5GLOGINNOV

D1.2

5G architecture and technologies for logistics use cases

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List of abbreviations and acronyms

Abbreviation	Meaning
3GPP	3rd Generation Partnership Project
4G	4th Generation (of cellular networks)
4K	Resolution with a horizontal pixel count of approximately 4,000
5G	5th Generation (of cellular networks)
5G PPP	5G Infrastructure Public Private Partnership
5GC	5G Core
5G-NR	5G New Radio
AI	Artificial Intelligence
AI/ML	Artificial Intelligence and Machine Learning
AMF	Access and Mobility Management Function
API	Application Programming Interface
ATP	Automated Truck Platooning
ATSSS	Access Traffic Steering, Switch and Splitting
BSS	Business Support System
CAD	Connected Automated Driving
CAM	Connected Automated Mobility
CAN	Controller Area Network (vehicular bus standard)
CAN bus	Controller Area Network
CCTV	Closed Circuit TeleVision
CMS	Container Management Systems
CN	Core Network
CNF	Cloud Native Functions
CNS	Complementary network service
CO2	Carbon dioxide
COREALIS	Capacity with a pOsitive enviRonmEntal and societAL footprInt: portS in the future era
COTS	Commercial-off-the-shelf
CP	Control Plane
CUPS	Control and User Plane Separation
DC	Dual Connectivity
DCET	Dynamic Control Loop for Environment Sensitive Traffic Management Actions
DM	Device Management
DN	Data Network
DSS	Dynamic Spectrum Sharing
E2E	End-to-End
EM	Element Management
eMBB	Enhanced Mobile Broad Band
eNB	Evolved Node B
EN-DC	Dual Connectivity configuration
EPC	Evolved Packet Core
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute

E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FMS	Fleet Management System
FTED	Floating Truck & Emission Data
GHG	Greenhouse Gas
GLOSA	Green Light Optimized Speed Advisory Systems
gNB	next generation Node B
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HPA	Hamburg Port Authority
HSS	Home Subscriber Server
HW	Hardware
I.T.S.	Intelligent Transport Systems
IaaS	Infrastructure-as-a-Service
IAB	Integrated access and backhaul
ICT	Information and Communications Technology
IoT	Internet of Things
ISG	Industry Standardization Group
KPI	Key Performance Indicator
LAN	Local Area Network
LL	Living Lab
LTE	Long-Term Evolution (4th generation of cellular networks)
MANO	Management and Network Orchestration
MBS	Metropolitan Beacon System
MC	Mission Critical
MEC	Multi-access Edge Computing
MEP	MEC platform
MIMO	Multiple-Input/Multiple-Output
MME	Mobility Management Entity
mMTC	Massive Machine Type Communication
MN-eNB	LTE Master Node
MNO	Mobile Network Operator
NFV	Network Functions Virtualization
NFVO	NFV Orchestrator
NR	New Radio
NR-CA	New Radio and Carrier Aggregation
NRF	Network Repository Function
NS	Network Service
NSA	Non-Standalone
OSM	OpenSource MANO
OSS	Operations Support Systems
PCF	Policy Control Function
PCRF	Policy and Charging Rules Function
PCT	Piraeus Container Terminal

PGW	Packet Gateway
PMR	Private Mobile Radio
PNF	Physical Network Function
PTZ	Pan-Tilt-Zoom
QoE	Quality of experience
QoS	Quality of Service
RAN	Radio Access Network
SA	Stand Alone
SBA	Service-based architecture
SCADA	Supervisory control and data acquisition
SGW	Serving Gateway
SLA	Service Level Agreement
SME	Small and medium-sized enterprises
SMF	Session Management Function
SMS	Short Message Service
SN-gNB	5G NR Secondary Node
SPAT/MAP	Signal Phase and Time / Map Data
SUL	Supplementary Uplink
TAVF	Test field for Autonomous and Connected Driving
TMS	Traffic Management System
TOS	Terminal Operating System
UC	Use case
UDM	Unified Data Management
UE	User Equipment
UHD	Ultra-High Definition (images)
UMTS	Universal Mobile Telecommunications System
UP	User Plane
UPF	User Plane Function
uRLLC	Ultra-Reliable Low Latency Communications
V2X	Vehicle-to-anything (any ITS-enabled vehicle or infrastructure)
VIM	Virtual Infrastructure Manager
VM	Virtual Machine
VNF	Virtual Network Functions
VNFM	VNF Manager
VoLTE	Voice over LTE
VoNR	Voice over NR
VPN	Virtual private network
VRU	Vulnerable Road Users
VSaaS	Video Surveillance-as-a-Service
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WP	Work Package

EXECUTIVE SUMMARY

Smart ports require communications systems to support low latency, high bandwidth and high reliability communication services in order to handle control and user/device data streams from various 5G-end-devices and port equipment (e.g. 5G-IoT devices, 5G-connected trucks). With legacy communication based on optical fiber and Wi-Fi, network deployment, operation and maintenance are costly and the network performance for such data handling is often suboptimal with poor stability and low reliability. 5G is expected to address such challenges thanks to its low latency, large bandwidth, capacity and high reliability as well as its support for private network solutions and end-to-end (E2E) application performance guarantee.

Deliverable D1.2 outlines the main 5G network architecture and its requirements for the 5G-LOGINNOV project based on the current relevant state of the art and beyond. The relevant state-of-the-art is the result of systematic work of various organizations, such as 3GPP and ETSI and various working groups within 5G PPP. This deliverable, together with other 5G-LOGINNOV deliverables within WP1 provide the first main 5G network architecture for the entire 5G-LOGINNOV ecosystem.

The proposed 5G architecture and implementation allow the deployment of all use cases within any individual 5G-LOGINNOV Living Lab. Any Living Lab will be able to test various 5G network layouts and settings in a controlled test environment and adapt it to the port operations.

1 INTRODUCTION

1.1 Concept and approach

5G-LOGINNOV project will deploy, evaluate and showcase the added value of 5G technology for logistics and port operation in three (3) Living Labs: Athens (GR), Hamburg (GE), and Luka Koper (SV). The participation of the port operator (PCT-Athens, Hamburg, Luka Koper) and major telecom industry stakeholders (MNOs, vendors, technology integrators) as well as the complementarity of the rest of the 5G-LOGINNOV consortium guarantee the technological significance as well as the business impact and market penetration of the 5G-LOGINNOV results and the developed solutions. 5G-LOGINNOV comprises also a palette of port-driven technological and societal innovations that will be implemented and tested in real operating conditions in three Living Lab environments, associated with the 3 5GLOGINNOV ports, namely Athens, Hamburg, and Luka Koper Living Labs (LLs) respectively. In more detail, the innovations are explained in the next section.

The objective is to specify the 5G network architecture needed to support the deployment of the innovative advanced use cases involving several cutting edge 5G features and technologies and new devices (e.g. slicing, eMBB, uRLLC, mMTC, MEC, 5G-NR, etc.) in order to be deployed at the Living Labs level, as was already described in Task T1.1. This task is closely related to the 3GPP roadmap and envisioned timelines regarding the upcoming releases of 5G standards (i.e. Rel.16 and as applicable Rel. 17).

Deliverable D1.2 - *5G architecture and technologies for logistics use cases*, describes the reference 5G architecture and the dedicated 5G technologies relevant to the 5G-LOGINNOV Living Labs and their innovative application deployment and project integration.

1.2 Purpose of the deliverable

This deliverable will provide 5G network requirements and specifications of the 5G technologies and components that will be used to support the successful operation of the defined 5G-LOGINNOV use case in each Living Lab, as specified in the deliverable D1.1. The objectives related to this deliverable have been achieved in full and as scheduled.

Table 1: Partners and roles

Partner	Role
Telekom Slovenije	Overall task coordination. Technical/scientific/functional/operational support to 5G network architecture requirements and Koper Living Lab 5G architecture.
VICOM	WP coordination and liaison with other tasks. Content contributor.
Internet Institute (ININ)	Koper Living Lab Leader. Technical/scientific/functional/operational support to 5G network architecture requirements and Koper Living Lab 5G architecture.
T-Systems	Technical/scientific/functional/operational support to 5G network architecture requirements and Hamburg Living Lab 5G architecture.
Vodafone Innovus	Technical/scientific/functional/operational support to

The objectives related to this deliverable have been achieved in full and as scheduled.

1.3 Intended audience

The dissemination level of D1.2 is public and hence will be used publicly to inform all interested parties about the 5G architecture and technologies for logistics use cases to be used in the 5G-LOGINNOV Living Labs.

This deliverable is of special interest to the 5G-LOGINNOV project consortium members as an internal document in order to exchange knowledge regarding 5G network deployment, implementation, and different configurations. This document is of particular interest to telecom operators and vendors not participating in the project, as it will provide an insight into the 5G NSA and SA network deployments. Last but not least, this document is also addressed to the European Commission.

1.4 Structure of the deliverable and its relation with other work packages and deliverables

This deliverable contains six chapters as follows:

Chapter 1 motivates the scope of the deliverable, summarizes the most important achievements, and outlines the structure of the document.

Chapter 2 provides standardization aspects related to the 5G-LOGINNOV network requirements and architectural design.

Chapters 3-5 describe 5G-LOGINNOV living labs 5G network requirements and architecture. It iterates the important architectural design principles and objectives, elaborates on the high-level functional architecture.

Chapter 6 concludes the deliverable by providing a summary of the 5G-LOGINNOV 5G network architecture requirements and design.

Deliverable D1.2 is closely related to other deliverables within WP1, especially deliverable D1.1 which presented a detailed description of the Use Cases. This deliverable also forms the basis for further work on WP2 and WP3, where necessary 5G infrastructure, technology, equipment and devices for the logistics hub and port operations will be developed, integrated, rolled out and evaluated.

1.5 5GPPP Architecture Working Group

A popular application is the 5G Infrastructure Public-Private Partnership (5G PPP), which is a joint initiative between the European Commission and the European ICT industry (ICT manufacturers, telecom operators, service providers, SMEs, and research institutions) and will provide solutions, architectures, technologies, and standards for next-generation global communications.

The challenge for the 5G Public-Private Partnership (5G PPP) is to ensure the European leadership in the areas in which Europe is strong or where there is the potential for creating new markets such as smart cities, e-health, smart transport, education, or entertainment, and media.

This project will strengthen the European industry to successfully compete in global markets and open new opportunities for innovation. It will open "a platform that helps in achieving the common goal of maintaining and establishing global technology leadership”.

5G-PPP is now in its third phase and many new projects were launched in Brussels in June 2018.

The main challenges for 5G infrastructure PPP are:

- Provide 1000 times the wireless area capacity and more varied service capabilities than in 2010
- Reach up to 90% energy savings per service provided.
- Reduce the average service creation time cycle from 90 hours to 90 minutes
- Create a secure, reliable, and trustworthy internet connection with "perceived zero" downtime for service delivery
- Facilitate very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people
- Ensure everyone and everywhere the access to a larger board of services and applications at a lower cost

The key objective of the 5G system is to support new implementation scenarios to address different market segments and to provide optimized support for a variety of different services, different traffic loads, and different end-user communities.

Concretely, 5G-LOGINNOV use cases will address the following 5G-PPP thematics, defined in the pre-structuring model (PSM):

- (Vehicular) T1: Autonomous driving (car, truck) – uRLLC traffic type
- (Vehicular) T2: Drone applications – RLLC, mMTC traffic types
- (Multimedia-4K streaming) T4: Precise positioning based on the 5G technical features and improvements relative to 3/4/5G – eMBB, uRLLC
- (Industry 4.0) T8: Sensors for monitoring (low-power devices, surveillance camera) – mMTC
- (Industry 4.0) T7: Supply chain – mMTC, uRLLC
- (Industry 4.0) T8: Dynamic Traffic Management with reactive response times – mMTC
- (B2B) T9: Router, CPEs – eMBB

2 STANDARDISATION ASPECTS

2.1 3GPP

2.1.1 Release 15

After initial delivery in late 2017 of ‘Non-Stand-Alone’ (NSA) new radio (NR) specifications for 5G, much effort focused in 2018 on timely completion of 3GPP Release 15 – the first full set of 5G standards – and on work to pass the first milestones for the 3GPP submission towards IMT-2020.
While initial specifications enabled non-standalone 5G radio systems integrated with previous-generation LTE networks, the scope of Release 15 expands to cover ‘standalone’ 5G, with a new radio system complemented by a next-generation core network. It also embraces enhancements to LTE and, implicitly, the Evolved Packet Core (EPC). This crucial way-point enables vendors to progress rapidly with chip design and initial network implementation during 2019.

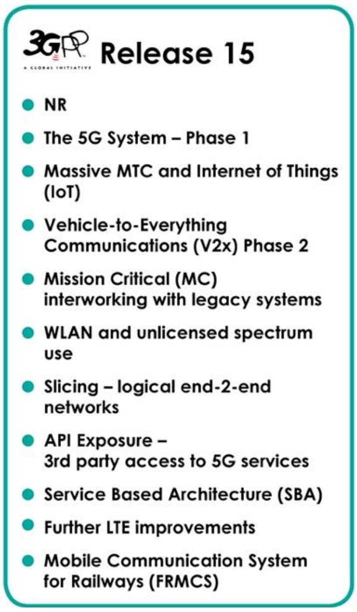

Figure 1: 3GPP - Release 15

As the Release 15 work has matured and drawn close to completion, the group’s focus is now shifting on to the first stage of Release 16, often referred to informally as ‘5G Phase 2’. By the end of the year, 83 studies relating to Release 16 plus a further thirteen relating to Rel-17 were in progress, covering topics as diverse as Multimedia Priority Service, Vehicle-to- everything (V2X) application layer services, 5G satellite access, Local Area Network support in 5G, wireless and wireline convergence for 5G, terminal positioning and location, communications in vertical domains and network automation and novel radio techniques. Further studies were launched or progressed on security, codecs and streaming services, LAN interworking, network slicing, and the IoT.

Other activities focused on broadening the applicability of 3GPP technology to non-terrestrial radio access systems – from satellites and airborne base stations to maritime applications including ship-to-shore and ship-to-ship communications. Work also progressed on new Professional Mobile Radio (PMR) functionality for LTE, enhancing railway-oriented services originally developed using GSM radio technology which is now nearing its end of life.

5G can be deployed in various deployment options, where SA options consist of only one generation of radio access technology and NSA options consist of two generations of radio access technologies (4G LTE and 5G). The early deployments will be adopting either non-standalone option 3 or standalone option 2 as the standardisation of these two options has already been completed [18].

Non-standalone option 3 is where the radio access network is composed of eNBs (eNode Bs) as the master node and gNBs (gNode Bs) as the secondary node (see the left side of Figure 2). The radio access network is connected to EPC (Evolved Packet Core). The NSA option 3, as it leverages existing 4G deployment, can be brought to market quickly with minor modification to the 4G network. This option also supports legacy 4G devices and the 5G devices only need to support NR (New Radio) protocols so the device can also be developed quickly. On the other hand, NSA option 3 does not introduce 5GC and therefore may not be optimized for new 5G use cases beyond mobile broadband. In addition, depending on how 5G devices are developed, the EPC may need to be retained longer than in the case of having EPS (Evolved Packet System) for 4G alone (instead of supporting NSA Option 3).

Standalone option 2 is where the radio access network consists of only gNBs (gNode Bs) and connects to 5GC (5G Core), and the 5GC interworks with EPC (see right side of Figure 2). SA option 2 has no impact on LTE radio and can fully support all 5G use cases by enabling network slicing via cloud-native service-based architecture. On the other hand, this option requires both NR and 5GC, making time-to-market slower and deployment cost higher than that of NSA option 3. Furthermore, the devices would need to support NR and core network protocols so it would take more time to develop devices. Finally, as the standalone 5G System would need to interwork with EPS to ensure service continuity depending on coverage, the interworking between EPC and 5GC may be necessary.

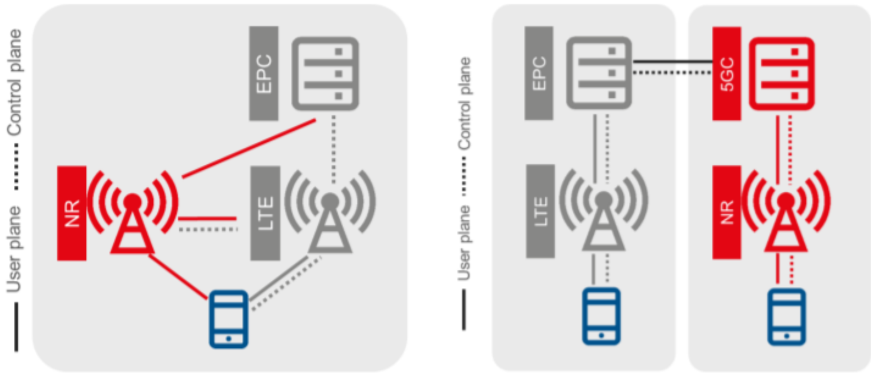

Figure 2: High-level architecture of NSA Option 3x and SA Option 2 [5].

3GPP defines NSA and SA architectures and Option 3x for NSA and Option 2 for SA has become an industry consensus. The NSA can deploy a 5G network to support eMBB services and can be software upgraded to SA in the future. Table 2 shows the key factors of both architectures [18].

Table 2: Comparison between NSA Option 3 and SA Option 2

	NSA Option 3x	SA Option 2
Standard	17Q4	18Q2
	Option3x support 5G initial fast deployment, Option 2 0.5~1year late	
Coverage	DC / NR-CA or DC / SUL	NR-CA (or SUL)
	EN-DC provides coverage and service continuity for NSA, NR-CA optimizes coverage for both NSA & SA and provides service continuity for SA	
Voice	VoLTE	EPS fallback (initially) or VoNR (target)
	Suitable solution with experience at the same level	
Service Readiness	eMBB	eMBB/uRLLC
Deployment complexity	DC	NR CA / LTE-NR spectrum sharing (SUL)
	NSA with mandatory DC needs LTE upgrade; SUL which extends SA Coverage need LTE upgrade, complexity at the same level	
Relevance with existing LTE	DC	LTE-NR spectrum sharing, SUL / Refarming
	DC, SUL is both relevant to LTE; Coordination after Refarming Legacy LTE is important, NSA/SA are both closely relevant to legacy LTE.	

2.1.2 Release 16

Release 16 is a major release for the project, not least because it brings our IMT-2020 submission - for an initial full 3GPP 5G system - to its completion (see details below).

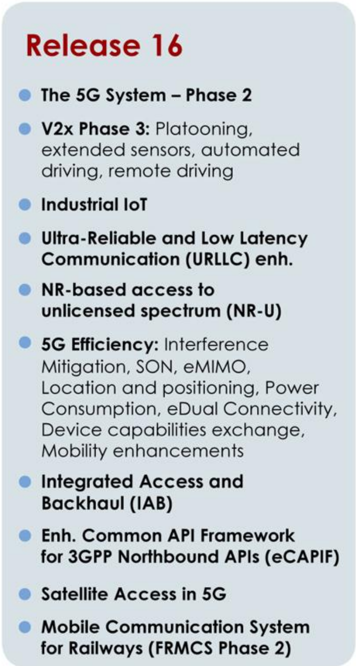

Figure 3: 3GPP - Release 16

In addition to that formal process, work has progressed on around 25 Release 16 studies, on a variety of topics: Multimedia Priority Service, Vehicle-to-everything (V2X) application layer services, 5G satellite access, Local Area Network support in 5G, wireless and wireline convergence for 5G, terminal positioning and location, communications in vertical domains and network automation and novel radio techniques. Further items being studied include security, codecs and streaming services, Local Area Network interworking, network slicing, and the IoT.

Technical Reports (the result of the study phase) have also been developed on broadening the applicability of 3GPP technology to non-terrestrial radio access (initially satellites, but airborne base stations are also to be considered) and to maritime aspects (intra-ship, ship-to-shore, and ship-to-ship). Work also progresses on new PMR functionality for LTE, enhancing the railway-oriented services originally developed using GSM radio technology that is now nearing the end of life.

As part of Release 16, MC services are extended to address a wider business sector than the initial rather narrow public security and civil defence services for which they had originally been developed. If the same or similar standards can be used for commercial applications (from taxi dispatching to railway traffic management, and other vertical sector scenarios currently being investigated), this would bring enhanced reliability to those MC services through wider deployment, and reduced deployment costs due to economies of scale – to the benefit of all users.

2.1.3 Release 17 – timeline agreed

New Release 17 Schedule:

- Rel-17 Stage 2 Functional Freeze, June 2021 (TSGs#92-e)
- Rel-17 Stage 3 Protocol Freeze, March 2022 (TSGs#95)
- Rel-17 Protocol coding Freeze (ASN.1, OpenAPI), June 2022 (TSGs#96)

Only the timeline for the work has changed; the content of Release 17 remains as approved during the December 2019 TSG#86 meetings. With this revised timeline, the broader 5G industry can rely on an informed and well-considered schedule that takes into account the particular situation created by life during a pandemic.

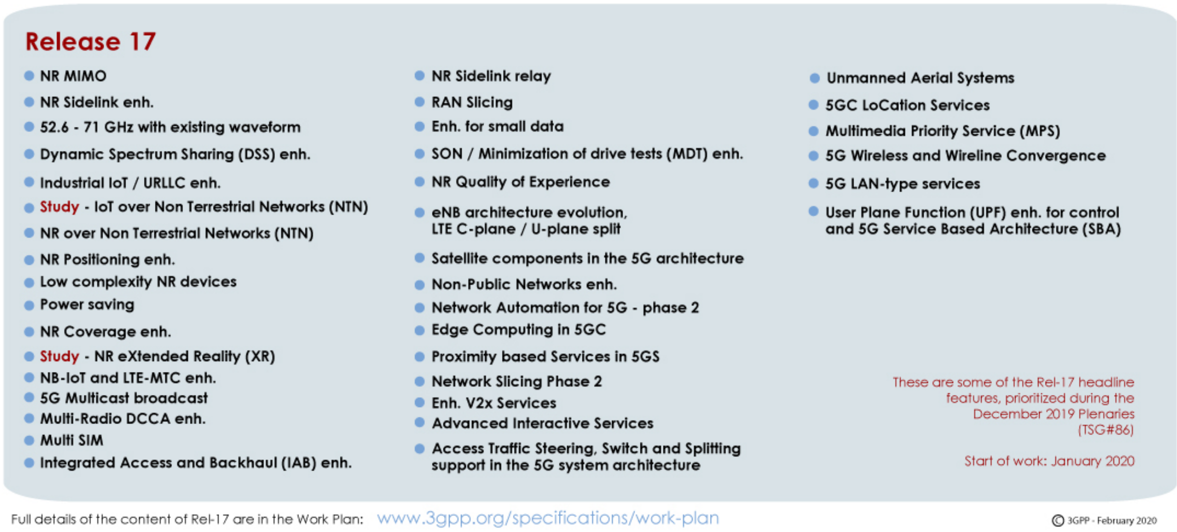

Figure 4: 3GPP - Release 17

The new commitment will greatly help companies advance their plans for network roll-out and new product development. The Release 17 schedule will now allow 3GPP the time it needs to complete the maintenance of Release 16 specifications as they become very stable. At the same time, it allows the groups to switch priority to some exciting Release 17 features.

Studies in several key areas are already in the pipeline. These include: coverage and positioning enhancements, NR and slicing QoE work, adding new frequency ranges, NR reduced capacity devices, enhanced support of non-public networks, supporting unmanned aerial systems, support for edge computing in 5GC, proximity-based services in 5GS, network automation for 5G (Phase 2) and access traffic steering, switch and splitting (ATSSS), among others.

Release 17 features to look out for including new work and enhancements for: URLLC for industrial IoT over NR, NR support over non-terrestrial networks, MIMO, integrated access and backhaul (IAB), MBS positioning, NR multicast, and broadcast services, RAN slicing for NR, NR Sidelink, multi-RAT dual-connectivity, support for multi-SIM devices for LTE/NR, NR small data transmissions in inactive state and multimedia priority service, to name a few.

The 5G System architecture is defined to support data connectivity and services enabling deployments to use techniques such as e.g. Network Function Virtualization and Software Defined Networking. The 5G System architecture shall leverage service-based interactions between Control Plane (CP) Network Functions where identified. The 5G architecture is defined as service-based and the interaction between network functions is represented in two ways [1].

2.2 ETSI

2.2.1 Multi-access Edge Computing (MEC)

Edge computing is a key technology to meet end-to-end latency requirements introduced by new 5G services and to improve the efficiency of the whole network operation through the deployment of computing and storage resources at the edge of the network, closer to the mobile users. The exploitation of edge resources offers the possibility to execute computing tasks in a distributed manner directly at the edge of the network, reducing the traffic load on the core of the infrastructure and guaranteeing faster service responses. This approach allows high scaling in distributed MNO environments. Edge technologies are particularly suitable for all use cases with needs in direction of ultra-low latency and high availability of bandwidth in the mobile network.

The main standardisation work for MEC is provided by 3GPP and ETSI. The following diagram is presenting the MEC deployment as a general overview [17].

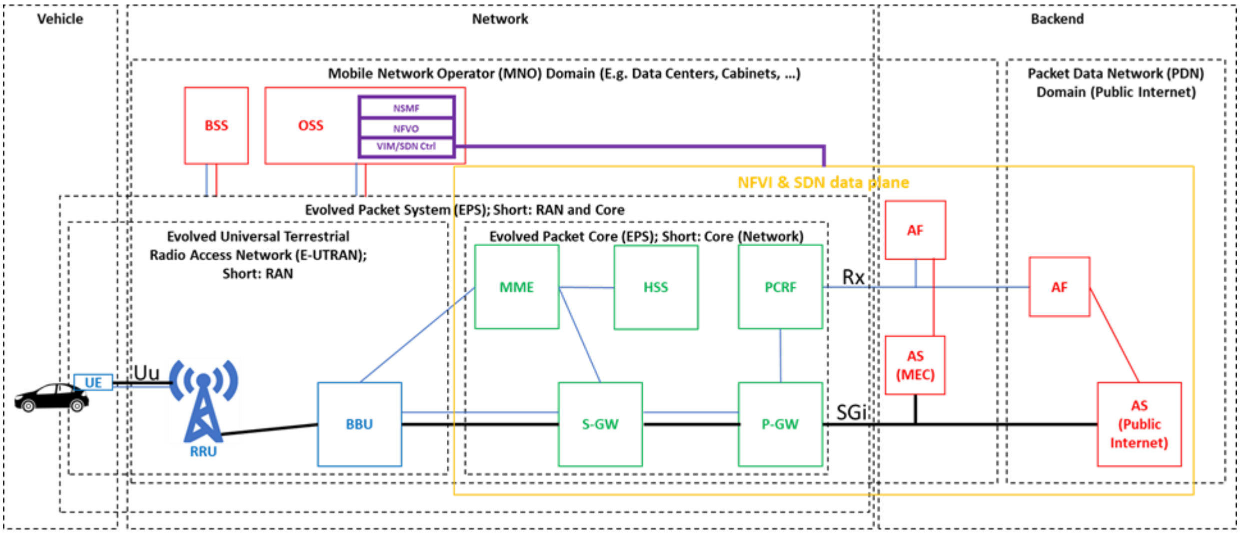

Figure 5: Mapping of High-Level Architecture to 3GPP 4G Evolved Packet System Architecture in LL Hamburg

Figure 5 shows how the high-level architecture can be mapped into the 3GPP 4G Evolved Packet System (EPS) architecture with Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the EPC. The RAN includes the eNB and User Equipment (UE) in the truck or vehicle.

The network domain consists of the eNB and the Core Network together with Operation Support System (OSS) and Business Support System (BSS). The Uu interface between eNB and UE is, therefore, the interface between the vehicle 7 truck and network domains. It is used for user- and control plane communication.

The Multi-access Edge Computing (MEC) framework, defined in the context of the ETSI MEC Industry Standardisation Group (ISG), provides an open and standardized environment for the efficient and seamless integration of edge applications from different vendors and providers across distributed platforms located at the edge of the network [14]. The MEC framework identifies two main components in a typical MEC architecture, i.e. the “MEC Host” and the “MEC System”. It manages the virtualized resources available at the edge nodes through a Virtual Infrastructure Manager (VIM) and it embeds a MEC platform (MEP) to facilitate the interactions among MEC applications and the steering of the mobile traffic flows to/from the target applications. In this context, [15] specifies the interfaces for onboarding and lifecycle management of MEC applications, as well as standard data models for descriptors and software packages to distribute multi-vendor MEC applications.

The figure below illustrates the ETSI MEC reference architecture in an NFV environment [14].

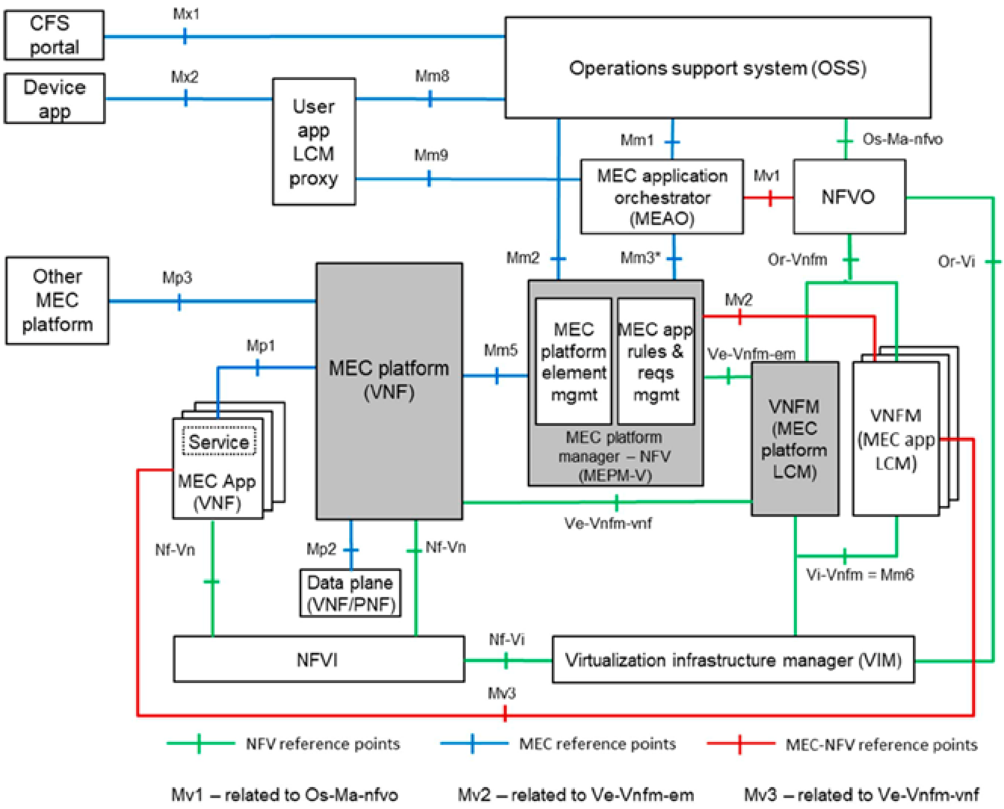

Figure 6: MEC Architecture Overview

Concerning Edge Computing integration into 5G systems, 3GPP has defined a list of enabling functionalities that are briefly discussed in [1], where a basic API for Application Function Influence on Traffic Routing is already specified.

2.2.1.1 Multi-access Edge Computing (MEC) pre-processing for VSaaS

Rising security concerns regarding the transfer of sensitive video surveillance data to the cloud, MEC is enabling the processing of video data within the edge of AI-enabled 5G CCTV networks. Instead of sending all video surveillance data to the cloud, MEC reduces security risks by processing the data locally and transferring filtered data to the cloud. This approach helps enterprises to significantly lower cloud storage costs and improve bandwidth utilization efficiency. Moreover, MEC also improves the responsiveness of video surveillance systems by reducing the latency involved in transmitting or receiving data to or from cloud-based backend servers.

2.2.2 Network Slicing

In 5G, heterogeneous services can coexist within the same network architecture through Network Slicing. According to ETSI [13], Network Slicing is an end-to-end paradigm initially discussed in the context of 5G to support new kinds of applications that need absolute resource guarantees in terms of latency, bandwidth, jitter, reliability, and privacy. The goal is an ability to use a common end-to-end infrastructure that can deliver diverse services with their corresponding assurance. From a mobile operator's point of view, a network slice is an independent end-to-end logical network that runs on shared physical infrastructure, capable of providing agreed service quality.

The technology enabling Network Slicing is transparent to business customers for whom 5G networks, in combination with Network Slicing, allow connectivity and data processing tailored to the specific business requirements. The customizable network capabilities include available data bandwidth (transmission speed), quality, latency, reliability, security, and services. These capabilities are typically provided based on a Service Level Agreement (SLA) between the mobile operator and the business customer. 5G mobile network will in turn enable network operators and service providers to host vertical industry segments by introducing new services and enhance business collaborations between providers and customers at large. From a technical perspective, network slicing opens the opportunity for the creation of a new ecosystem for delivering customized and cost-efficient services to vertical segments.

Figure 7 shows three different network slice configurations, adopted for 3GPP Release 15. Each of the coloured blocks here represents a virtual network function (VNF), where at one end of the connection, are mobile devices and on the far right are data networks (DN1, DN2, DN3). Network slice #3 is an example of a straightforward deployment where all network functions serve a single network slice only. The figure also shows how a UE receives service from multiple network slices, #1 and #2. In such deployments, there are network functions in common for a set of slices, including the AMF, the related policy control (PCF) and the network function services repository (NRF). This is because there is a single access control and mobility management instance per UE that is responsible for all services of a UE. The user plane services, specifically the data services, can be obtained via multiple, separate network slices. Slice #1 provides the UE with data services for Data Network #1, and slice #2 for Data Network #2. Those slices and the data services are independent of each other apart from interaction with common access and mobility control that applies for all services of the user/UE. This makes it possible to tailor each slice e.g. different QoS data services or different application functions, all determined through the policy control framework.

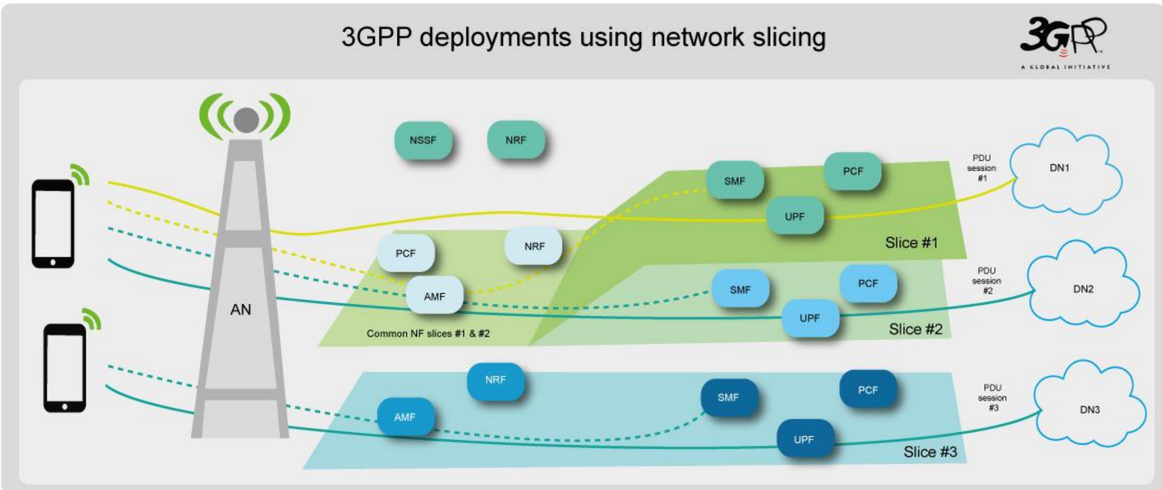

Figure 7: Network functions composing network slices

Network slice supports multi-tenancy for a new set of services focusing on the use cases that do not necessarily fit into traditional virtual networking or VPN solutions. They require a much higher degree of resource assurance as well as stricter guarantees of those resource availabilities. For example, low-latency communications for V2X, high-throughput for immersive multimedia applications, extremely reliable network for emergency response situations. There are several differentiating aspects among these use cases from traditional isolation techniques, such as [13]:

- Once allocated, the resource may be under the control of the network slice service operator (or tenant) for autonomous control of the resources.
- Guarantees should be met with, even under active contention of resources in other best-effort flows.
- Every flow (per stream QoS) should receive the assured treatment, i.e. two flows within the same slice should not compete with each other.

Figure 8 presents a reference framework for network slicing with three entities interacting for the use of a network slice, namely:

- **Tenant**: a user of a network slice who creates a service with a particular network slice type. A network slice type distinguishes the kind of network resources needed to fulfill service requirements.
- **Network Slice Provider**: provides a network slice as a service to the tenant for control and operations of resources in the service.
- **Network Slice Agent**: a network slice entity in the infrastructure provider's domain. It understands processes and maps Network Slice Provider information within its domain.

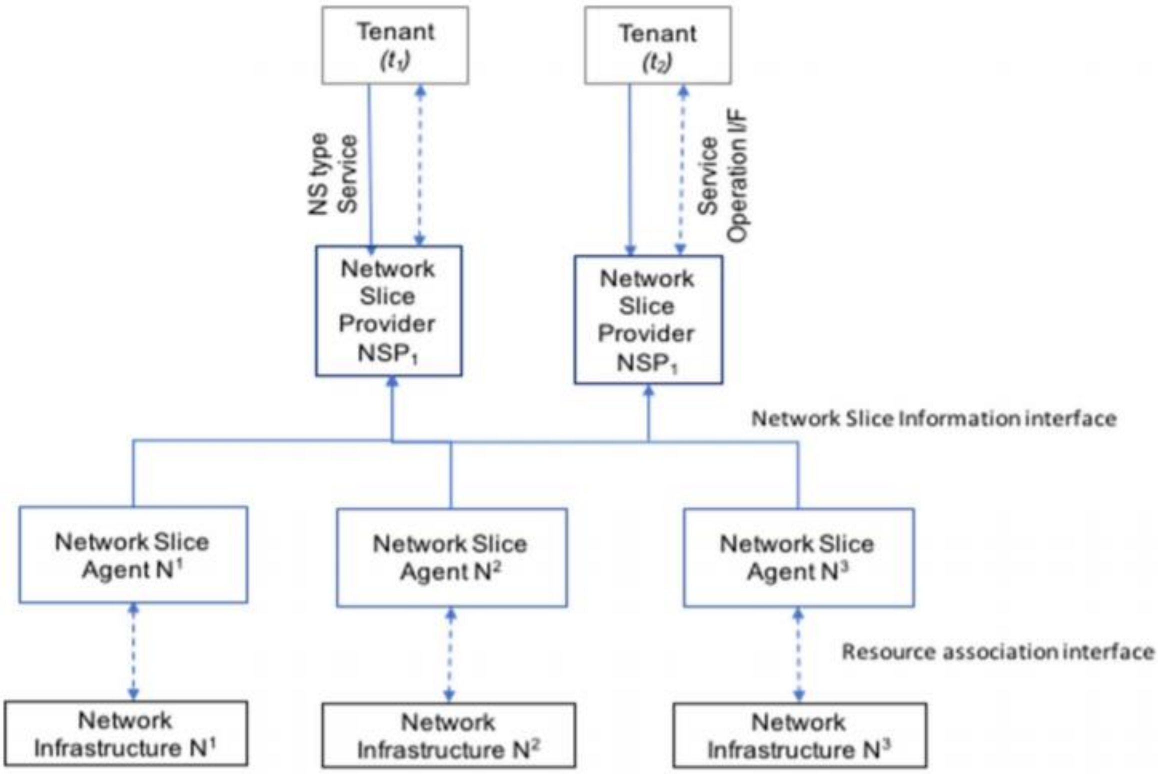

Figure 8: 5G Network Slicing Reference Framework

2.2.3 NFV-MANO (Management and Orchestration)

The MANO architectural framework has the role to manage the underlying virtualized infrastructure and orchestrate the allocation of resources needed by the Network Services (NSs) and VNFs. Such coordination is necessary as NFV decouples software implementations of NFs from the physical resources they use. The overarching role of the MANO is to provide and maintain a suitable network function chaining to create an E2E service. Network Functions Virtualization (NFV) introduces a new set of management and orchestration functions in addition to existing Element Management (EM) and Operations Support Systems (OSS) functions. This new set of management and orchestration functions is referred to as Network Functions Virtualization Management and Orchestration (NFV-MANO), and is used to manage and orchestrate:

- The relationship between the Virtualized Network Functions (VNFs) and the NFV Infrastructure (NFVI).
- The interconnection of VNFs and/or other Physical Network Functions (PNFs) and/or nested Network Service(s) (NS) to realize an NS.

The ETSI NFV Architectural Framework with the main functional blocks and reference points is depicted below in Figure 9 [16], with the NFV-MANO subset marked on the right-hand side of the figure.

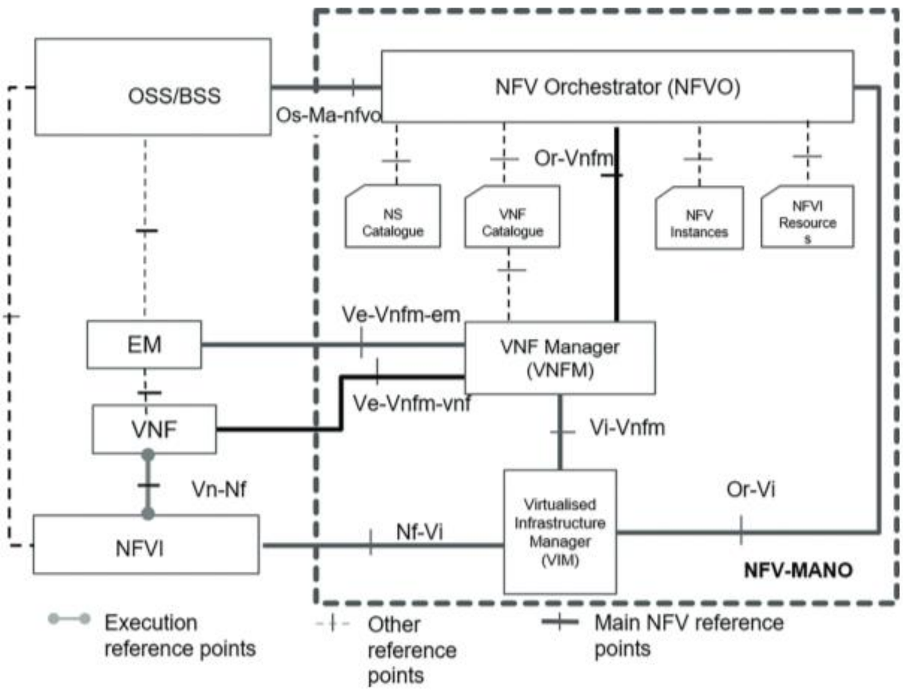

Figure 9: ETSI NFV Architectural Framework

The NFV-MANO, which was originally described in the ETSI GS NFV- MAN 001 [16], comprises the following functional blocks:

- NFV Orchestrator (NFVO),
- VNF Manager (VNFM),
- Virtualized Infrastructure Manager (VIM).

Two main responsibilities of the NFVO are the orchestration of NFVI resources across multiple VIM instances, fulfilling the Resource Orchestration functions, and the lifecycle management of NS, fulfilling the Network Service Orchestration functions. The VNFM is mainly responsible for the lifecycle management of VNF instances. The VIM is responsible for controlling and managing NFVI compute, storage, and network resources [16].

3 LIVING LAB 1 – ATHENS

3.1 5G Requirements

This section describes the 5G network architecture that will be deployed in Athens Living Lab for the realization of the 5G-LOGINNOV innovations as described in detail in D1.1. 5G-LOGINNOV aims at optimising port operations through the optimal assignment of container jobs based on location and other custom sensor data of internal trucks, improving safety and security within the port premises through analytics of 4K video streams, predictive maintenance services of yard equipment and reduction of the environmental footprint through the optimal job allocation of 5G connected trucks in port operations.

The envisioned use cases can be categorized based on the 5G end device type, i.e., truck or IoT device. The former entails the installation of a 5G telematics device on trucks connected to various on-truck sensors (CAN-Bus, custom sensors, e.g., container presence sensors, and localization). The aggregated telemetry data from the fleet of 5G connected trucks will be used for the optimal assignment of container jobs, the predictive maintenance service and the coordination with external trucks. The later, envisions the deployment of 5G IoT devices with NFV-MANO support that consist of a compute node to perform locally video analytics tasks (based on VNFs that deliver computer vision modules and other monitoring services), a high-resolution camera acting as a sensor (input data for the analytics services) and a 5G interface to establish cellular communication at the port premises. The analytics services deployed at the IoT devices focus on two main areas. The first is related to safety/security at the port premises where the video analytics will focus on detecting the human presence in restricted areas (e.g., at railways, areas with increased crane manoeuvres, etc.), triggering also respective alerts in case of positive incidents (i.e., human detected). The second computer vision approach is targeting a logistics application, where the IoT device will be deployed at quay side cranes to detect the presence/absence of container seals at the loading/unloading process of vessels. In both video analytics scenarios, additional monitoring of operations will be enabled through 4K video streams delivered at PCT backend system from the 5G-IoT devices.

The project's objectives will be pursued within the following use cases:

- UC2: Device Management Platform Ecosystem
- UC3: Optimal selection of yard trucks
- UC4: Optimal surveillance cameras and video analytics
- UC5: Automation for ports: port control, logistics and remote automation
- UC7: Predictive Maintenance

The MNO (Vodafone) will provide the 5G technology that will be deployed at the Piraeus port. In this context, in Athens Living Lab a 5G network will be deployed at the port premises, focusing on key enabling technologies of enhanced localization services, low latency transmissions and enhanced Mobile Broadband (eMBB) service to meet the use case requirements.

3.2 5G Architecture and technologies

3.2.1 The architectural design of LL setup and testbed

The Athens Living Lab at Piraeus port will develop a set of use cases and platforms that communicate over the deployed 5G network with different types of end devices. 5G technologies will enable the use case innovations exploiting the eMBB service, low latency transmissions and enhanced localization services of the cellular infrastructure at the port premises, including MANO-based services and orchestration, pioneering far-edge computing services, computer vision and AI/ML video analytics. Figure 10 shows a high-level overview of Athens Living Lab use case layout including various 5G end devices (5G-IoT device, 5G connected yard/external trucks). Several MANO orchestrated modules will be deployed for surveillance (Streaming management), managing the inference of video analytics from the deployed 5G-IoT devices and alert generation (Inference management), and the module that aggregates data from the fleet of 5G connected yard/external trucks (Telemetry management).

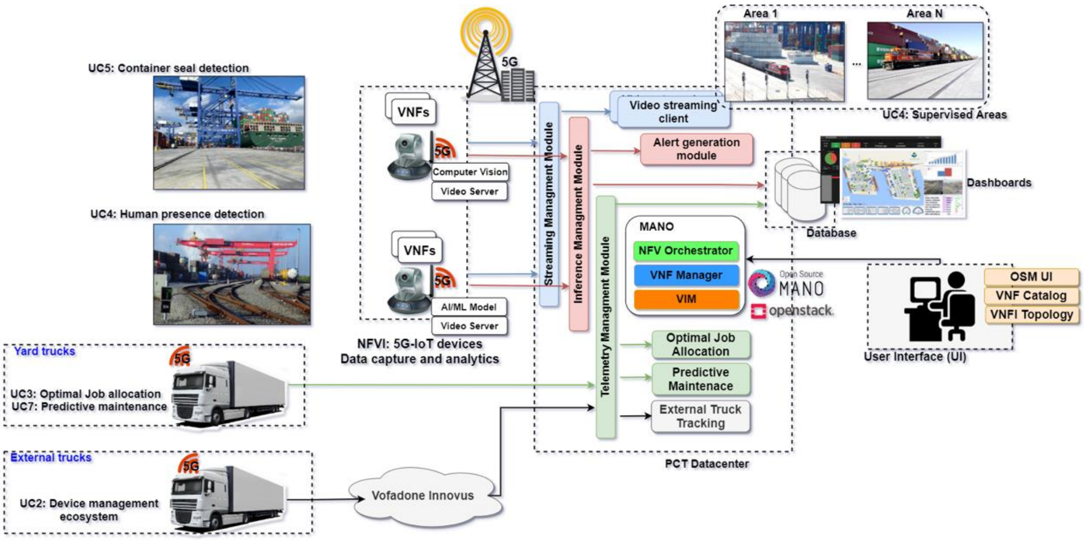

Figure 10: Use case architecture and layout overview, Athens Living Lab.

3.2.2 Radio Network Architecture

The set of use cases that will be deployed and evaluated in Athens Living Lab have been described in detail in deliverable D1.1. The deployment of the 5G network at PCT premises will match the requirements and needs of port operations, tailored to the envisioned use cases, also considering the infrastructure requirements and hardware specifications of additional 5G-IoT devices that will be designed and deployed, as described in more detail in D1.3.

Initially, the deployment at Piraeus Port will follow the specifications of Release 15. The radio access network will consist of two base station units, as illustrated in Figure 11, upgrading the in-place 4G cellular infrastructure at the port premises to support the 5G-LOGINNOV use cases and innovations.

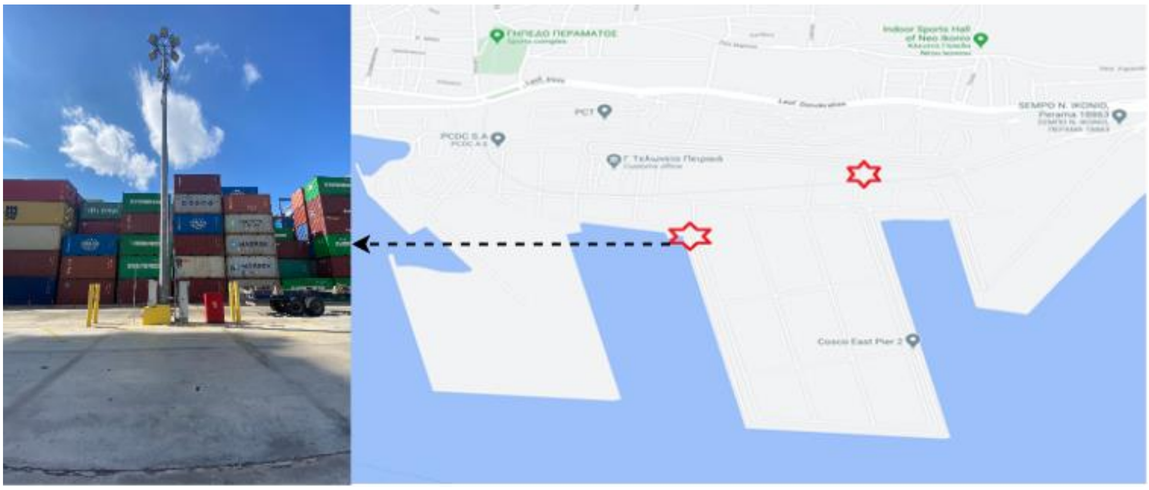

Figure 11: Deployment sites of 5G radio units, Athens Living Lab.

The scope of the 5G-LOGINNOV project is to build the 5G protocol stack for both gNB and UE allowing for end-to-end deployment of a 5G network at PCT premises. The first target is to develop and deploy the 5G Non-Stand Alone (NSA) RAN software on commercial hardware components and establish a cellular connection and traffic flow with NSA-capable 5G UEs (yard trucks, external trucks, IoT devices, etc.) at the Piraeus port. In the NSA specification, the gNB is supplemented by the LTE eNB that carries control plane information (5G signaling) while the data plane is handled by gNB. The 4G and 5G base stations are connected with an NSA capable 3GPP Rel-15 4G evolved packet core network (EPC) over the S1 interface. Additionally, coordination between the eNB and gNB stations is enabled by the X2-C interface for routing and managing the flow of IP traffic. The NSA specification is also reference as E-UTRAN New Radio – Dual Connectivity (ENDC) mode and is shown in Figure 12[1], interconnecting various end devices at PCT premises.

[1] The 5G protocol stack at the gNB can also be split across different units, the central unit (CU), providing support for the higher layers of the 5G stack, e.g., up to the PDCP layer, and serveral distibuted units (DUs) that provide support for lower layers, coordinating over the F1 interface

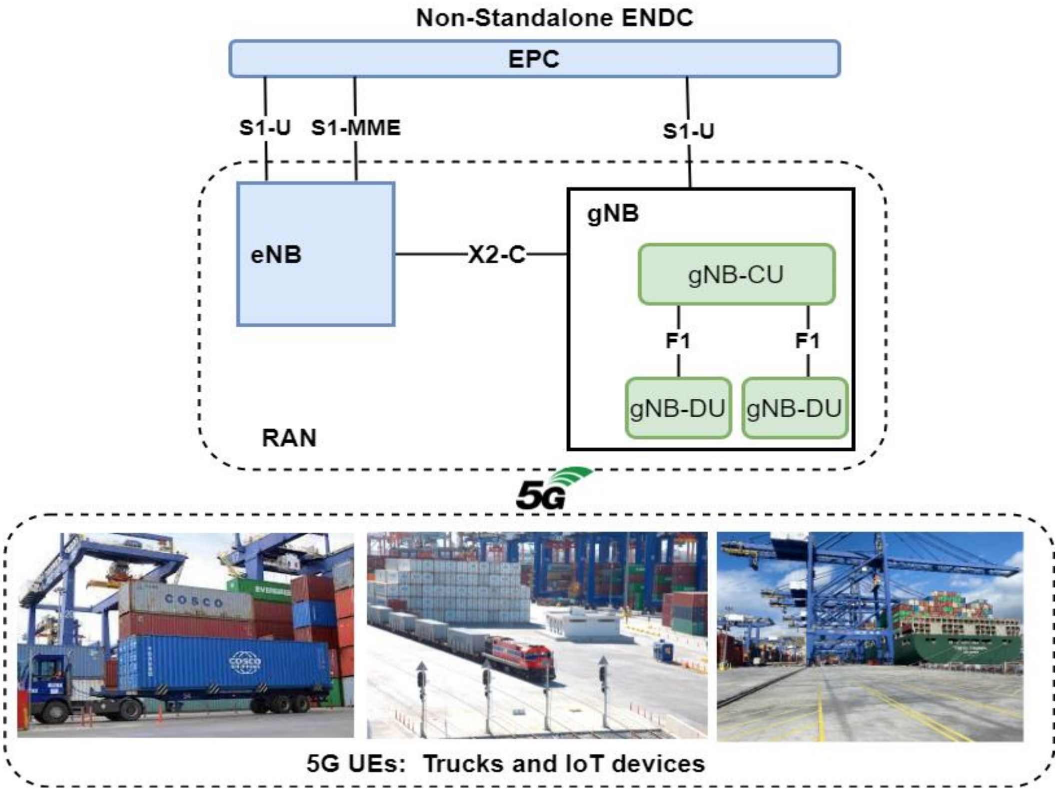

Figure 12: Non-Standalone ENDC overview, Athens Living Lab

Non-Standalone 5G NR technology will provide increased data bandwidth at the port premises, exploited by distributed 5G-IoT devices that deliver voluminous video streams to PCT management platform, targeting optimization of port operations and improvement of personnel safety/security, via video analytics services. The design of the RAN network requires careful consideration of several parameters. Vodafone has extensive operational experience at the port premises and access to all historical data parameters relevant for facilitating the optimal deployment of the access network at the port premises. Figure 13 depicts the cellular coverage and deployment at PCT premises, based on the current 4G infrastructure, that will be used (partially) to facilitate 5G communications for indoor and in-car/truck coverage.

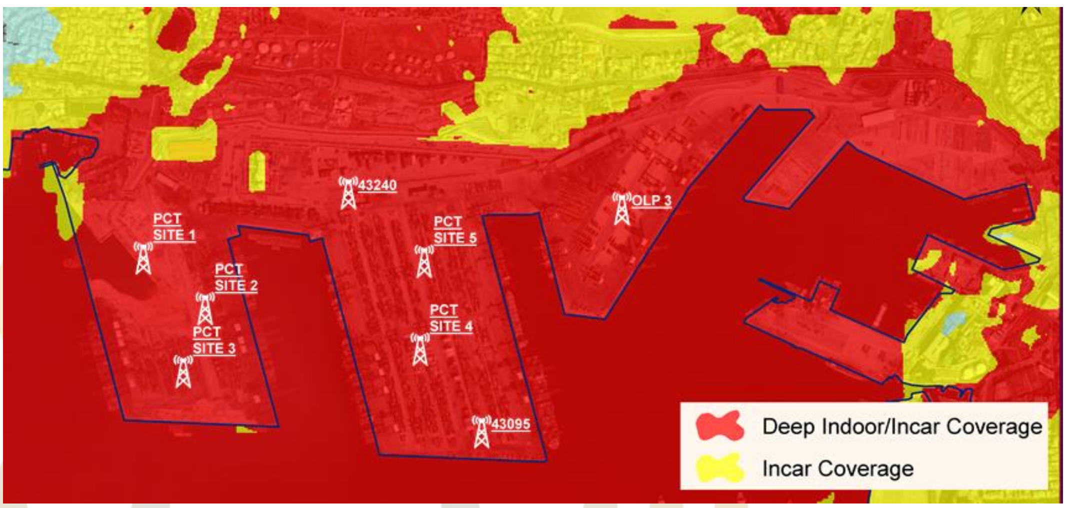

Figure 13: LTE coverage areas, Athens Living Lab

Table 3 illustrates the target operating frequency bands and coverage for the anchor LTE base stations and data plane gNBs.

Table 3: Uplink and Downlink frequency bands for the 4G and 5G base stations, Athens Living Lab

Basestation	Uplink (UL) operating band	Downlink (DL) operating band
eNB 1	842-852 MHz	801-811 MHz
eNB 2	1725-1750 MHz	1820-1845 MHz
eNB 3	2500-2520 MHz	2620-2640 MHz
gNB 1,2	3600-3700 MHz (TDD)	

The second gNB in the initial deployment at the port premises will cover the same area, acting as a support node in case of failure of the primary base station.

3.2.3 Core Network Architecture

The current core network deployment utilized for cellular communications at the port premises resides outside the port of Piraeus, and under the operation of Vodafone. Gradual upgrades will take place following the specifications of 3GPP Rel-15. NSA (option 3) will establish the initial 5G network at the port premises, and potentially move to full 5G core architecture (option 4) at a later stage (Figure 14).

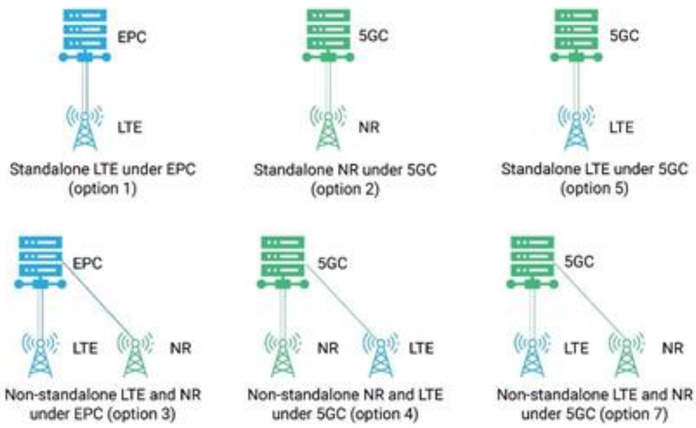

Figure 14: 5G deployment options

Figure 15 shows the evolution of the 4G EPC core towards the next-generation core network that will support 5G communications. In the initial monolithic design, the service and packet gateway elements (SGW and PGW, respectively), were responsible for the management of both user plane and control plane functions. In the next releases, Control and User Plane Separation (CUPS) was introduced, 3GPP TR 32.867, Release 14. CUPS allows for reduced latency on application service, e.g., by selecting data plane nodes closer to the end-user RAN without increasing the number of control plane nodes. This functionality entails independent evolution (i.e., scaling) of the control plane (CP) and user plane (UP) functions, tailored to the intended UE usage type and application.

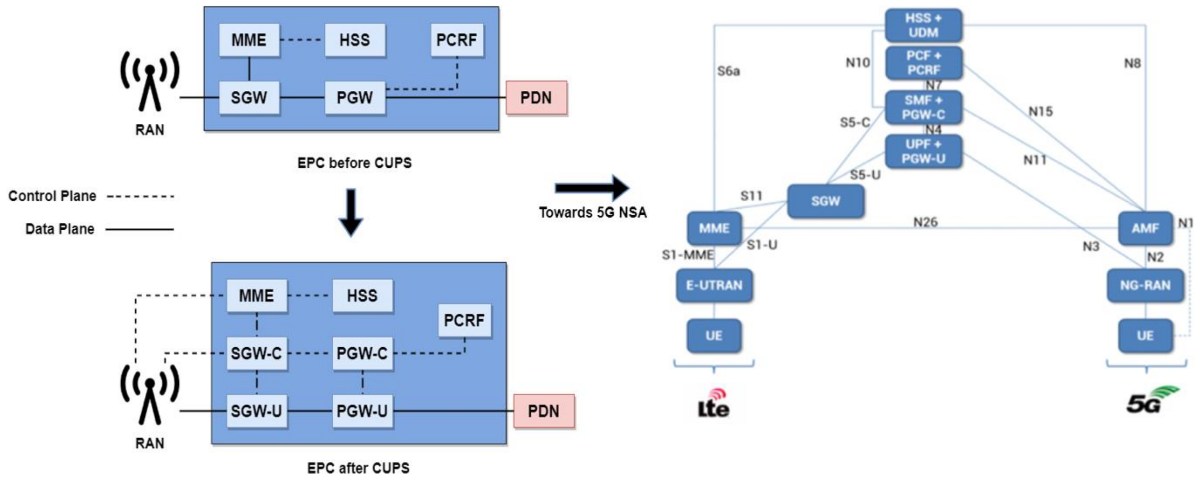

Figure 15: EPC towards NSA core, Athens Living Lab.

The 5G NSA core architecture follows a similar approach to CUPS while also introducing new network core elements. Towards this direction, the virtualization of network functions is a key enabling technology, uncoupling the hardware dependency of the initial monolithic design of network core elements and moving (virtual) network functions and management into software and the cloud. The placement of the virtual network core elements closer to the end devices will enable the required low latency transmissions for the coordination of the fleet of 5G connected trucks at the Piraeus port. Currently, Vodafone supports a full CUPS core, and partially virtualized NSA core as illustrated in the rightmost part of Figure 15. To support failure occasions of network core elements without interruption of service Vodafone supports multiple core deployments, 3x EPC H/W specific and 2x EPC virtual, Figure 16.

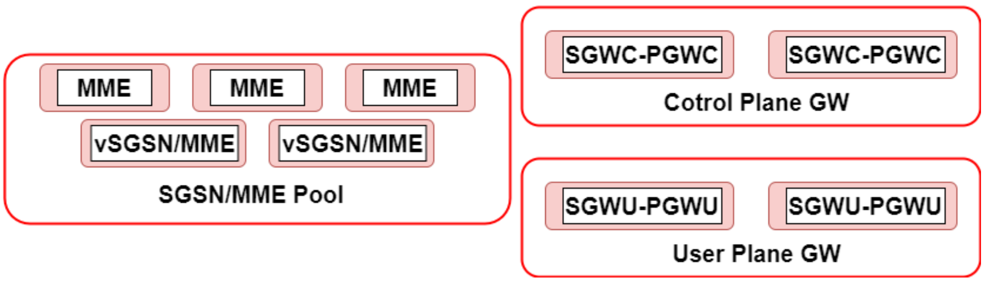

Figure 16: Network core options, Athens Living Lab

Current LTE deployment at PCT premises provides a target latency to the end devices between 35-50ms. Once the 5G NSA deployment is completed, the expected latency will decrease and in the range of 10-35ms. Towards the end of the project, a mobile core network is foreseen to be placed on-site (at the Piraeus port), which will further drop the experienced latency at below 10ms.

3.3 5G Technologies and innovations to be deployed

3.3.1 NFV-MANO supported innovations

To support the envisioned use cases, and in particular UC4 (Optimal surveillance cameras and video analytics) and UC5 (Automation for ports: port control, logistics and remote automation) in Athens Living Lab a MANO (ETSI Management and Network Orchestration) platform will be developed by ICCS, and later migrated at the Piraeus port premises. The developed platform will be based on Open Source MANO (OSM), an ETSI-hosted project developing an Open Source Network Function Virtualization (NFV) Management and Orchestration software stack aligned with ETSI NFV. The envisioned platform will exploit 5G technologies and enable computer vision analytics at the UE side, i.e., at novel 5G-IoT devices (described in detail in D1.3) deployed at several key port areas, as far-edge computing services. The VIM orchestrator exploited by OSM will be based on a subset of services of OpenStack (Victoria release). OpenStack is an open-source cloud operating system that controls large pools of computing, storage, and networking resources, i.e., the NFVIs, all managed and provisioned through APIs with common authentication mechanisms. The VIM orchestrator will be the interface towards the NFVI devices, i.e., the 5G-IoT nodes, that will host the VNFs (software applications that deliver network and service functions) and deliver the respective solutions for facilitating far-edge computing services in port operations.

In particular, the developed solution builds on the 5G network support for (automated) lifecycle management of the various service components, including both computing and communications/network resources. Leveraging but also further extending the operational scope of such capabilities, ICCS will develop a portable (far) edge computing service that on the one hand, integrates sensing, processing and communication functionalities, and on the other allows the remote and automated management and orchestration of the end-to-end computer vision analytics service; this includes a series of novel capabilities such as instantiating the service, (re-)configuring (computer vision) components, updating overall software, increasing bandwidth and/or the resolution of inspection, etc.

5G-LOGINNOV MANO platform will showcase the potential of service orchestration of computer vision analytics (at scale and on-demand), aiming at the optimization of port operations as well as the improvement of personnel safety/security within the port of Piraeus. To this end, the video analytics VNFs will be deployed at the 5G-IoT device(s) providing Artificial Intelligence (AI) services for human presence detection (UC4) at specified risk areas (e.g., railways, areas with increased crane manoeuvres/operations, etc.), and generating respective alerts. Additionally, optimization of port operations will be achieved by computer vision VNFs that detect the presence/absence of cargo-container seals (UC5). This service is of paramount importance for port operators as it verifies that container load remains intact during its stay at the terminal, proving to both shippers and customs authorities that the terminal has no liability regarding container contents. Currently, the seal-checking process at PCT requires human presence at the quay side and about 30 seconds per container to complete. Reducing this time by e.g., 3 seconds per container, results in 9000 seconds (or about 2.5 hours) reduction of vessel stay at the port and removes the need for human presence at an area with high safety risks. Additionally, the 5G-IoT devices will exploit 5G NR technology that provides increased data bandwidth to deliver high resolution (e.g., 4K) video streams from several sites at PCT, providing enhanced monitoring of port operations. Overall, the envisioned solutions can be placed on commodity x86 servers and similar types of commercial off-the-shelf (COTS) hardware, to expedite deployment and facilitate interoperability across ports.

3.3.2 5G-connected external/yard truck innovations

At Piraeus port, the internal yard trucks are crucial assets in several port activities, as they facilitate the horizontal movement of containers between stacking areas and loading/unloading areas for vessels and rail. The operation of those internal trucks (currently about 170-yard trucks are active) within the port area of about two square kilometres, when handled sub-optimally, can be the cause of increased traffic jam incidents and queues in loading/unloading places, posing significant delays to several work chains at the port premises, increase fuel consumption and CO_2 emissions and reduce the life-cycle of tyres that are a significant cost factor (e.g. annual cost of tyres in the port of Piraeus exceeds 4M Euro). Figure 17 shows a snapshot of yard truck operations at PCT where the location, speed, moving direction and current freight (i.e., number of carried containers) of each truck is illustrated.

Figure 17: PCT management platform for tracking internal yard truck operations, Athens Living Lab

Current accuracy of GPS system combined with (average) trucks speed of 35Km/hr often results in feeding the container job assignment algorithm with truck positions that are more than 50 meters away (or about 20 containers away) from the actual truck location, hence providing a sub-optimal allocation of container jobs. This results in truck drivers performing several manoeuvres (in a relatively limited space), potentially causing traffic incidents, increased fuel consumption (and CO_2 emissions), as well as causing significant delay, e.g., in the loading/unloading process of vessels, hence extending the vessel stay at the port premises. 5G-LOGINNOV will install a 5G telematics device at the trucks connected to several on-truck sensors (GNSS, container presence sensors, CAN-Bus, etc.) to optimize the allocation of container jobs to yard trucks (UC3), based on the aggregated telemetry data from the fleet of 5G connected yard trucks. The enhanced localisation services and low latency transmissions of 5G technology will constitute the key element blocks for realizing the objectives of the use case targeting the optimal operation scheduling of 5G-connected yard trucks. The envisioned use case will have a direct impact on the environmental footprint of port operations by decreasing the travel distance, CO_2 emissions and fuel consumption of yard trucks (via selecting the closest/optimal available truck to jobs), as well as expediting port operations.

The aggregated telemetry (CAN-Bus and other sensor) data from connected trucks will also be used by the predictive maintenance AI algorithm (UC7), Figure 16. Predictive maintenance is a significant contributor to increasing operational efficiency and reducing unplanned downtime of expensive equipment by identifying and solving problems before they occur (additionally optimize the schedule of purchases based on aggregated data and prediction of potential issues, optimize storage of parts, and proactive, instead of corrective, maintenance). This innovation is based on findings of the COREALIS[2] project, and additionally through 5G-LOGINNOV 5G technology will be exploited that provides a flexible, reliable and predictable environment to remotely keep track of the connected assets on a real-time basis, i.e., end-to-end monitoring of assets performance in all phases of daily port operations.

Figure 18: Predictive maintenance service, Athens Living Lab

Especially for trucks moving outside port area (UC2) a hybrid device is proposed including location, sensor and CAN-Bus measurements utilizing 5G and existing network. Information outside the port is used to estimate imminent traffic from/to the port area.

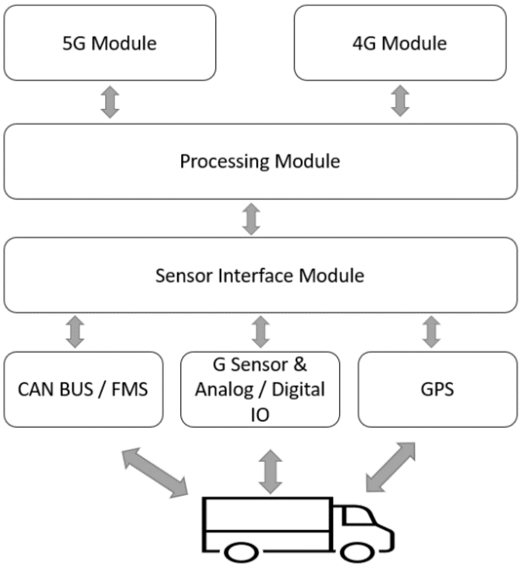

Figure 19 Connected Truck

[2] COREALIS is a H2020 project that proposes a strategic, innovative framework, supported by disruptive technologies, including IoT, data analytics, next generation traffic management and 5G, for modern ports to handle future capacity, traffic, efficiency and environmental challenges.

Table 4 provides a summary of the 5G technologies to be deployed in the Athens Living Lab.

Table 4: 5G technologies deployed in Athens Living Lab.

Radio Access Network	LTE and NR
Number of cell sites	2-3 Cell Sites
Frequencies used	3.6 GHz
Frequency Bandwidth	3,6 GHz 140 MHz
Mobile Core	3GPP Rel.15
Virtualised infrastructure	Yes, CUPS
MEC	On roadmap 2023
NFV	OpenSource MANO
eMBB	Yes, Rel.15
Network Slicing	On roadmap 2023
mMTC	NB-IoT Rel.13

4 LIVING LAB 2 – HAMBURG

4.1 5G Requirements

Hamburg Living Lab will demonstrate the potential of leveraging positive environmental impact by using 5G in data exchange for traffic management in particular outside the port and the hinterland. It will develop and implement a methodology to capture the effect of the traffic infrastructure on regional emissions, making them comparable (standardised) by quantifying such influences under defined TMS congestion and other relevant factors (driver profile, vehicle profile, loading, etc.).

To this purpose, the following interactions with system elements of traffic management will be demonstrated:

- UC8/9 - Floating Truck & Emission Data (FTED)
  For use cases 8 and 9, emission data from floating vehicles/trucks will be made available in a cloud-based centre to enable situation monitoring on emissions.
- UC10 - 5G GLOSA & Automated Truck Platooning (ATP)-under 5G-LOGINNOV Green initiative
  For this use case, the current and predicted traffic light signalling will be made available from traffic centres to vehicles, to allow an optimised trajectory planning for automated vehicle manoeuvring across intersections, saving energy and emissions.
- UC11 - Dynamic Control Loop for Environment Sensitive Traffic Management Actions (DCET).
  For use case 11, data received in UC8/9 and other data typically used in environmental traffic management will be used to trigger traffic management measures (strategies) in traffic control (e.g. changing traffic light framework programs, set speed limits, or provide instructions and directives to vehicles)

The living lab Hamburg will demonstrate 5G innovations for logistics in the Hinterland of the harbour of Hamburg by using the public 5G network operated by the Deutsche Telekom. This public 5G network covers the designated test field for "connected and automated driving" (TAVF) of the city centre of Hamburg.

Within this environment, the LL Hamburg will illustrate on one hand how new functionalities of 5G as MEC, precise positioning as uRLLC can improve the efficiency of logistic operations, but on the other hand, also prove that improved 5G network functionalities as mMTC and eMBB are essential for any future mobile network application.

In this context, the LL Hamburg will illustrate the use of network slicing, MEC, 5G enabled precise positioning, uRLLC, mMTC and eMBB in its use cases according to their functional abilities.

4.1.1 Network Slicing

While a 5G network connection for UC 8/9 and UC 11 is not time-critical, the provision of an information system to enable an optimised trajectory planning for automated vehicle manoeuvring across intersections in UC 10 requires a connection with high reliability and low latency below 10ms. Having in mind an increasing population [24], several sensors, and connected devices in urban areas 5G connectivity will be essential for critical applications with strict connectivity requirements.

Hereby, network slicing is one of the key aspects of 5G that will allow network and service operators to satisfy specific connectivity demands of specific use-cases. By this, it can be ensured that each use case will always have the required resources.

The LL-Hamburg will illustrate the use of two different virtualized and independent networks based on the available public 5G network.[3]

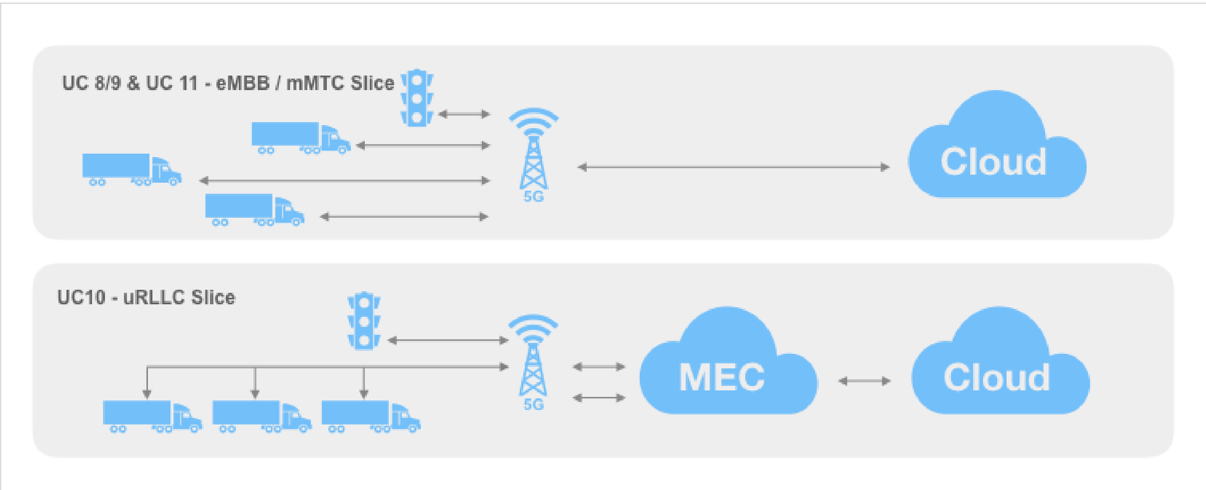

Figure 20: Network Slices LL - Hamburg

Each of the two slices will allow using the available network with the use-case specific required level of service quality, security, and reliability. As UC 8/9 and UC 11 mainly rely on bandwidth-related services the eMBB / mMTC slice will provide to direct link to the cloud applications, while the mission-critical application in UC 10 will be served by the uRLLC slice and guaranteed a high level of security, reliability, and low latency.

[3] As the LL Hamburg use cases rely on the public 5G network it is not ensured that network slicing will be available in all areas of the designated test field. Network slicing depends highly on 3G PPP release 16 and above, while public 5G network mostly comply with release 15. So, it might be necessary to simulate required functionalities as session management function (SMF), access and mobility management function (AMF), network slice selection function (NSSF), i.e, if not available.

4.1.2 MEC and uRLLC

UC 10 will establish a V2X information system by combining 5G functionalities with GLOSA to enable automated truck platooning. The optimised trajectory planning for automated vehicle manoeuvring across intersections enabled by real-time information on current and predicted traffic light signalling will require reliable connectivity and analytic capability with a low latency below 10ms. By using a MEC between the 5G core network and the connected vehicles with reducing network transfer delays to meet the specific ultra-reliable and low-latency requirements necessary to serve automated truck platoons.

The MEC will bring the analytics of the LL-Hamburg uses cases much closer to the connected vehicles by processing and combining mission-critical traffic information with manoeuvres of the vehicles and infrastructure data from the cloud. Efficient and safe driving inside a platoon requires information being shared among the platoon as synchronous as possible. The following vehicles should be on-time aware of relevant actions of the leading vehicle (imminent reduction/increasement of speed), otherwise unnecessary braking or the dissolvement of the platoon cannot be prevented.

The uRLLC functionality is furthermore a prerequisite for the required precise positioning used in all four use cases of the LL Hamburg. While precise positioning of stationary objects does not require the use of 5G technologies, the application on fast-moving vehicles as passenger cars, light, and heavy commercial vehicles requires the improved connectivity capabilities of 5G as uRLLC. Under consideration of the movement of the platoon, the impact of uRLLC will further be improved by 3GPP Release 16, which introduces enhancements of session continuity and therefore reduces the influence a handover has on the reliability of low latency services.

4.1.3 Precise Positioning

The LL Hamburg will use in all four use cases 5G enabled precise positioning on lane-level.

Firstly, this requires an accuracy of the position within an error bound of lateral of 0,57m (0,10m for 95%) and longitudinal of 1,40m (0.48m for 95%) on freeways [23]. Therefore, conventual GNSS position information will not be sufficient. Secondly, the given position has to be provided in a high frequency and a low latency to be reliable in a fast-moving vehicle.

The four use cases will combine uRLLC with the precise positioning service Skylark that provides accuracy for the position of up to 0.10m. Figure 21 shows the Skylark service co-branded by Deutsche Telekom, a partnership that was already announced in March 2020 [8] with further product details published in [7]. It should be noted that network centric Precise Positioning Services do not necessarily require 5G and are already available in 4G/LTE. Nevertheless, when it comes to rolling out any type of scalable service uptake, e.g. reliable Floating Truck Emission Data use cases (UC8/9) or Collision Warning for Automated Truck Platoons in a European Metropolitan Region such as Hamburg, the core functions of the 5G network uRLLC, MEC and network slicing become crucial elements of the services planned to be implemented in Hamburg.

Figure 21: Precise Positioning Service as planned to be used in LL Hamburg

4.1.4 5G Security Requirements

Rising security concerns regarding the transfer of sensitive video surveillance data to the cloud, MEC is enabling the processing of video data within the edge of AI-enabled 5G CCTV networks. Instead of sending all video surveillance data to the cloud, MEC reduces security risks by processing the data locally and transferring filtered data to the cloud.

Logistic use cases in the Hamburg LL result in deep security, safety, and data protection challenges, and require a holistic approach to security. Due to its growing ecosystem complexity, logistic applications raise deep security, safety, and data protection concerns. Strong protection is therefore mandatory. To provide direction in approaching cybersecurity, several standards, regulations, and directives in various stages of maturity are proposed for providing security assurance and guidance.

Protection mechanisms are needed in: truck/car, network, and back-end tiers; all software and hardware levels; and for the full data life-cycle. Some of the main security and privacy points of vigilance are the following:

1. User (people, cars, infrastructure) in the ecosystem have become targets of choice for hackers: the number of attacks recently discovered and published is continuously growing.

2. Safety and security can no longer be handled separately: failures and threats blend into interaction vulnerabilities as trucks are cyber-physical systems.

3. The connected logistic ecosystem is data-shaped: different data are collected, analysed, and shared with all ecosystem stakeholders through multiple paths, and must be protected. A key trade-off for protecting data at rest, and in transit, is finding the right balance between data integrity, critical for the safety of vehicles and their surroundings, and data privacy, to minimize the amount of collected data.

Key questions for protection include for each stakeholder the choice of the most relevant tier to deploy security mechanisms. Should an end-to-end approach to security be adopted, using cross-cutting security management planes, or should tier-by-tier solutions be favoured. The main security requirements can be summarized in the following items:

- Cultivating a cybersecurity culture.
- Adopting a cybersecurity life cycle for complete development over the life cycle.
- Assessing security functions through testing phases: self-auditing & testing.
- Managing a security update policy.
- Providing incident response and recovery.

Taken together these general guidelines should ensure a secure delivery of services in the ecosystem.

4.2 5G Architecture and technologies

4.2.1 The architectural design of LL setup and testbed

The LL Hamburg set-up is mainly based on the idea to use telco products (DTAG) as the basis for the use case demonstration. Standard 5G in combination with MEC (MobilEdgeX as product) is the network backbone for the lab. DTAG connections are also used to link mobile devices (e.g. trucks), RSU's (e.g. traffic lights), and the related backbone infrastructure (e.g. TMS Traffic Management System from SWARCO). Dedicated functions, especially with requirements for low network delay, will be deployed in a so-called MEC environment. MEC deployment is based on standard procedures like Docker. Figure 22 demonstrates this relation between the components in the LL Hamburg.

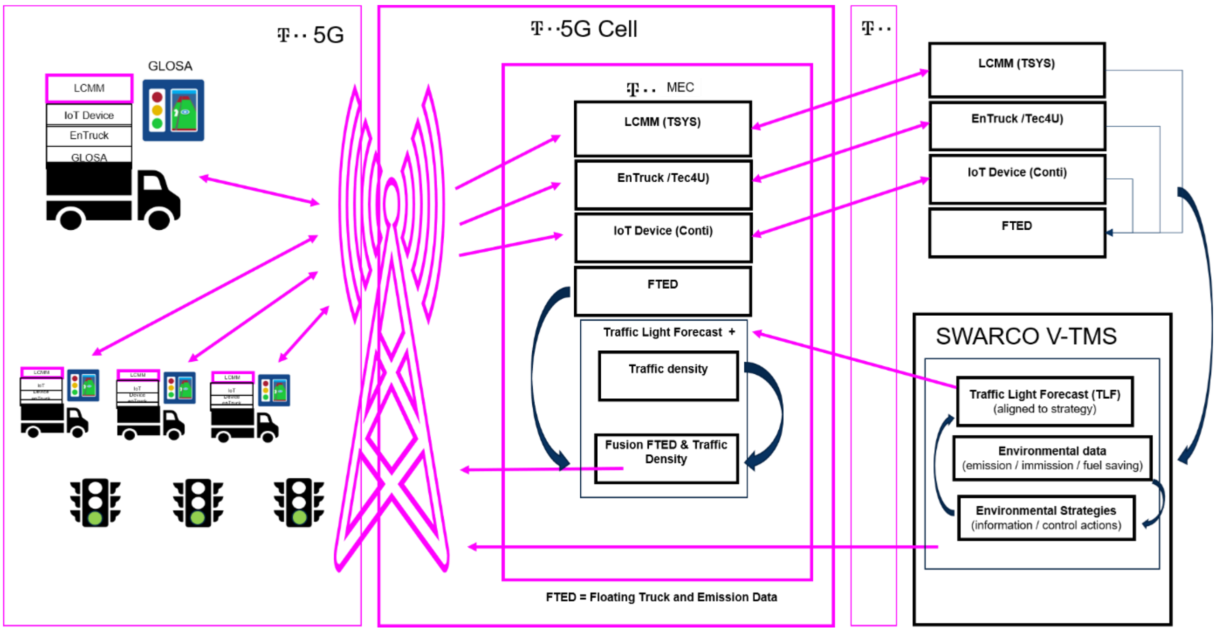

Figure 22: Hamburg Living Lab overview

4.2.2 5G Network Architecture

The 5G mobile network is a big step to provide many new features for Telco customers. The following pictures illustrated the main components for a 5G network.

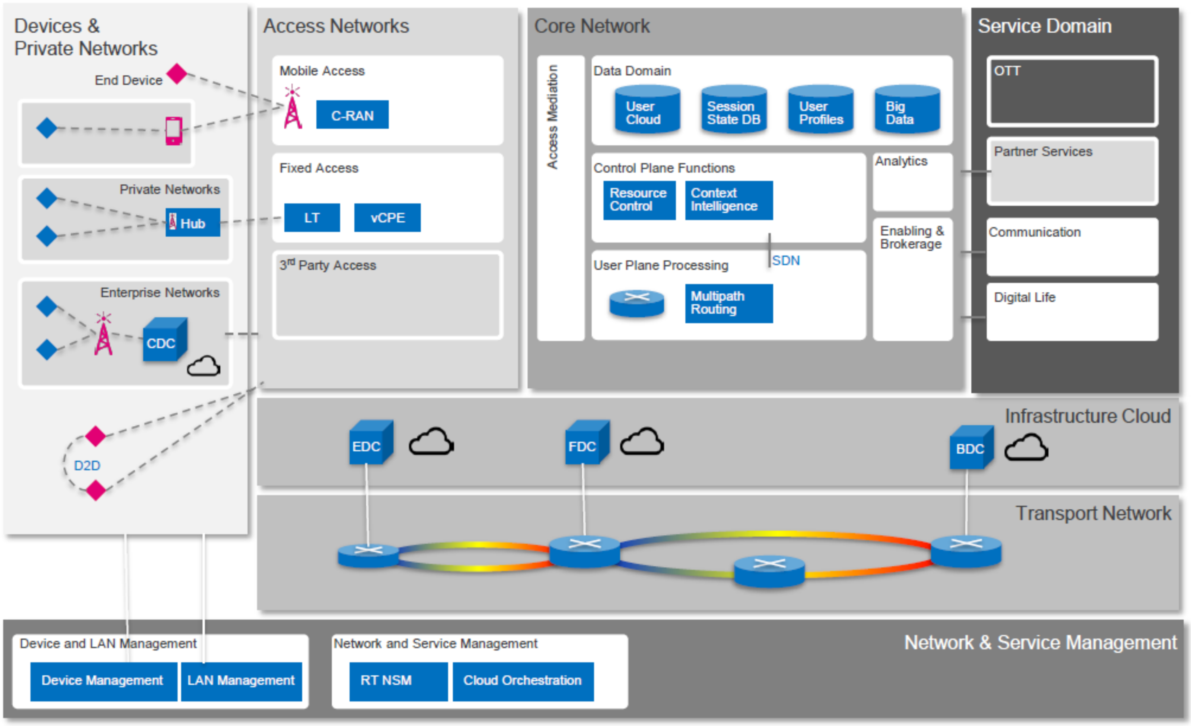

Figure 23: 5G Main Components

From a core network evolution perspective, there are two main steps to supporting 5G New Radio (NR). The first step – a 5G Evolved Packet Core (EPC) with 5G NR Non-Standalone (NSA) operation – is to move forward from the existing EPC. This is the current situation for LL Hamburg (5G production network Deutsche Telekom AG - 3GPP R15).

There are three major advantages for 5G:

- **Massive machine to machine communications** – also called the Internet of Things (IoT) that involves connecting billions of devices without human intervention at a scale not seen before.
- **Ultra-reliable low latency communications** – mission-critical including real-time control of devices, industrial robotics, vehicle to vehicle communications and safety systems, autonomous driving, and safer transport networks.
- **Enhanced mobile broadband** – providing significantly faster data speeds and greater bandwidth. New applications will include fixed wireless internet access for homes, outdoor broadcast applications without the need for broadcast vans, and greater connectivity on the move.

In the 5G NSA approach, the existing 4G core (EPC) is working as an anchor network mainly for signaling purposes. This EPC is combined with new extended radio functions – focused on the provisioning of additional mobile bandwidth capabilities (5G New Radio – 5GNR). T-Mobile / Deutsche Telekom is using additional frequencies from old UMTS solutions (2,1 GHz band) to offer more capacity for the clients. This function (dynamic frequency usage) is adapted from 3GPP R16.

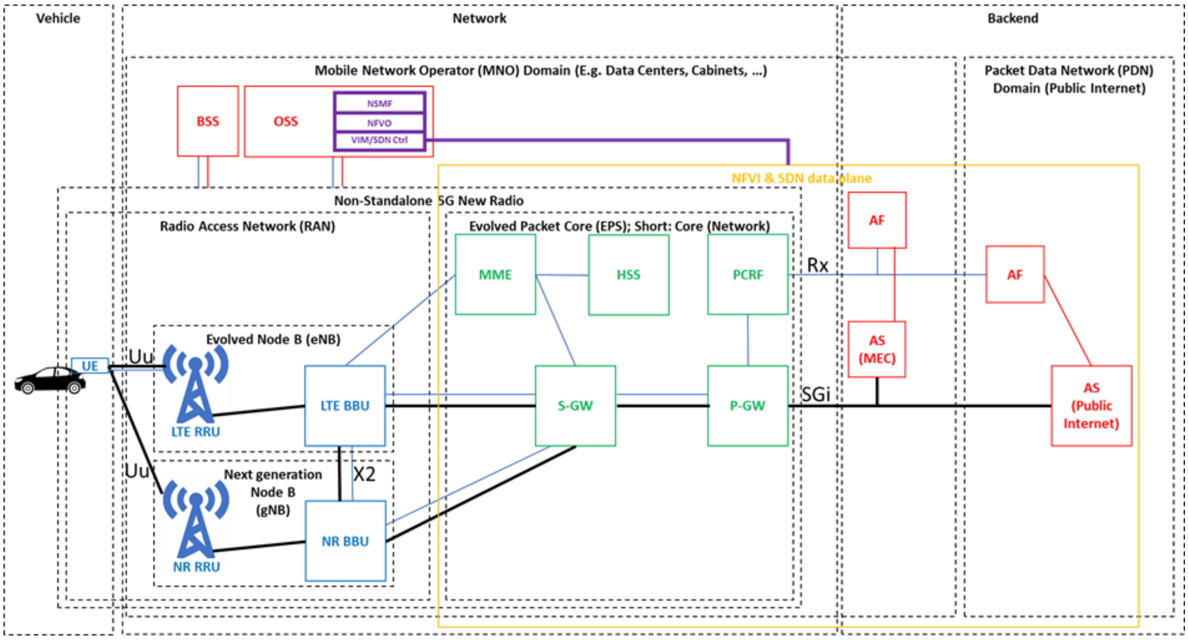

Figure 24: 5G Main Components 5G NSA Solution

The second step – 5G NR Standalone (SA) – is a new 5G Core (5GC) using a service-based architecture (SBA). The new architecture is fully software-based and will support network slicing. Network slicing will offer separated virtual networks for dedicated clients. With this approach, the mobile operator can offer qualities (e.g. signal latency) and capacities (e.g. bandwidth) in the network. This service will be provided on extremely high SLA levels.

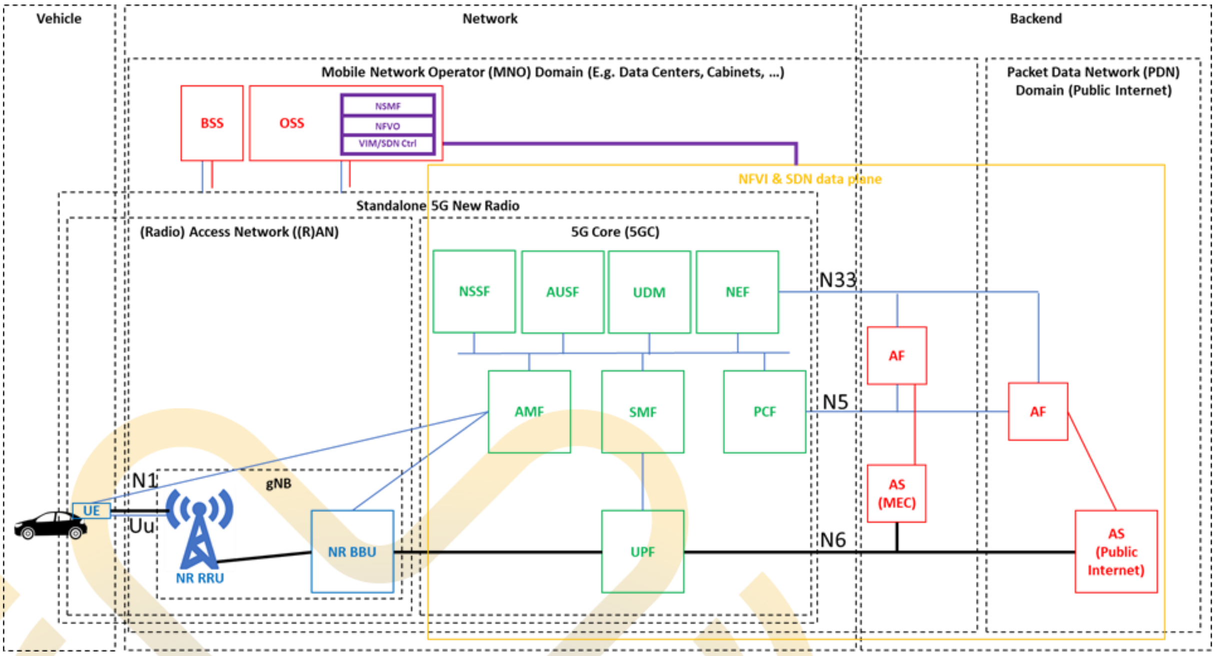

Figure 25: 5G SA System

4.2.3 5G Technologies and innovations to be deployed

Figure 26 gives an overview of the logistics terminal operation inside the Port of Hamburg. As one can see, the river Elbe divides the city of Hamburg into two parts, i.e a northern and southern section relative to the river. It can be seen that most of the terminals for container handling are in the southern part of the city. For these terminals, the multimodal accessibility for container delivery to the road (motorway) and rail (cargo hubs) are crucial for the overall ports' operation efficiency. This is of special importance as 10,000 TEU container ships nowadays are complemented by “XXL-size” cargo ships transporting up to 24,000 containers. These “Mega”-Container ships must be navigated safe and fast along the Elbe river to Hamburg's main terminals, located in the southern part of the city. The challenge for such a sensitive ecosystem is to ensure an efficient organization along the entire multi-modal transport chain including the specifics of water, road, and rail cargo altogether. Therefore, the City of Hamburg published the first I.T.S. policy directive for the promotion of logistics and I.T.S. innovation projects in April 2016 and extended it in June 2018 [19], with a focus on political support measures linked to the I.T.S. world congress planned in October 2021 in Hamburg.

The strategic balance of conflicting requirements linked to port logistics and low emission zones in the city centre, the professional handling of goods' transport along the multi-modal supply chain as well the efficient hand over from Mega-Containerships to last mile hub- and micro-hub warehouses became one of important KPIs of the I.T.S. policy directive.

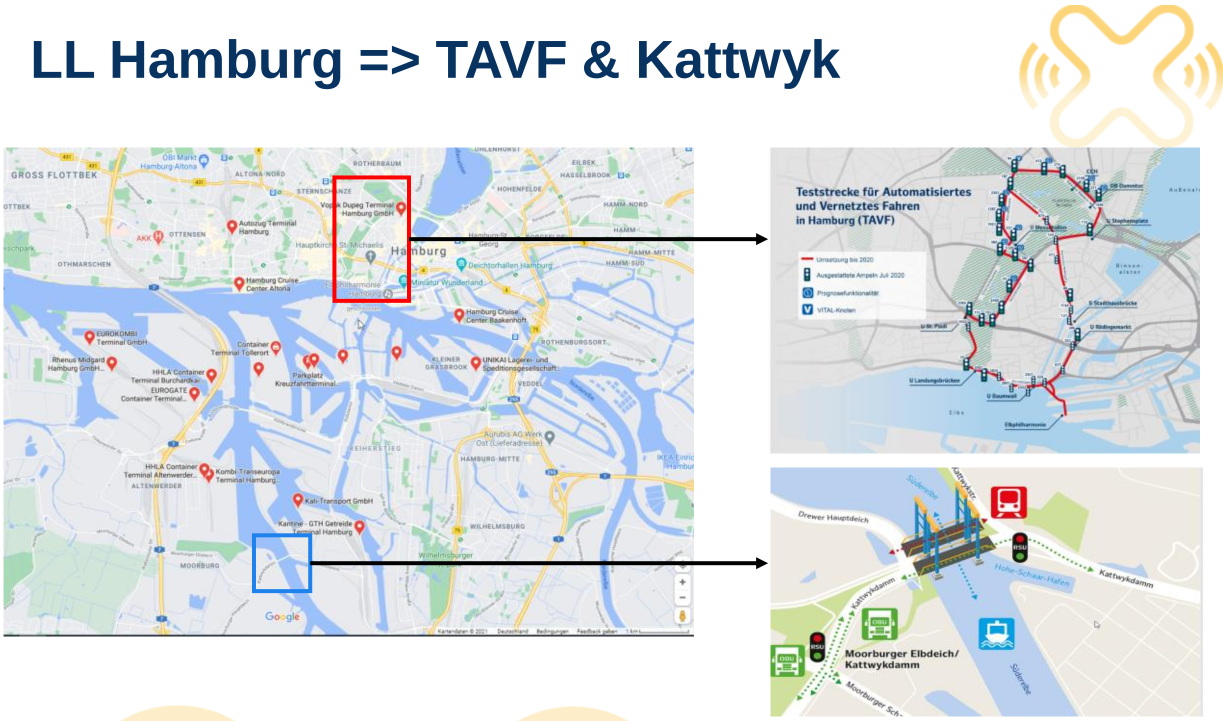

Figure 26: Geographical distribution of Container-Terminals and 5G-Loginnov test Fields

In 5G-Loginnov, the contribution to the overall political challenge is planned to be implemented in the 2 rectangular boxes one can see in Figure 26. The red coloured rectangular box in the upper part of Figure 26 shows the location of the Test field for Autonomous and Connected Driving (TAVF) and is located directly in the “heart” of the city. The Road network and infrastructure of TAVF belong to the traffic authority of the city and all traffic light intersections of the test field are equipped:

- with “classical” V2X technology using 802.11p WLAN communication standard and
- with “cellular” V2X technology using 5G Release 16 mobile communication of the Deutsche Telekom AG providing 5G services to the public.

With regards to 5G infrastructure aspects in TAVF, Use Case 10 is the most relevant making use of the 5G features low latency communication (uRLLC) and 4K Video broadband communication (eMBB). To navigate a platoon stable and safe within the busy urban road network of Hamburg, avoiding collision with Vulnerable Road Users (VRUs) such as pedestrians and bicycles a special APP will be used known as GLOSA (Green Light Optimal Speed Advisory). As shown in Figure 27, the innovation lies in the uplink of traffic light Signal Phase and Time information combined with the specific Topology Information of the Intersection leading to a SPAT/MAP message which is transmitted to the 5G-Mobile Edge Server of Deutsche Telekom and from there to the GLOSA APP. Additionally, 5G enabled Precise Positioning will be used to enhance the accuracy of the GLOSA-APP and to improve the collision warning alert message. It should be mentioned that for 5G enabled GLOSA truck platoons, Vehicle-to-Vehicle messages with latency requirements of less than 25 Milli-Seconds are needed as stated by Chandramouli and Liebhart [2].

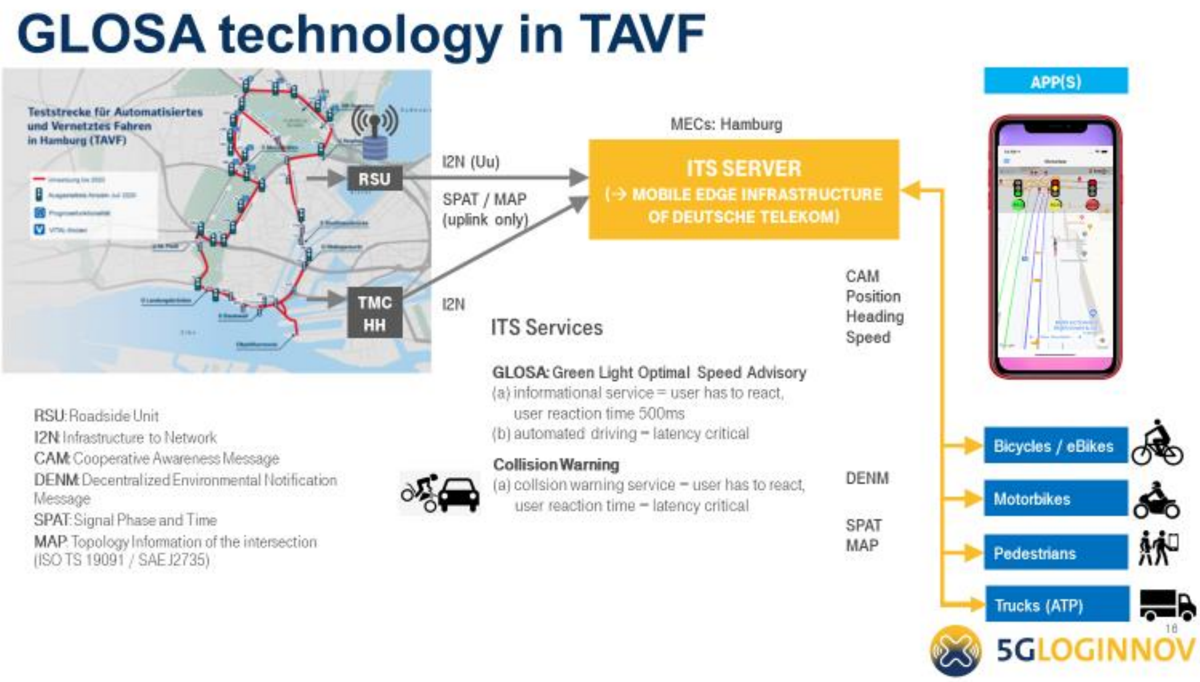

Figure 27: GLOSA APP technology as planned in the TAVF test Field

The innovative approach planned in Hamburg is to measure the environmental impact of traffic management actions linked to traffic light signalling used in 5G enhanced GLOSA (red coloured box in Figure 26) as well GHG savings possible when extending Green Light for truck platoons based on I.T.S. G5 and 5G enhanced Floating Truck Emission Data analysis offered by T-Systems smartphones, Continental IoT devices and tec4u Entruck on-board-units. Additionally, Continental and tec4U will implement 5G technologies in their devices and existing applications to be able to enable a native use of 5G technologies. The significant savings expected will also be used for business deployment as fuel savings give stimulus for logistics service providers to join the project and the overall I.T.S. strategy of the city of Hamburg as well as the port of the future implementation plans announced by the Hamburg Port Authority (HPA).

Table 5 provides a summary of the 5G technologies to be deployed in the Hamburg Living lab.

Table 5: 5G Technologies LL Hamburg

5G Service/Application	Deployed
Radio Access Network	Production network 3,6 Ghz / 2.1 Ghz
Number of cell sites	3,6 GHz more than 20 sites / 2.1 GHz over 98% full coverage in Hamburg
Frequencies used	3.6 GHz / 2.1 GHz
Frequency Bandwidth	2,1 GHz – 20 MHz / 3,6 GHz 90 MHz
Mobile Core	3GPP R15 with DSS
Virtualised infrastructure	only partly
Orchestrator	DTAG internal
Network Slicing	not deployed yet
MEC	available (MobileEdgeX)

5 LIVING LAB 3 - KOPER

5.1 5G Requirements

This section deals with the definition of the architectural requirements and selected 5G architecture to be deployed in the Koper Living lab of 5G-LOGINNOV. The main applications and services that will be supported are based on Industry 4.0 scenarios and include use cases related to port control, logistics, and remote automation. More specifically, a logistics support scenario will be implemented where operating port machinery (such as lifts, forklifts, terminal tractors, etc.) will be equipped with industrial cameras for capturing and transfer of UHD streams to the Container Management Systems (CMS) for identification of container markers and detection of structured damage to containers using advanced video analytics based on AI/ML techniques. Also, transfer of remotely gathered information will be enabled to other port support systems, e.g. Terminal Operating System (TOS).

The Koper Living Lab targets the implementation of novel 5G technologies (MANO-based services and network orchestration, Industrial IoT, AI/ML-based video analytics, drone-based security monitoring, etc.) and cutting-edge prototypes tailored to be operated in the port environment. This represents not only operational but also development challenges, particularly with regards to possible immaturity of some of its 5G components and consequently a possibility to disrupt/affect the established operations of the port. To overcome deployment and operational challenges of the current 5G technologies in the port environment, the implementation of the Living Lab infrastructure is planned as a controlled and independently operating subsystem, and the interconnection points with the operational infrastructure (e.g. integration of 5G mobile network with the operational port network) will be carried out using proven and verified equipment. 5G capabilities and services under test (e.g. eMBB, mMTC, MEC, the use of drones) represent an add-on to the existing port infrastructure and complement the overall service portfolio, not substituting any of its vital parts [4].

The deployment of the 5G mobile network in the Port of Koper will rely on the availability of commercial 5G products, especially those related to the support of eMBB and mMTC features. The deployment plan already considers this, and the use of products and components that are either already commercially available or announced is planned. However, in case of delays in the commercial rollout on the part of 5G vendors and consequently unavailability of some components/ features, these will be replaced with the most suitable prototypes and open-source implementations already available in the 5G ecosystem.

These objectives will be pursued within the following use cases:

- UC1 - Management and Network Orchestration platform (MANO).
- UC5 - Automation for Ports: Port Control, Logistics, and Remote Automation.
- UC6 - Mission Critical Communications in Ports.

5G technology will be provided by ININ and Telekom Slovenije as part of commercial mobile infrastructure and integrated into the 5G-LOGINNOV Koper Living Lab to support identified use-cases.

5.1.1 Radio Network requirements

To be able to carry out all use cases within the Koper Living Lab, it is necessary to carefully plan and set up a 5G network, including preliminary measurements. The requirements of the 5G network are determined according to the selected Use cases, which were described in detail in D1.1, and other infrastructure, which is defined in more detail in D1.3.

5G network in Koper LL will be based on the 5G NR NSA architecture deployed over the commercial mobile infrastructure and 5G NR SA deployed over the private 5G infrastructure. The NR NSA radio access network will consist of two base station sites. Evaluating the current 4G LTE coverage is a key factor for ensuring the correct anchoring in the midterm phase in which the control plane needs to be driven by LTE Infrastructure.

Figure 28: Cellular network coverage in Koper Living Lab

An important part of the requirements of the 5G network is KPIs, which are defined and discussed in more detail in deliverable D1.4. KPIs such as latency, reliability, end-to-end latency, availability, bandwidth and connection density to name a few.

5G NR in SA mode will be deployed as part of a private 5G system which will be prepared in a compact form and will enable simple reallocation of the gNb site inside the Koper LL. Optimal location will be chosen based on the needs and operational requirements of the planned use cases.

5.1.2 Core Network requirements

The Port of Koper operates under strict security and regulatory requirements and in order to meet these criteria, also the core network must be properly designed and deployed. The layout of the network based on the commercial infrastructure will depend on the availability of equipment and the possibility of implementation within the Koper LL. We are striving for incremental network deployment, we believe that during the 5G-LOGINNOV project time frame commercial 5G core network equipment operating on SA mode will be available, which will enable more advanced network deployments adapted to ports. 5G SA deployment will depend on the availability of the equipment and from mobile equipment vendors.

The 5G network deployment scenario options can be seen in Figure 29, from where the most relevant for the current project are the NSA (option 3x) and SA (option 2). These allow for incremental 5G network deployment following the vendor timeline for the technology availability on the market and respecting the involved MNOs network deployment and migration strategy per region. At the first phase of the project, the NSA (option 3x) will be supported and at the second phase, it is aimed to support SA (option 2).

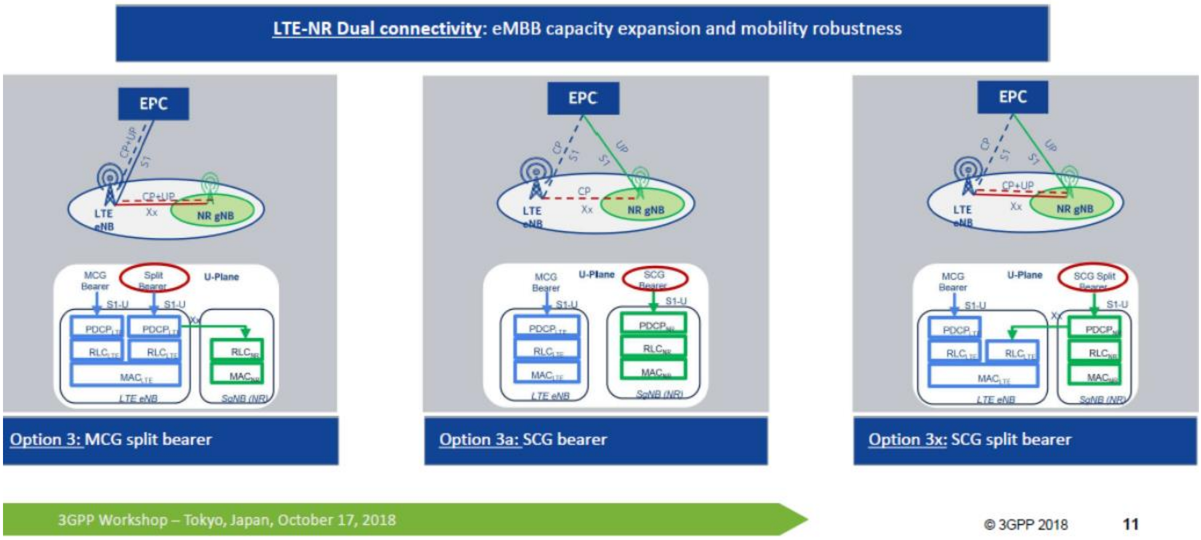

Figure 29: 5G NSA deployment options in Koper LL

Telekom Slovenije used a simple typical scenario for EPC upgrade to support 5G deployment (Figure 30) where physical EPC is upgraded to support NSA and capacity expansion is based on physical EPC. When evolving to 5G SA, this physical EPC based on dedicated hardware cannot be used in a virtualized environment. This scenario depends on the capabilities of the existing network equipment vendors.

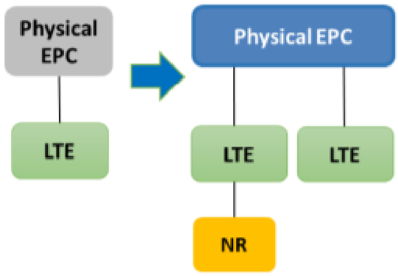

Figure 30: EPC Upgrading for NSA Deployment

In the case of Private 5G system network deployment will operate in 5G SA mode and will be prepared as a compact solution deployed over the portable IaaS infrastructure provided by ININ.

5.1.3 Security considerations

Within the Ports and Logistics vertical, one of the key requirements is to ensure overall secure communications and the architectural solution in Koper Living Lab must offer the elements that make it possible. This also applies to services and applications running over these networks. When designing a 5G network, the operator will use the concepts and philosophy of the security architecture built into the 5G specifications to improve network resilience.

In the case of 5G networks, where key elements will be software-based, this process has to take particular care of matters such as secure software development, security assessment and testing, version control, secure software update and alike [10]. Whilst 3GPP specifications define key functional elements, interfaces and related security requirements, there are multiple security considerations when it comes to deployment scenarios for a full 5G system, which is sometimes categorized into horizontal (e.g. security at the network level, slicing, application-level security, confidentiality and integrity protection) and vertical security considerations (e.g. NFV, distributed cloud) [11].

One of the key considerations is how the network functions in the new 5G core are to be deployed and here virtualization is a key technology for enabling flexible deployments. Standardisation of virtualization in mobile networks, and associated security aspects, is needed due to a multivendor environment, but also because of the dynamic nature of mobile network management to support, for example, network slicing. This is carried out in ETSI ISG NFV which has been working on standardizing network function virtualization and its security aspects from more general network management and orchestration point of view. On the other hand, 3GPP security experts are looking at virtualization security aspects from a mobile network architecture point of view [12].

Once the network is deployed, operators have to manage and operate the network in a secure manner. This includes the application of standard baseline security measures for network security and resilience and appropriate reinforcement of technical measures that are of particular relevance for risks in the 5G environment. Additionally, 5G network assets that need to be secured are: i) Endpoint Devices (i.e. UEs, sensors, etc.); ii) Networks (including physical and virtualized elements), comprising the network Application Plane (VNFs), the Control Plane (SDN and NFV Orchestrators and Controllers), and the Data Plane; and iii) end-user applications [6].

Koper LL, even though located in the territory of the Republic of Slovenia, carries a status of an autonomous security zone, for which some specific security and regulatory constraints apply. The partners involved in the activities linked to and taking place in the Koper LL will consider these constraints and will work closely together and under the guidance of the Port of Koper representatives to ensure compliance and execution of any required formal procedures within the context of the project timeline.

To support strict port security and regulatory requirements, commercial MNO infrastructure will be extended with MEC capabilities that will assure smart routing of the port-related network services and applications traffic directly to the operations support systems of the Koper LL. In addition to commercial MNO services, the private 5G mobile network with dedicated cloud infrastructure will be built and tailored to the needs of port operation and targeted UCs.

Concerning the use of drones and video streaming cameras in the seaport such as Port of Koper, the national legislation and regulations of the Republic of Slovenia as well as specific provisions for the port zone will be considered to make sure that all formal requirements are met.

5.2 5G Architecture and technologies

5.2.1 The architectural design of Living Lab setup and testbed

The General E2E architecture of the Koper Living Lab is shown in Figure 31. In order to assist all of the planned use cases, we will set up two 5G networks in the Port of Koper, namely the private 5G SA network and the 5G NSA commercial network. During the project, an incremental upgrade of the commercial 5G NSA network with the 5G SA option 2 is planned, but only if commercial equipment will be available on time.

Koper LL general architecture which incorporates network and application components will be based on:

- 5G Radio Access Network (RAN),
- 5G Core Network (CN),
- Service Infrastructure/Application Components and
- Private MANO.

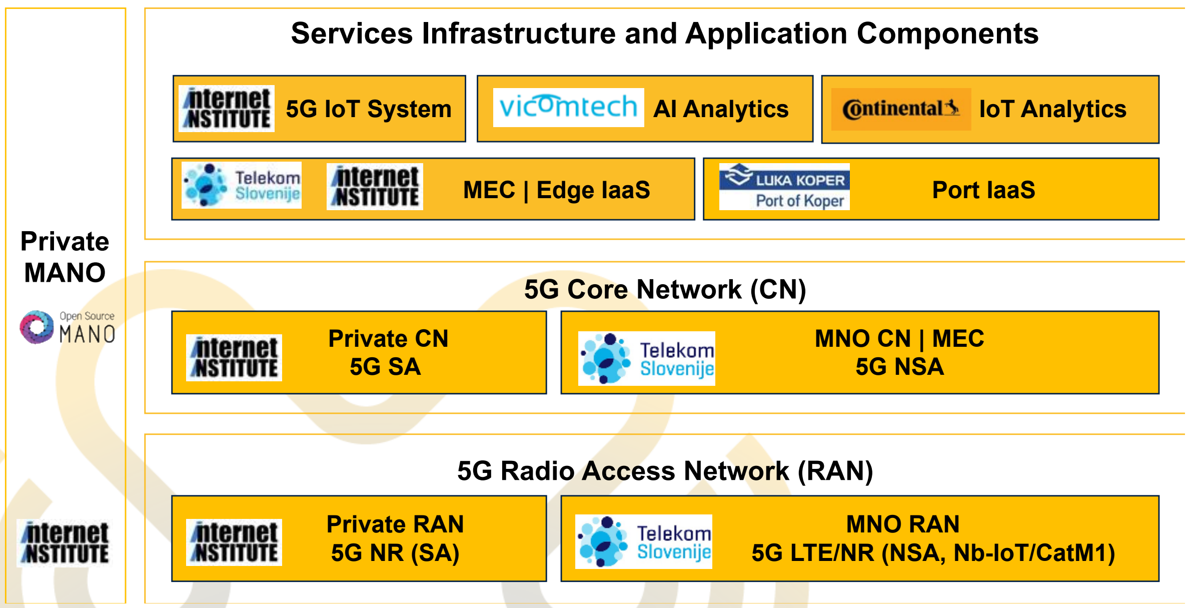

Figure 31: High level network scheme for Koper Living Lab

The IaaS requirements will be covered by placing dedicated physical servers at the data centre at the Koper LL location that will serve as a private IaaS (Infrastructure-as-a-Service) in terms of NFV-based terminology. Regarding the radio network, it is one of the design goals of the LL Koper to provide both flavours of 5G connectivity: Non-Standalone (NSA) and standalone (SA).

The first variant (NSA) will be deployed by Telekom Slovenije using their production core network and dedicated 5G base stations at the LL Koper location as shown in Figure 32. The SA variant (Figure 33) will be deployed as a completely private 5G network using the aforementioned IaaS infrastructure at LL Koper and placing the base station at a strategically chosen location within the living lab. Two mobile networks will operate independently and will allow testing various use case scenarios on SA/NSA 5G topologies.

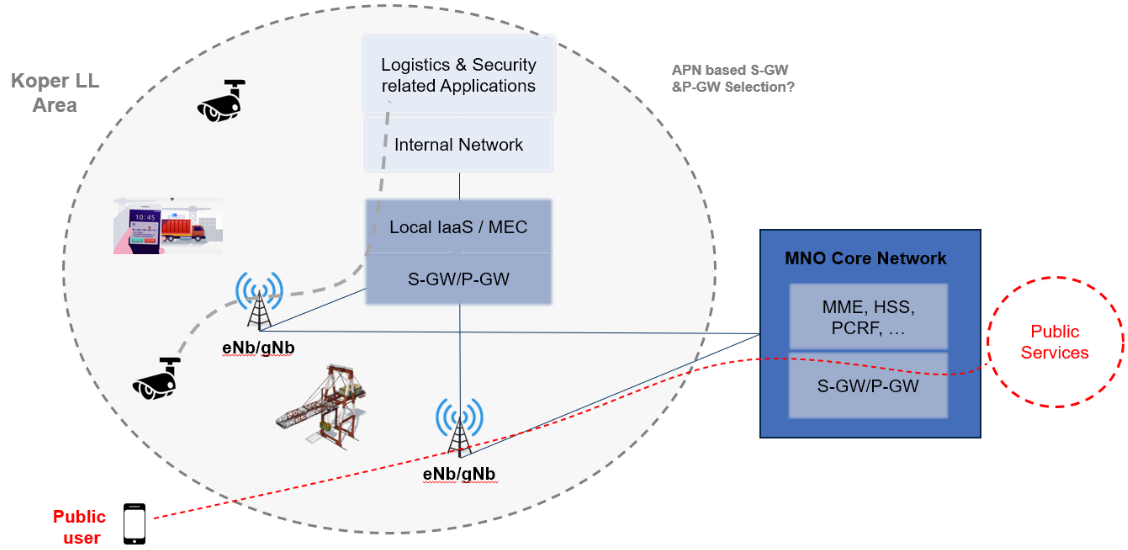

Figure 32: MNO 5G NSA system architecture in Koper LL

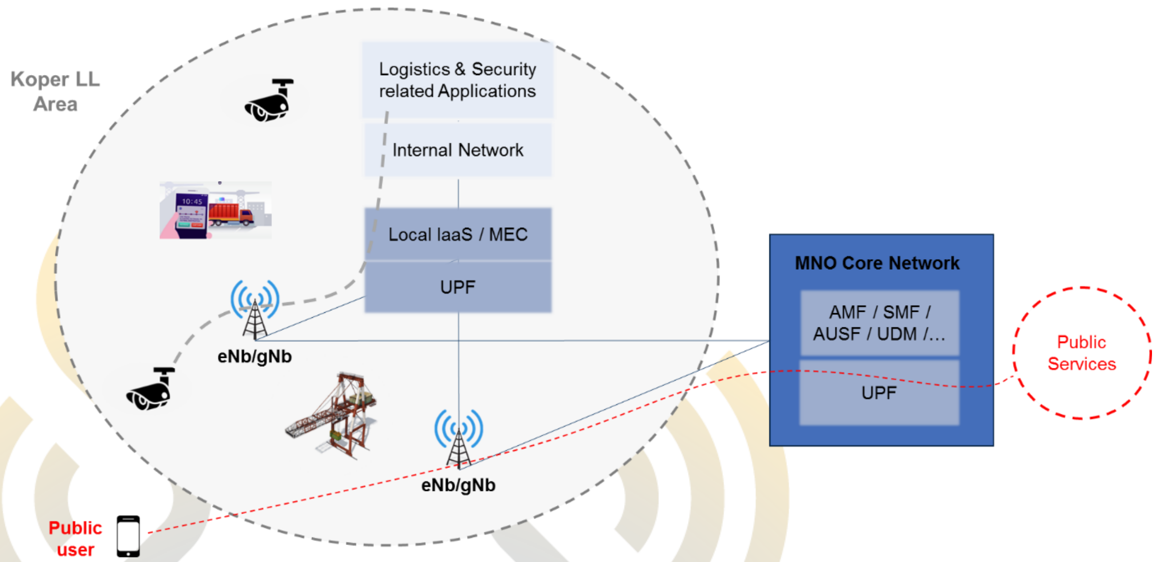

Figure 33: MNO 5G SA System Architecture

For the trial purposes, the radio and core network equipment to be deployed by Telekom Slovenije is provided by Ericsson. At the first phase of the project, the NSA (option 3x) will be supported, and later in the second phase, if 5GC solution available, the existing EPC core will be upgraded to 5G Core to support SA (option 2) Figure 33.

Table 6: 5G deployment options for Koper LL

Deployment Option	Number of gNBs	Frequency	Deployment type
5G NSA Option 3X	2	LTE 800 MHz LTE 1800 MHz NR 2600 MHz	Upgraded EPC Private IaaS
5G SA – Option 2	1	5G NR – 3.500 MHz (n78)	5G CN (Private IaaS); 5G NR (Private Iaas/Cloud RAN)

5.2.2 Radio Network Architecture

The 5G RAN architecture of the 5G-LOGINNOV Koper LL will be based on the deployment model defined by 3GPP. In the first stage of the project, it will be based on the deployment of the 5G Non-Standalone Architecture implemented with Option 3x as per 3GPP Release 15. The architecture will provide both NR and LTE radio access. Figure 34 depicts 5G NR overall architecture, as is defined in the 3GPP TS 38.300 specification [2]. In this architecture, the gNB node provides the NR user plane and control plane protocol terminations towards the UE and is connected via the NG interface to the 5GC. The ng-eNB node provides E-UTRA user plane and control plane protocol terminations towards the UE and is connected via the NG interface to the 5GC.

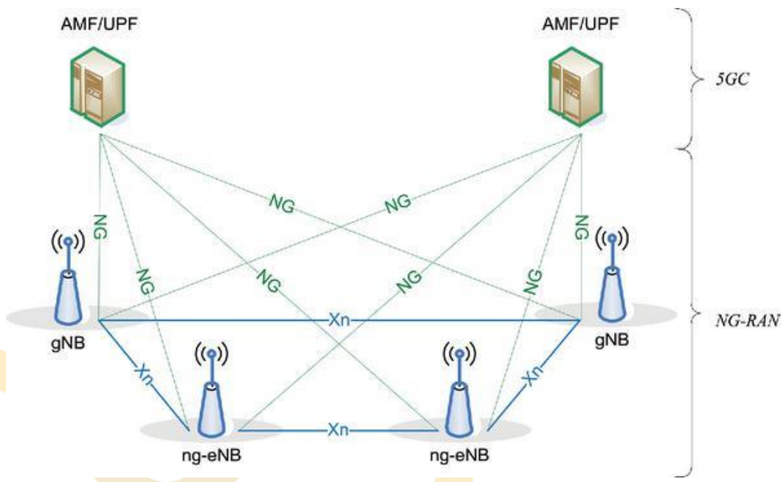

Figure 34: 5G NR in relation to the 5G system [21]

At Koper Living lab the initial 5G radio access network is going to be deployed on NR 4x4 MIMO 20MHz at 2600 MHz FD mode (n7), with an LTE anchor layer 2x2 MIMO 10 MHz in B20 at 800 MHz and 2x2 MIMO 20 MHz in B3 at 1800 MHz. LTE carrier is 4x4 MIMO 15 MHz in B7 at 2700 MHz. During the project, we plan to install additional antennas NR NSA in band n78 (3500MHz) with 100MHz bandwidth and LTE anchor B3. Data on base stations that are physically located within the Koper LL are shown in Table 7.

Table 7: gNBs and ng-eNBs in Living Lab Koper

PLUKAK	PLUKA
3x NR2600 4T4R	3x NR2600 4T4R
3x LTE2600 4T4R	3x LTE2600 4T4R
3x LTE800 2T4R - anchor for 5G	3x LTE800 2T2R - anchor for 5G
3x LTE1800 4T4R - anchor for 5G	3x LTE1800 2T2R - anchor for 5G

In the initial phase of the project, analyzes of the coverage of the Port of Koper based on Telekom Slovenije's commercial 5G network were prepared with the help of network planning tools. Figures 35 and 36 show the coverage of 5G NR FDD 2600 MHz within Koper LL. More specifically, Figure 35 shows the coverage of the same area with a signal strength of -108 dBm or better, which should in principle be sufficient to perform use cases, defined in Koper Living Lab.

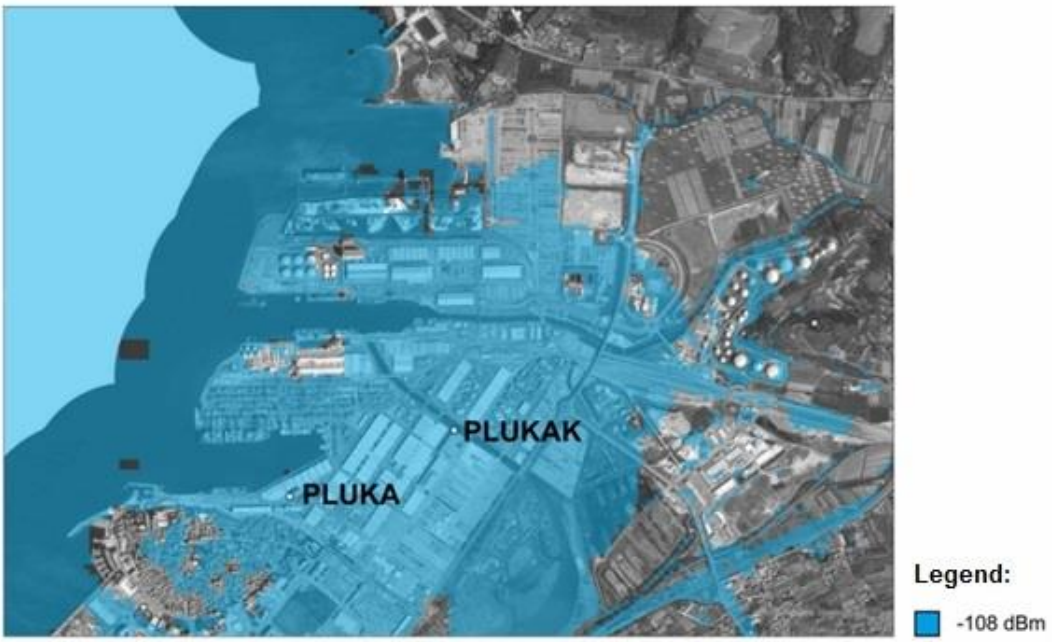

Figure 35: NR FDD 2600 MHz coverage (-108 dBm or better)

Figure 36: NR FDD 2600 MHz coverage at Port of Koper

5.2.2.1 LTE-NR Dual Connectivity

E-UTRAN New Radio - Dual Connectivity (EN-DC) is a technology that enables the introduction of 5G services and data rates in a predominantly 4G network. This approach permits cellular providers to roll out 5G services without the expense of a full scale 5G Core Network. LTE-NR Dual Connectivity (EN-DC) operates by overlaying NR to LTE networks connecting to the 5G enabled Evolved Packet Core Network (EPC) through the S1 interface. It enables the devices to set up a split bearer, which uses two separate connections, one to an LTE Master Node eNB (MN-eNB) and one to a 5G NR Secondary Node (SN-gNB). In NSA mode, the Master Node is the eNB and the Secondary Node is always the 5G NR. Control signalling towards the UE and the core network is handled by the eNB and downlink user data is transferred on either LTE or NR connection. The X2 interface is used between the eNB and the NR Node. When a split bearer is established, the user-plane towards the device and the core network is terminated in the Secondary NR Node. The user data sent to the device using LTE is transferred through the X2 interface. This is referred to as 3GPP Option 3x. A flow control scheme is used for the user data over the X2 interface (X2-U) to keep buffers in the eNB filled at the right level.

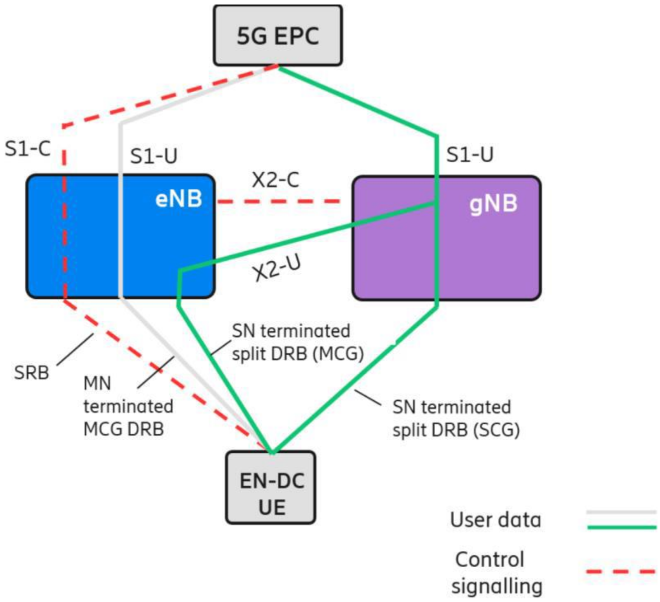

Figure 37: 5G NR NSA (EN-DC) Option 3x overview

A split bearer is typically established as soon as the UE is in NR coverage and it is removed when the UE/device leaves NR coverage. It is noted that mobility is handled in LTE by removing the split bearer if the device finds a better LTE cell than the serving cell. If all prerequisites are met, the split bearer can be set up again in the target LTE cell.

5G network NSA Interfaces:

- S1-C: Connects RAN to EPC. Used for S1-C signalling connection, terminated by the eNB;
- S1-U: Connects RAN to EPC. Carries S1-U user plane bearer. It is terminated by the eNB for legacy UEs, and certain bearers of the NR UE such as VoLTE. While it is terminated by the gNB for the NR UE bearer;
- X2-C: Connects the eNB and the gNB and carries X2 control signalling;
- X2-U: Connects the eNB and the gNB and carries user data of Split bearer;
- E6: Control plane interface between the Packet Processing block in the gNB and the Radio processing block in the eNB.

5.2.2.2 Narrowband IoT

Narrowband IoT is designed as a new radio access mode that has its Cat-NB1 category. NB-IoT thus enables the deployment of a Low Power Wide Area (LPWA) cellular network. The LPWA cellular network operates in the licensed part of the radio spectrum, which means that there are no problems with overlapping frequency bands as with LPWA networks in the unlicensed part of the read spectrum.

The Living Lab Koper area is covered by the NB-IoT network, which is based on the existing LTE technology. The NB-IoT network within LL Koper will serve to provide the M2M communication required in UC5. As part of UC5, telemetry data will be collected from some of the vehicles (e.g. terminal tractors) that operate within LL Koper. This information will be collected from the vehicle CAN-Bus, using the 5G-enabled IoT Device, and transmitted via the 5G network, to the backend installed within the internal IT infrastructure. Figure 27 shows the high-level architecture of the NB-IoT network within Living Lab Koper.

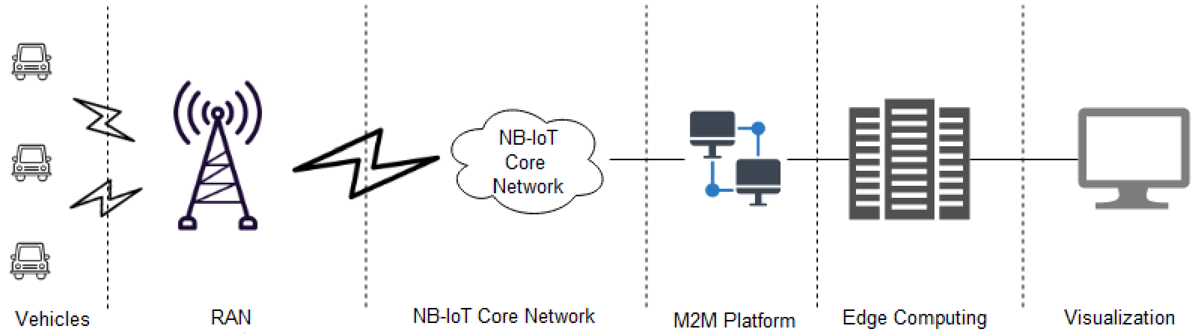

Figure 38: NB-IoT high-level scheme

The Figure 39 shows the coverage of base stations with the NB-IoT network in the area of the Koper LL. Coverage (light green) is provided by two base stations, which are physically located inside the Koper LL. Each base station has three cells, based on 800 MHz.

Table 8: Bands used in Telekom Slovenije for NB-IoT

E-UTRA Operating Band	**Uplink (UL) operating band** **BS receive** **UE transmit** **FUL_low – FUL_high**	**Downlink (DL) operating band** **BS transmit** **UE receive** **FDL_low – FDL_high**
8	880 MHz - 915 MHz	925 MHz - 960 MHz
20	832 MHz - 862 MHz	791 MHz - 821 MHz

Figure 39: NB-IoT coverage in Port of Luka

5.2.3 Core Network Architecture

Telekom Slovenije will deploy an overlay 5G EPC core network that will be connected to LTE and 5G NR radio. Given the project timeline and 5G components availability, the initial deployment will be done using 5G Non-standalone (NSA) Option 3X. The New Radio (NR) base stations are connected via the 4G network. An LTE anchor is required for control plane communication and mobility management. The 4G evolved packet core (EPC) is enhanced for this purpose. We used the 3x option because it represents a relatively easy and fast upgrade of the existing mobile network. Currently, the core network is composed of the EPC, running a standard-compliant implementation of an LTE stack, including the Mobility Management Entity (MME), Home Subscriber Service (HSS), Serving Gateway (SGW) and PGW services as shown in Figure 40. The various deployment options have been described in more detail in previous chapters.

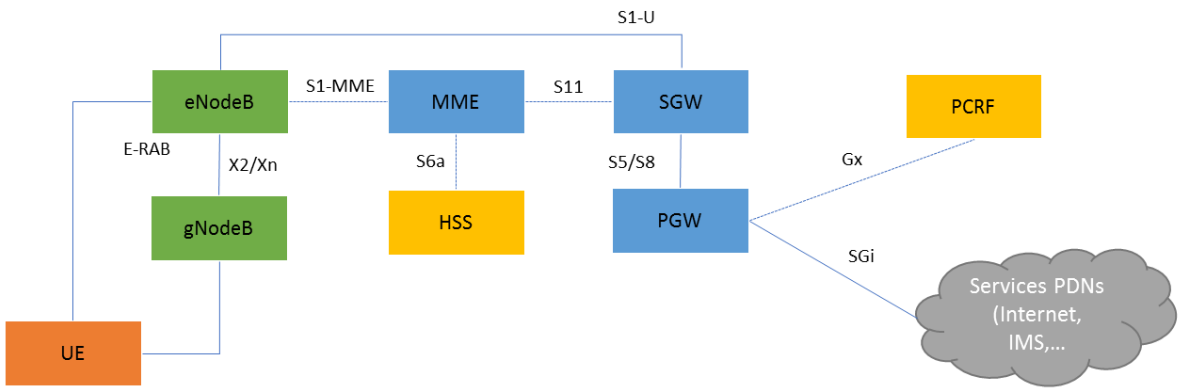

Figure 40: Telekom Slovenije Evolved Packet Core

Packet core nodes:

- **PGW**: provides connectivity from the UE to external packet data networks by being its point of exit and entry of traffic.
- **SGW**: routes and forwards user data packets, while also acting as the mobility anchor for the user plane during inter-eNodeB handovers and as the anchor for mobility between LTE and other 3GPP technologies
- **MME**: the key control node for the LTE access network. It is responsible for idle mode UE paging and tagging procedure including retransmissions.
- **HSS**: a central database that contains user-related and subscription-related information. The functions of the HSS include mobility management, call and session establishment support, user authentication and access authorization.
- **PCRF**: provides the QoS authorization that decides how a certain data flow will be treated in the PCEF and ensures that this is in accordance with the user's subscription profile.

Transition to 5G is being done by enabling support for 5G bearers in the existing 4G-LTE infrastructure. 5G mobile broadband services are available in a primarily 4G network via mobile terminals that support dual connectivity to 4G LTE and 5G NR base stations at the same time. To enable dual connectivity, the 4G infrastructure needs to support connecting to a 5G NR base station (gNodeB). Figure 41 shows a 5G gNodeB connected to the 4G EPC at the data plane level. The 4G EPC also supports the switching of bearers between 4G eNodeBs and 5G gNodeBs. The 5G gNodeB connects to the LTE eNodeB to receive requests to activate and deactivate 5G bearers but does not connect to the MME. The 5G gNodeB acts as a secondary node in a dual connectivity setup and provides the 5G data path.

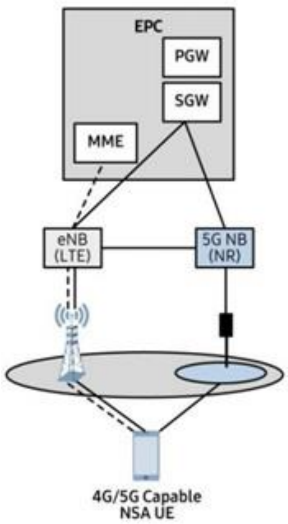

Figure 41: Adding 5G data plane to existing LTE sites [20]

In the later phase of the project, if commercial 5GC will be available, we will deploy a dedicated 5G core in Koper Living Lab and thus support SA Option 2. This of course depends on the technological availability and agreements with vendors. The adoption of cloud-native technology and the new 5G Core architecture will impact other parts of the core network as infrastructure, voice services, automation and orchestration, operations and management and security. This will allow new services to be created faster and in a more agile way. Built on microservices, enabling independent life-cycle management and fast service design, and ready to support network slicing, the 5G Core will cater to fast service delivery and end-to-end service level agreements (SLA).

Currently, due to logistical and technological limitations, we cannot deploy a separate dedicated mobile core within the Koper Living Lab, so we will use the layout of Telekom Slovenije premises. During the project, we will strive to deploy a separate 5G mobile core within Koper LL and test such network layouts.

5.2.4 Network Slicing

Networking slicing on the commercial part of the 5G network (in the first phase of the project - 5G NSA option 3x) will not be utilized. During the project, network slicing will be assured, if commercial technology will be available and 5G SA Option 2 is deployed in Koper Living Lab.

5.2.5 Private 5G System Architecture

The main objective of the Private 5G System deployment is to assure completely self-dependent 5G communication infrastructure, running on the COTS hardware and using novel deployment and operational techniques (OSM-based orchestration). It is designed to support fully orchestratable layered architecture, consisting of the following abstracted layers:

- infrastructure,
- virtualization and/or containerization,
- network services and
- applications.

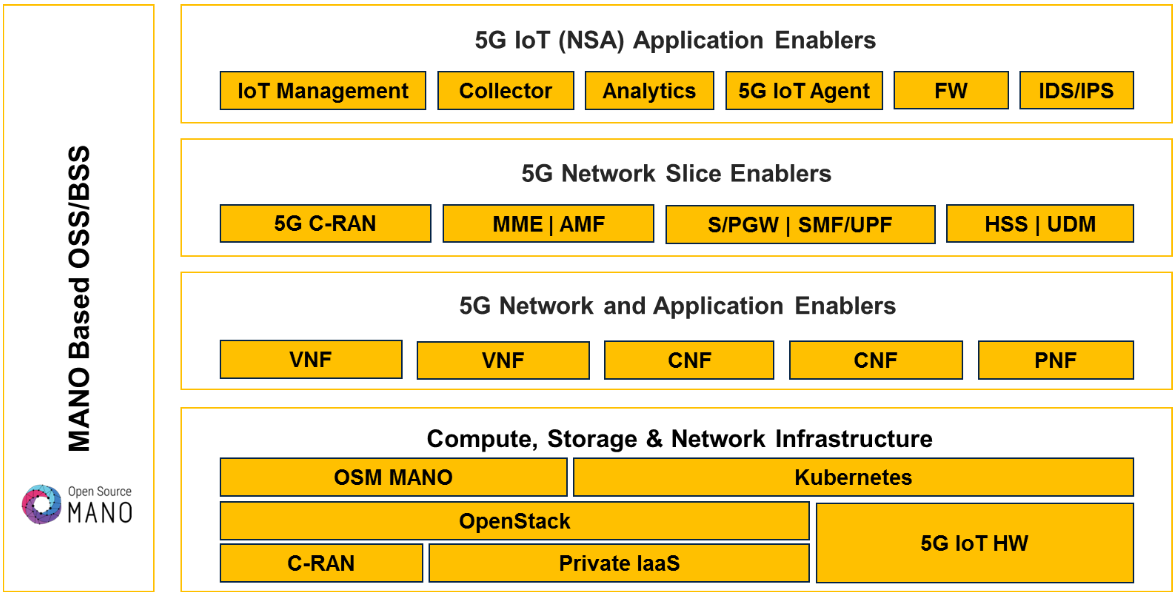

Figure 42: Private 5G deployment architecture

Operations of the entities in each layer will be controlled and coordinated by the orchestrator that will enable cloud-like features such as rapid deployment, dynamic reconfiguration of network services and slices or provide advanced failover mechanisms to assure the highest network service availability.

The infrastructure of private 5G deployment encompasses the following areas:

- providing physical infrastructure to host the network services and applications for use cases,
- offer different means of deploying services and applications that can be managed by the orchestrator.

Physical infrastructure will be completely separated from the port IaaS and will act as an independent IaaS capable of running its own cloud and hosting service and applications. On top of the private IaaS, OpenStack platform will provide the basic virtualization layer that will enable provisioning VMs, and VNFs when deploying with the help of the orchestrator. Additionally, Kubernetes will be installed as a containerization platform on bare-metal and/or OpenStack-based cloud. This will allow use cases to deploy their applications as VNFs or containers while providing the highest grade of cloud-native functionalities and orchestration mechanisms.

Private 5G deployment will support three types of NFV-based deployments:

- VNF (Virtual Network Function),
- PNF (Physical Network Function) and
- CNF (Container Network Function).

VNF corresponds to a virtual machine being deployed in the Private IaaS with features such as life-cycle management and the capability to support day 0 to day 2 configuration directly from the orchestrator. On the other hand, the PNF is deployed as a physical device and while life-cycle management and similar features are not orchestrated, some dynamic reconfiguration can still be achieved with the orchestration platform. Additionally, Kubernetes-based deployments by using Helm charts are supported as CNFs.

The main goal of such a design choice is being able to offer various options regarding application and service provisioning and management for both, administrators (i.e. Private 5G system admin/develop operations) on one side, and also use case users on the other.

The network services layer provides the basic elements of the network and 5G connectivity within the private deployment:

- 4G/5G core elements (e.g. MME/AMF, HSS/UDM),
- 5G RAN elements (e.g. eNb/gNb).

The deployment will support 5G SA model and will be provisioned using NVF-based deployment. It will include VNFs/CNFs on the core network side and PNF for gNb. This will allow the orchestration and dynamic management of 5G mobile core network elements (i.e. AMF, SMF, UPF) and exploiting such orchestrator features as dynamic 5G slice reconfiguration while enabling dynamic scalability or rapid deployment.

Finally, the orchestrator will provide the glue that ties all the layers into one common NFV-based deployment platform. For the Private 5G deployment, the OpenSource MANO (OSM) orchestrator will be used to efficiently deploy and manage the virtualized/containerized applications (VNFs/CNFs) while also allowing a certain degree of management for physical devices (PNFs).

The basic steps to be taken for the Private 5G network service/application to be deployed via OSM in a distributed application manner are the following:

- prepare the application to run as a container or multiple containers in a stateless manner,
- prepare “docker-compose” descriptor and/or Kubernetes helm-chart,
- manual deployment via Docker/Kubernetes to test if the application runs correctly before making steps required to enable orchestration,
- for each CNF prepare the CNF descriptors which define the operational and configurational aspects of a virtual machine,
- prepare network service (NS) descriptor that describes the topology and relation between CNFs running the application,
- onboard VNF and NS descriptors onto the OSM local repository,
- finally, on the OSM, configure and deploy the application as a network service (NS) composed of VNFs.

For testing and monitoring purposes, the qMON monitoring tool [20] will be deployed and will allow continuous end-to-end 5G network service monitoring.

On the application layer, the private 5G deployment will support hosting additional and 3pty applications, such as deep packet inspection, IPD/IDS or some use case application. With the presented architecture, the only requirements for such applications are the following:

- containerized application,
- descriptors for VNF (CNF) and NS to fully support orchestration provided by the OSM.

Software solutions and platforms to be used with private 5G deployment are summarized in the following table.

Table 9: Software solution and platforms to be used with private 5G deployment

Technology	Platform	Supported deployment	Usage	Private 5G deployment
Virtualization	OpenStack	VM	Host virtual machines	A virtual machine running OpenSource MANO orchestrator and UC applications
Containerization	Docker Kubernetes	Container	Host containers	Kubernetes with the docker engine hosting distributed

				applications for UC applications
NFV	OpenSource MANO	VNF CNF PNF	Deploy VNF/CNF/PNF	Elements of the 5G private mobile network deployed as VNFs/CNFs
Monitoring	qMON	VNF/CNF	Network performance monitoring	End-to-end network services and application monitoring.
Visualizations	Grafana	CNF	Graphical representation of KPIs	Real-time dashboards presenting network, application and radio KPIs based on qMON monitoring.

5.3 5G Technologies and innovations to be deployed

The baseline 5G network and cloud infrastructure will be designed and deployed on the premises of the Koper LL. To support strict port security requirements, commercial Mobile Network Operator (MNO) infrastructure will be extended with Multi-access Edge Computing (MEC) capabilities that will assure smart routing of the port-related network services and applications traffic directly to the operations support systems of the Koper LL. In addition to commercial MNO services, the private 5G SA mobile network with dedicated cloud infrastructure will be built and tailored to the needs of port operation and targeted UCs.

Within UC5, telemetry data from vehicles (e.g., terminal tractors) will be collected. This information will be collected from the vehicle CAN-Bus, using the IoT Device, and transmitted via the 5G network, to the port operation support system. An NB-IoT network will also be available for IoT devices if required.

5G network within Koper Living Lab will be designed to support the deployment of the innovative advanced use cases involving several cutting-edge 5G features and technologies and new devices (e.g. slicing, eMBB, uRLLC, mMTC, MEC, 5G-NR, etc.).

Table 10 provides a summary of the 5G technologies to be deployed in the Koper Living Lab.

Table 10: 5G technologies to be deployed in Koper LL

Radio Access Network – Commercial infrastructure	LTE and NR deployed at 2 cell sites
Radio Access Network – Private 5G System	NR, deployed as portable cell site
Frequencies used	800 MHz, 1800 MHz, 2600 MHz and 3500 MHz
Mobile Core	EPC with NSA support and 5GC for private 5G system
Virtualised infrastructure	Open Stack, Kubernetes
Orchestrator	MANO orchestrator
Network Slicing	Deployed as part of private 5G system

Edge Computing/MEC	Deployed as part of private 5G system / On roadmap 2023 as part of commercial 5G system
NFV	OSM
Monitoring	qMON testing from ININ
Containerization	Docker
eMBB	Yes
mMTC	Yes (NB-IoT)

6 CONCLUSION

Deliverable D1.2 described the selected 5G network architecture that will be implemented by each 5G-LOGINNOV Living Lab. The document also outlines the network requirements determined based on eleven different use cases. When choosing the network architecture always is needed to consider the level of development of commercial and private 5G networks and the telecom partners are aware that not all the commercial 5G SA components may be available during this project. This document represents the basis for further Living Labs activities developed, deployed and evaluated as part of work packages 2 and 3.

In 5G-LOGINNOV use cases, 5G network will provide high bandwidth and low latency to sufficiently support video upload and reliable PLC communications for the remote control of cranes. 5G's large bandwidth and massive connectivity capabilities effectively support the backhaul of multi-channel High Definition (HD) videos and sensor data. In combination with edge computing and AI, 5G can help synchronize and coordinate port devices and production systems. Deploying 5G alongside AI and edge computing allows for the completion of more tasks automatically, improving the intelligence and operational efficiency of ports. Within 5G-LOGINNOV project it is considered to be deployed several 5G technologies and services as 5G NR, 5G core, network slicing, MEC, NFV-MANO in order to support applications such as precise positioning, traffic management applications, high-performance CCTV surveillance applications (including VSaaS), real-time tracking & enhanced visibility and maintenance support.

The presented architectural designs within the 5G-LOGINNOV 5G ecosystem are based not only on the currently available hardware and software from 3GPP, the integration and collaboration possibilities with non-3GPP technologies but also takes into account the envisaged development of 3GPP Rel.15 and beyond.

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