNet will exploit the 5G coverage provided by two different environments (indoor and outdoor), allowing a very wide set of possibilities to host experiments fitting the requirements. In particular, the outdoor coverage (TIM Field TO box in Figure 4) is provided by the 5G TIM commercial network described in the previous section and will be available for TrialsNet UCs implementation in the selected areas of Parco del Valentino as well as other locations that will be further identified during the progress of the activities. The indoor coverage (TIM LAB TO box in Figure 4), also based on 3GPP NSA Option 3 architecture, can be used to validate the UC in ideal network conditions.

3.1.1.3 5G-TOURS network solutions at Palazzo Madama and GAM

Some UCs that will be implemented in TrialsNet will be located inside Palazzo Madama and Galleria d'Arte Moderna (GAM) museums therefore requiring a pervasive 5G indoor coverage coupled with high performance in terms of throughput and latency that cannot be provided by the outdoor signal. On such basis, TrialsNet will exploit the two ad-hoc 5G network solutions that were deployed by 5G-TOURS project providing a 5G indoor coverage inside the two museums [7] [8]. In particular, from the network implementation point of view, the 5G indoor coverages are connected to the TIM commercial network whose CN node is located in Milan and are based on the 3GPP NSA Option 3 architecture. From this perspective, the indoor coverages are a full-fledged extension of the outdoor coverage, providing a smooth transition and stable connectivity when moving between the two environments.

The solution active in Palazzo Madama is based on the Ericsson R4422 Radio unit (RU) coupled with the Cellmax CMAX-DFM3-43 CI53Atenna System, which allowed an effective masking solution thanks to the small size (210x210x48mm). Besides the technical requirements in terms of network performance, fundamental aspects considered during the design phase were the environmental impacts to ensure that the electromagnetic emissions respect the limits imposed by the regulatory body, as well as the architectural and decorative aspects of the museums to be respected. In relation to the secondo point, Figure 5 shows an installation detail for Radio 4422 in the seat and antenna masking in the pole.

Figure 5. Installation detail and masking solution at Palazzo Madama.

The solution implemented at the GAM is based on the Ericsson Radio Dot System as it was identified as the optimal solution to match both technical and aesthetical requirements. The solution provides indoor connectivity through remotely powered active antenna elements using standard enterprise Local Area Network (LAN) cabling while sharing centralized baseband and radio resources. More in detail, the solution at GAM consists of an Indoor Radio Unit (IRU) 8846 that provides connectivity to the 8 Radio Dot 4479 single-band 4x4 Multiple Input Multiple Output (MIMO) radios over industry-standard twisted pair cabling. Figure 6 and Figure 7 show the used equipment and some examples of installations at GAM respectively.

The baseband unit (BB) for the two 5G indoor coverages is shared and provided by the Ericsson Baseband 6630 located in the TIM network exchange point which is few kilometres far from Palazzo Madama and GAM. To provide the 5G fronthauling connection between the radio inside the museums and the baseband, two dedicated optical fiber connections were installed. For Palazzo Madama, the fiber also provides a dedicated 1 Gbit Internet connection to connect the servers that could be requested for the implementation of the UCs.

Figure 6. Radio DOT4479 (on the left) and Internal RU 8846 (on the right).

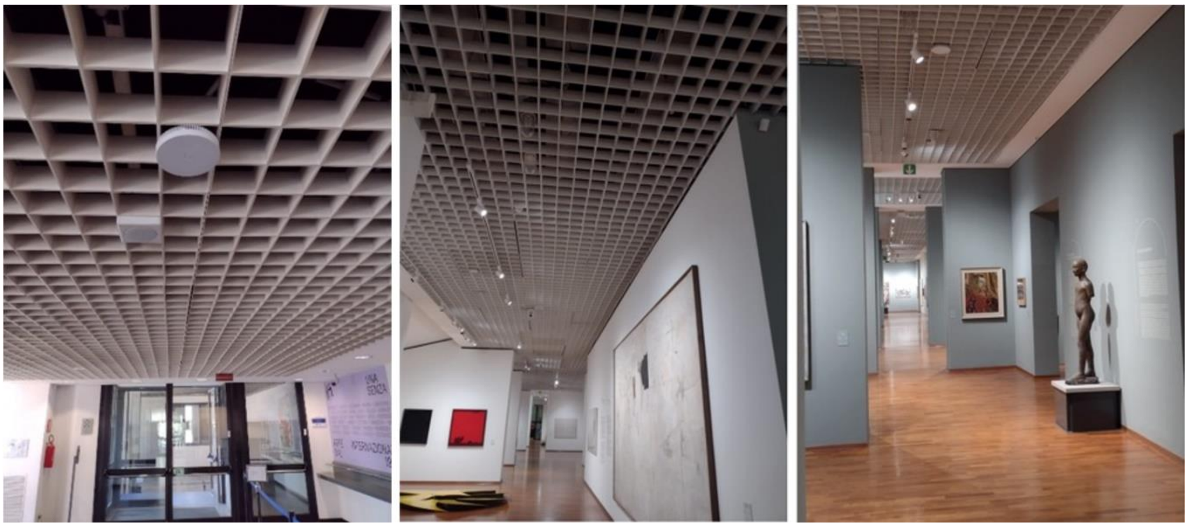


Figure 7. DOT installation at GAM.

3.1.1.4 XR platform solutions

The TIM eXtended Reality solutions are a set of platforms, developed by TIM, that offer the possibility to build Augmented Reality (AR) e VR digital services in various fields such as culture, retail, entertainment, education. The two main platforms, here described, are the **XR Platform** and **XR Streaming Platform** that will be used in the project to support the development of UC12 "City Parks in Metaverse" and UC13 "XR Museum Experience" for the Italian cluster in Turin.

As said, both platforms are used to develop AR/VR or more in general Mixed Reality (MR) digital services but with a substantial difference related to the rendering functionality, i.e., the capability to show digital content on the screen/device of the user starting from a 2D/3D Model.

In the case of **XR Platform,** this rendering functionality is performed directly by the end user device, as indicated in Figure 8, meaning that the user equipment (UE) must have the computational ability to perform this graphical functionality.

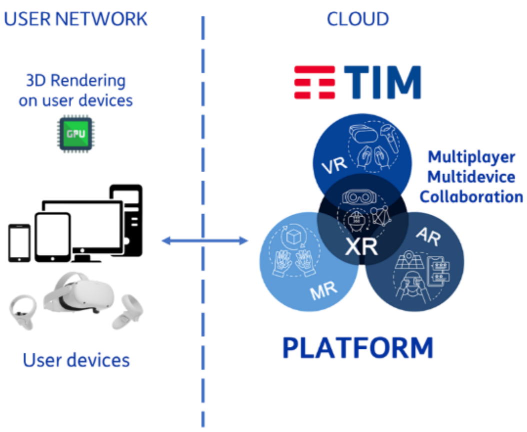


Figure 8. High-level architecture of TIM XR Platform.

In the case of **XR Streaming Platform,** the rendering functionality is moved on the cloud (or telco edge cloud), as shown on Figure 9, it means that the user device could be "thin", less performant and with smaller computational ability than the ones that are expected to be used with the XR Platform. The rendering functionality is done by a server with the render APP, and through the network the user device receives a video stream that contains the digital content related to the XR experience. In this way, the user can experience a very high quality of detail of the 3D content regardless of the device.

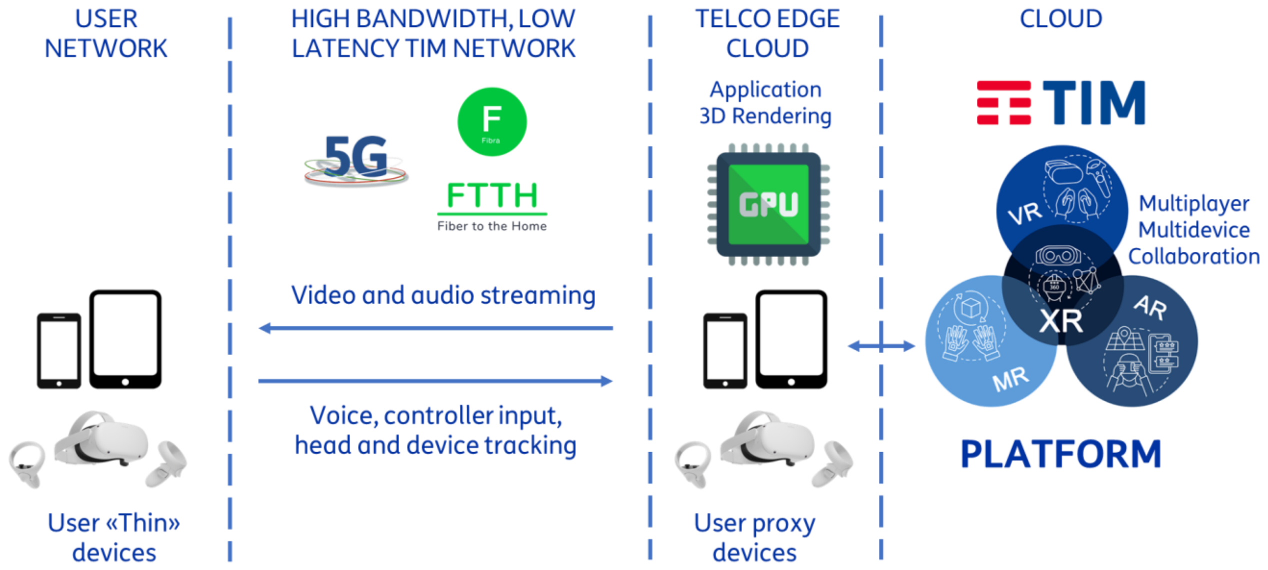


Figure 9. High-level architecture of TIM XR Streaming Platform.

In this case, an important role is played by the network since high bandwidth and low latency are needed to allow the user device to send to the server-side components some parameters, e.g., head-mounted display (HMD) tracking data, controllers input, sensors input data such as gyroscope, accelerometer, etc., that are required to select the right stream to be sent back to the user device in real time.

With the XR Streaming platform, the difference between an AR and VR experience lies simply in transmitting a video with or without transparency. If the video content (always related to a 3D content processed by the server) has a transparent background, it is possible to overlay it on the image of the smartphone/tablet webcam to obtain an AR experience. If the content of the surrounding 3D environment is also added, it can simply transform the service experience into a more immersive VR.

By separating the 3D surrounding environment from the scene objects (DTs), it is possible to dynamically switch between an AR and VR experience (on devices where AR is possible), as well as having multiple users involved in the same experience with different visual options (AR or VR). For example, with two users connected to the same experience using a tablet and a VR headset, the user with the tablet can see and interact with different DTs in their real environment, while the user with the VR headset can do the same but immersed in a virtual 3D environment. The interaction between avatars and VoIP session (to naturally speak each other) completes the experience for both users.

It is important to emphasize that the two platforms are not mutually exclusive. In cases where devices are powerful enough or where user-side device control is possible, or even where high details in the experience are not essential, it is possible to use the XR Platform, which still has lower costs on the server side.

The XR Platform is a TIM Software as a Service (SaaS) product already commercially available to its customers with different offers for various application areas, while the XR Streaming platform is currently being experimented in TIM Innovation Labs in Turin and Rome. The servers that manage the XR Platform are available in the cloud, while the servers of the XR Streaming platform are physically located between the two laboratories. The functional description of the two solutions is provided below.

The **TIM XR Platform** is a cloud-native solution available as SaaS and offers various capabilities. The platform allows for multi-player AR and VR experiences in diverse scenarios. Additionally, it enables real-time modifications of AR and VR content without the need to update end-user applications. Users can also create and manage AR and VR experiences with the help of user-friendly web dashboards provided by the platform. Furthermore, the XR Platform offers cross-platform Software Development Kit (SDK) packages (Android, iOS, PC) that can be easily integrated into apps. Another significant feature of the platform is the ability to augment near real-time data generated by third-party systems. The TIM eXtended Reality Platform consists of two main functional components that deal with the AR and VR.

The main AR platform components are described in Table 1. Both AR Mapper and AR SDK components leverage on ARKit [9] and [10], which are the frameworks provided by iOS and Android to develop AR apps, respectively. With this platform is easy and fast to build an AR experience, it is a 3-steps procedure as follows:

- **Create**: creation of the structure of AR experience using the AR Composer.
- **Define**: it consists of
  - **Set-up** in terms of definition of 2D and 3D anchors by scanning the environments and upload of augmentations, and
  - **Refine & test** as enhancement of augmentations by refining their size/placement and testing using the AR Mapper.
- **Publish**: AR experience publishing and fruition by users.

Table 1. XR Platform AR functional components.

Component name	Description
AR Composer	A Web tool to create and manage AR experiences by defining the contents to be displayed (such as info panels, videos, images, audios, 3D models, way finders, live data, etc.) through simple templates.
AR SDK	Android/iOS SDK which, integrated into third-party apps, allows you to enjoy AR experiences created using the AR Web Composer and refined through the AR Mapper.
AR Mapper	Android/iOS APP that allows you to set the spatial anchors as well as refine the positioning of the augmentation defined through the AR Web Composer.
AR Backend	Multi-tenant platform for the management of AR experiences and their fruition by users.

The main VR platform components are described in Table 2. In addition to the features previously mentioned, through the means of VR Package SDK, the XR Platform also manages the following: VR sessions, avatar replication, spatial voice replication, objects replication, laser, teleport, and grab functionalities. The package also includes events and call-backs, as well as a hierarchical distinction between users, allowing for differentiation between guide/visitor or instructor/learner roles. With this platform it is easy and fast to build a VR multiplayer experience, it is a 3-steps procedure:

- **Create:** the VR Web Manager defines and manages the VR sessions and registers the users.
- **Integrate:** Unity developer creates the VR project and integrates the package enabling multi-player functionality offered by the TIM XR Platform.
- **Publish:** VR experience is published, and end-users can make use of it.

Table 2. XR Platform VR functional components.

Component name	Description
AR Composer	A Web tool to create and manage AR experiences by defining the contents to be displayed (such as info panels, videos, images, audios, 3D models, way finders, live data, etc.) through simple templates.
Photon services	Cloud services used for multi-player management (such as synchronization events, VoIP sessions, etc.).
VR Backend	Multi-tenant platform that creates and manages VR experiences and enables their fruition by users.

The **TIM XR Streaming Platform** is an experimental platform developed by TIM that enables the creation of a MR app with a multiplayer collaborative virtual 3D environment, based on XR Cloud Rendering paradigm, that, thanks to the advantages of 5G networks, allows high-end extended reality visuals directly into the headset or smartphone from across the internet.

TIM XR Streaming platform is based on NVIDIA CloudXR solution [11] for streaming VR, AR and MR contents from a remote server, where computation actually takes place, to a XR device, allowing the final device to display high quality content. The NVIDIA CloudXR SDK is a Graphics Processing Unit (GPU)-accelerated VR/AR streaming platform that was built to stream OpenVR-based applications from a remote server. Using CloudXR, VR/AR content can be streamed over ethernet, Wireless Fidelity (Wi-Fi), cellular, and other standard networking technologies. The NVIDIA CloudXR SDK comprises a server driver, the client SDK, and sample client applications.

The server driver serves audio and video content from an OpenVR application to a client by integrating with SteamVR, encoding the rendered frames and system audio, and sending the frames and sound to the client for decoding and display. The server driver also accepts motion and control data from the client device by using SteamVR, which is supplied as a prebuilt package with its own installer.

The Client SDK contains header files and library files for adapting a thin client to support the server. The following client are supported:

- **Tethered headsets** (Windows Operating System (OS)): HTC VIVE, HTC VIVE Pro, Valve Index
- **Untethered headsets** (Android OS): HTC VIVE Focus 3, Oculus Quest and Quest 2

For AR-based on ARCore, refer to [12] for a list of devices that are certified by Google. The typical supported devices are Samsung Galaxy Tablets and Phones and Google Pixel Phones. For AR-based on ARKit, refer to [13] for a list of compatible devices. The requirements are iOS 14.2 and Xcode 12.2. The typical supported devices are Apple iPad and iPhones

The SDK provides a way to stream graphics-intensive XR content by accessing a high-powered graphics server and streaming over a radio signal (5G or Wi-Fi, for instance) to a relatively low-powered client, such as an Android-based all-in-one HMD, or a PC-connected HMDs like the Vive Pro. The SDK also enables streaming of OpenVR applications to several 5G-connected Android devices, including 5G-enabled phones. This enables more mobile access to high-powered servers, as well as access to graphics-intensive applications on relatively low-powered graphics HW.

In Figure 10 the CloudXR Server presents a virtual HMD driver to SteamVR. This allows existing OpenVR applications to see the HMD as being locally connected, and thus does not require any changes at the application level. The CloudXR server receives frames and audio from the OpenVR application and subsequently encodes and transports them to the CloudXR client. On the client, the Cloud XR Client APP receives and decodes the frames and audio and presents them to the end device runtime. This application also relays controller and HMD tracking data and other inputs back to the server. In this virtual environment, players are represented by animated [14] and can communicate with each other via VoIP and interact with the 3D models that are present in the scene.

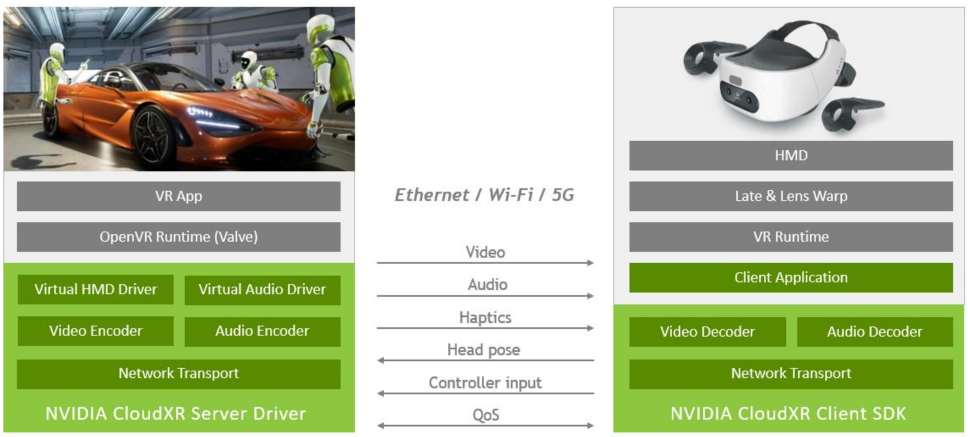


Figure 10. NVIDIA CloudXR APP architecture.

The current architecture requires each end user to use their own device (VR viewer or AR tablet/smartphone) by connecting, via CloudXR, to a high-performance server. Each individual player uses an instance of the application on a server, meaning that with the current solution a number of servers that is equal to the number of players is requested. The developed Unity [15] application is running on server and communicates with the other instances running on the other machines via the Photon multiplayer engine [16]. The Photon engine is a specialized engine designed for real-time multiplayer development, offering a range of powerful features such as low-latency communication and being cross-platform compatible. It also provides synchronized voice capabilities between instances, making it an ideal choice for VR or AR apps where voice chat is the preferred method of communication with other users.

In the TIM laboratories located in Turin and Rome, there are 5 servers equipped with RTX-3090 GPUs and Intel Core i9 processors. These servers are connected to a 1Gb down/100Mbps up Fiber-to-the-Home (FTTH) fiber connection. Some servers are directly reachable from the public internet, while others are accessible via ZeroTier Virtual Private Network (VPN) [17]. High efficiency video coding (HEVC) is used as the video codec for streaming to devices. For a full High-Definition (HD) experience, the bandwidth required is about 15/20Mbps for tablets/smartphones and 30/40Mbps for VR headsets (one stream per eye). To avoid "motion sickness" effect, the maximum latency of 30/40ms requires a network latency of about 20/30ms maximum, as the server-side application uses approximately 10ms.

The current implementation of the XR Streaming platform is based on version 3.2 of the NVIDIA CloudXR SDK. The upcoming version 4.0 of the NVIDIA CloudXR SDK will abandon the Windows OS (needed due to SteamVR) and will allow for greater flexibility in application containerization. TIM is also exploring other technological alternatives as the ones listed in [18].

3.1.1.5 Symphony IoT platform

The Italian cluster will include a complete IoT platform provided by NXW to manage the lifecycle of the data coming from the sensors used to implement the trials. The IoT platform is based on Symphony (see Figure 11), a complete Building Management System (BMS) characterized by a modular architecture. It enables a smooth and unified interaction with a variety of HW devices, IoT sensors and actuators. Symphony internally incorporates a set of services like a notification-based event management system, analytics reports, automatic actuation logics, technical system monitoring, energy management etc. Furthermore, within the context of UC5, Symphony will play a crucial role in creating a middleware layer between the sensor layer, effectively consolidating and presenting a unified layer of data to the tools responsible for rendering and processing the data with advanced 3D visualization techniques, ultimately contributing to the creation of an immersive metaverse experience. Moreover, there is consideration to open the Symphony IoT platform to third parties who wish to connect their sensors or devices to Symphony. This potential expansion would enable external entities to integrate their own HW into Symphony's middleware layer, allowing for broader data consolidation and contributing to a more comprehensive and interconnected metaverse experience.

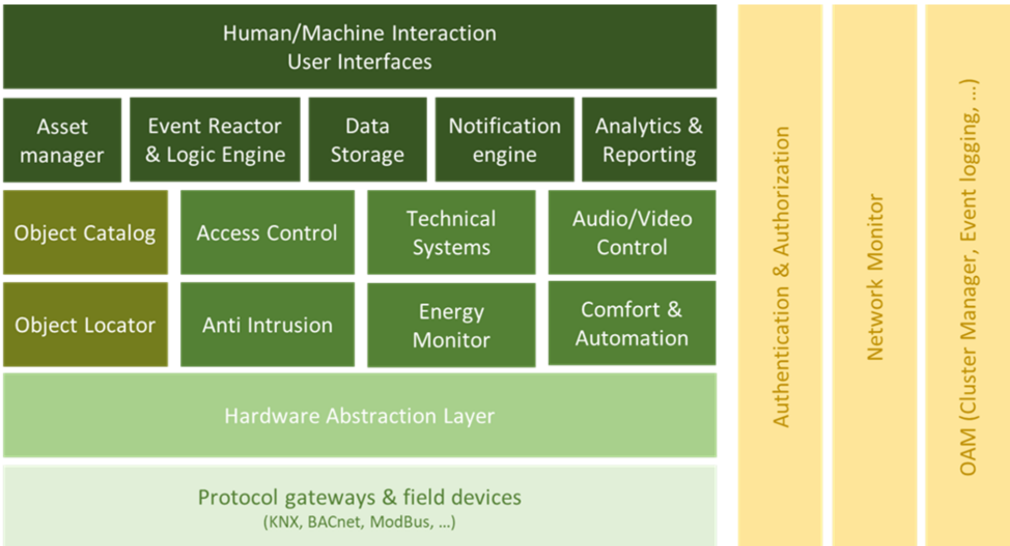


Figure 11. Symphony high-level architecture.

In the context of UC5, Symphony will act as IoT Gateway to create a unified layer to read and write the sensor data. More in detail, the functionalities that will be exposed by the platform are:

- **Device agnostic Sensor Reading:** Symphony will abstract the low-level details of the fieldbus technologies. The platform will expose to the data consumers a unified APP in terms of connectivity protocol and data model, to the data consumer. In addition, Symphony's versatile framework enables seamless integration with external devices, empowering users to effortlessly collect data and unlock new possibilities across a wide range of emerging UCs.
- **Secure data storage:** Symphony Data Storage offers aggregation, rate limiting and sub-sampling, configurable data retention policies and synchronization across multiple instances deployed in edge and cloud environments. With no single point of failure and high availability, Symphony Data Storage is built to handle massive amounts of data. ElasticSearch, Apache Cassandra, and PostgreSQL are just a few of the databases it internally supports as a backend. Additionally, a dashboard powered by Grafana is coupled with it for data visualization.
- **Configurable Dashboard:** The Symphony Visualization APP provides system operators with a web-based graphical user interface (GUI). The GUI can be completely customized, allowing users to choose the type of data to be displayed on dashboards, as well as the filters that will be used and the graphs' layout. The Visualization APP can be utilized as a local dashboard to make it easier to examine the data that was initially gathered from the sensors.
- **Event based notifications:** The system configurator can build intricate rule chains using Symphony Event Reactor to handle data from the devices and meet certain UCs. It is an extremely flexible and configurable system for handling complex events. Symphony Event Reactor, provides a powerful tool for configuring rules that can analyze and process data extracted from devices, enabling the system to send notifications and trigger specific actions based on the stream of data, thus enhancing the overall operational efficiency and responsiveness.

3.1.2 Support to the UCs implementation

As anticipated in the introduction of section 3, the large-scale trials in the Turin site will be performed relying on the TIM commercial network deployment that will be properly integrated with platforms and network solutions described in 3.1.1, based on the specific UCs requirements defined in D3.1 and D5.1. More in detail, the KPIs of the different UCs will need to be properly measured in order to perform the validation activity. Nevertheless, KPIs measurement in the context of a commercial network (especially for what concern the radio access network) is not trivial since these rely on specific counters that are dependent on the equipment and are used only for network operational and management purposes. Therefore, to measure the KPIs, application-level tools will be used. In the following sections, performance measurements of the 5G commercial network in Parco del Valentino and of the 5G ad-hoc coverages inside Palazzo Madama and GAM are reported. Further measurements will be performed if needed during the different implementation phases of the UCs.

3.1.2.1 Preliminary performance measurements at Parco del Valentino

The 5G connectivity provided by the commercial network deployed by TIM will be exploited in the context of UC5 [1] and UC12 [3]. The commercial network also supports the private APN from 5G EVE as described in section 3.1.1.2. Preliminary on-field measurements have been recently performed (March 2023) in the target areas, namely the events area (the area hosting public, cultural and entertainment events) and the Borgo Medievale where the UCs will be implemented (see Figure 12).

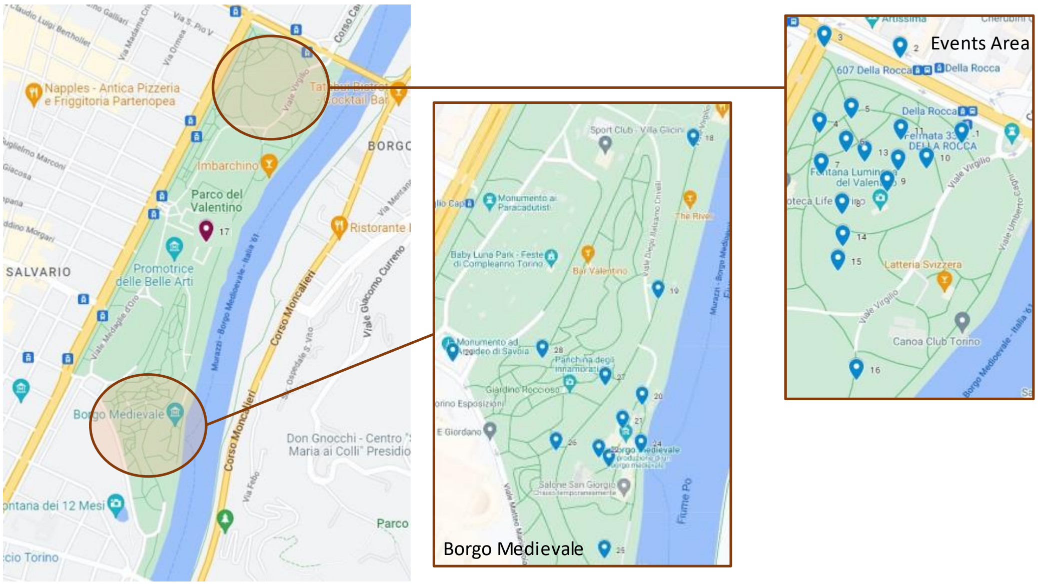


Figure 12. UCs candidate areas.

The measurements activity consists in evaluating the signal strength received by commercial terminals (Samsung S21 series), and performing a speed test (Ookla), aimed at checking both coverage and performances (i.e., downlink and uplink throughputs, E2E latencies) of the 5G network and will be used as baseline targets towards the fulfillment of network requirements defined for the two UCs. Further measurements and tests will be performed during the development phase as well as the final trial phase. In each of the 29 samples, Network Cell info Lite and Ookla Speed test have been used (see Figure 13), to get information about time, positioning, signal strength, Evolved Node B (eNB)/ gNodeB (gNB), Throughput, latencies and jitters.

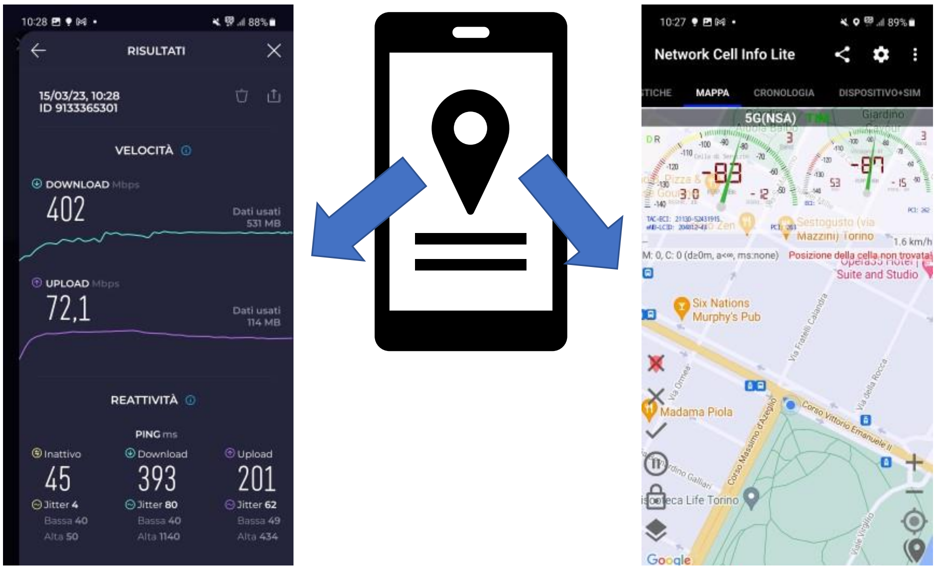


Figure 13. Data collected per sample.

Because the network performances depend on the network load and usage, those values must be considered as a reference, and need to be confirmed by most accurate measurement with known network conditions. As expected, latency and jitter vary greatly depending on load conditions even in the same test sample, for this reason the UC network usage will be considered. Just as preliminary result, the throughput values can be drawn (see Figure 14) to give a first overview about the performances expected in the area. In particular, samples 1 to 15 are included in the events area, while samples 18 to 29 are located around the Borgo Medievale. Samples 16 and 17 are taken in intermediate area, not involved in the UCs.

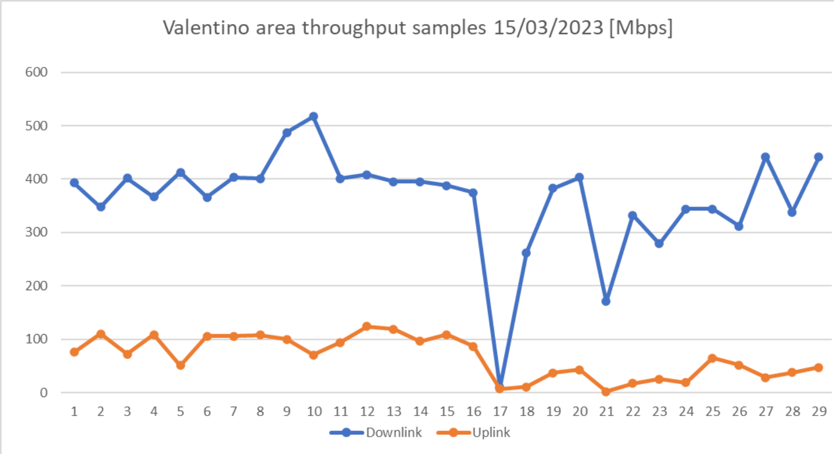


Figure 14. Throughput samples (March 15th, 2023).

3.1.2.2 Network performances of 5G-TOURS network solutions

The two 5G indoor network coverages, deployed by 5G-TOURS, will be exploited in the context of the UC13 [3]. In the following, the network performance that were measured during the trial's activities of 5G-TOURS are reported [8].

The network deployed at Palazzo Madama provided performances up to 1.2 Gbps for the downlink and up to 120 Mbps for the uplink thanks to the EN-DC functionality allowing the aggregation of 5G and Long Term Evolution (LTE) carriers. From the NSA perspective an optimized configuration of the LTE Anchor provides a stable service also in mobility. Overall, in terms of latency, the best measured value was 10ms. The 5G indoor coverage is provided in the Atrium (i.e., museum entrance), the Piano Nobile (i.e., first floor) and Sala Ceramiche at the second floor (see Figure 15 and Figure 16). It should be highlighted that all the other areas are anyway covered by the outdoor 5G commercial network.

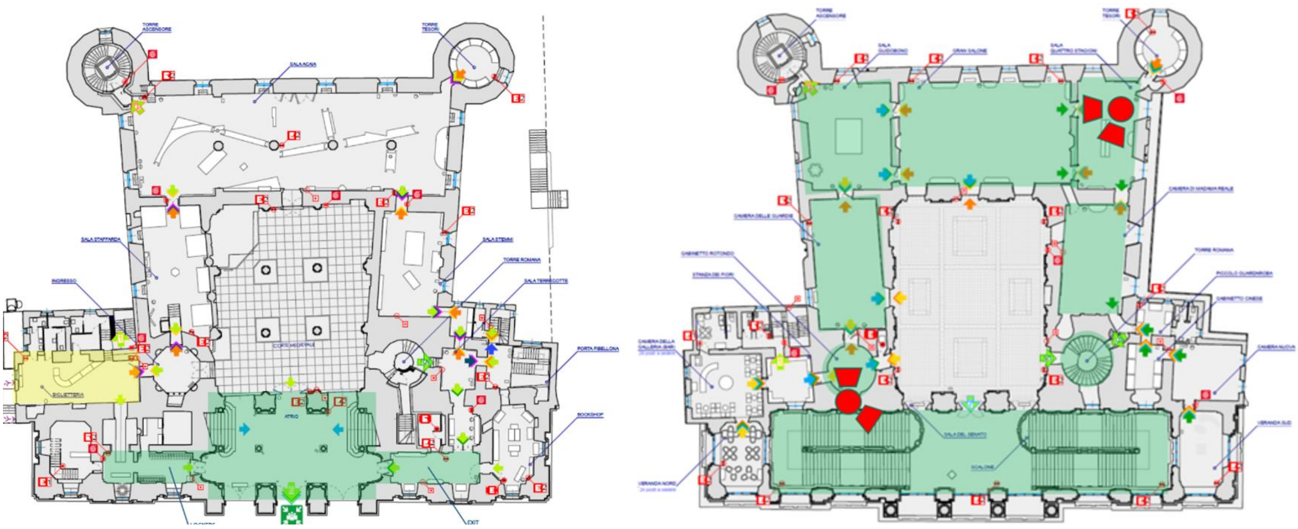


Figure 15. 5G indoor coverage of the atrium (left side) and Piano Nobile (right side) at Palazzo Madama.

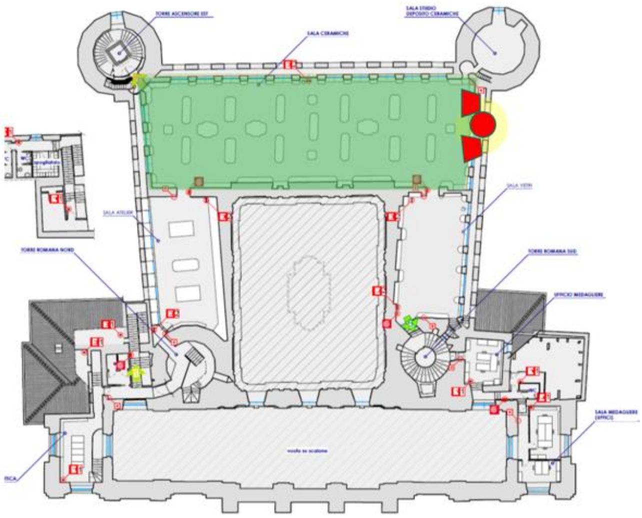


Figure 16. Palazzo Madama 5G indoor coverage of Sala Ceramiche at Palazzo Madama.

For what concerns the GAM network solution, the measured average throughput was 900 Mbps for the downlink and 90 Mbps for the uplink. The best measured value for the latency was 10ms. These results were achieved after the optimization of the LTE outdoor anchors configuration, to fit the New Radio (NR) DOT needs, and using the EN-DC feature. This solution guarantees the above network performances also inside the exposition rooms close to the corridors. Compared to the performance measured at Palazzo Madama, the lower values are because the LTE signal inside the GAM was attenuated by the concrete infrastructure of the building thus not providing the best performances in terms of throughput for the LTE EN-DC component, lower than the one that can be obtained in line-of-sight or through the windows (as in case of Palazzo Madama). Figure 17 reports the museum areas that are covered by the 5G indoor signal and the related positions of the DOT antennas.

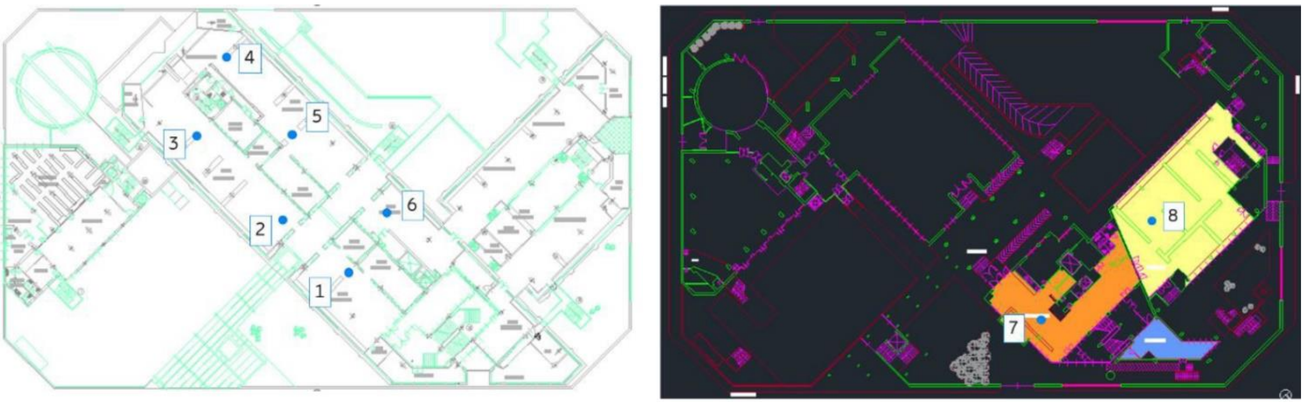


Figure 17. 5G indoor coverage at GAM's first floor (left side) and ground floor (right side).

3.1.3 Enhancements of the infrastructure

As reported in section 3.1.1.1, the 5G commercial network of TIM will evolve to the 5G SA architecture based on Rel-16 products during the lifetime of the project. Performances and UCs requirements fulfilment will be evaluated in need.

3.2 Italian cluster (Pisa site)

The Pisa site of the Italian cluster will host the deployment and validation of three UCs UC7 "Remote Proctoring", UC8 "Smart Ambulance", and UC9 "Hannes Prosthesis" [2], supported by a 5G network covering the indoor and outdoor experimental areas in the CNR campus in Pisa which represents the main trials site. In addition, three additional locations will be involved for the deployment of the UCs:

- The hospital of Fondazione Monasterio in Massa, hosting the training surgical room of UC7 and emergency unit of UC8
- The TIM site in Turin, hosting part of the 5G Core Network (5GCN) and the Ericsson Orchestration system
- The Ericsson 5G laboratory in Genoa where the UC9 will be initially deployed to be moved later in Pisa

Figure 18 provides an high level architecture of the overall scenario centered in the Pisa site and connected to Massa and Turin for the implementation of the UCs. In particular, the light-green boxes highlight the locations and system used for UC7, the light-blue boxes refer to UC8, while UC9 is represented in a light orange. As reported above, will be demonstrated in the Pisa premises after a first experimental phase in Genoa.

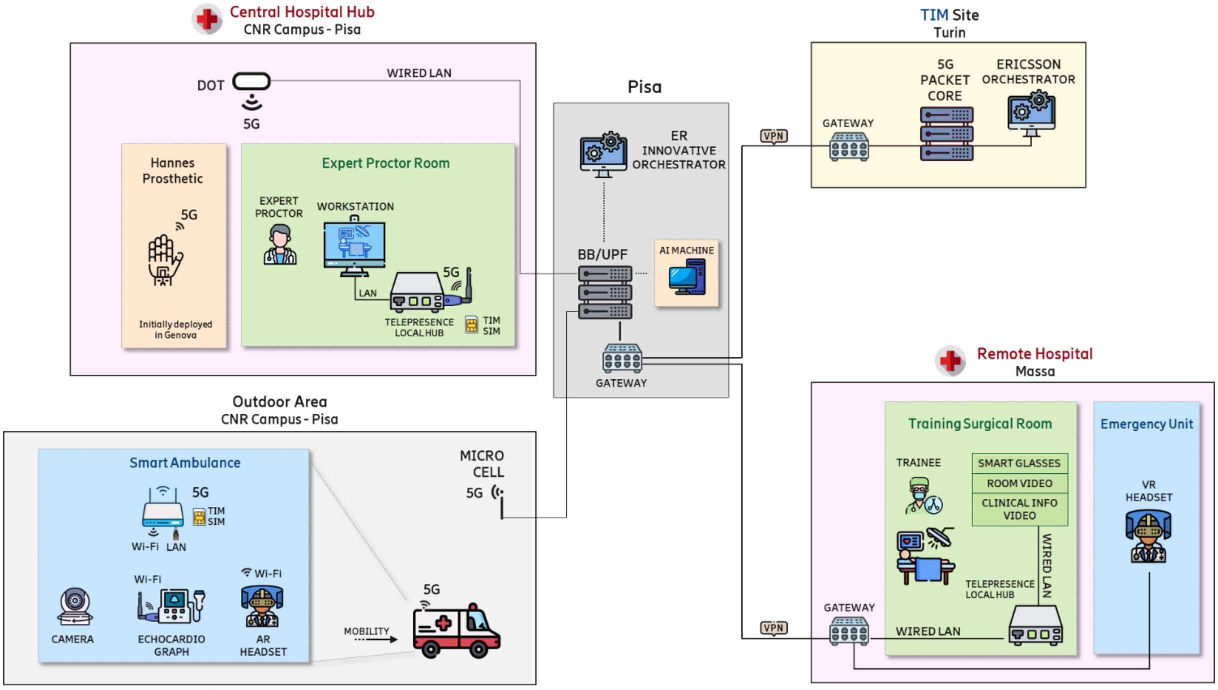


Figure 18. High level architecture for the Pisa site.

3.2.1 Infrastructure components and functionalities

As illustrated in the high level architecture reported in Figure 18, the Radio Access Network (RAN), which is based on Ericsson systems, consists of a BB and related antennas. The BB system will be hosted in a dedicated room inside the CNR Building A and connected to the CN systems which will be located partially in Pisa and partially in Turin, as explained later in this section. On the radio side, the BB system is connected to two antennas:

- An indoor antenna system (Ericsson Radio Dot) supporting the operation of UC7 and UC9
- An outdoor antenna system (micro cell) supporting the operation of UC8

At the time of release of this deliverable, the definition of which commercial Ericsson system will be used for the outdoor coverage is in progress.

The CN, which full description is reported in sub-section 3.2.1.1, is partially hosted in TIM premises in Turin and partially in TIM premises in Pisa. Turin and Pisa sites are connected through a VPN which is subtended between two specific packet gateways.

The overall 5G infrastructure is supported by the commercial Ericsson Orchestrator, located at TIM's premises in Turin. Additionally, a second orchestration module, labeled as “ER Innovative Orchestrator” in Figure 18 and detailed in Section 4.2.2, is co-located with the BB system in Pisa. It is specifically designed to manage vertical UCs that require a more challenging handling of E2E Quality of Service (QoS) with optimal usage of the underlying infrastructure resources. The orchestration of all the various infrastructure components is extended to ensure effective mapping based on actual traffic behaviour. The mapping must be fully dynamic and automatic for each specific service, including those that impose a guaranteed and deterministic performance level.

The hospital in Massa and the Pisa site are also connected through a VPN which is subtended between two specific packet gateways.

3.2.1.1 Cloud CN at TIM premises

5G CN handles a wide variety of essential functions in the mobile network, such as connectivity and mobility management, authentication and authorization, subscriber data management and policy management, among others. 5G CN functions are completely software-based and designed as cloud-native. Figure 19 illustrates a sketch of the CN architecture. The two main components are described hereafter:

- **User Plane Function (UPF):** This module is responsible for efficiently and reliably handling the user data (use plane traffic) flowing within the 5G network, is hosted in the TIM site (Central Office) in Pisa "La Figuretta". TIM policies impose that, for security and confidentiality reasons, the UPF shall be located inside TIM premises. The distance between the TIM site and the CNR Campus is about 5 km. A dedicated optical fiber link will be established between the two sites by TIM. The use of a fiber optic link will ensure that the latency introduced in the connection will be negligible (on the order of a few tens of microseconds).
- **Unified Data Management (UDM):** This module is hosted in the TIM site in Turin and is in charge of creating the credentials needed for authentication, granting access depending on user subscription, and sending those credentials to the other NFs. It retrieves the credentials from the User Data Repository (UDR). For all the UCs, UDM ensures secure and authorized access to the 5G network, enabling the seamless operation of the respective applications and services in each UC.

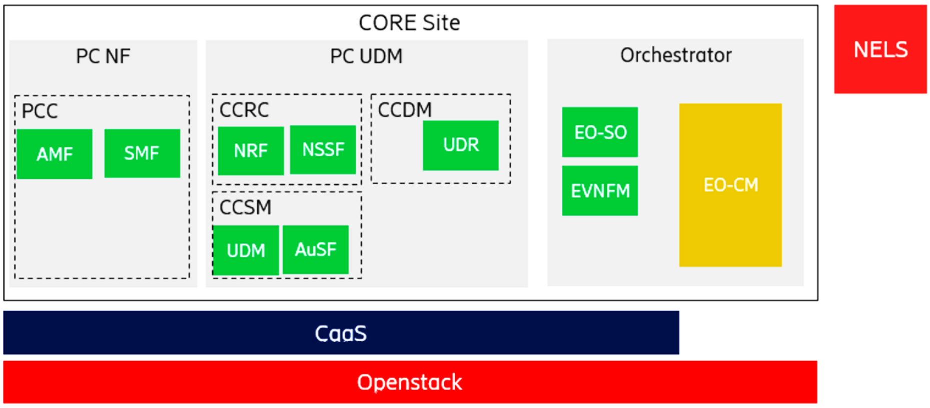


Figure 19. Architecture of CN in TIM site in Turin.

Different key 5G features are supported by the UDM NF, such as:

- Access and Mobility management Function (AMF) that accesses the UE and the RAN.
- Session Management Function (SMF), that handles the calls and sessions, and contacts the UPF accordingly
- Network Repository Function (NRF), which "controls" the other NFs by providing support for NF register, deregister and update service to NF and their services.
- Network Slicing Selection Function (NSSF): In the 5G environment, where a variety of services are offered, the NSSF (Network Slicing Selection Function) system is a solution to choose the best network slice available for the service requested by the user.
- Authentication Server Function (AUSF): 5G authentication and Key Agreement method 5G AKA are carried out via the authentication server function.

3.2.2 Support to the UCs implementation

The infrastructure described in Section 3.2.1 is jointly planned and will be deployed by Ericsson and TIM with the support of CNR and Fondazione Monasterio. This network, as anticipated, will provide the connectivity to support UC7, UC8, and UC9. The mobile network infrastructure is indeed deployed with a special attention to UCs needs, providing Edge components (e.g., UPF) to route the 5G traffic flow toward the local instances of the UCs Applications. More specifically:

- In UC7, a portable system “Telepresence system local hub” is connected to 5G via a Customer-Premises Equipment (CPE) which uses a SIM card provided by TIM to ensure access to the network in the assigned spectrum. The CPE can be directly connected to the Telepresence System or can act as a dedicated Wi-Fi hotspot, where the Telepresence System can be connected using the best available Wi-Fi technology.
- In UC8, a specific 5G modem/router is used to connect the ambulance to the 5G network. At the time of release of this deliverable, two options are investigated. In a first option, the antenna is shaped like a "hockey puck" and magnetically anchored to the top roof of the ambulance. This solution has the advantage that the Wi-Fi hotspot is completely indoors, and the 5GHz bandwidth can be used for better wireless network performance. In a second option, it is considered to mounting the 5G modem, antennas, and router on the exterior of the ambulance in a single, aerodynamic, and ruggedized "shark fin" casing. This simplified form factor reduces installation complexity and cost, but the Wi-Fi hotspot is outside the ambulance, and the 5GHz bandwidth cannot be used.
- In UC9, the trial will be first implemented and tested in the Ericsson R&D laboratory in Genoa, where a 5G network infrastructure based on 3GPP Rel-15 5G NSA is already in place. The NSA provides connectivity for combined LTE and 5G NR systems based on LTE CP function. In the second phase of the project, the trial systems will be moved to Pisa in the same indoor location where UC7 is hosted. Here a SIM card provided by TIM will grant the access to the indoor 5G coverage.

The CNR campus in Pisa, which will host UC7 and UC8 (and later UC9) is currently covered by the commercial 5G TIM network. For the specific scopes of the project trials, Ericsson and TIM will deploy and activate the mentioned new 5G dedicated network, with both indoor and outdoor coverage, with enhanced capabilities enabled by dedicated transport and orchestration functionalities.

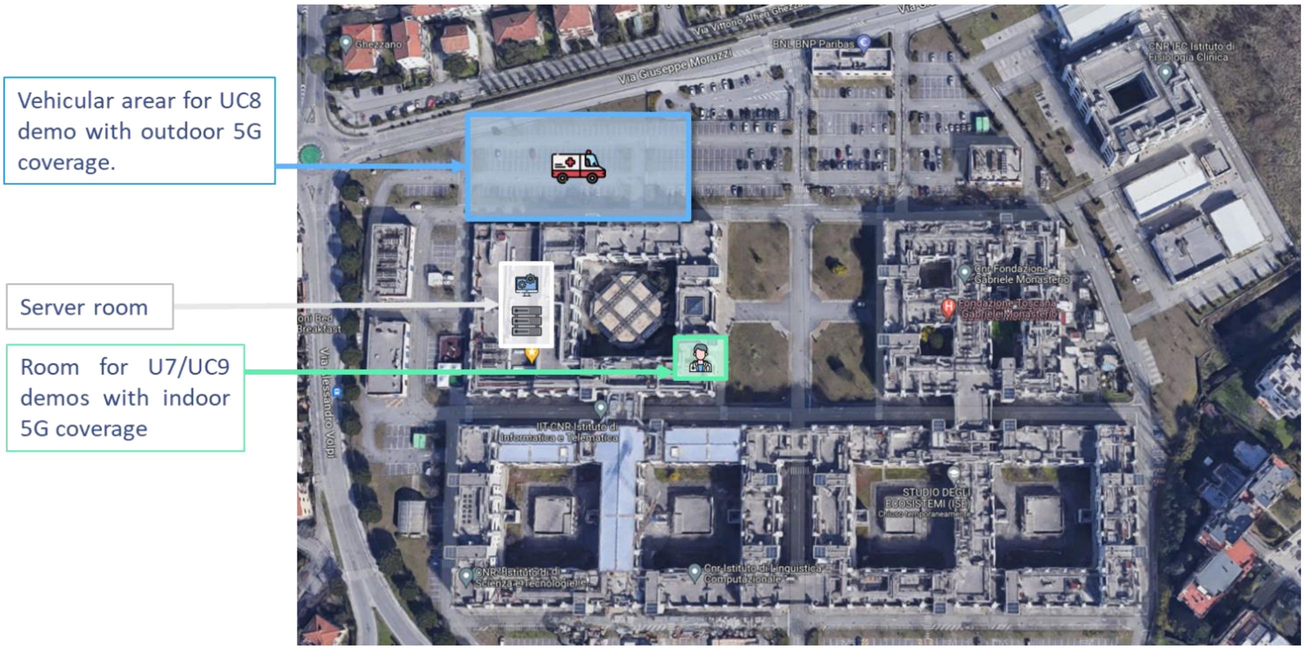


Figure 20. Demos and server areas in the CNR Campus.

Figure 20 illustrates the area of the CNR campus where the experiments will take place. As can be seen in the figure, an outdoor area has been identified and will be allocated for the experiments related to UC8. This area will be covered by dedicated 5G connectivity through an antenna placed on the facing wall. Inside the building, a room has been identified for the experiments of UC7 and specifically to accommodate the expert surgeon who will guide the training session in connection with the Massa Hospital. In the same room, the equipment related to UC9, initially developed, and tested in Genoa, will be later hosted. The room will be covered by dedicated indoor connectivity through an Ericsson Radio Dot (EDT) antenna device. Finally, the main server room of the

CNR campus will host the BB radio system, the orchestrator developed by Ericsson Research, and subsequently, the AI server to support UC9.

As anticipated in Section 3.2.1.1, a specific fiber-based communication link will be established between the server room in the CNR campus and the TIM site (Central Office) in Pisa because the UPF, for TIM policies, will be hosted in the TIM site.

3.2.3 Enhancements of the infrastructure

Since the network will be deployed from scratch, the primary goal is to develop a working solution according to the current plan. Possible enhancements will be considered if the experimentation of UCs identifies specific needs.

3.3 Spanish cluster

The Spanish cluster is based in Leganés (Community of Madrid) for which the implementation of the uses cases will rely on the 5G/B5G infrastructure provided by 5Tonic [19]. 5Tonic is an open laboratory for research and innovation that focus on 5G technologies. The 5Tonic co-creation laboratory was established to provide an open environment where members from business, industry and academia could collaborate with the telecoms innovation projects. The aim is to support innovation and help organizations work together to develop applications and business ventures. Ericsson provides the 5G system that supports the experimentation with the key objective of fostering 5G research and development and strengthening the competitiveness of European industry in the areas of 5G and innovation [20]. Figure 21 depicts the Spanish cluster overall architecture.

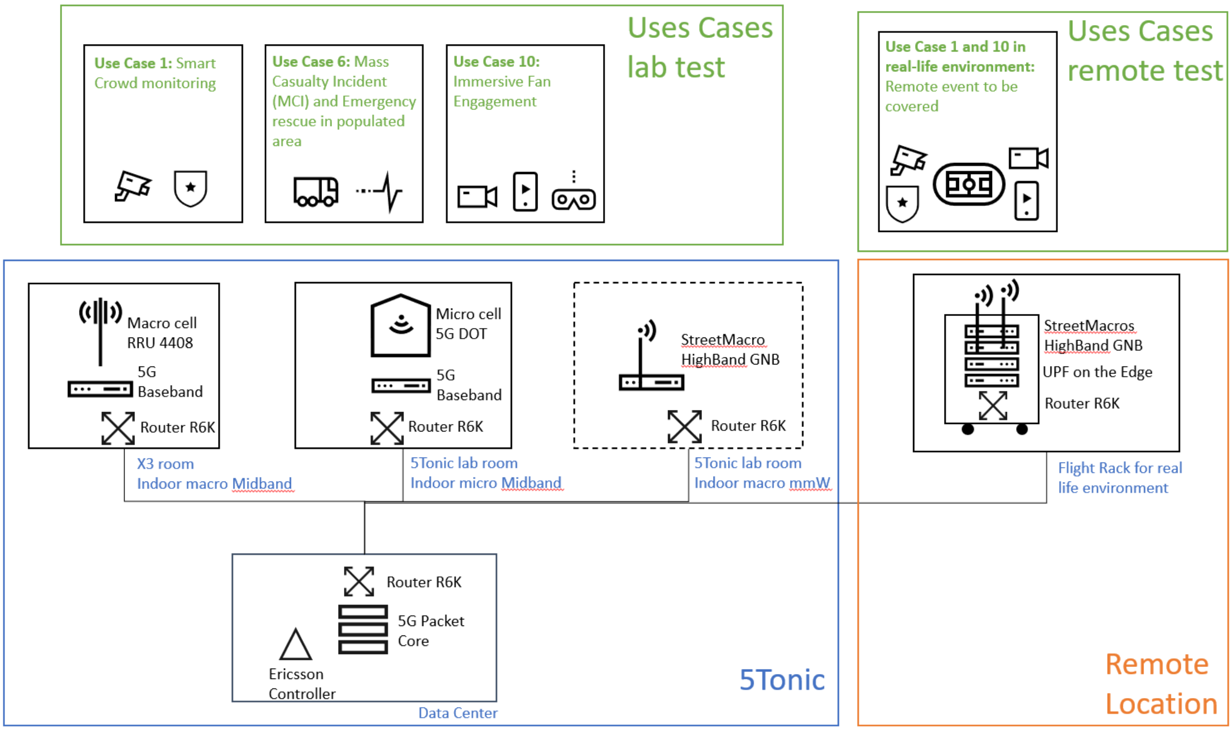


Figure 21. Spanish cluster overall architecture.

The UCs that will be implemented in the Spanish cluster are UC1 “Smart Crowd monitoring” [1], UC6 “Mass Casualty Incident (MCI) and Emergency Rescue in Populated area” [2], and UC10 “Immersive Fan Engagement” [3]. Their implementation will require a part of the infrastructure deployed on-site in addition to the labaoratory part. For that purpose, Ericsson has developed a flight rack that contains the infrastructure with Radio Access equipment and UPF that could support these uses cases in the venues that will be selected.

5Tonic infrastructure (see Figure 22) is in a continuous process of improvement and evolution, by incorporating new technologies that allows to experiment with new UCs where 5G technology is key for innovation. In the following sections the detailed infrastructure provided by Ericsson in the 5Tonic laboratory that will support the project is described.

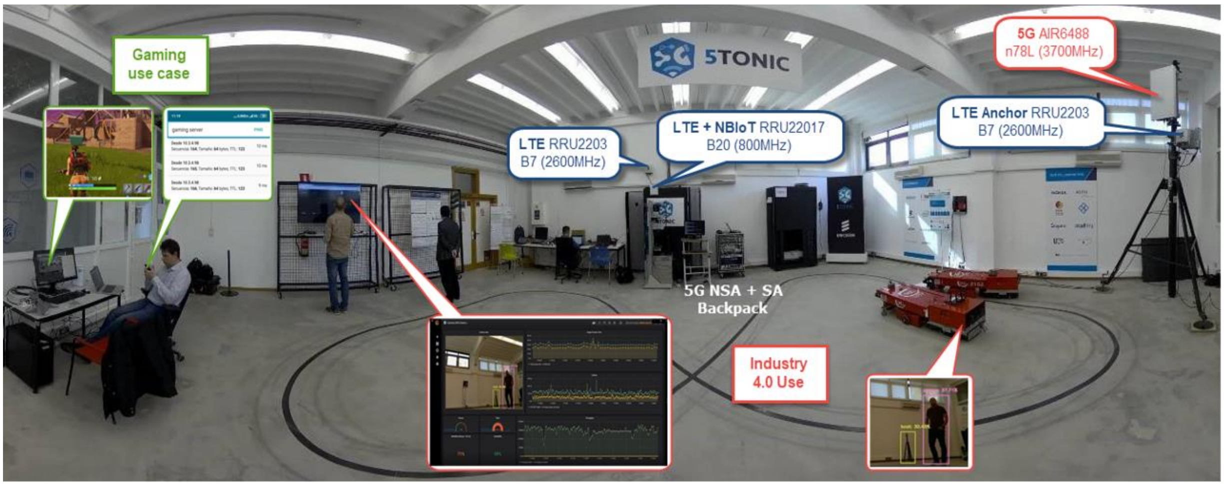


Figure 22. 5Tonic experimentation facilities.

3.3.1 Infrastructure components and functionalities

The Figure 23 shows the overall architecture for the Spanish cluster, including the different locations of the equipment and how these will support the UCs implementation in the laboratory and in the remote locations.

5Tonic has two main areas of RAN coverage called X3 room and 5Tonic lab room respectively, with 5GC CP centralized in the data center (DC). It is also planned a future deployment with high-band node based on the StreetMacro gNB, that will be located also in the 5Tonic lab room. To support the remote tests in real-life environment, a flight rack with high-band antennas and UPF on the Edge will be used.

The actual solution implemented is with 5G RAN equipment in mid-band (n78 - 3.5 GHz) and Stand-alone technology, where the LTE as anchor is not needed and the Core supports both control and UPs. Software installed in RAN and Core components are 3GPP Rel-16 compliance.

The following sections will explain the different parts of radio coverage and the elements that compose the 5G/B5G network.

3.3.1.1 RAN in X3 room

The main area of coverage, also called X3 room, is the experimentation room and is shown in Figure 23. This main experimentation facility of 5Tonic is where the concurrent experiments are executed. The goal of this area is not only to have access to 5G technology but also to have access to the experimentation tools like for example the KPI framework or the graphical dashboard of the experiments.

Figure 23. X3 room coverage area.

This experimentation room has 5G mid-band outdoor antenna deployed for covering the experimentation facility as well as the outdoor space of 5Tonic. The Figure 24 shows a diagram of the RAN equipment used in the the X3 room coverage area.

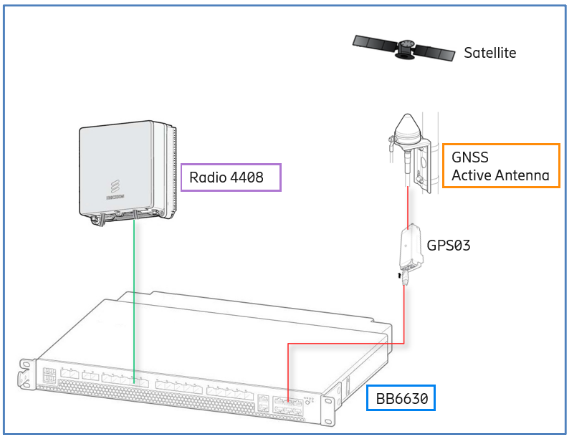


Figure 24. RAN equipment diagram for the X3 room area.

This RAN deployment is composed by the following equipment:

- **RRU 4408 n78L (B43):** Micro radio designed for more flexible and easier deployments and still efficient single and multiband. It consists in a four duplex Transmit (TX)/Receive (RX) branches supporting up to 4 x 5 W output power
- **Baseband 6630:** This equipment provides switching, traffic management, timing, baseband processing, and radio interfacing. It has the capability to be configured in mixed mode (more than one Radio Access Technology (RAT)).
- **Router 6675:** High-capacity access router, designed to provide high density 10 interfaces. It supports VPN services over Internet Protocol (IP)/Multi-Protocol Label Switching (MPLS) networks, service provider Software Defined Networking (SDN), service exposure using Network Configuration Protocol (NETCONF)/Yet Another Next Generation (YANG), extensive QoS and precise synchronization features.
- **Global Positioning System (GPS) receiver (Rx):** This component consists of a Global Navigation Satellite System (GNSS) Active antenna and a GPS signal is needed to have a time and phase synchronization required for 5G with Time-Division Duplexing (TDD) strategy. Precise signal is needed to synch the Download Link (DL) and Upload Link (UL) frames and to synch between the node B sites.

Figure 25 shows the RRU 4408 used for this deployment. Note that is the small antenna below the big antenna that is in the back that was the AIR6488 used in the first 5G deployments.

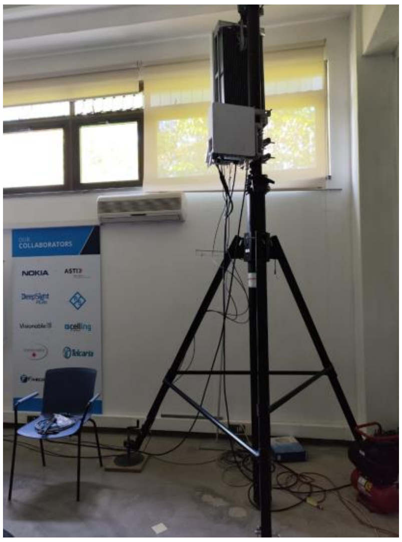


Figure 25. X3 RRU 4408 n78L (B43) antenna.

3.3.1.2 RAN in 5Tonic laboratory

5Tonic also provides coverage to the 5Tonic laboratory room. This coverage is provided using DOTs antennas (small cells) that works in mid-range bands (same n78 band) for 5G NR and has indoor coverage purpose. Figure 26 is a picture of this room, with the DOTs antennas in the roof close to the desk where the experiments are performed.

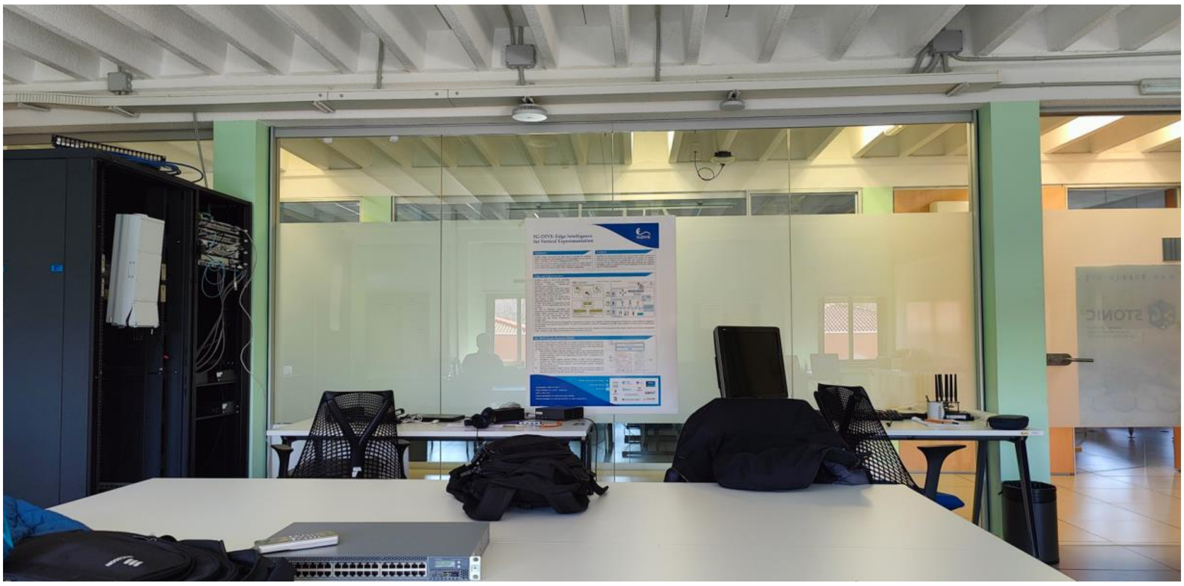


Figure 26. 5Tonic laboratory coverage.

The Figure 27 shows a diagram of the RAN equipment used in the 5Tonic laboratory coverage area:

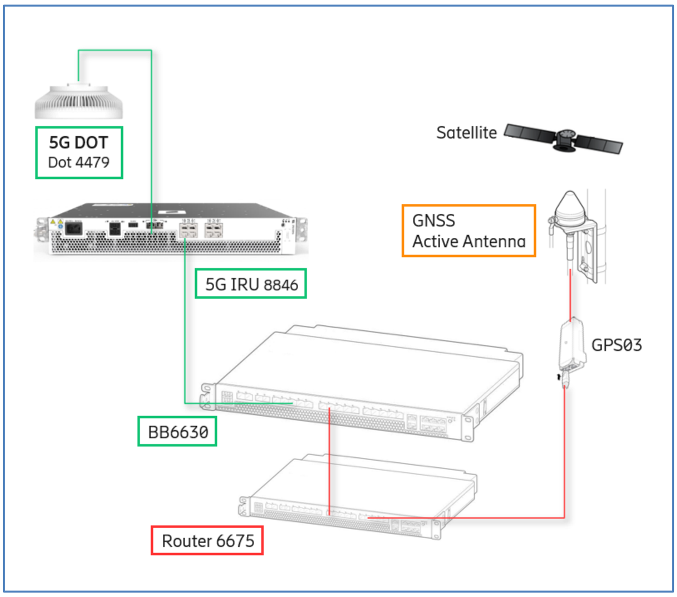


Figure 27. RAN equipment diagram for 5Tonic laboratory area.

This RAN deployment is composed by the following equipment:

- **5G DOT:** Smallest Ericsson's radio used to cover indoor areas for NR 5G purpose. Is a 4x4 MIMO antenna that offers an innovative and high performing solution that effectively connects indoor users to the whole mobile eco-system.
- **5G IRU:** This equipment has the transmission of signals as main purpose. It provides an interface to the Radio DOTs (RDs) through the Radio Dot Interface (RDI) and supplies power to the RDs through the RDI.

- **Baseband 6630:** Equipment that provides switching, traffic management, timing, baseband processing, and radio interfacing. Ithas the capability to be configured in mixed mode (more than one RAT).
- **Router 6675:** High-capacity access router, designed to provide high density 10 interfaces. It supports VPN services over IP/MPLS networks, service provider SDN, service exposure using NETCONF/YANG, extensive QoS and precise synchronization features.
- **GPS receiver:** As was already mentioned in the previous sections, it is used for time and phase synchronization in TDD.

Figure 28 shows the 5G DOT antenna used for this deployment with the IRU and the Baseband in the Rack in the back. This 5G DOT covers the area of the experiments performed in the desk below, as this mechanic arm.

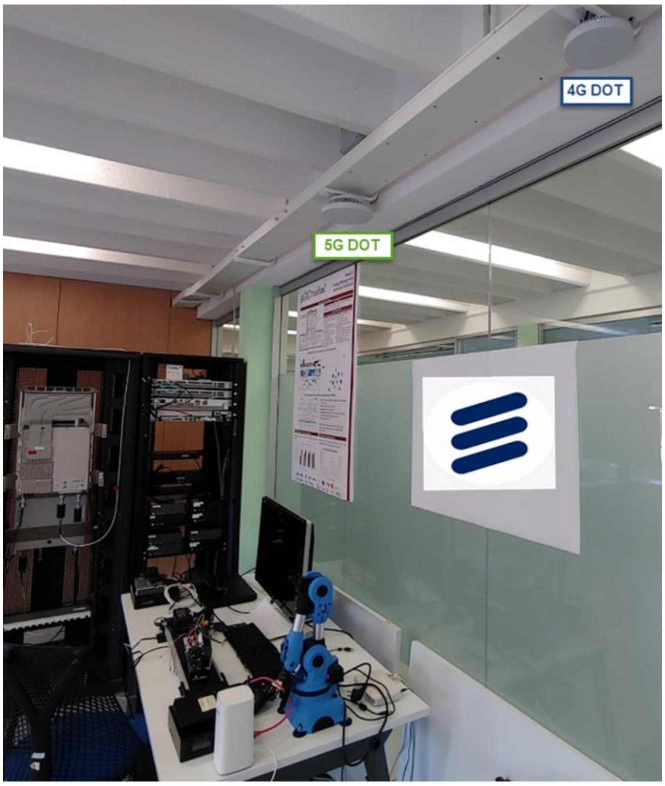


Figure 28. 5G DOT antenna, IRU and Baseband.

3.3.1.3 5G Core

The 5GC is deployed at the 5Tonic DC and it contains the basic NFs required for supporting the 5G System:

- **Basic NF:** NRF, Network Slice Selection Function (NSSF).
- **Subscriber NF:** UDM, UDR.
- **Control NF:** AMF, SMF, Policy Control Function (PCF).
- **User Plane NF:** UPF.
- **Exposing:** Network Exposure Function (NEF).

The 5GC is the cloud-native version of Ericsson and runs on top of a Kubernetes deployment. The Kubernetes-based solution is a container as a service (CaaS) platform that runs directly on the underlying HW [21], this provides the support for cloud-native applications as the fastest and most cost-efficient way:

- Automation of a Kubernetes over bare-metal cloud infrastructure is easier to achieve since the lack of a virtualization layer significantly simplifies the architecture, with fewer products and components to maintain, and fewer people needed to operate the technology,
- A Kubernetes over bare-metal infrastructure is more suitable for distributed cloud infrastructure deployments to provide edge solutions, where 5GC or Cloud RAN applications are needed,
- The introduction of new acceleration technologies (smart Network Interface Controller (NIC), etc.,) becomes easier for new 5G UCs,

- APP performance is better and more deterministic,
- Savings in the magnitude of 30 percent are possible, including costs for energy, operations and maintenance, software licenses, and HW.

The 5GC running on top Kubernetes over bare-metal infrastructure delivers a simplified architecture compared to running containers in VMs, and greater efficiency, performance, and automation can be achieved. The solution is simpler stack and makes better use of the underlying HW compared to virtualized infrastructure, enabling more efficient continuous integration and continuous deployment capabilities.

3.3.1.4 Portable system

Ericsson developed at 5Tonic a portable system, based on the concept of Non-Public Network (NPN) [22], which is able to provide 5G NR coverage to sites outside 5Tonic premises but using the 5GC and the experimental infrastructure of 5Tonic. This portable infrastructure could support UCs implementation in remote locations.

The design of the NPN deployment shown in Figure 29 takes the advantage of the new capabilities provided by 5G, such as Control User Plane Separation (CUPS) and UP flexibility, to deploy at vertical premises only the equipment required for providing the access network (gNB) and the local break-out of the UP (UPF, transmission routers).

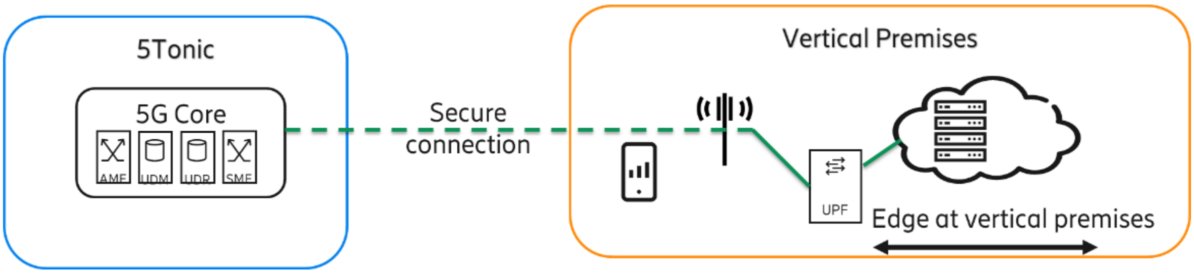


Figure 29. Diagram of NPN deployment.

The on-premises equipment uses a secure connection towards 5Tonic facilities in order to get access to the CP part of the 5GC. The secure connection used is Internet Protocol Security (IPSEC), a secure network protocol suite that authenticates and encrypts packets of data to provide secure encrypted communication between 5GC and 5G RAN. With this on-premises equipment, the 5Tonic 5G coverage can be extended to external premises and hence provide the same capabilities that 5Tonic has, including all the experimentation infrastructure.

3.3.1.5 Controller

Ericsson has a system that is used to orchestrate elements from the network deployed. This element is an open application that is developed to be able, at the RAN side, to collect the configuration of the gNB and counters information related to network behaviour. This system could also make changes in the network configuration and even change RAN features on real-time, but this feature would not be available in the context of the UCs implementation. The system could also operate over the UPF with the same purpose.

3.3.2 Support to the UCs implementation

Ericsson support the UCs with active measurements of the network KPI. This activity provides the verticals with relevant information that helps to understand the UC behaviour over the 5G network. For that, the Table 3 shows the Network KPI framework that are collected and was reported in the following deliverables: D3.1 [1], D4.1 [2] and D5.1 [3].

Table 3. Common Network KPIs.

Metric	Description
Downlink throughput per user	Number of bits contained in the service data units delivered to Layer 3 that can be transferred from the network to a device over a certain period of time.
Uplink throughput per user	Number of bits contained in the service data units delivered to Layer 3 that can be transferred from a device to the network over a certain period of time.

Downlink cell capacity	The maximum amount of data (number of bits contained in the service data units delivered to Layer 3) that can be transferred from the network to all devices in a specific cell (a geographic area covered by a single cell) over a certain period of time.
Uplink cell capacity	The maximum amount of data (number of bits contained in the service data units delivered to Layer 3) that can be transferred from all devices in a specific cell to the network over a certain period of time.
APP-level latency	Amount of time it takes for the APP to receive a response or output after sending a request or input to a server or network. It is a measure of the delay that the device experiences when interacting with an APP. This KPI is calculated as the duration between the transmission of a small data packet from the device with the successful reception in the APP connected to the UPF and located in the Edge computing and the response back time.
Reliability	the KPI network Reliability measures the probability of transmitting an amount of layer 2 packets within the required maximum time. The maximum time is the time to deliver an amount of data packet from UE to the APP located in the EDGE. (This measurement considers the protocol layer 2 Service Data Unit (SDU)).
Coverage	Geographic area where a network signal can be received and used by a device.
Service availability	Percentage of time the E2E system is fully operational, this being defined as the ratio of uptime over the total time (uptime plus downtime). This KPI measures with an ICMP packet between the UE and the APP located in the EDGE. If the ICMP packet reaches the destination successfully within an estimated time the availability is OK, if not the availability is NOK (Not OK).

The *software probe* is a component that extracts KPIs from the end-user traffic with the granularity of *flow* for IP traffic. A *flow* is identified by a tuple of origin IP address, destination IP address, origin Port, destination Port, type of protocol. This approach allows to obtain KPIs related to the APP flow, which provides insights about the performance of a specific APP in the 5G System.

The *software probe* can be deployed in any Linux-based system (tested in ubuntu servers and raspberry PI), Mac, and Windows, native or virtual, and it is configured to capture the APP traffic from a system network interface. There are two deployment options: (i) when it is possible, the probe is deployed in the System Under Test (e.g., in the APP host or in the client host) (ii) the probe can be deployed in an independent system that receives a copy of the APP traffic using port mirroring.

In Figure 30, two probes running on the Session Under Test (SUT) host in the (v)APP and UE sides, and another probe that receives a port mirroring of N3 interface (UP) are depicted. In addition to the deployment options, the software probe supports the following capabilities: Layer 2 packet capture, Gateway Tunneling Protocol (GTP), Layer 3 capture (VPN, e.g., network TUNnel (TUN)/ Test Access Point (TAP)).

The *software probe* exposes a Representational State Transfer (REST) API that allows to control the probe, including the definition of the Berkeley Packet Filters (BFP) filter, which defines the APP traffic.

The *software probe* can generate the KPIs Round-Trip Time, One-Way Delay and Throughput, for both uplink and downlink. Other KPIs like Jitter and Reliability can be generated from the data exposed by the *software probe* in the real-time database.

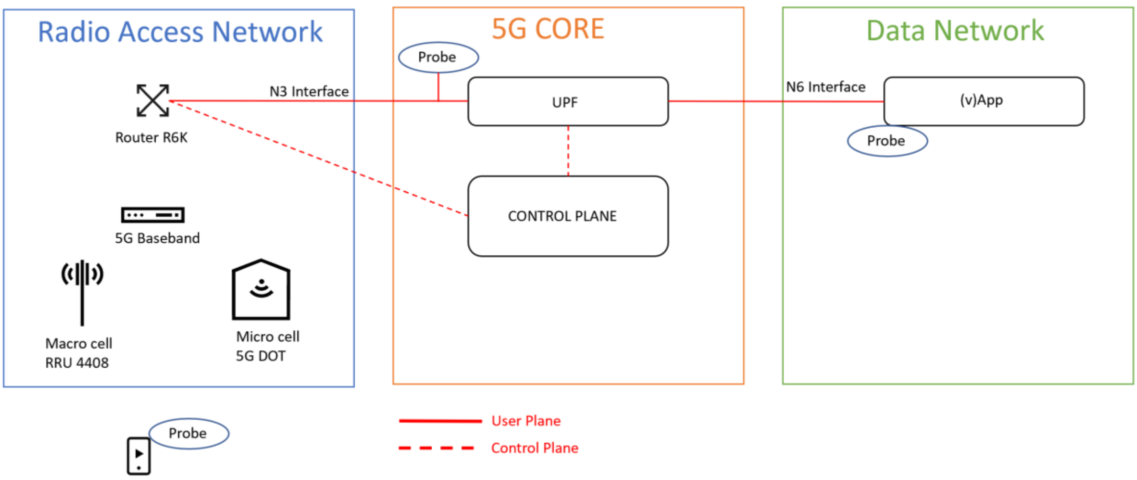


Figure 30. Software probe deployment options.

Besides the *software probe,* statistics coming from the basebands nodes and the routers are used as metric sources. As part of the KPI framework, TrialsNet will deploy different collectors to retrieve information from these systems: Throughput information from cell or per router interface, including Virtual Local Area Network (vLAN) interfaces, and cell status for:

- **Real-time database:** All the information generated by the metric *sources* is stored in an influxDB database, with the timestamp of the metric. This information is used for the derivation of KPIs and for the visualization.
- **Visualization:** The visualization system is based on Grafana as it is shown in Figure 31, which allows the creation of dashboards tailored for the UCs under test.

Figure 31. Example of Grafana dashboard.

In addition to the passive measurement of the KPIs, 5Tonic provides a set of tools for performing active measurements of the KPIs, including net-tools (ping and iperfs) and Speed Test alternatives.

3.3.3 Enhancements of the infrastructure

The actual 5G infrastructure deployed in 5Tonic has supported many UCs related to industry, gaming as the requirements is aligned with what is achievable by the network. However, the analysis of the needs from actual UCs, in terms of high user data rate with small jitter experience, requires the network setup evolves to be feasible.

With this objective, Ericsson and terminals manufacturers roadmap have been studied and conclude the deployment of high band frequencies in combination with Stand-alone technology will the best solution.

High-band have the advantages of:

- Having wider bandwidth and could aggregate more carriers.
- There is a latency reduction in high-band compares with mid-band due to numerology.
- High-band is not largely deployed in Spain compared to mid-band, so it will be easier to deploy in real-life scenarios with not affective operator's user traffic.

Actual Software does not support the combination of high-band with SA, however high-band equipment exists and is supported in a NSA. When Software will be available to support SA case, the network will be updated.

The Figure 32 shows a diagram of the RAN equipment for high band that will be used in the 5Tonic, which is composed by:

- **StreetMacro 6701:** This equipment is for high-band frequency (n257) and includes baseband, RU and antenna.
- **GPS receiver:** As was already mentioned in the previous sections, it is used for time and phase synchronization in TDD.

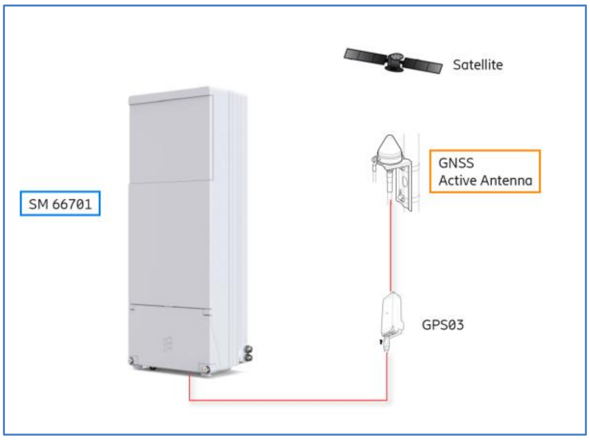


Figure 32. RAN equipment diagram for high-band solution.

Figure 33 shows a picture of the Highband equipment and the installation in the 5Tonic lab coverage area. This equipment is the Ericsson solution for a massive deployment in big cities (is known as StreetMacro), and when the software will support SA technology, will be the B5G solution in the road to achieve demanding requisites of the UCs.

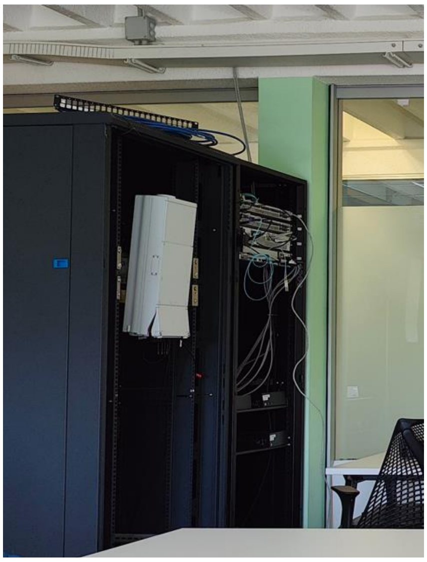


Figure 33. 5G StreetMacro 66701 for high band frequency located in 5Tonic laboratory.

3.4 Romanian cluster

The Romanian cluster will host the deployment and validation of the UC1 “Smart Crowd Monitoring” and UC4 “Smart Traffic Management” and will be based in Iasi, leveraging both the indoor 5G SA Rel-16 infrastructure from the Iasi Orange 5G Lab as well as the outdoor 5G NSA commercial network provided by Orange Romania. In conjunction with the infrastructure from Belgium, presented in Section 3.5

Orange 5G Lab is part of an international initiative of the Orange Group that aims to support economic players and researchers to better understand the opportunities, value and utility of 5G and to develop solutions that will truly make a difference in the digital economy. Located on the premises of the Faculty of Electronics, Telecommunications and Computer Science from TUIASI, the Iasi Orange 5G Lab offers its partners and experimenters the newest 5G communication network, advanced platforms and equipment, as well as a dedicated team of experts from Orange, Continental Automotive and the Technical University “Gheorghe Asachi” from Iasi.

3.4.1 Infrastructure components and functionalities

The Orange 5G Labs, from both Bucharest and Iasi, are the main places that will host the infrastructure for the Romanian cluster’s UCs and will be the desired places for testing and validation of the related applications. The Bucharest 5G Lab is located inside the CAMPUS Research Center of the Polytechnic University from Bucharest (UPB) and currently implements a full 5G SA infrastructure, comprising 5G RAN, Core, Edge Computing and advanced SDN Network in the DC.

The Iasi 5G Lab is located inside the Iasi Technical University (TUIASI) and currently hosts only 5G SA RAN components. In the next months it will be updated so that it will have similar edge-computing capabilities as the Bucharest laboratory and in medium-term the RAN will be extended so that the UC area will be covered with 5G SA connectivity. For this reason, initially the commercial 5G NSA network will be used for piloting and testing of the developed solutions.

A summary of the Romanian cluster testbed’s capabilities is presented in Table 4, providing the testbed’s early expected resources availability at project start.

Table 4. Romanian testbed current capabilities.

<table>
<tr><th>5G Infra\ Location</th><th>RAN NSA/ SA</th><th>5GCN</th><th>IP Transport</th><th>IaaS</th><th>MANO</th><th>Security</th><th>MEC</th><th>Slicing</th></tr>
<tr><td>Iasi Outdoor coverage</td><td>5G NSA, future SA</td><td>Ericsson 2.15</td><td rowspan="2">Cisco NXOS IPFABRIC

Orange Commercial Transport Network</td><td rowspan="2">Openstack
Kubernetes</td><td rowspan="2">OSMv12</td><td rowspan="2">Fortigate
1000D
DDOS</td><td rowspan="2">Col-located
IaaS with 5GC</td><td>APN-Based</td></tr>
<tr><td>Iasi/Bucharest 5G Lab Indoor coverage</td><td>5G SA</td><td>Nokia Compact Mobility Unit (CMU) 21.1</td><td>S-NSSAI based</td></tr>
</table>

Figure 34 depicts the overall architecture of the Romanian cluster that is capable to provide multi-slices implementations, with QoS/QoE guarantee in the concurrent services implementation, as eMBB (1500Mbps DL/150MBps UL) or Ultra-reliable low latency communication (URLLC) (E2E one way delay <4 ms), based in 3GPP Network Slice Selection Assistance Information (NSSAI) parameters[23].

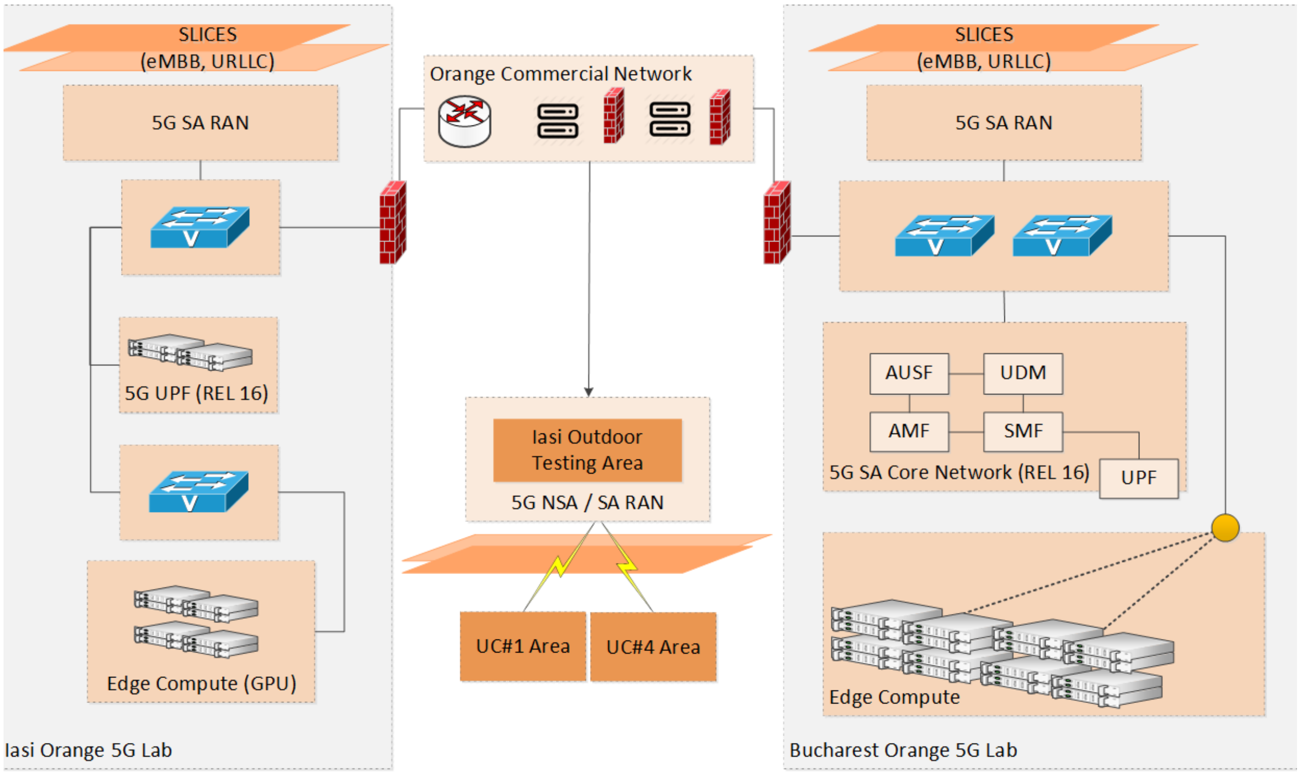


Figure 34. Orange 5G Labs architecture.

The Romanian testbed will pilot the envisioned Smart Crowd Monitoring and Smart Traffic Management within two different phases, looking at first at the preliminary results using the current commercial 5G NSA network and then evaluating the applications performance when running on a 5G SA private network.

- **Phase 1:** Testbed deployment started with a commercial 5G NSA implementation in Iasi, for early trials, with the 5G NSA RAN and Core Option 3x (virtualized core solution). In the scope of the project, a private APN will be created, so that all the traffic from the surveillance cameras installed in the UC areas, as described in D3.1 [1], will be directed to the edge-compute facility from the Iasi 5G Lab. The Phase 1 will also include testing and validation activities that will be performed indoor, in the Orange 5G Labs from Iasi and Bucharest, through a private 5G SA 3GPP Release 16 network.
- **Phase 2:** In this phase, Orange's testbed is expected to implement an outdoor 5G service over SA network in a private mobile network concept, that is integrated in the Bucharest 5G Lab testbed from CP and a local UPF in Iasi (CP/UP separation) that is 3GPP Rel-16 compliant. The 5G is running on dedicated virtualized infrastructure, Nokia CMU 5G SA Option 2 implementations as seen in Figure 35.

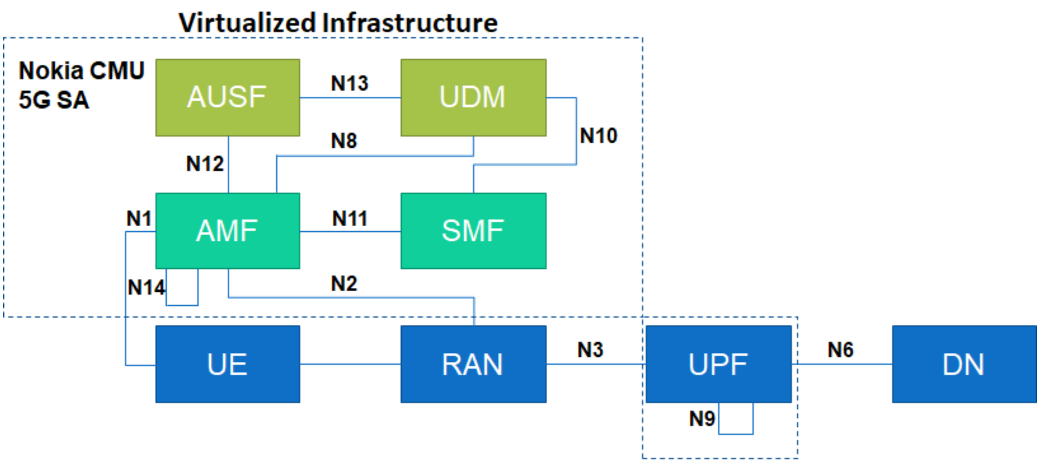


Figure 35. 5G SA implementation in the Romanian testbed.

3.4.1.1 RAN infrastructure

From all available 5G NSA architecture options, Orange Romania started its 5G deployment in n78 band (3.5 GHz) using 5G NSA Option 3x. By using Fourth Generation of mobile communications (4G) as the anchor point of the CP, a good service continuity can be met while supporting rapid network construction in the initial stage of 5G deployment. Considering n78 is a TDD band and that the DL traffic is considerably higher than the UL, and also due to coexistence of LTE TDD in 3.5 GHz spectrum, ORO selected 8:2 the DL/UL timeslot ratio (DDDDDDDSUU with a 3ms shift, with 5 ms repetition, as illustrated in Figure 36. In the Iasi and Bucharest Orange Romania 5G Labs, the DL/UL slot assignment has been configured 4:1 (DDDSU with 2.5 ms repetition), as there is no LTE TDD deployment. If the traffic pattern on certain sites indicates that the UL traffic has a higher percentage than the DL, then the DL/UL timeslot ratio may be changed to ensure best 5G performance [24].

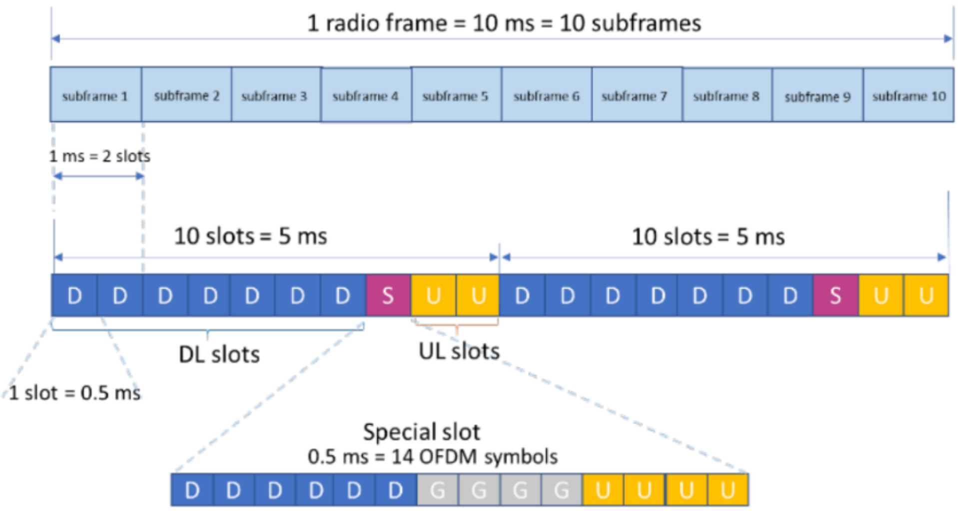


Figure 36. NR radio frame structure with ORO DL/UL configuration in LTE TDD ecosystem.

As described, for Phase 1, the commercial 5G NSA network will be used for the development and large-scale trial of the envisioned UCs in the designated areas as well as the private 5G SA network from the 5G Labs indoor premises. For UC1, that will take place on the Stefan cel Mare pedestrian alley, the 5G NSA coverage is provided as seen in Figure 37, by a site that features three 5G sectors (three n78 cells for NR and 3 LTE 800 cells as the anchor for 5G in NSA configuration). The same configuration is available for the site found in the proximity of the UC4 Podu Ros intersection area that is 5G NSA covered as seen in Figure 38. The details about the RAN cells from the Bucharest and Iasi 5G Labs are depicted in Table 5 and Table 6, while in Table 7 and Table 8 the details for the commercial outdoor cells from the UC1 and UC4 trial areas are showcased.

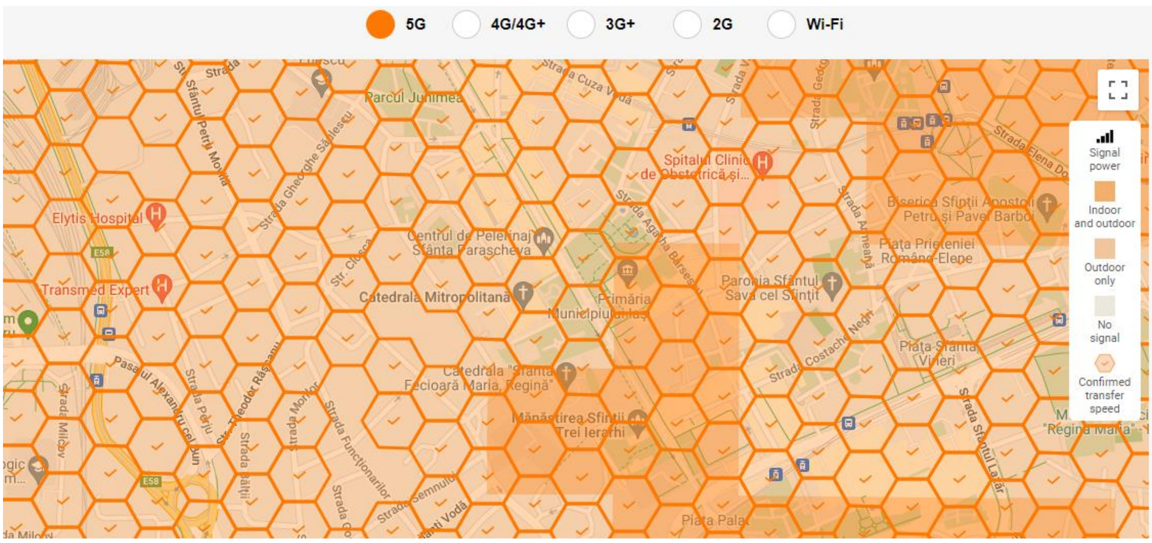


Figure 37. 5G NSA Stefan cel Mare pedestrian alley coverage simulation map.

Figure 38. 5G NSA Podu Ros Intersection coverage simulation map.

Table 5. ORO Testbed – Iasi 5G Lab cells.

SITE NAME	gNB ID	NR CELL NAME	NRDU-CELL ID	PCI	CI	TX and RX Mode	BAND	BW
BA0833_ERI_NR	408334	BA0833_NR_4	4	100	4	4 TX and 4 RX	N78	100 MHz

Table 6. ORO Testbed – Bucharest 5G Lab cells.

SITE NAME	gNB ID	NR CELL NAME	NRDU-CELL ID	PCI	CI	TX and RX Mode	BAND	BW
gNB_10_UPB	300103	gNB LAB 10_UPB_indoor_NR37_1	1	110	1	4 TX and 4 RX	N78	100 MHz
gNB_10_UPB	300103	gNB LAB 10_UPB_box_NR37_2	2	210	2	4 TX and 4 RX	N78	100 MHz

Table 7. ORO Testbed – Stefan cel Mare pedestrian alley 5G NSA cells.

SITE NAME	gNB ID	NR CELL NAME	NRDU-CELL ID	PCI	CI	TX and RX Mode	BAND	BW
BA0133_NR	401334	BA0133_NR_1	1	96	1	64 TX and 64 RX	N78	100 MHz
BA0133_NR	401334	BA0133_NR_2	2	97	2	64 TX and 64 RX	N78	100 MHz
BA0133_NR	401334	BA0133_NR_3	3	98	3	64 TX and 64 RX	N78	100 MHz

Table 8. ORO Testbed – Podu Ros Intersection 5G NSA cells.

SITE NAME	gNB ID	NR CELL NAME	NRDU-CELL ID	PCI	CI	TX and RX Mode	BAND	BW
BA0250_NR	402504	BA0250_NR_1	1	132	1	64 TX and 64 RX	N78	100 MHz
BA0250_NR	402504	BA0250_NR_2	2	133	2	64 TX and 64 RX	N78	100 MHz
BA0250_NR	402504	BA0250_NR_3	3	134	3	64 TX and 64 RX	N78	100 MHz

3.4.1.2 Core architecture

Orange 5GC testbed is based on virtualized network infrastructure, for both 5GC options, the NSA and SA variants.

The NSA Core architecture is composed of a Virtual Evolved Packet Core (vEPC) deployed in an Openstack infrastructure [25]. The existing core architecture can support broadband connectivity, configurable UL/DL speed at UE level at increased rate, ≈ 1000Mbps for DL and ≈ 100Mbps for UL. For the existing core architecture, the 5G services are manually configured, by using dedicated QoS, traffic prioritized in the case of UC4, APNs and network provisioned capabilities in terms of throughput, as the main UC that can be served by this architecture is mainly the eMBB.

The SA Core architecture uses the 5G SA CMU CN solution from Nokia, which is running on a virtualized infrastructure in the Bucharest 5G Lab atacenter. Three main components are integrated, the Cloud Mobile Gateway (CMG), the Cloud Mobility Manager (CMM), and the Authentication and Policy Control (APC).

These components implement the 5G SA 3GPP defined NFs [26], represented in Figure 35 as follows:

- The Authentication and Mobility Management Function (AMF), managed by the CMM and handles UE tracking, authentication of UE inside the core.
- The Session Management Function (SMF), managed by the CMG and handles Protocol Data Unit (PDU) sessions, selection of the UPF for data service based on the QoS needs and session authentication via the UDM.
- The UPF that handles the data sessions payload, payload prioritization, multi-access edge computing integration communications to the access domain.
- The AUSF managed by the APC and handles authorization, authentication, and accounting (AAA),
- The UDM acts as a subscriber management frontend for 5G SA users; finally, the Unified Data Repository (UDR) works as a subscriber profile repository.

The testbed facility supports different slices based on 3GPP NSSAIs parameters, providing eMBB with throughput up to 1.5Gbps for DL and 150Mbps for UL and URLLC with a one-way delay of <4ms, the overall slicing architecture being shown in Figure 39. At the RAN level the slicing performance is ensured by leveraging gNB-specific 5G Quality Indicators (5GQIs) functionality for proper slice implementation (Uplink Preallocation, SR Period Configuration). The two slices have different Data Network Names (DNNs), “orange5glab” for the eMBB slice and “orangeurllc” for the URLLC slice.

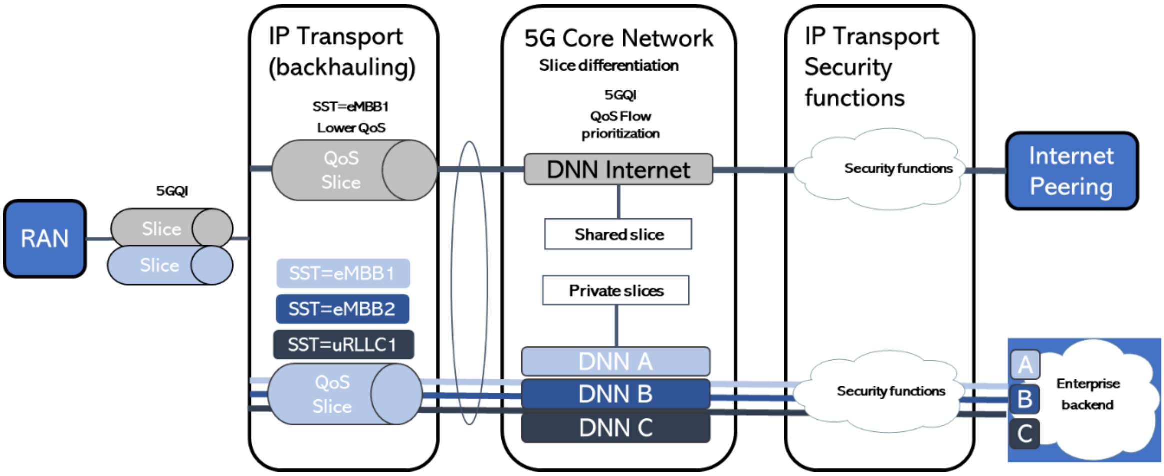


Figure 39. Romanian testbed slicing architecture.

3.4.1.3 Network and management functions

In the testbed, Figure 39, OSMv12 is ORO’s orchestrator that is compliant with European Telecommunications Standards Institute (ETSI) MANO architecture [27] and is offering an orchestrator tool that integrates with infrastructure controllers and can build different VNFs and Network Slices across all the platforms inside the lab. It can connect and communicate with Virtual Infrastructure Managers (VIMs) for virtualized segment and from the container segment. It will act as an umbrella deployment and management tool for different slice networking deployment, 5G ready UCs.

Ansible [28] and Terraform [29] are the automation core tools triggered from Continuous Integration and Continuous Deployment (CI/CD) managers that create the automation back bone of the 5G lab used for provisioning and configurations of any applications. This tool is facilitating automation in TrialsNet and makes the environment ready for any integration oriented in 5G SA present and future UCs that will come through the open-call program.

3.4.1.4 Virtualized network infrastructure

The edge-compute facility that will be used in the Romanian testbed will be hosted in the Iasi 5G Lab Datacenter. It will feature two Hewlett Packard Enterprise (HPE) servers of which one will be fitted with a NVIDIA GPU for Machine Learning (ML) acceleration in the object and person detection tasks.

This testbed infrastructure will be ready to host and accommodate applications and services, using OpenStack as the virtualization environment management software. This way, an instance of OpenStack All-In-One will be deployed on the GPU server and, on top of that, multiple VMs will be instantiated and orchestration capabilities will be provided through the Open-Source MANO (OSM) [30] software. The other server will be running in a bare-metal configuration, being able to accommodate both standalone applications, as well as containerized ones by leveraging Docker [31] or Kubernetes [32] Orchestration tools.

3.4.1.5 APPs onboarding platform

In the context of unitary APPs onboarding steps, the Romanian testbed onboarding platform, developed in the context of H2020 VITAL-5G project [33], will be implemented as a flexible platform, which can be adapted to serve and streamline the specific needs of the UC1 and UC4 APP developers and third party experimenters, being focused on the creation, deployment, management and validation of applications, including service and network monitoring, slice inventories, service and testing capabilities and orchestration.

By setting up an integrated web portal, where the APP developers can select the needed resources from the service catalogue, ORO aims to ease the integration of applications that require novel 5G services. The platform also helps with vertical service life cycle management (LCM), blueprint validation, service testing and monitoring, results analysis, AI-based diagnosis, and multi-slice inventory management, its architecture being depicted in Figure 40.

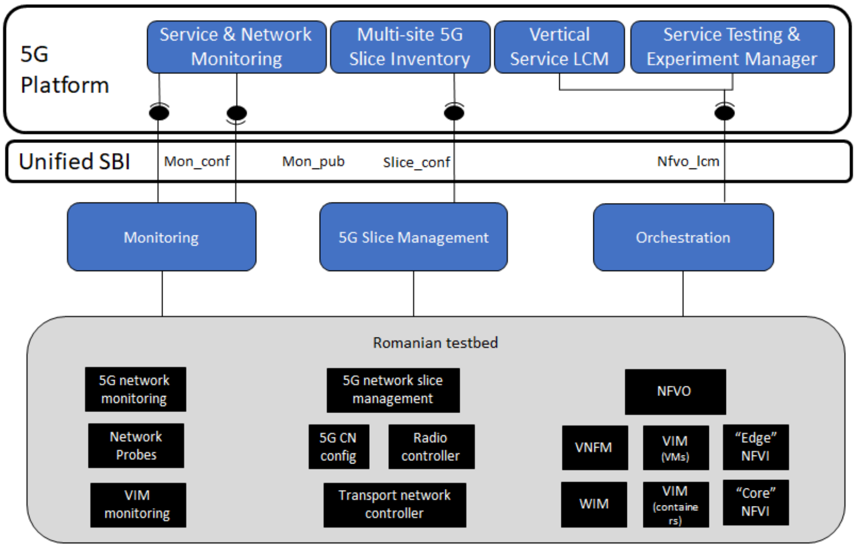


Figure 40. Romanian testbed applications onboarding platform architecture.

3.4.1.6 Transport and Security

Orange testbed is an IP/MPLS transport network, consisting of access, aggregation and CN layers, interconnected through high-speed links, 100 Gbps broadband connectivity between the network elements, QoS control and fast services delivery. The 5G testbed focus is mainly for the integration and deployment of the architecture in the Data Centre (DCs), designed as a CN element for the IaaS/CaaS integration for the Network APP deployment and also for the 5G CN components within the virtualized environment.

The 5G testbed is split into three main components:

- 5G transport network in the Bucharest testbed, deployed as a cluster of advanced network equipment, in the DC, mainly for the integration of the virtualized infrastructure and 5G CN,
- 5G transport network in Iasi, deployed as an extension of the IP network infrastructure for the gNB aggregation and Video Analytics applications experimentation in Iasi,
- E2E transport network service configuration, manual configuration of the network, dedicated traffic VPNs, QoS definition and service traffic and KPIs assurance.

Within the scope of TrialsNet the transport network will be designed in order to fulfill the 5G transport requirements, through the architecture illustrated in Figure 41, with two main key objectives of:

- To ensure the high transport capacity and QoS for the further network service slices transported by the network,

- To provide dynamic resilient and redundant transport paths.

The DC transport solution is using the IPFABRIC [34] concept, using Border Gateway Protocol (BGP) Ethernet Virtual Private Network (EVPN) as CP and Virtual Extensible LAN (VXLAN) as data plane encapsulation. The solution offers a lot of benefits versus the legacy layer-oriented Datacenters using Core, Distribution and Access layers respectively.

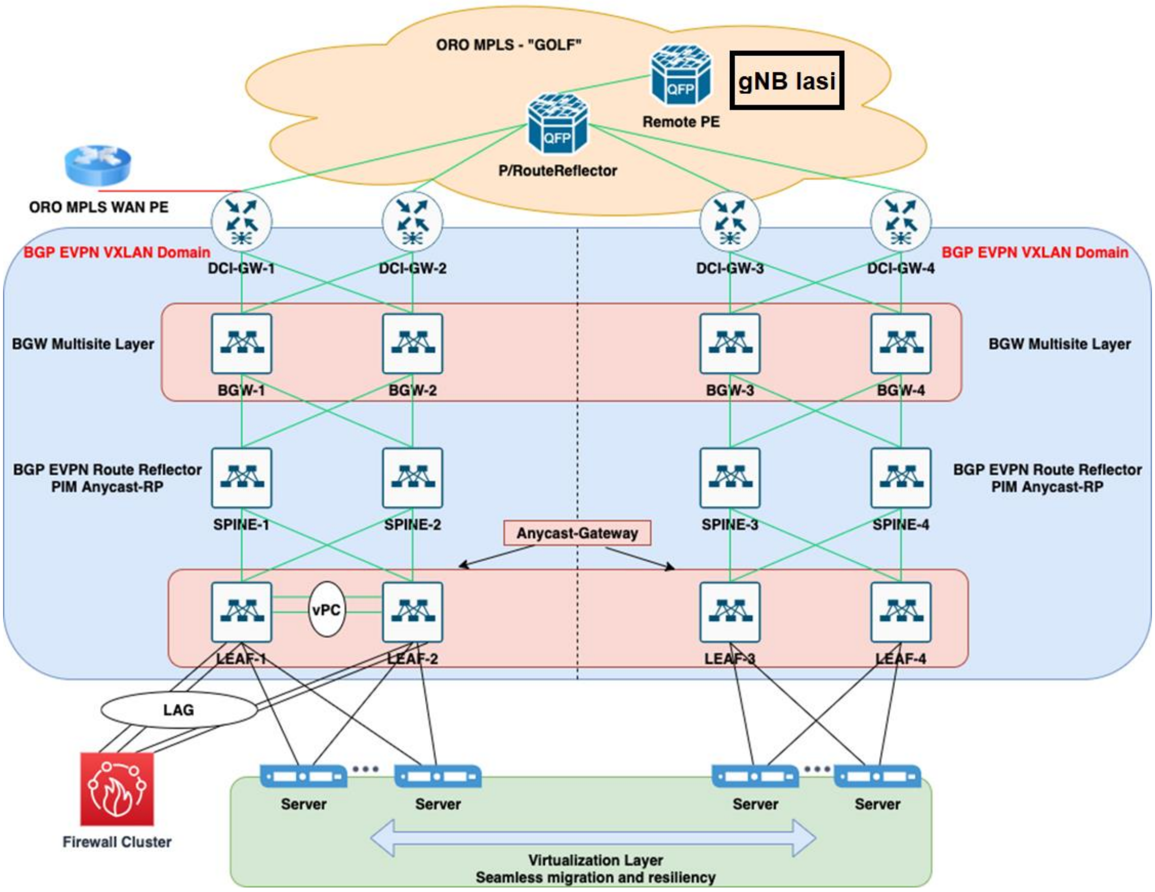


Figure 41. Romanian testbed transport network design.

In the scope of the TrialsNet project, ORO will install in the premises of the Iasi 5G Lab Datacenter a security solution designed to alleviate the issues and concerns that may appear in the open-call experimenters onboarding and operation phases. A firewall deployment, as shown in Figure 42, will streamline the access procedure to the testbed for the experimenters and will assure the proper isolation between different network applications and services.

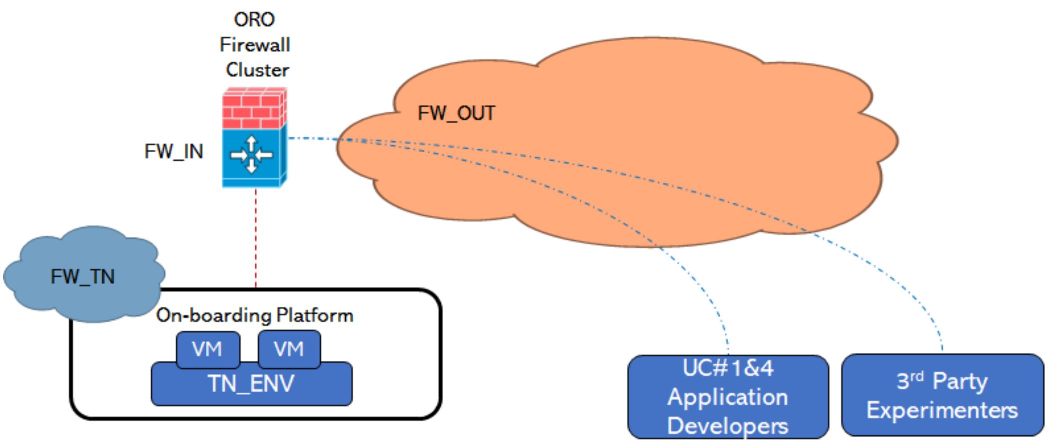


Figure 42. Romanian testbed firewall implementation.

3.4.1.7 Testbed monitoring

Another key component in 5G networks is represented by network and services monitoring capabilities, the process of data collection of a variety of metrics, benefitting by different open software tools used for monitoring (e.g., Prometheus) and data presenting through dashboards. The monitoring stream is focused on three main streams:

- Infrastructure monitoring, collecting the data from the infrastructure components, e.g., UE, RAN, CN, Transport, virtualized infrastructure, MEC.
- Network and service performance monitoring, evaluating network resources, services status, users.
- Devices monitoring, collecting data related to the traffic volumetry through specific slices, as well as information related to the radio link quality.
- 5G networks must perform the monitoring process, for resources and elasticity profiling, testing and services validation, gathering general information about network infrastructure but also about the 5G services and related slices parameters. In 5G, the service is monitored since the deployment phase, the services specific metrics and KPIs are collected and further used for preventive activities, network control, quality measurements, fault detections and E2E validation. The 5G monitoring framework is highlighted in Figure 43, while a dashboard example, showing the network E2E latency, is shown in Figure 44.

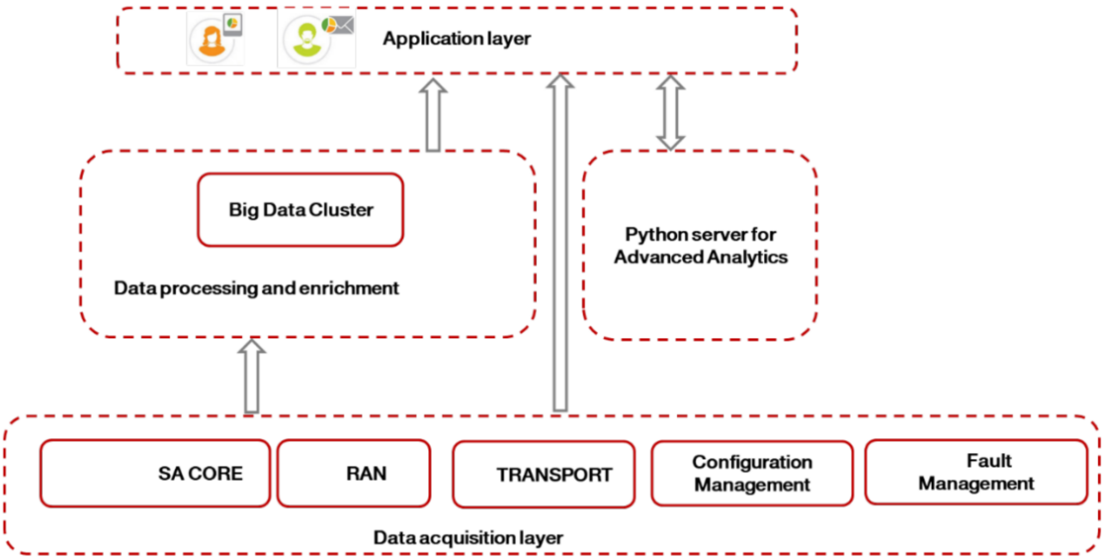


Figure 43. Romanian testbed 5G SA monitoring framework.

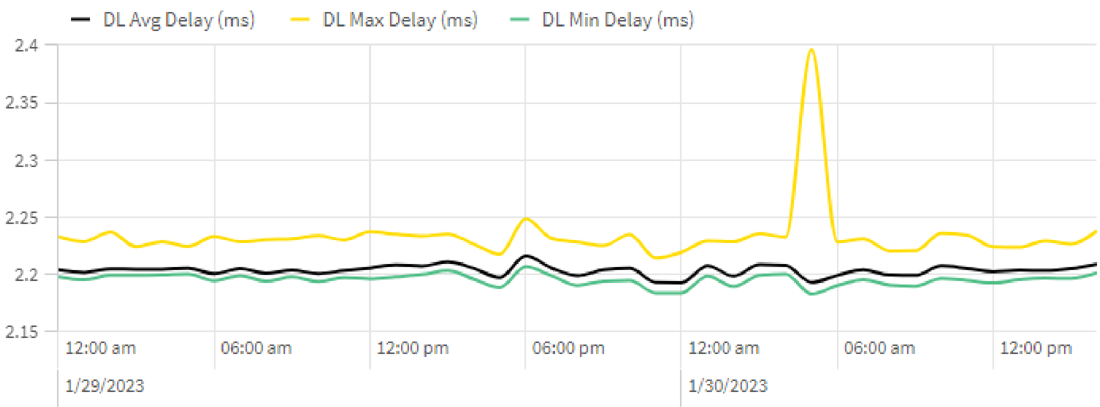


Figure 44. 5G SA network monitoring platform.

3.4.2 Support to the UCs implementation

To implement the UCs that will be developed in the Romanian cluster, the ORO testbed will actively measure the following network and infrastructure KPIs in order to provide the developers and experimenters with the relevant data to understand the UC behavior over the 5G/B5G infrastructure.

3.4.2.1 Network oriented KPIs

Based on network tests one can extract several generic functional KPIs at network and at slice level. By setting up probes in different points of the flow from the UE to the core, one can review KPIs on UE side, at the UPF Data Network Interface and also in various points of the RAN and Core. The ORO testbed will measure a set of network KPIs to facilitate the extraction of common insights, which are reported in Table 9.

Table 9. ORO testbed network KPIs.

Metric	Description
Minimum UL throughput	UE transmitting IP packets to the N6 interface.
Minimum DL throughput	UE receiving IP packets from the N6 interface.
Maximum latency	5G PPP definition: Roundtrip Time (RTT) of UE IP packets transmitted to the N6 interface.
Network reliability	5G PPP definition: Transport layer packets are lost between the UE and the N6 interface.
UL peak throughput	5G PPP definition: Single UE transmitting IP packets to the N6 interface.
DL peak throughput	5G PPP definition: Single UE receiving IP packets from the N6 interface.
User Experienced Downlink Data Rate	Downlink data rate as perceived at the Application layer. It corresponds to the amount of APP data (bits) correctly sent within a certain time window.
User Experienced Uplink Data Rate	Downlink data rate as perceived at the Application layer. It corresponds to the amount of APP data (bits) correctly sent within a certain time window.
Packet Delivery Ratio (PDR)	Percentage value of the amount of sent network layer packets successfully delivered to a given system entity within the time constraint required by the targeted service, divided by the total number of sent network layer packets.
Packet Loss	Percentage of the amount of sent network layer packets failed to be delivered to a given system entity within the time constraint required by the targeted service, divided by the total number of sent network layer packets.
APP Guaranteed Data Rate	Guaranteed bit rate for the APP to function correctly.
Coverage area	The geographic area within which the Mobile Network Operator voice/data services can be accessed and used by the subscriber.
Reliability	The amount of Application layer messages or network layer packets (depending on the measurement level) successfully delivered to a given system node within the time constraint required by the targeted service, divided by the total number of sent messages or packets.
System Bandwidth	Maximum aggregated system bandwidth including frequency guard bands.
E2E Latency	The time required from the moment a data packet is transmitted by the source APP, to the moment it is received by the destination APP.

Guaranteed Network Latency	The guaranteed maximum time required from the moment a data packet is transmitted by the source to packet gateway.
Jitter	The variation in the latency on a packet flow between two systems. Jitter can be caused by network congestion, timing drift and route changes.
Dropped packets per second	UPF IP dropped packets detected minute by minute. The number of packets is obtained by combining packets direction (Ingress/Egress) and space where the process is performed (kernel or user space).
Forwarded packets per second	UPF IP forwarded packets. The number of packets is obtained by combining packets direction (Ingress/Egress), space where the process is performed (kernel or user space).
Dropped bytes per second	Number of dropped bytes per second as measured in the UPF.
Forwarded bytes per second	Number of forwarded bytes per second as measured in the UPF.

3.4.2.2 Infrastructure oriented KPIs

The infrastructure oriented KPIs (Table 10) are defined to determine the computational/memory/disk load related to the RAN, Core, and Network Function Virtualization (NFV) infrastructure (servers that hosts UCs applications) software modules. In addition, the testbed components involved in measuring the KPI are also listed in Table 10.

Table 10. ORO testbed infrastructure oriented KPIs.

Metric	Testbed components	Partners involved	Description
CPU load	UC applications, VMs	Testbed & APP developers	Average Central Processing Unit (CPU) usage during platform operations (e.g., APP on-boarding, processing orchestration requests, performing LCM operations).
Memory load	UC applications, VMs	Testbed & APP developers	Average memory usage during platform operations (e.g., APP on-boarding, processing orchestration requests, performing LCM operations).
Disk usage	UC applications, VMs	Testbed & APP developers	Current disk usage at the VM where the APP is running.
Compute load/infra load	UC applications, VMs	Testbed & APP developers	Compute load and Infrastructure load during platform operations reported to the total available pool of resources.
GPU load	UC applications, VMs	Testbed & APP developers	Average GPU usage during APP operations (e.g., AI/ML, video processing).

3.4.3 Enhancements of the infrastructure

In the scope of the project, in order to improve the E2E system latency for UC1 and UC4, the 5G network architecture will be further developed in a Distributed Cloud/MEC type of approach with the deployment of a virtualized UPF in the Iasi 5G Lab Datacenter. This UPF will be integrated in the 5G SA CN from Bucharest (CP), will be connected to the Iasi gNBs and the local edge-compute facility and will have direct access to several DNNs (including Internet), implementing the ETSI 5G SA MEC architecture [35], as it's shown in Figure 45.

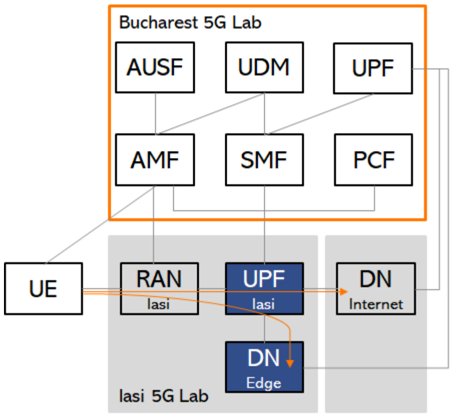


Figure 45. ETSI MEC Architecture [36].

The closest UPF will be selected based on the Tracking Area Code (TAC) of the gNB that serves the UE. In this way the CP traffic will be handled by the Core components from the Bucharest 5G Lab (AUSF, AMF, SMF for the access, authentication and SMFs), while all the user-plane traffic between the connected 5G devices from Iasi and the edge-compute facility or the Internet will flow directly through the local UPF instance from Iasi.

The extension facility in Iasi will be connected via the IP/MPLS high speed technology with 10 Gbps links to the central cluster which performs advanced network control functions, as well as network analytics, computation and data storage. The proposed design, highlighted in Figure 46, is taking into consideration all the network segments and transmission characteristics, for latency between UE and base station (URLLC slice) ≈ 3ms, gNB to 5G CN ≈ 1.5ms and 5G CN to MEC less than 0.5ms, as they are collocated and fiber links interconnected, offering the E2E delay budget of ≈ 4.5ms, under analysis from the Network APP perspective for the UC1 and UC4 envisioned developments based on video feeds from surveillance cameras.

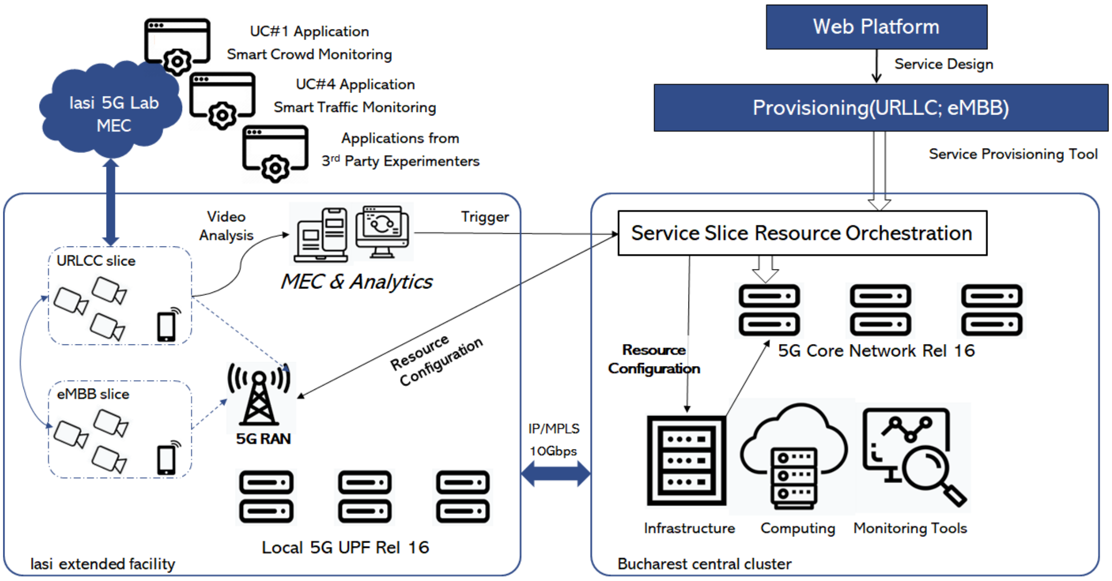


Figure 46. Romanian testbed MEC implementation.

3.5 Romanian cluster (experimental facilities in Belgium)

The Romanian cluster with experimental facilities located in Belgium will deploy and validate the UC4 Smart Traffic Management [1]], focusing on testing and validation of the zero-touch service management techniques and their impact on service performance. For the purpose of large-scale testing and validation of UC4, the facilities discussed in Section 3.4 are complemented by the ones available in Belgium. This complementary setup will be used to provide cross-country validation of UC4 and zero-touch service management techniques applied to smart traffic management services￼ The testbed ecosystem described in this section is managed by IMEC, and it comprises of a set of experimentation facilities located in Antwerp and Ghent (Belgium). This ecosystem provides an extensive experimentation setup based on real-life testbeds such as CityLab, Smart Highway, 5GOpen, and portable 5G. As such, the overall setup will be extensively used as a supporting trial site for the Romanian cluster and UC4, where IMEC will use both network and virtualized infrastructure resources to build and test the 5G and beyond enablers such as zero-touch network and service management, flexible and autonomous radio resource management (RRM), and creation of flexible and virtualized vertical service deployments following the design of Edge Network APPs. As explained later in Sections 3.5.2 and 3.5.3, 5GOpen testbed is currently being integrated with the Smart Highway setup on the E313 highway in Antwerp, and as such, the 5G-equipped Smart Highway will be extensively used for testing and pre-trialling activities (activities prior to trials in Iasi) of UC4, in particular, zero-touch service management mechanisms of 5G and beyond EdgeApps. On the other hand, portable 5G testbed will be leveraged for deploying and testing flexible RRM techniques. After extensive testing within the IMEC testbed ecosystem, the software solutions for zero-touch service management operations (containerized deployments of MANO components, applications, AI/ML models, etc.) will be deployed on the Iasi infrastructure, where the trials of UC4 will be performed.

3.5.1 Infrastructure components and functionalities

This section provides more details about the infrastructure components and functionalities of all experimentation facilities that the IMEC testbed ecosystem combines.

3.5.1.1 Smart Highway testbed

The **Smart Highway test site** is built on top of the E313 highway, and it consists of a highway strip of 4 km equipped with Roadside Units (RSUs). This testbed, shown in Figure 47, is designed for Vehicle-to-Everything (V2X) communication & distributed/edge computing research, thereby providing means for creating scalable and reliable V2X system, with opportunities to validate automotive requirements for automated driving with industry in real-life trials. Besides the RSUs that are deployed along the highway, there are three Onboard Units (OBUs) which are either in-vehicle or rooftop units. The important feature of such OBUs is their flexibility and adjustability, as they can be easily mounted on any regular car. In addition to that, testbed is equipped with two testing vehicles that can be used in experimentation activities.

Figure 47. Smart Highway testbed components.

The Smart Highway testbed consists of seven RSUs in total, and they are deployed on top of the gantries along the E313 highway in Antwerp, as illustrated in Figure 47 these RSUs are mounted on top of the real highway, they are connected to the fiber network of the road operator, which makes them able to fetch information about electronic traffic signs on the highway, and to give a stable backhaul connection for edge processing on the RSU. Each of those RSUs is fully managed remotely, which facilitates the federation of testbed resources and resource usage by external experimenters. The testing car is a BMW X5 with automatic gearbox from 2014 that is provided by the University of Antwerp. The car is equipped with an OBU, power system, and communication HW. Both in-vehicle and rooftop OBU are equipped with computing capabilities as well. This car can be driven and used as a mobile node in a 6G V2X context, and as such it will be used for UC4 local testing in Antwerp.

The antennas of the communication modules are mounted on top of the RSU/OBU. The RSU/OBU is able to support V2X radio links, such as short-range based on ITS-G5 and C-V2X with PC5 interface [37] working on 5.9 GHz, to support V2X communication between RSU and OBU, or between two OBUs. Currently, the long-range communication via The Radio interface between UT-RAN and the User Equipment (Uu interface) (the radio interface between UTRAN and the UE) is based on 4G and will be upgraded toward 5G NR. Both commercial and Software-Defined Radio (SDR) communication modules are integrated in the RSUs/OBUs. This gives experimenters the freedom to choose which communication modules they would like to use for testing and allows for benchmarking tests as well. As already mentioned, both RSUs and OBUs have computing power onboard for enabling distributed edge computing.

The Smart Highway architecture empowers researchers to place functions at different computational locations ranging from the OBU up to the cloud, leveraging RSUs as distributed edge computing units. Latency, network load and processing time can be further reduced by dynamically selecting the location of the data processing and the used communication links. The testbed concerns various APP domains such as Smart Mobility, Cooperative, Connected and Automated Mobility (CCAM), and Autonomous Driving.

3.5.1.2 5GOpen testbed

The **5GOpen testbed**, shown in Figure 48, is located in Antwerp offering indoor and temporarily outdoor 5G connectivity based on two gNBs and a 5GC Stand Alone deployment where different combinations of Open RAN combinations can be tested. IMEC has obtained a Belgisch Instituut voor postdiensten en telecommunication (BIPT) test license, which is valid for the 3800-4200MHz frequency range (band n77) and the stretch on the road covered by the above-mentioned Smart Highway testbed. One of the planned activities is to extend this license to the CityLab locations where gNBs are scheduled for deployment.

Figure 48. 5GOpen testbed components.

Currently, 5GOpen testbed is deployed as a testbed in a box, containing both radio and core capabilities, offering tools to pursue 5G validation, integration and testing, in both office and open environments Figure 48 shows the 5GOpen testbed components. These testbed components are currently being integrated with the Smart Highway testbed, and as such, 5G-enhanced Smart Highway testbed will be extensively used for UC4 testing and pre-trialling activities.

3.5.1.3 Portable 5G testbed

The portable 5G testbed is located in Ghent, offering a transportable 5G standalone network in a box solution that can be used for 5G network testing, experimentation and novel research on 5G and beyond network technologies. The testbed consists of two portable 5G units including both Commercial Off-The-Shelf (COTS) and SDR equipment enabling flexibility for extensions and customization beyond features offered in 3GPP releases and capability for E2E experimentation involving business-critical and/or mission-critical applications with demanding QoS requirements in dynamic wireless environments.

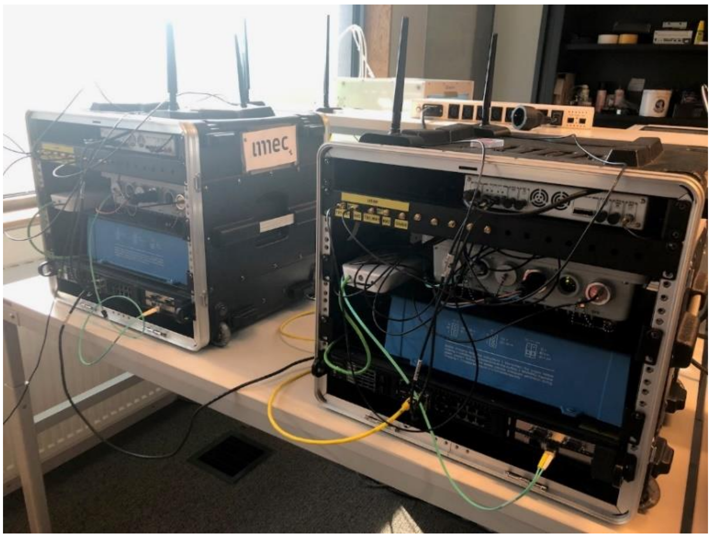


Figure 49. IMEC's 5G portable (network in-a-box) units.

The portable 5G units can be used both as UE and as Open-RAN (O-RAN) compatible base station (small cell) in combination with the 5GCN either as a system in a box or running the 5GC on a central data server. The two portable 5G (network in-a-box) units are shown in Figure 49. Each one of the 5G units include:

- The Accelleran O-RAN solution, which provides the Accelleran dRAX lab kit consisting of the software for the Central Unit (CU), the Distributed Unit (DU) and the near real-time Radio access network Intelligent Controller (RIC)
- The Benetel outdoor RU that is O-RAN compatible
- COTS 5G modem (5G UE) – Quectel RM502Q and RM500Q
- COTS 4G router (LTE UE) for remote access, management and logging purposes
- A powerful computing unit with GNSS support and accurate timing synchronization
- A power unit that allows the equipment to run over a battery or the power grid
- An SDR USRP 2943R that can be combined with open-source LTE/5G solutions, such as srsRAN and Open Air Interface (OAI)
- OpenWi-Fi module

In addition to the two portable 5G units, the portable 5G testbed includes a portable 5G UE unit mounted in an easily transportable case for performing 5G (and B5G) tests and experiments on location. This UE unit can be combined with the two other portable units or can be used as a standalone UE equipment for testing and evaluating private or commercial 5G networks. The portable 5G UE unit is shown in Figure 50. As it can be observed, the unit consists of:

- COTS 5G modem (5G UE) - Quectel RM502Q [38]
- OnePlus 10 Pro Android smartphone [39]
- COTS 4G router (LTE UE) for remote access, management and logging purposes [40]
- A Gigabyte computing unit with GNSS support and accurate timing synchronization
- A 1Gigabit network switch
- A portable screen

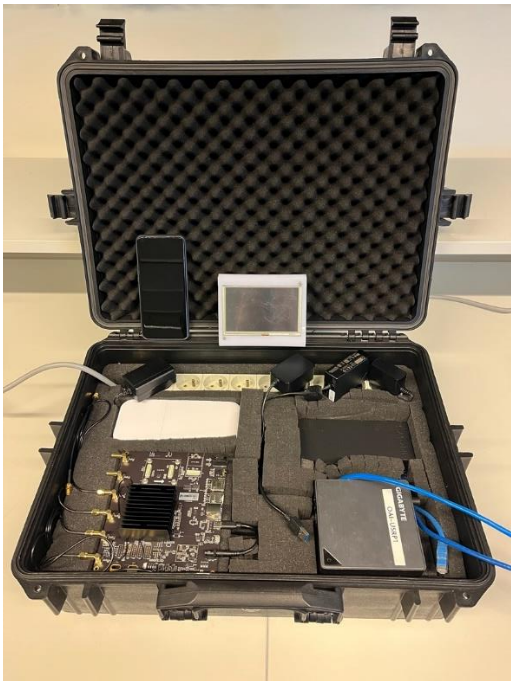


Figure 50. IMEC's portable 5G UE unit.

3.5.2 Support to the UCs implementation

The UC4 that will be implemented in Iasi, Romania, will be tested in the IMEC testbed ecosystem as well, with the goal of validating the capabilities of advanced mechanisms for the zero-touch service management and flexible and autonomous RRM of such realistic vertical services. The UC will demonstrate the effectiveness of intelligent traffic management within a robust zero-touch management of edge services, as illustrated in Figure 51.

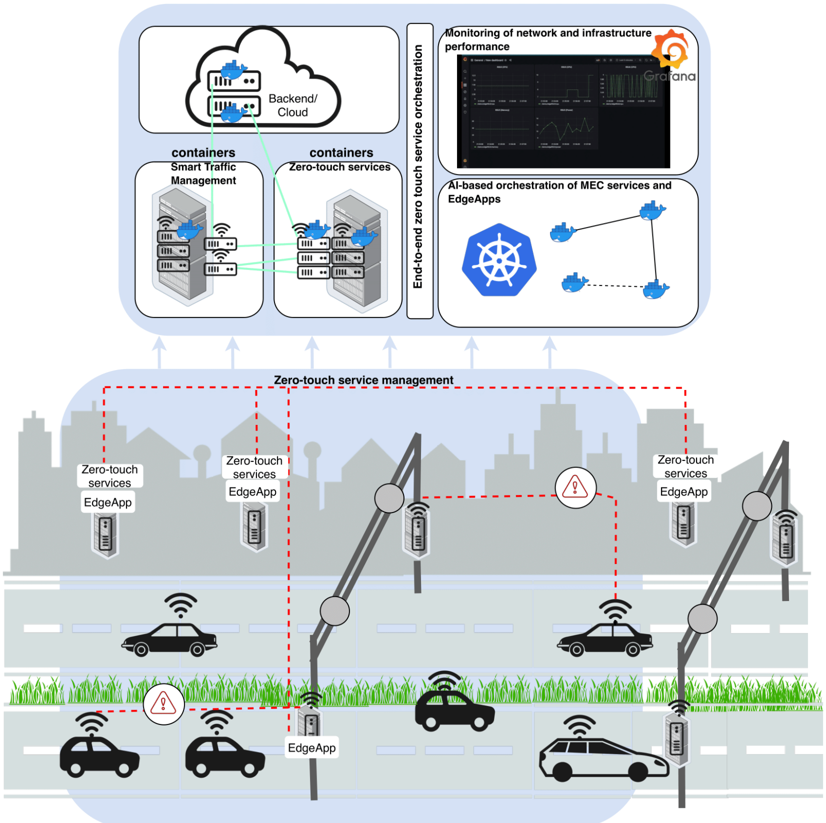


Figure 51. Deployment of smart traffic management EdgeApps and corresponding zero-touch services.

The APP design presented as EdgeApp framework in this deliverable (Section 4.1.2), will be used to enhance the vertical-specific Application layer developed by TUIASI, with additional components that will facilitate the service orchestration. As efficient MANO are necessary for vertical services to experience the full potential of 5G and beyond technologies, the design of such applications needs to consider specific 5G network requirements (performance requirements) but also orchestration capabilities that will enable smooth and uninterrupted service for users (vehicles and vulnerable road users (VRUs) in smart traffic management scenarios).

In addition, the flexible and autonomous Radio Resource Management (RRM) will facilitate the UC in terms of optimally configuration of available wireless technologies (5G and Wi-Fi) based on the data traffic requirements and the wireless environment conditions. The flexible and autonomous RRM will be implemented under the O-RAN framework umbrella [41]. O-RAN-based 5G and Wi-Fi networks and their wireless resources will be optimally configured for enabling reliable and low latency transmission of information generated by the sensors envisioned in the UC such as cameras and IoT sensors. Furthermore, interoperability and interworking between 5G and Wi-Fi will be investigated enabling traffic aggregation, load balancing and increased reliability of the transmitted data towards the network edge or the VRUs.

During the trialing activities, various testing and validation scenarios will be defined to test the impact of pro-active zero-touch service management on the actual service performance (e.g., E2E latency, reliability, availability), studying the relationship between KPIs such as service deployment/scaling time and service reliability and downtime, which are essential for ensuring safety of VRUs in busy traffic environments like Podu Roș Intersection Area.

3.5.3 Enhancements of the infrastructure

The integration of 5GOpen testbed with CityLab and Smart Highway testbeds is ongoing and planned to be finalized during 2023, for the purpose of providing 5G connectivity in all test sites within IMEC testbed ecosystem, and to ease the integration of zero-touch mechanism into the Romanian cluster. In addition, testing vehicles are part of the Smart Highway testbed and as such will be equipped with corresponding 5G modems and additional testing equipment. Also, some of the planned upgrades for both CityLab and Smart Highway testbed are related to the sensors (air quality, lidar) are planned for purchase and installation in order to enrich the testbed capabilities for testing smart city and automotive applications, AI/ML capabilities at the network edge, among others.

3.6 Greek cluster

This section provides a description of the Greek cluster. The Greek cluster will be utilized for the following UCs:

- UC2: Proactive Public Infrastructure Assets Management
- UC3: Autonomous APRON (the airport area, where aircrafts are parked, loaded, unloaded, and serviced)
- UC6: Mass Casualty Incident (MCI) and Emergency Rescue in Populated Area
- UC11: Service Robots for Enhanced Passenger’s Experience
- UC13: Extended Reality (XR) Museum Experience

In the next sub-sections, the infrastructure capabilities of the Greek cluster are detailed in terms of the network infrastructure used, the accompanying platforms and the corresponding equipment and devices.

3.6.1 Infrastructure components and functionalities

3.6.1.1 5G network infrastructures

UCs of the Greek cluster will be trialled at the Athens airport and at public venues in the city of Athens. In the Greek cluster a public 5G network will be used, for leveraging its high-speed connectivity, low latency, and wide coverage. Specifically, the network uses NSA architecture and operates at a frequency of 3.5 GHz. The allocated band for this network is 80-100 MHz, which will provide high-speed connectivity and low latency to support the data-intensive applications required by the UC. Future versions of the public network will also be used.

In addition, a WINGS owned, private network infrastructure will be utilized in order to conduct testing activities, validation and demonstration, prior to the deployment in the field. The Figure 52 depicts the architecture in a high-level manner.

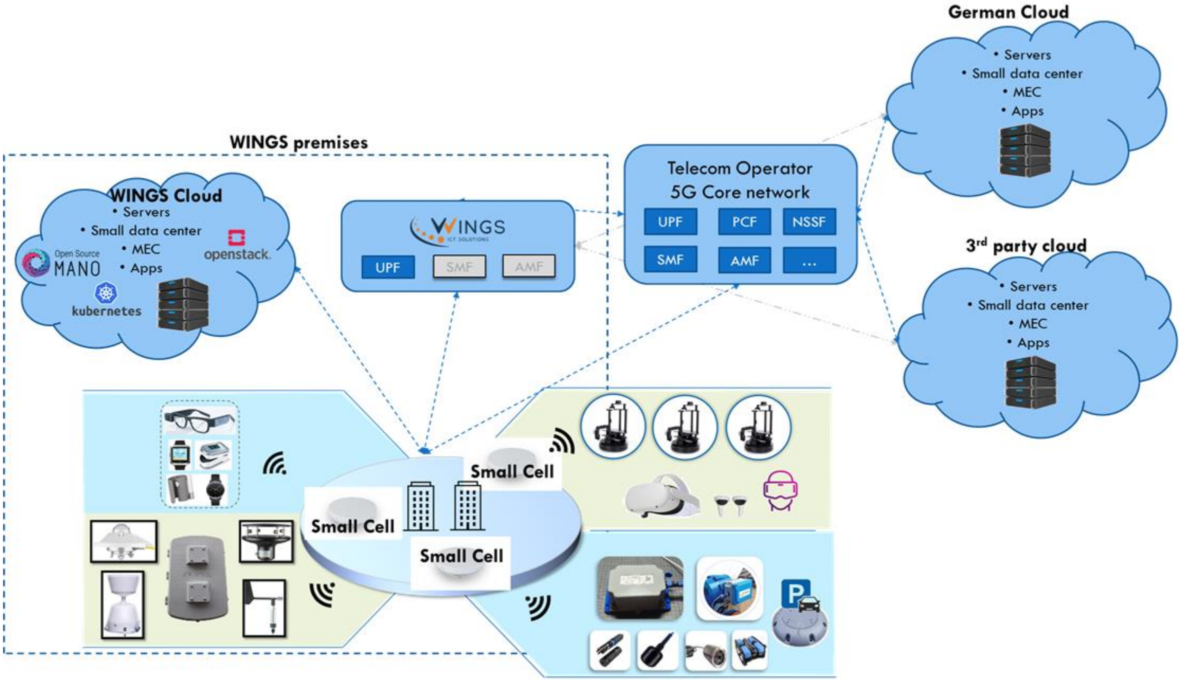


Figure 52. WINGS testbed architecture for experiments.

The WINGS testbed provides E2E 5G/B5G functionality, along with extensive cloud and edge computing capabilities, leveraging the 3GPP (Release-16 and beyond) Public Network Integrated Non Public Network (PNI-NPN) with shared CP (at a first phase) and isolated, Stand-alone Non-Public Network (SNPN), with all NFs (UP and CP) inside WINGS premises, isolated from the public network in the final phase. The site offers a range of 5G/B5G services and will be gradually evolved to 6G. It supports- various vertical domains, with WINGS providing the necessary HW, software, and configurations to enable the testbed to handle these UCs. WINGS testbed serves as a testing ground for services, equipment, and new features before they are commercially released.

WINGS has progressively extended the existing software, HW, and network functionality to support Cloud, Mobile Edge Computing (MEC), Extreme Edge and IoT functionalities. WINGS has demonstrated advanced UCs on DTs, Collaborative Robots with native-AI B5G/6G capabilities of the system. Also, the required frameworks to build, test, and validate innovative 6G applications are part of the overall infrastructure.

The WINGS testbed utilizes AI mechanisms to support diagnostics, intelligent management, and orchestration. The management of the facility is done using a combination of existing and new software, covering DevOps [42], AI/MLOps [43], monitoring, profiling, diagnosis, and service-aware resource allocation and orchestration. An AI-enhanced MANO component inherited from 5G-TOURS project [44] is used to enable advanced automation and optimization. Monitoring, profiling, and diagnostic components provide information on available resources and network capabilities to help find the optimal deployment of a vertical service.

The WINGS testbed utilizes open-source software such as Openstack, Kubernetes and OSM MANO to provide a flexible and scalable infrastructure for verticals, as well as other open-source tools like Kafka [45], MQ Telemetry Transport (MQTT) [46] and Robot Operating System (ROS) [47] . These components can support VMs, containers, and serverless execution of code from cloud to extreme edge devices such as raspberry pi.

The WINGS testbed prioritizes protection and privacy-preserving mechanisms to ensure reliability, security, privacy, confidentiality, and integrity of data. Open-source tools like Keycloak or Blockchain technology [48] may be used where appropriate, and OpenNAC [49] for Network Access Control. Strong authentication, user management, and secure services will be provided with minimum effort from the verticals. The solutions selected will comply with General Data Protection Regulation (GDPR) article 5 to ensure appropriate security and protection against unauthorized or unlawful processing, accidental loss, destruction, or damage. They will employ consolidated Public Key Infrastructure (PKI) certificate-based cryptographic systems for critical communications to encrypt personal data during transmission.

3.6.1.2 WINGSPARK++ platform

WINGSPARK++ [1] (see Figure 53) is a fully integrated management system for transportation and infrastructure that provides solutions for various stakeholders such as public and private transport providers and infrastructure operators. WINGSPARK++ utilizes advanced monitoring, fault detection, performance optimization, security, and configuration capabilities in the areas of infrastructure, parking, and stations. As part of the TrialsNet project, data collected from multiple sources will be transmitted through the 5G network, enabling further data extraction, and processing. The resulting data will be ingested into a highly scalable datastore, which will serve as input for AI processing. WINGSPARK++ will leverage advanced AI technologies to analyse data and provide insights, such as infrastructure faults. In addition, the platform will enhance its user interfaces with-a dashboard that will provide insights and alerts to the remote experts. To further improve accessibility and convenience, mobile apps will also be developed, providing users with easy access to information and insights on the go. WINGSPARK++ will be used in UC2, UC3 and UC11.

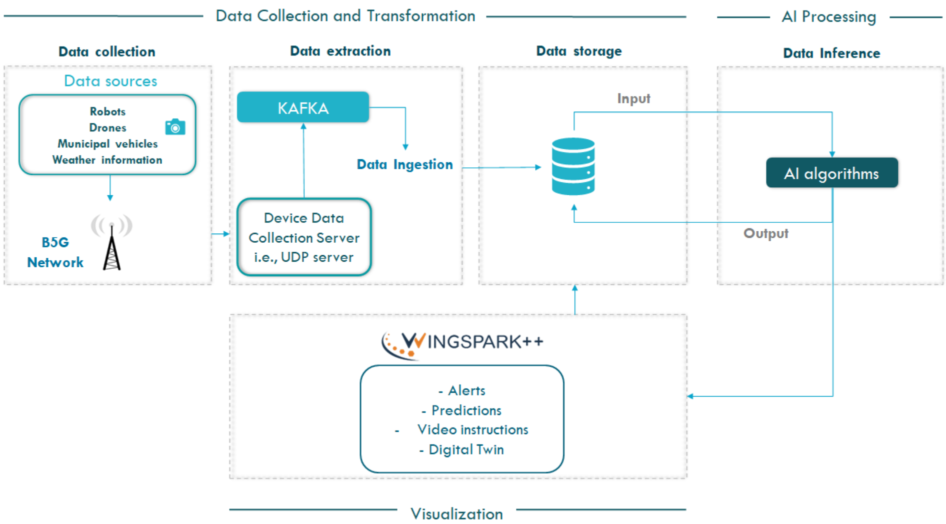


Figure 53. Overview of WINGSPARK++ platform.

3.6.1.3 STARLIT++ platform

WINGS STARLIT++ (see Figure 54) is a cloud-based platform that will be used for UC6. The services provided will be an extension of the functionalities of the existing STARLIT platform [1] STARLIT++ will exploit devices such as cameras, drones and robots to develop an electronic triage monitoring APP to handle victims' health data, triage status, and its dynamic development through secondary and transport phase, current location, while support for evacuation operations will also be provided. The devices capture images, video, and other data, which are transmitted over 5G networks to a central platform for processing and analysis using AI models and techniques. For the MCI case, devices, will also comprise wearable devices for monitoring of vital signs, such as heart rate, oxygen saturation, body temperature, blood pressure, etc. The platform comprises AI powered mechanisms for providing insights on a range of factors (e.g., estimated number of victims, potential issues for first responders to address in the field, estimated location of users, user's vital signs evolution, forecasting of future issues and health emergencies, notification for designated doctors and first responders, etc). In addition, the routing algorithms to be developed (adapted to the particular needs of the project) for the calculation of the optimal evacuation routes, will be connected as a service to the STARLIT platform. This way, a direct and continuous transfer of data is to be utilised, to make use of the latest updated information collected and to channel the generated information through the common applications/interfaces to be decided and defined for each scenario (e.g., a smart device or XR glasses, tec.).

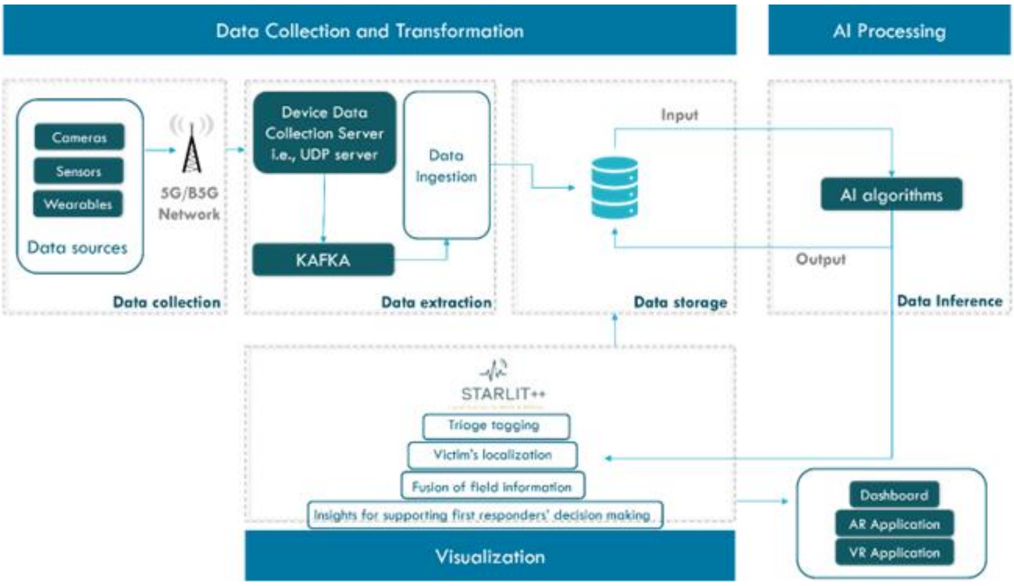


Figure 54. Overview of STARLIT++ platform.

3.6.2 Support to the UCs implementation

Table 11 summarizes the KPIs of the UCs in the Greek cluster as reported in [1], [2] and [3]. Since the trials will be performed on a 5G public infrastructure (see sub-section 3.6.1.1), the KPIs will be measured at the APP level through proper tools selected according to the specific metrics as described in the following. Throughput measurements will be collected via probes, iPerf and Ookla. Latency measurements will be collected at the application layer by adding timestamps to requests between functional entities/service components of the overall APP. Then the difference in time will be calculated between the request from one entity (e.g., client) and the response from the other entity (e.g., server). Additional measurements will also be collected e.g., with the use of iPerf. Location accuracy will be measured as the difference between the position to which a device (e.g., robot) is directed and the actual position where it ends up and the difference between the position of a device estimated by the overall system and the actual position. Service reliability will be measured by measuring the packet loss rate at the application layer (packets that arrive delayed or erroneous are considered as lost packets). Service reliability will be calculated based on packet loss and RTT latency measurements.

Table 11. KPIs for UCs in the Greek cluster.

Metric	Description
Downlink throughput per device	The amount of data that can be transmitted over the network in a certain amount of time
Uplink throughput per device	The amount of data that can be transmitted over the network in a certain amount of time
App latency (glass to glass)	Delay between the image captured by the camera and it showed in the screen of the user device
Location accuracy	Accuracy in the positioning of the device
Latency	Round-trip time for successful delivery of a packet from Tx (e.g., device) to Rx (e.g., dashboard) plus the time it takes to send the response back
Service availability	Capability of transmitting a given amount of traffic within a predetermined time duration with high success probability (calculated based on packet loss)
Service reliability	Success probability of transmitting a layer 2/3 packet within a maximum latency required by the targeted service (ITU-R M.2410)

3.6.3 Enhancements of the infrastructure

As already mentioned in section 3.6.1.1, UCs of the Greek cluster will be trialled at the Athens airport and at public venues in the city of Athens. At these locations the trials will mostly rely on the commercial network. A WINGS owned, private network infrastructure will be utilised, in order to conduct testing activities, validation and demonstration, prior to the deployment in the field but also to allow for greater flexibility in the experimentation. As part of the effort to support the envisaged KPI target values, work in the scope of the project will focus on the enhancement of the testbed with respect to the integration of the platforms and applications for the UCs (see also section 3.6.1.2), with the small cells and the 5GCN functions. Further enhancements include adaptation of the WINGSPARK++ platform for UCs 2, 3 and 11 and of the STARLIT++ platform for UC6, as described in sections 3.6.1.2 and 3.6.1.3 respectively. Initial testing will take place in Q1 of 2024. Further testing will take place at the Q1 of 2025 with execution of the final trials towards the end of the project (Q3 of 2025).

4 TrialsNet Innovations

One of the main objectives of TrialsNet project is to propose innovations that will be experimented during the UCs implementation. In particular, the TrialsNet's innovations are categorized into horizontal innovations (related to transversal B5G/6G functionalities) and vertical innovations (related to specific UCs) and are aligned with technologies and framework defined in Section 2.

4.1 Horizontal Innovations

The TrialsNet horizontal innovations include the zero-touch service management, the B5G applications framework, and the DTs applied to next generation mobile network.

4.1.1 Zero-touch service management

Zero-touch network and Service Management (ZSM) has been defined as a concept of automated orchestration of network resources using emerging techniques of AI/ML, game theory, and optimization, to pursue the 6G KPIs [50]. In the context of the TrialsNet project, zero-touch service management mechanisms will be carefully designed taking into account the performance requirements of UCs, in terms of network E2E latency, throughput, reliability, and other relevant metrics, while measuring the infrastructure load and energy consumption on the edge computing units. The objective of such enhanced service management techniques is to automate network resource provisioning, while monitoring the service real-time performance, and to improve decision-making process for operations such as service deployment and life-cycle management in heterogeneous and distributed 6G network environment. Although the concepts of ZSM will be designed and implemented to support various UCs that fall under 6G umbrella, enabling efficient management of mission-critical applications, they will be mainly tested in the context of Smart Traffic Management, i.e., UC4 in the Romanian cluster. In this section, the overview of ZSM state-of-the-art is presented, along with the innovations related to Automated orchestration for vertical 5G and beyond services that will be applied and tested in the Romanian cluster, i.e., UC4 implementation and scenarios that will be tested and trialled first in the IMEC testbed ecosystem and then transferred to Iasi network infrastructure.

4.1.1.1 State-of-the-art

[50]Pervasive Artificial Intelligence (PAI) is envisioned to be one of the main 6G pillars for creating zero-touch solutions anytime and anywhere in the network, to enable network self-configuration, self-monitoring, and self-healing [50]. According to Baccour et al. [50], PAI is expected to empower the promises of 6G toward achieving an intelligent communication environment by creating connected intelligence. Thus, bringing intelligence and performing orchestration in an automated manner is inevitable in 6G systems, given the heterogeneity of Software-Based Architecture (SBA) of 5G and beyond networks, where most of the NFs (along with the application services) are virtualized and require proper configuration and management. In addition, 6G systems are expected to connect a massive number of heterogeneous devices connecting to the network over a diverse set of network slices stretching over numerous technological domains (radio, edge, core), as illustrated in Figure 55, which brings severe challenges to traditional centralized MANO approaches towards achieving high scalability and sustainability [51].

The increased complexity and heterogeneity in 6G systems demand innovative approaches based on pervasive and connected intelligence to remove limitations of existing decision-making techniques, i.e., to reduce large delays in 6G orchestration operations that may negatively impact service performance. The ubiquitous use of AI/ML to boost decision-making power has already emerged as promising in the research and industry for years, and B5G and 6G systems, it is important to go one step further and combine AI/ML with NFV and SDN technologies, ultimately enabling automation and intelligence of network on different layers, starting from the radio, over edge, to the network core and data network.

However, such an agile operation with automated incorporation of changes in service deployments still remains challenging in most of the existing orchestration solutions. For addressing such challenge, ETSI [52] identifies ML and in general AI as key enablers for increasing automation, where AI-powered mechanisms require fast access to data, abstraction of intelligent and contextual information from events and rule-based systems, supervision, streamlined work and lifecycle management. With the support from AI/ML, network optimization can be performed at different timescales, thereby enabling more intelligent orchestration operations, which are currently not specified by ETSI NFV MANO. As stated in [52], ETSI Internal Steering Group (ISG) NFV considers incorporating AI/ML into their already standardized MANO stack, although the ETSI NFV is not explicitly considering AI/ML for applications in operation automation but rather in requirements to properly feed data and collect actions from AI/ML modules [53]. Currently, the automation mechanisms in the NFV MANO framework are implemented as rule-based auto-scaling and auto-healing policies specified in VNF descriptors, which schedule scale or heal actions to be executed when a certain performance condition is met. However, fully automated procedures are not tackled by ETSI NFV MANO but by standardization groups such as ETSI ISG ZSM [53] and ETSI ISG Experiential Networked Intelligence (ENI) [54].

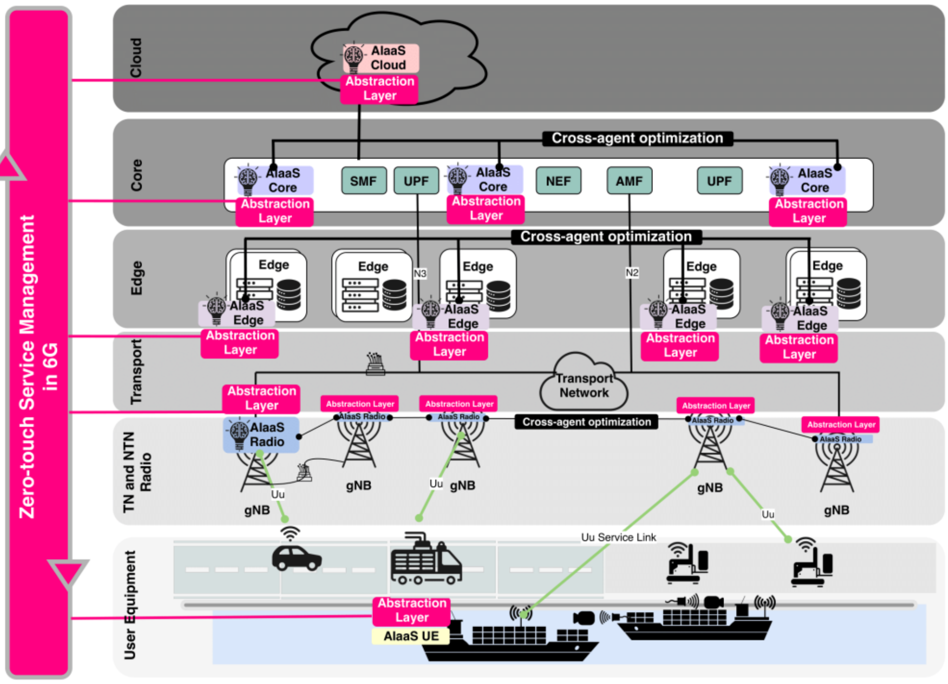


Figure 55. Zero-touch service management in 6G.

Some of the specific and promising approaches to create decentralized zero-touch management frameworks for coping with 6G network dynamicity are presented by Baccour et al. [50], Cherguj et al. [51], Grasso et al. [55], and Fu et al. [56], among others. In particular, Baccour et al. [50] introduced a platform for embedding PAI as a Service (PAIaaS) in 6G ecosystems, aiming to unify and standardize PAI services at all network architecture levels to improve service deployment while taking into account stringent service performance requirements. Due to the strong decentralized nature of AI functionalities, Baccour et al. [50] leverage blockchain to model smart contracts for achieving joint optimization of interactions between distributed decision-makers. In their recent work, Chergui et al. [51] propose a decentralized 6G zero-touch management framework for improving management scalability issues, and for reducing reaction times of self-configuration and self-healing processes. In this case, scalability is achieved by penetrating decision-making power into distributed network elements performing life-cycle management of network slices, and zero-touch management by enabling a closed-control loop that assists entities that perform life-cycle management. In addition, Grasso et al. [55] propose a Deep Reinforcement Learning (DRL)-based network management framework for Unmanned Vehicle (UAV) edge networks, showcasing significant improvements in the task execution time on distributed edge computing nodes hosting delay-sensitive applications.

Another approach is presented by Fu et al. in [56], who propose a Deep Q-network (DQN) algorithm to configure the complex and high-dimensional joint resource allocation problem. The orchestrator leveraging a built-in AI algorithm, analyses the system resources status and task attributes to dynamically allocate corresponding computing, caching and communication resources for specific tasks. Nevertheless, despite promising results, this DQN-based solution poses significant challenges in edge computing environments, due to excessive amounts of resources it requires for online training and inference. In case of real-life application of such solution, it might be difficult to perform the training process in an online manner due to an enormous scale of the network, as DQN consumes a lot of time and computing resources. Therefore, DQN-based schemes need to be trained offline, while further adjustments can be applied online when needed. Such adjustments might not be efficiently decided and applied in case of extremely time-sensitive tasks, which could lead to inefficient neural networks causing wrong actions that result in failed tasks. Furthermore, dimensioning of neural networks is extremely difficult in the wireless network environments, given the ever-changing topologies, where the number of working edge computing nodes, access points, caching servers, and (mobile) users, fluctuate all the time. Any change in the topology would require retraining. Finally, the main limitations for creating and applying most of the AI/ML models are the dimensionality of learning and the complexity of decision making [56]. To improve the decision-making, large amounts of data are required for the training phase. As such training requires computational capabilities that are usually not present in the edge environments, Fu et al. [56] propose using distributed ML, which includes data parallelism, i.e., distribute the same model to different computing machines that separately train the model using smaller datasets, whereas the final outcomes should combine and harmonize the output from the distributed training engines.

Given such overview of state-of-the-art, the development of zero-touch service management solutions for 6G networks is considered as a complex and challenging task that requires the integration of multiple technologies and approaches that need to be carefully designed and harmonized (Figure 56). Nevertheless, its potential in terms of increased efficiency, reliability, and scalability, is unprecedented, pushing the need for innovation and more real-life testing and validation of pervasive zero-touch services in 6G ecosystems.

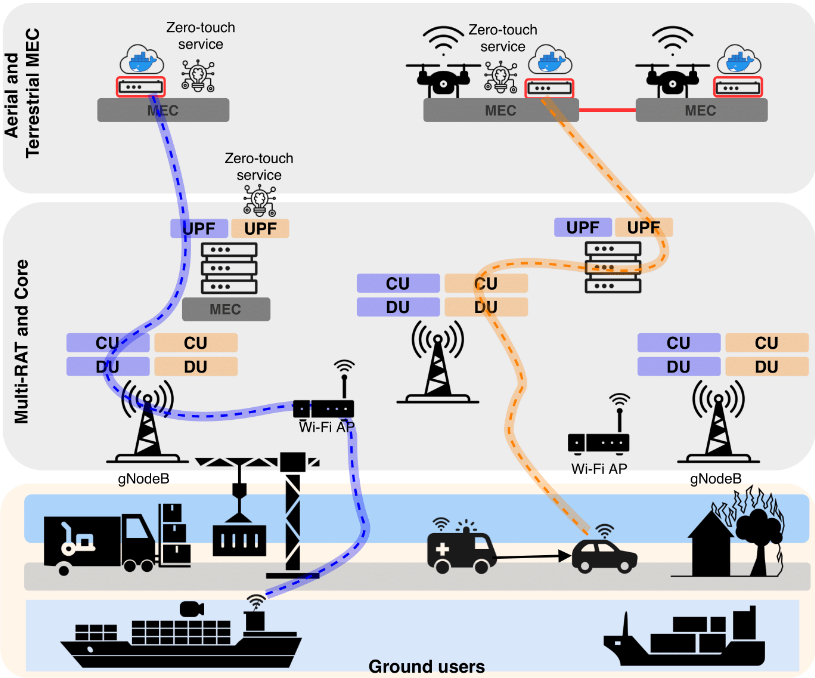


Figure 56. Zero-touch services for automated and intelligent orchestration of Multi-RAT MEC systems.

4.1.1.2 Automated orchestration for vertical 5G and beyond services

The traditional NFV MANO systems defined by ETSI NFV [57] perform service placement, scaling, migration, and termination, based on information gathered from various network segments. By studying the existing solutions and their applicability to service orchestration, several challenges are identified and need to be carefully addressed:

- **Manual orchestration operations:** The stringent requirements for vertical services, such as latency-sensitive smart traffic monitoring system, require extensive (uplink) broadband and reliable connectivity of up to five-nines. This urges for real-time monitoring of the network performance to achieve improved decision-making.
- **Insufficient operational efficiency:** The efficiency of NFV MANO operations needs to be improved (e.g., lengthy scaling procedure that hinders service reliability and response time), as i) the operations of processing monitored data and making decisions are traditionally manual and require human intervention that is prone to mistakes and additional delays, and ii) network complexity significantly increases with heterogeneous and distributed resources, which is even more significant in 5G and beyond

systems because of the presence of various service provider, equipment manufacturers, infrastructure providers, and Mobile Network Operators (MNOs). The application of AI/ML techniques to enable automated NFV MANO operations combines data analytics and learning in closed-loop, thereby outperforming complex and lengthy optimization schemes, heuristic ones that are problem-specific and domain-dependent, and open-loop approaches that are prone to human errors, which makes them all ineffective in swift responses to dynamic network changes and user mobility.

- **KPI fluctuations:** Dynamic changes in KPIs occur due to fluctuations in the demands from users, and their mobility patterns, which is particularly challenging when large numbers of moving users (e.g., vehicles and VRUs in smart traffic scenarios) are simultaneously connected to the orchestrated edge services. Thus, orchestrators need to improve their operation by learning from the environment, identifying or even predicting changes in KPIs, and translating these changes into required NFV MANO operations that will maintain service performance at the desired level.
- **Increased load of NFV MANO:** From 5G onward, the virtualization is realized in the CN, and partially on the radio side. Also, vehicles are getting equipped with computing units, which become mobile edge nodes that can host VNFs. Therefore, NFV MANO solutions are expected to orchestrate all these VNFs. Such an ever-increasing load on the MANO solution may hinder the performance of its operations within the response time required to capture fluctuating KPIs. This phenomenon can be detrimental to service performance (e.g., increased response time from a mission-critical edge service to the users due to insufficient computing/network resources) and must be prevented.
- **Insufficient and inconsistent input data:** huge amounts of data are collected from surrounding infrastructure (edge nodes, sensors, gNBs) for orchestrators to coordinate distributed service deployments, which is more complex than in centralized clouds. This becomes more challenging due to the mobility and varying network connectivity, which may cause delays or jitters in data collection. This lack of sufficient and consistent input data leads to inefficiencies in decision-making, e.g., where/when to migrate service from one edge to another.
- **Support for multi-domain orchestration:** the access to vertical edge services should be ensured across different domains, as users (vehicles, VRUs, etc.) move along the roads, traversing from one edge domain to another. To this end, coordination among multiple orchestrators is required. Such MANO operations are performed across different NFV domains for particular edge services and can be realized by using particular learning framework.

Addressing the previous challenges will transform traditional MANO for 5G and beyond systems into a fully autonomic system that is able to adapt the services and infrastructure to respond to changes in user demands, business goals, and/or environmental conditions. In particular, AI/ML could provide the Network Intelligence (NI) for MANO systems through the Zero-Touch Services (ZTSs), which are the pipelines of effective AI/ML algorithms that detect/anticipate new requests or fluctuations in the network activities and help orchestrators to respond to such changes in a fully automated manner. Unlike the legacy analytical-based models with many parameters that can affect KPIs, the data-based models are enabling a closed-loop approach to perform MANO of vertical services (Figure 57), which is crucial for automation and optimization. This is precisely where AI/ML plays a fundamental role.

This evolution toward automated MANO is aligned with autonomous networks proposed by ETSI [58], which require an automated distinction between service types, analysing the service performance and adjusting the service based on the varying network conditions. To mitigate the challenges listed above, integrate AI/ML techniques into a closed-loop framework to realize a fully autonomous NFV MANO, as these techniques are now sufficiently mature to provide solutions for complex optimization and decision-making processes. However, due to the complexity and heterogeneity of services tailored to vertical industries in 5G and beyond systems, it is impractical to automate MANO operations by applying a single ML model per MANO operation. On the contrary, suitable AI/ML techniques should be applied as Zero-touch services, which focus on a particular task (e.g., mobility pattern, resource utilization), whose outcomes are then jointly considered in NFV MANO, where the final decision on how and which MANO operation to perform is made.

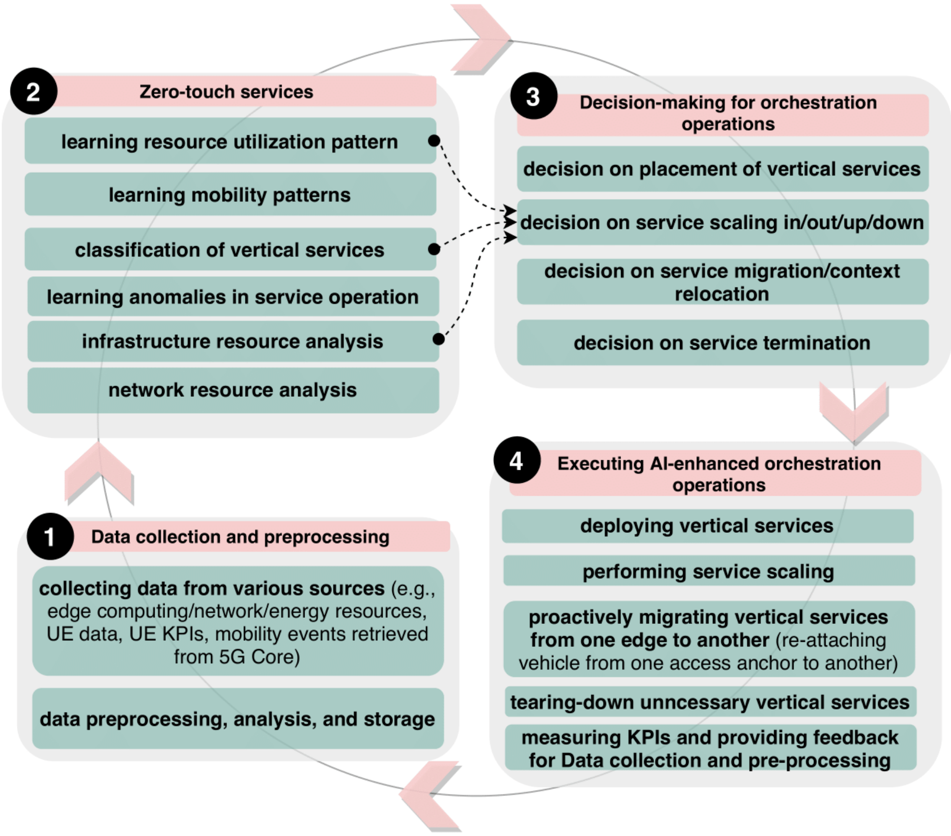


Figure 57. Closed-loop framework for NFV MANO in 5G and beyond systems.

Thus, Figure 57 defines the following phases of a closed-loop framework:

- **Data collection and pre-processing:** In charge of collecting data from various sources, which is then pre-processed and shared with the Zero-touch that apply corresponding AI/ML techniques.
- **Zero-touch services:** Get the relevant data and make predictions/decisions that support orchestrators in improving their operations.
- **Decision-making for MANO operations:** Instantiation/scaling/migration/termination is performed based on the decisions that are harmonizing outputs from a group of Zero-touch services. For example, Figure 57 showcases how the decision on service scaling should be made considering the outputs from learning resource utilization pattern, infrastructure resource analysis, and further adjusting the decision to a particular service class that is identified by the Zero-touch service that classifies MEC vertical services.
- **Executing AI-enhanced MANO operations:** Usually performed by edge platform and virtualized infrastructure managers, which apply decisions made by orchestrators, and re-configure service deployments.

The closed-loop framework proposed in Figure 57 is generic, but some widely used frameworks described in [59], such as Monitor-Analyze-Plan-Execute-Knowledge (MAPE-K) and Observe-Orient-Decide-Act (OODA), can be applied. Notice that the actual mapping between the Zero-touch service and the different closed-loop framework blocks can vary depending on implementation. Therefore, the ZSM implementation in the Trialsnet project will incorporate several 6G zero-touch services, creating the closed-loop framework that will enhance the operation of smart traffic management services deployed at the network edge.

4.1.2 B5G applications framework

To be able to benefit from 5G technologies in terms of ultra-low latency, high reliability, and extensive throughput, the vertical services need to be properly managed and orchestrated, but their design also needs to be tailored to particular UCs, considering vertical service-specific requirements towards 5G. Thus, by applying the cloud-native principles and programmability of service function chains to the design and development of vertical services in 5G and beyond ecosystems, Edge Network Applications (EdgeApps) can be defined as a fundamental building block of the 5G-enhanced vertical service chains in the 6G context. Such EdgeApps are deployed on top of the edge and cloud network infrastructure and used for creating any complex 5G vertical service by abstracting the underlying 5G network complexity, and thus bridging the knowledge gap between vertical stakeholders, network experts, and APP developers. The basis of the EdgeApp framework is defined leveraging the knowledge and experience from the H2020 VITAL-5G project and definition of Network APPs [33]. The framework is further complemented with extensions of the so-called Service Enabler Architecture Layer (SEAL) defined by 3GPP [60].

In the context of the TrialsNet project, the design of EdgeApps will be implemented for smart traffic management services within UC4, making them suitable for resource-constrained edge networks, while at the same time making their interfaces open and programmable for connecting to i) users such as VRUs via different radio access technology (5G and Wi-Fi), and to ii) other EdgeApps to build complex vertical services for addressing city resilience. To optimize service operation for applications developed by external experimenters, it will be required to follow certain guidelines for network application design and deployment, which will be mainly based on the EdgeApp framework.

4.1.2.1 State-of-the-art

The proliferation of 5G deployment will undoubtedly spawn new opportunities for numerous vertical industries, including manufacturing, automotive sector, e-health, and transport & logistics. In [61], Malandrino and Chiasserini study the potential of different industries, i.e., the high-traffic applications, to become 5G verticals and gain from integrating 5G in their day-to-day operations. They performed such an analysis based on a large-scale, real-world, crowdsourced mobile traffic trace, and they also made a classification of the existing applications based on their total traffic, peak rate, and sparseness [61].The outcome of their analysis reflects on the large group of applications that could actually benefit from 5G integration, where most of them belong to major over-the-top content providers, while further at a more general level, Malandrino and Chiasserini [61] derive an important justification of leveraging 5G in all emerging applications. In their work on the advanced 5G architectures for future EdgeApps and verticals, P[62] atachia et al. provide a telco-oriented perspective on the deployment of EdgeApps, focusing on the adjustments that need to be accommodated in the 5G network itself. They identify the gaps in current network deployments of telco operators, which hinder the implementation of innovative UCs, and then propose the adaptations such as DevOps and AI/ML-based cognition, which need to be deeply integrated in the telco network infrastructure to enable E2E network automation capabilities. Such adaptations will be applied through several future 5G functionalities and services, i.e., i) EdgeApps on-boarding, which enables managing EdgeApp packages from various tenants, ii) EdgeApp experimentation APIs that will expose standardized OpenAPIs to provide access to the lifecycle management of EdgeApps and EdgeApp catalogues, iii) EdgeApp orchestrator, which will be in charge of the overall EdgeApp deployment, iv) MANO client API (SOL005) service that interfaces experimentation and operation with EdgeApp orchestrator, and v) CI/CD service that will provide CI/CD pipelines to coordinate the execution of tests by interacting with various orchestrators.

Furthermore, Patachia et al. [62] envision that the changes applied in 5G networks will pave the way towards an increased development and testing of 5G EdgeApps, thereby enabling dynamic allocation of 5G network, computing and storage resources, as well as flexible deployment of vertical services in distributed cloud infrastructures. However, the aforementioned EdgeApp-oriented 5G frameworks are not standardized yet, and as of early 2021, there are several European projects that focus on EdgeApps and their design and development, which progress in research directions that will support vertical industries towards better understanding and integration of 5G in their service paradigms.

In particular, based on the overview of satellite network integration in the 5G ecosystem studied and experimented in the 5GENESIS project [63], Fornes-Leal et al. [64] demonstrate how an integration of satellite backhauling can extend 5G coverage to the rural and underserved areas by deploying 5G applications on the network edge, as a part of a smart farming UC. The concept of EdgeApps that is proposed, and present could be also leveraged in such UCs, where the requirements on the bandwidth and low latency to enable faster field sweeps, higher accuracy, and lower energy consumption, can be also embedded in the EdgeApp blueprints and descriptors. Another initial work on the EdgeApps is given by Apostolakis et al. [65] related to designing

EdgeApps tailored for Public Protection and Disaster Relief (PPDR) UCs, which will be deployed in a fully virtualized containerized 5G network within the 5G-EPICENTRE project. For the PPDR UCs the benefits of such work will be two-fold: enhancements in the network performance, and automated operations supported by Kubernetes (K8s)-based support.

4.1.2.2 EdgeApp framework

The framework for future 5G and beyond applications, such as EdgeApps, should use as a baseline the so-called SEAL architecture, which is standardized by 3GPP [66] as a part of Release 16, and an effort to address an ever-increasing demand for vertical applications. Aiming to enable the operation of such applications in 5G and beyond systems and to cope with the proliferation of vertical industries, 3GPP is fostering innovation in the application layer, focusing on the standardization of vertical applications [67]. In line with that, Shah et al. [67] provide an overview of the SEAL standard and its position in the 5G network, explaining how vertical industries can leverage SEAL to efficiently develop and deploy their applications in the 5G ecosystem. According to Shah et al. [67], the fundamental goal of creating SEAL architecture is to facilitate the development of vertical applications by enabling developers to completely focus on the core functionalities of their applications, i.e., Vertical Application Layer (VAL), and further leverage SEAL for the auxiliary services that could help core ones integrate better with 5G systems.

The functional architecture of the SEAL framework is shown in Figure 58, and it consists of the following elements:

- **VAL Client:** Is responsible for providing client functionalities specific to vertical applications, and the same time interacting with the VAL server and SEAL clients. Some examples could be UE client running in the vehicle that is receiving collision-avoidance assistance from edge network applications, or VRUs' UE client receiving instructions to avoid dangerous intersections.
- **VAL Server:** Provides a server functionality specific to vertical applications, thereby interacting with VAL client and SEAL servers. This definition corresponds to the role of EdgeApps running at the 5G Edge and providing server functionality for various vertical UC scenarios.
- **SEAL Client:** Similarly, as VAL, provides client-side functionalities specific to SEAL service, and interacts with the VAL client and SEAL servers.
- **SEAL Server:** Is responsible for providing server-side functionalities specific to SEAL service, while interacting with the SEAL clients and VAL servers.

As it could be noticed from the aforementioned description, VAL clients and VAL servers provide vertical application specific functionalities, while the SEAL clients and SEAL servers provide a common framework as a support for multiple vertical applications.

Some of the most common SEAL services are:

- **Location Management (LM):** Provides sharing location data between client and server for vertical application usage,
- **Group Management (GM):** Allows vertical applications to manage a group communication, i.e., to create and manage the group, as well as group specific policies and group members,
- **Configuration Management (CM):** Provides initial configuration for all users and notifies them in case any change in the configuration happens, while supporting creating and maintaining UE configuration and user profile configuration for vertical applications,
- **Identity Management (IM):** Supports users' authentication and authorization,
- **Key Management (KM):** Supports secure generation and distribution of encryption keys to VAL users,
- **Network Resource Management (NRM):** Enables vertical applications to switch and manage radio bearers (unicast and/or multicast). However, such architecture of future vertical applications still does not consider any QoS requirements specific for the vertical, which is a complex task given that vertical users (e.g., vehicles, automated guided vehicles, and vessels) connect to different services in the backend, either in the edge or in the cloud that belong to different beneficiaries.

To introduce how NI and Zero-touch services, i.e., ZTS, fit the EdgeApp ecosystem, Figure 58 illustrates the relationship between SEAL, VAL, and vertical-specific servers/clients. In this case, providers of network infrastructure, NFs, communication services, and vertical services, are decoupled from service users to allow cost-effective and flexible service composition. Additionally, a new role is expected to provide ZTSs in the form of AI/ML algorithms. Specifically, these ZTSs should not only be supported at MANO layer as described in Section 4.1.2, but also for the corresponding network slice(s) in CP and UP. For example, deploying the ZTSs for MANO operations (e.g., scaling) may not be sufficient to respond promptly to KPI fluctuations, and vertical service users can notice performance degradation.

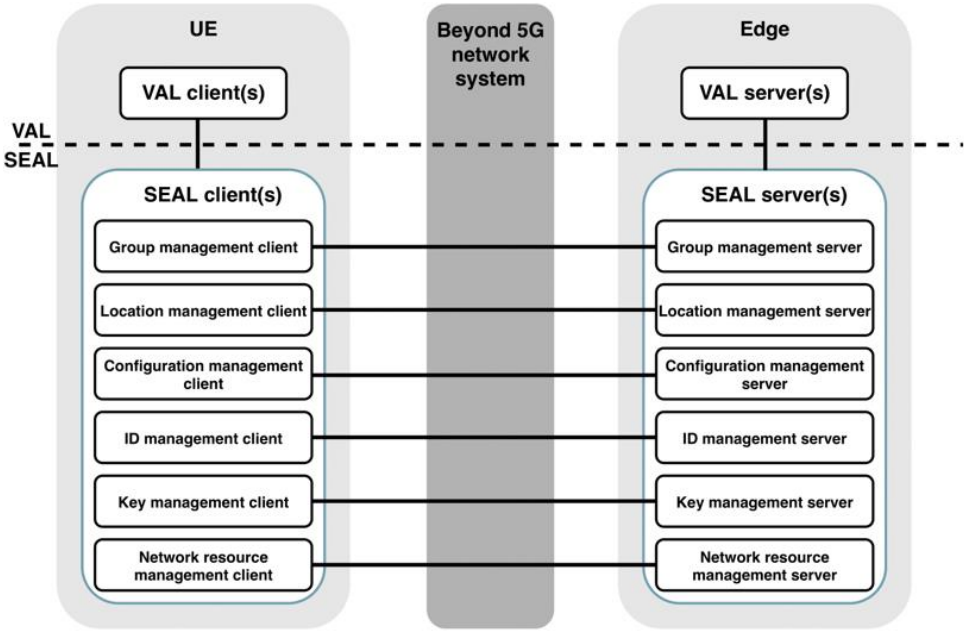
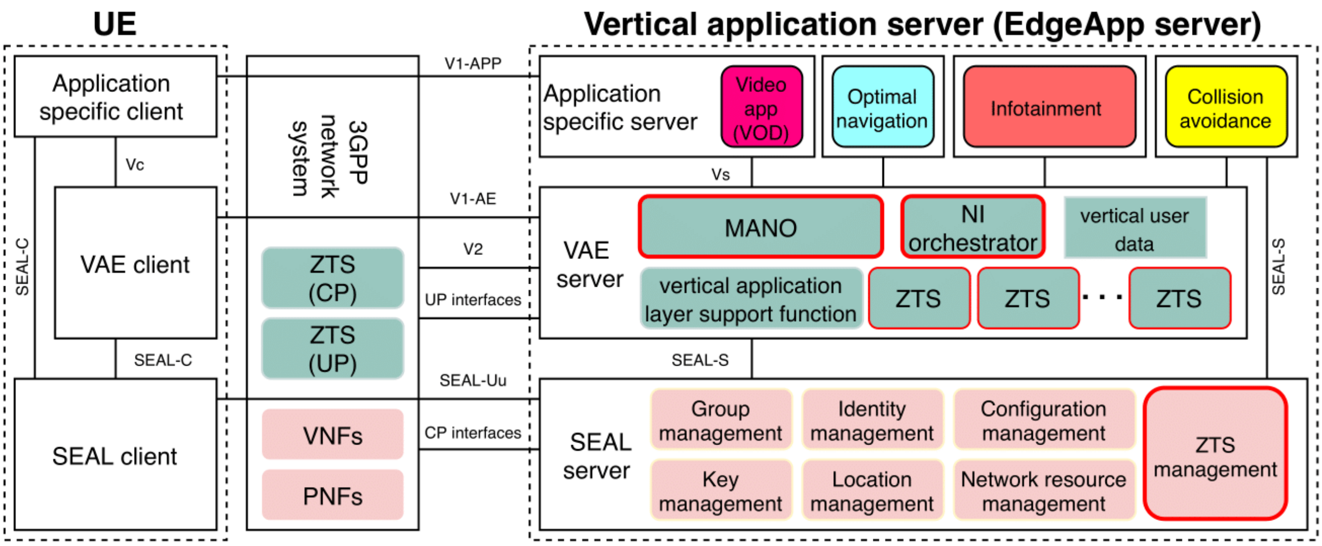


Figure 58. SEAL framework.

To this end, ZTSs in CP and UP can play a key role in adjusting scheduler policies and manipulating packets (e.g., packet marking/dropping), respectively. Moreover, in Figure 59, an enhancement for the VAL functional model from 3GPP is proposed, to be able to manage ZTSs for vertical services and corresponding network slices. It can be seen that the EdgeApp application layer support functions at the Application Enabler (VAE) layer exploit several SEAL services to support vertical applications operations (see 3GPP TS23.286 and TS29.486). Here, several additional functional entities are proposed. First, ZTS management service at the SEAL server, which can be exploited by means of SEAL server interfaces to interact with 3GPP network system for modifying ZTSs. Second, NI orchestrator at the VAE server, provides support functions to communicate the requested ZTSs to the 3GPP network and manages the applied ZTSs. This NI orchestrator can harmonize different ZTSs running inside the vertical APP. Third, the MANO entity at the VAE server, which combines input from different ZTSs, enabling vertical applications to interact with the overall MANO system and impact the effectiveness of their decision-making process.



Functional entity & Reference point	Descriptions
V1-APP & V1-AE	V1-APP supports interaction related to vertical applications, V1-AE supports interaction related to vertical application layer support functions.
V2	Between VAE Server and vertical control function. The control function provides UE parameter for communication.
Vs, Vc	Support interactions related to vertical application layer support function and application specific server/client.
SEAL-S, SEAL-C, SEAL-Uu	Include a number of reference points for respective management in SEAL architecture.
application specific server/client	Provide server/client side functionalities (e.g., smart traffic management server) corresponding to the applications.
VAE server/client	V2X Application Enabler (VAE) server/client provides the client/server side vertical application layer support functions.
SEAL server/client	Various Service Enabler Architecture Layer (SEAL) services offer certain functionalities as APIs for vertical applications.

Figure 59.Overview of VAL functional model.

4.1.3 Digital Twins applied to next generation mobile network

DTs create fully synchronized virtual representations of real-world systems, which may be used as interactive counterparts for AI and ML algorithms. This technology is expected to be particularly important in the next generation mobile networks. By leveraging the DT adaptability and scalability properties, network operation, management, and orchestration can transparently integrate new AI/ML algorithms faster, more scalable, and more precise. Next, the role of DTs in next-generation mobile networks, presenting possible application scenarios and highlighting their advantages is discussed. In the context of the TrialNet project, a DT of the network will be implemented for the Spanish cluster facilities available in 5Tonic.

4.1.3.1 DTs in a nutshell

Also known as Industry 4.0, the fourth industrial revolution marks the beginning of a new era that is characterized by ubiquitous connectivity, and the integration of intelligence and flexible automation in industrial processes [68]. However, in practice, the high cost of scaling, and the need to speed up estimations of how the production environment operates, push toward the design of new paradigms. In fact, an important aspect of the envisioned Industry 4.0 is the transfer of data from physical objects to a virtual domain. This will result in increased monitoring that, combined with AI and ML methods, can lead to optimized production procedures without the need for human intervention.

Physical objects or processes coupled with a digital replica of them, are called Cyber-Physical Systems (CPSs). CPSs consist [69], [70] of (i) a real space that captures the physical object or entity, also called physical twin, (ii) a virtual space that captures a cyber representation of the physical one, also called DT, and (iii) a link that is used for the communication between the physical and the virtual space. This link allows for updates of the virtual model when a change in the real object occurs. In fact, this link between the real and the virtual space constitutesthe main difference between CPSs and traditional models for the prediction of entities' behaviour in the physical world. Figure 60 depicts a CPS.

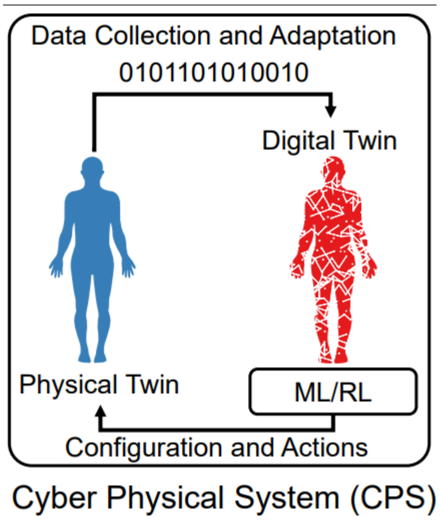


Figure 60. Interactions of a DT with a CPS.

Using DTs is expected to increase operational efficiency, due to the interconnectivity of the real and the virtual spaces. This will allow for the collection of large and precise datasets to monitor or even optimizereal physical systems by analysing the virtual ones in real- time, i.e., without the need to physically perform (possibly expensive) trials on the real systems - traditionally performed through human intervention. DTs have already been applied across multiple domains, ranging from manufacturing [71] to healthcare [72], while there is a growing interest in the integration of DTs in communication networks towards the realizationof the ZSM paradigm.

Next generation mobile network systems are vastly developing in order to address the constantly increasing need for emerging applications, such as robotics or autonomous vehicles. Their complexity will increase significantly to incorporate automation and intelligence, while their management cost has already become a huge impediment for the network operators. The use of DTs, although not yet widely employed within the network community, is a key technology for improving the operation of next generation mobile networks. Why the twinning of network appliances, network services, or even specific modules within the communication networks may be of critical importance for 6G networks is discussed next.

4.1.3.2 DTs for mobile networks

This section discusses in detail the DT paradigm and its role in next generation networks, and three specific UCs in which it is envisioned that next generation communication networks will be highly improved using DTs are presented next.

In principle, DTs could use a variety of methods, ranging from traditional statistical and analytical models to data-driven techniques such as ML algorithms. Compared to traditional network simulators, the great advantage of DTs is the link and the real-time synchronization with the physical twins they represent. ML and Reinforcement Learning (RL) techniques can leverage this link to model the physical object's behaviour by observing its historical and current data, enabling accurate and real-time DTs that could boost operations and management in next- generation mobile network systems. The use of such methods to build DTs will result in the development of native-AI 6G networks.

Figure 61 depicts the role of ML techniques in building DTs and their interaction with the physical twin. RL algorithms play a significant role in assembling DTs: given the actual status of the physical network (i.e., the physical twin), RL techniques select or suggest appropriate actions to self-optimize the mobile network system operations. For instance, in a network environment, the RL agent could be trained to power on/off network cells or to steer applications' traffic based on the actual traffic load combined with the prediction provided by the DTs that simulate the network behavior. Such a DT could act both for the self-management of the physical twin and for the support of the network operator management operations by suggesting appropriate actions to be taken depending on the real-time mobile network status.

When the real system faces states that it had not encountered before, a distribution shift occurs because the data that will be given as input to the physical twin will be drawn from a different distribution than that over which the DT was trained. In these cases, the DTs leverage both historical and real-time data provided by the physical twins, and then adjust accordingly their internal model. This procedure relies on the link between the physical and the DT, and in Figure 60 is called data adaptation. Along with real-time data collection, data adaptation continuously captures the actual mobile network status and accurately models the physical twin behaviour. When the ML/RL algorithm captures the physical twin with enough accuracy, the DT may request a resource reconfiguration at the physical twin, in order to make it operate more efficiently.

DTs can be powerful enablers of new features in next generation mobile networks because they provide scalable models of physical objects. Thus, they could be plugged as separate modules across the network architecture and be employed in various domains of the network, allowing for improvement and speeding up the operation of autonomous networking algorithms. Figure 61 depicts the fact that DT could be used in multiple areas of next generation mobile networks. The network domain of CPSs comprises all the HW and software components that provide network services to application service providers. For instance, an enhanced Mobile Broadband (eMBB) network service is used by a Content Delivery Network (CDN) provider to deliver multimedia files. Another example would be an Ultra Reliable Low Latency Communication (URLLC) service, in order to provide Industry 4.0 services. Network operators and service providers interact through an exposure layer that allows the efficient interplay between them. The network domain also comprises the infrastructure and the environment where the network services are provided. That is, next-generation mobile networks may also include sensing services that are, by their own nature, tightly attached to the environment where they are executed.

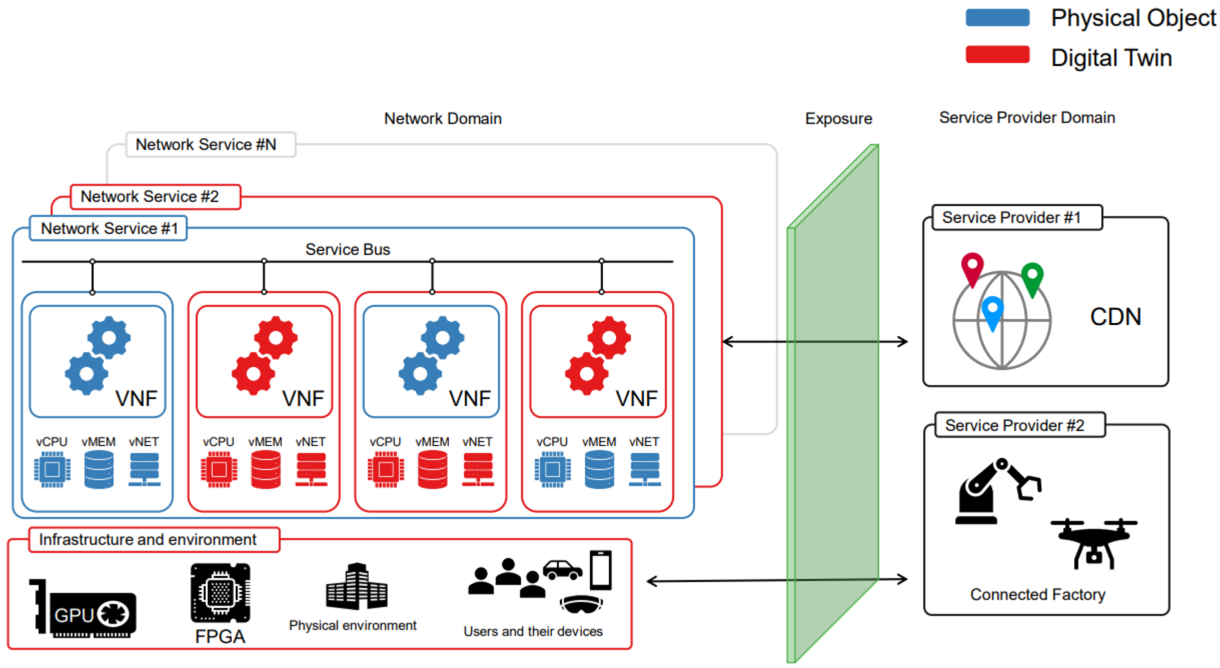


Figure 61. DTs domains for mobile networks.

In this context, the three main scenarios that are envisioned for DTs are described here after.

Digital Twinning of network appliances: The recent trends in network softwarization resulted in the creation of targeted and cloud-native functions [73] that interact using a common service bus, as depicted in Figure 61. An example is the recent split of the Network Data Analytics Function (NWDAF) into the Model Training Logical Function (MTLF) and the Analytics Logical Function (AnLF) in the 5GC in 3GPP Rel-17. This increased the complexity of MANO algorithms, which now have to handle a plethora of configuration variables in order to find the optimal operation points. In practice, the variables that may be configured range from the resource orchestration ones, such as the available computing capacity, to the internals of each VNF. In this context, the surge of AI/ML algorithms allows a seamless transition toward this view, leveraging the great availability of data coming from the network. Here, DTs can play a fundamental role in improving the quality of training, monitoring, and governance of the deployed models. In particular, the DTs may be of crucial importance for:

- the model **training**, especially for RL-based models, that require a tight exploration of state and policies to find the best solution. More specifically, the RL models could take advantage of the DT models they are interacting with,in order to avoid impacting the normal mobile network system operations in a production environment.

- the **monitoring** can use DTs to perform sandboxed decisions, comparing them to the ones of the real operational system managed by the AI/ML algorithm, identifyingpossible drifts between the two models, allowing hence for a fast reaction close to the element that made a decision. This impacts the model governance.
- the model **governance** (i.e., track interactions with the AI/ML models and their results), as parallel ones canbe trained (with data coming from either the DT and the physical system) to allow a hot swap when the contextualconditions are changing.

Besides these operational advantages, DTs can be used both in a full and a hybrid setup. For example, a DT may capture a VNF running on a specific network infrastructure, a real VNF running on top of a twinned infrastructure, or a twinned VNF running on top of real infrastructure. These scenarios can be used for improving training, monitoring, and governance of the model, as well as creating mixed network services that can be used in the real system. The composed network services can, in turn, also be considered DTs for other domains of the network, e.g., the MANO framework or the service provider, as discussed next. The DT that will be developed for the Spanish cluster includes this family of DTs.

Digital Twinning of network services: The emergence of novel network applications with complex requirements (e.g., AR/VR, Metaverse, Vehicular Networks), makes themanagement of next generation mobile networks based ontraditional solutions impracticable. Here, DTs can enable the efficient control and management of the mobile network, by providing a data-driven virtual model for it. The real-timedigital representation of the physical twin can be leveragedby:

- The MANO framework, to perform what-if analysis, troubleshooting, network planning, and optimization. An updated and high-fidelity DT, based on real-time data collected from the network, makes the mobile network's behaviour predictable and enables the proactive testing of novel optimization algorithms (e.g., to optimize RRM or energy efficiency), the measurement of network infrastructure and software up- dates/upgrades impacts or anomalies detection without affecting current physical system operations. Furthermore, the integration of DT in the next generation mobile network can be a key enabler for network automation and full ZSM.
- The service providers can benefit by interacting with DT services and capabilities to optimize the providednetwork service. For instance, the interaction between theservice provider and DT may result in service requirements negotiation to accommodate the network service that otherwise would not be served given the predicted future physical twin status. On the other side, the service provider may leverage the interaction with the DT, to drive and tune network services as network analytic services, to ensure the optimization of its private metric.

The digital twinning of network services may be providedas a unique virtual entity that models the behaviour of theentire mobile network, or as multiple DTs that capture single physical twins and interact with each other to mimic the behaviour of the whole physical system. Nevertheless, depending on the UC and scenario, the DT maybe not be limited to mimicking only mobile network-related aspects, but it couldbe extended to cover, as discussed next, also environmentproperties offering a more complete view of the physical twin.

Digital Twinning of the environment: Next generation networks will provide more than data transfer between terminals and service providers, additionally offering (remote) sensing capabilities of the underlying environment. High-level, this scenario provides an interoperation of wireless communication and sensing capabilities that can empower (especially IoT) service providers with more contextual information about the surrounding environments, or even enrich the services with more UCs, such as event detection at home or in a vehicular environment. Usually, these capabilities are provided using features of the wireless access network [74]. Other environmental metrics could be used, such as coarse user location and trajectories. Hence, this functionality could also be offered as DT to service providers, to improve their business intelligence processes with network sensing data, but also to avoid possible leakages of private or confidential data from the network. That is the interaction with a DT of the sensed environment may happen with privacy-preserving guarantees for the end users and the infrastructure provider.

4.2 Vertical Innovations

In this section, we discuss how specific network innovations can directly impact the development of specific vertical UCs by enhancing specific functionalities. In the context of the TrialsNet project, we initially envisioned two of them, although more solutions will be devised in the lifetime of the project to support emerging requirements from the different UCs.

4.2.1 AI mechanisms for diagnostics and resources efficiency

6G will support the delivery of solutions for verticals. Solutions rely on various AI components and are distributed in the infrastructure. TrialsNet will conduct work and enhance a diagnostics framework to assure that the proper performance is delivered by different segments of the 5G/B5G infrastructure (often assuming that some segments are a “black box”). Moreover, the diagnostics framework will monitor the vertical components hosted in the infrastructure, with respect to their non-functional behaviour to ensure compliance with the anticipated behaviour. AI mechanisms will be comparing (infrastructure and vertical components) to propose potential improvement actions.

Furthermore, framed in this context is that 6G should support the delivery of solutions for verticals in a manner that will be characterized by sustainability, trustworthiness, performance and efficiency. In this direction, TrialsNet will conduct work for supporting flexibility in terms of functionality allocations and resource requests. Triggers will be related to the improvement of the energy efficiency, trust aspects (e.g., in case of multi-domain, device, and stakeholder contexts), the need of improving the performance and resource-efficiency of the infrastructure and services, service priorities.

In the light of the above, actions will be related to the tuning of the computational and communication resources, which can be requested by the infrastructure, in principle through network exposure mechanisms. In addition, there will be actions related to the allocation of functionality and data to the appropriate parts of the infrastructure to improve KPIs/KVIs. More specifically, system, network and edge device metrics are continuously collected and analysed by the diagnostics mechanisms. A first aim is to identify potential sources of any slowdowns or performance bottlenecks before they begin to severely affect the system as a whole. Different actions, events and alerts can be generated based on the analysis performed. Decisions on potential actions are enforced by orchestration mechanisms (e.g. OSM based).

Essentially diagnostics mechanisms analyse the performance of deployed services without extensive knowledge of the service’s functionality, metrics, and overall usage. More specifically considering certain metrics/KPIs (e.g. CPU/Random Access Memory (RAM)/disk/network utilization, latency, etc.), diagnostic mechanisms can detect anomalies in the observed behaviour or performance degradations. Once such an event has been identified additional mechanisms can evaluate what actions can be taken like for example offloading/migrating services from edge to cloud nodes and vice versa. Diverse AI algorithms can be utilized such as Self-Organizing Maps (SOMs) [75] and Depth-based spatial clustering of applications with noise (DBSCAN) [76] as an alternative for the clustering of the observed data, as well as custom algorithms for topological investigation, correlation and root cause analysis based on adjacency lists [77].

AI mechanisms can also be utilised for predicting the behaviour and performance of monitored services and nodes across the underlying infrastructure, based on time series forecasting. In this case, the goal is to create a view of the future state of the infrastructure and deployed services. This future state is used to determine if there is a need for pre-emptive actions to prevent upcoming critical events. When an anomaly is detected in this future state appropriate resource optimisation mechanisms are proactively triggered to decide on actions to prevent the predicted anomaly.

Such mechanisms will be part of the WINGS testbed (described in section 3.6) and will be used in the scope of the UCs associated with the Greek cluster, mostly focusing on UC2, UC3, UC6 and UC11.

4.2.2 Automatic orchestration of network slices to ensure QoS in mobility

In the increasingly virtualized radio network, towards a cloud native scenario, servers hosting the cloud elements also requires a high-quality transport infrastructure. In essence, there are three domains that continuously interact together: radio, transport, and cloud. These domains shall be “coordinated” by the common umbrella of an E2E orchestrator.

In the context of UC8 “Smart Ambulance”, the implementation of automatic orchestration involves the dynamic allocation and management of network resources, such as computing, storage, and network connectivity, to meet the specific needs of ambulance services. In the context of UC8, it involves allocating and configuring network slice resources that are dedicated to ensuring the QoS requirements of the ambulance services on the overall path towards the destination hospital. The allocation shall be done in real-time, considering the current network conditions and the available resources. Once the resources are allocated, the network slices shall be configured with the appropriate settings to ensure the desired QoS. This includes configuring traffic prioritization, QoS mechanisms, security policies, and other parameters to optimize the performance.

These tasks are particularly challenging due to the dynamic nature of mobility (high speed of the ambulance in an emergency), where network conditions, user mobility, and handovers between different network cells introduce complexities that can impact QoS and deteriorate the communication of critical clinical data from the ambulance to the hospital and vice versa. Ensuring smooth handovers and minimizing disruptions during handover processes are significant challenges, especially when this impact radio, transport, and cloud coordination.

On large scale, the role of transport in backhaul and fronthaul (whatever is the technology used like packet, optical, or a combination) is crucial. In this respect, the ER Innovative Orchestration system has the specific characteristic of transport-awareness. It means that the orchestrator takes the responsibility for overall E2E deployment across the radio network, including the transport segment, working with the Virtual NFs Manager, the Network Management System, the Element Manager System, and controllers in the three different domains: radio, transport, and cloud. The orchestrator uses transport awareness to guarantee a wide range of QoS levels, including the very high ones that are necessary to meet the most stringent requirements of the smart ambulance scenario on large scale. Transport-awareness orchestration ensures E2E QoS without over-provisioning of transport resources.

The RRM will automatically support the action of the orchestrator by taking care of the availability and allocation of radio resources, such as frequency bands and channel capacities. This involves optimizing resource allocation, load balancing, and interference management to guarantee QoS while minimizing delays and packet loss during handovers.

5 Conclusions

Based on the requirements defined for the different UCs in the context of WP3, WP4, and WP5, WP2 will design, integrate, and deploy the platform and network solutions in support to their implementation in the context of large-scale trials. The envisioned 6G applications will require very demanding performances in terms of ultra-low latencies, very high throughputs, and solid reliability, thus requiring proper infrastructures.

This deliverable D2.1 has described the preliminary infrastructure aspects of the Italian, Spanish, Romanian, and Greek clusters. In particular, for each cluster, the document reported the components and functionalities of the related infrastructures, how these will support the UCs implementation, and the enhancements that will be implemented starting from the initial deployment.

This document has provided also the description of the TrialsNet 5G framework consisting of i) a methodology based on an iterative approach that will be followed to derive the requirements of the next generation mobile networks and ii) the definition of the baseline and advanced 5G technologies that will be used in the different clusters.

In addition, the deliverables also introduced the TrialsNet's innovations that will be experimented in the context of the UCs implementation. Such innovations have been identified in horizontal innovations (covering transversal aspects of B5G systems such as zero-touch management, B5G application framework, and DTs for next generation mobile networks) and vertical innovations (related to specific UCs such as AI mechanisms for diagnostic and resources efficiency as well as automatic orchestration of slice resources to ensure QoS in mobility).

The next WP2 deliverable D2.2 will provide an update on the design and initial integration aspects status of the platform and network solution that will be based on the progresses of the activities related to the UCs implementation.

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