5G smarT mObility, media and e-health for toURists and citizenS

Deliverable D3.1
Baseline architecture and deployment objectives

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Deliverable History

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List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
5GPPP	5G Public-Private Partnership
4G	4th Generation mobile network
5G	5th Generation mobile network
5GC	5G Core
5G EVE	5G European Validation platform for Extensive trials
5G-Xcast	Broadcast and Multicast Communication Enablers for the Fifth Generation of Wireless Systems
5G-MoNArch	5G Mobile Network Architecture for diverse services, use cases, and applications in 5G and beyond
5GT	5G-Transformer
5GT-VS	5GT Vertical Slicer
AI	Artificial Intelligence
AIA	Athens International Airport
AIR	Antenna Integrated Radio
AL-FEC	Application Layer - Forward Error Correction
API	Application Programming Interface
APN	Access Point Name
AR	Augmented Reality
A/V	Audio/Video
BBU	Based Band Unit
BM-SC	Broadcast Multicast Service Centre
BPF	Baseband Processing Function
BSS	Business Support System
CAS	Cell Acquisition Subframe
CAT-M	Category M
CCVPN	Cross domain and Cross layer VPN
CMG	Cloud Mobility Gateway
CMM	Cloud Mobility Management
CN	Core Network
CP	Control Plane
CPF	CP Function
CP-OFDM	Cyclic-Prefix Orthogonal Frequency Division Multiplexing
CPU	Central Processing Unit
CSI-RS	Channel State Information Reference Signal
CSMF	Communication Service Management Function
DL	Downlink
DMRS	Demodulation Reference Signal
DSL	Domain Specific Language
DU-MCF	Distributed Unit-Multicast Function
eCPRI	enhanced Common Public Radio Interfaces
EGMF	Exposure Governance Management Function
eMBB	enhanced Mobile Broadband
eMBMS	enhanced MBMS
EMC	Electromagnetic Compatibility
ENI	Experimental Network Intelligence
enTV	enhanced TV
EPC	Evolved Packet Core
eSIM	embedded Subscriber Identity Module
ETSI	European Telecommunication Standards Institute
EU	European Union
FDD	Frequency Division Duplex
FeMBMS	Further evolved Multimedia Broadcast & Multicast. Service
gNB	gigabit eNodeB
gNB-CU-MC	gNB-CU Multicast Function

G-RNTI	Group Radio Network Temporary Identifier
GSM	Global System for Mobile communication
GUI	Graphical User Interface
H2020	Horizon 2020
HARQ	Hybrid Automatic Repeat Request
HPHT	High Power High Tower
HSS	Home Subscriber Server
IFA	Interface
IoT	Internet of Things
IP	Internet Protocol
ISC	Intra Slice Controller
ISD	Inter Site Distance
IPsec	Internet Protocol security
ITU	International Telecommunication Union
KPI	Key Performance Indicator
KVaP	KPI Validation Platform
LC	Lifecycle
LCM	Lifecycle Management
LDPC	Low Density Parity Check
LoRA	Long Range
LPLT	Low Power Low Tower
LPWAN	Low Power Wide Area Network
LTE	Long Term Evolution
LWM2M	Lightweight M2M
M2M	Machine to Machine
MANO	Management and Orchestration
MAPE	Monitor Analyse Plan Execute
MBMS	Multimedia Broadcast Multicast Service
MBMS-GW	MBMS Gateway

MBSFN	Multicast Broadcast Single Frequency Network
MCCH	Multicast Control Channel
MCE	Multi-cell/Multicast Coordination Entity
MCH	Multicast Channel
MDAS	Management Data Analytics Service
MEC	Mobile Edge Computing
MFN	Multi-Frequency Network
MIMO	Massive Input Massive Output
MIoT	Massive IoT
ML	Machine Learning
MME	Mobility Management Entity
mMTC	massive MTC
mmWave	Millimeter Wave
MNO	Mobile Network Operator
MooD	Multicast operation on Demand
MSO	Multi-Slice Orchestrator
MTC	Machine Type Communications
MTCH	Multicast Transport Channel
NB-IoT	Narrow Band IoT
NBI	Northbound Interfaces
NF	Network Function
NFV	Network Function Virtualization
NFVI	NFV Infrastructure
NFVO	NFV Orchestrator
NR	New Radio
NS	Network Slice
NSA	Not Standalone
NSD	NS Descriptor
NSI	NS Instance
NSMF	NS Management Function
NSSI	NS Subnet Instance

NSSMF	NS Subnet Management Function
NWDAF	Network Data Analytics Function
OAM	Operation and Maintenance
ONAP	Open Networking Automation Platform
OPEX	Operational Expenditure
OSM	Open Source Mano
OSS	Operation Support System
PDSCH	Physical Downlink Shared Channel
PGW	Packet Gateway
PMCH	Physical Multicast Channel
PNF	Physical Network Function
PTM	Point to Multipoint
PTP	Point to Pont
PTRS	Phase-Tracking Reference Signal
QoE	Quality of Experience
QoS	Quality of Service
R&D	Research and Development
RAM	Random Access Memory
RAN	Radio Access Network
RMA	Radio Multicast Area
ROM	Read Only Memory
RRH	Remote Radio Head
SA	Standalone
SA2	System Architecture 2
SA5	System Architecture 5
SAI	Service Area Identifier
SBA	Service Based Architecture
SC-PTM	Single Cell Point-to-Multipoint
SDN	Software Defined Networking
SDO	Standards Development Organization
SFN	Single Frequency Network
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SLA	Service Level Agreement
SMF	Session Management Function
SRS	Sounding Reference Signal
TDD	Time Division Duplexing
TV	Television
UC	Use Case
UE	User Equipment
UL	Uplink
UP	User Plane
UPF	UP Function
URLLC	Ultra-Reliable Low Latency Communication
V2X	Vehicle to Everything
VCUDB	Virtual Centralized User Database
VEPC	Virtual EPC
VEPG	Virtual Evolved Packet Gateway
VHSS	Virtual HSS
VIM	Virtual Infrastructure Manager
VMME	Virtual MME
VNF	Virtual Network Function
VNFC	VNF Component
VNFM	VNF Manager
VoLTE	Voice over LTE
VPN	Virtual Private Network
VR	Virtual Reality
VS	Virtual Service
VSB	VS Blueprints
VSD	VS Descriptors
VSI	VS Instances

VUDC	Virtual User Data Consolidation
WCDMA	Wideband Code Division Multiple Access
WEF	Wireless Edge Factory
XCF	XHaul CP Function
xMB	Extreme Mobile Broadband
XSC	Cross Slice Controller
XUF	XHaul UP Function

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Executive Summary

The scope of this deliverable is to report on the initial activities for the network planning in 5G-TOURS. The project spans three trial sites (Turin, Rennes, and Athens), which are part of the 5G EVE infrastructure.

The main contributions of this document can be summarized in the following three areas:

- The initial discussion on the overall 5G-TOURS architecture, which relies on the 5G EVE platform, and the possible needed extensions to support the innovative use cases defined by WP2 "Use Cases design". In particular, we discuss the extensions of the Management and Orchestration (MANO) framework, which needs to support the following three functional innovations developed in the project:
    - The introduction of Artificial Intelligence (AI) into a Data Driven management of the network. In particular, the relationship between the 5G-TOURS architecture and the ones defined by the major standard development organizations, such as ETSI or 3GPP, are discussed.
    - The inclusion of specific Broadcast modules in the architecture. This is of paramount importance for the immersive media use cases which will be developed in the Turin trial site. In particular, we focus the discussion on the relevant standard elements defined by 3GPP.
    - The integration of an enhanced Service Layer in the management system, to provide the verticals with efficient ways to manage their network slice. This innovation, which is going to be developed throughout the platform, also has to rely on the available software components created for the host platform, 5G EVE.
- The detailed development plan for the infrastructure in the three trial sites. We especially discuss the capabilities of the sites along the following three main dimensions:
    - The extensions planned by each partner involved in the trial sites about the planned extension with respect to the 5G EVE platform. Some of the use cases need additional infrastructure (both hardware and software) to support the needed network requirements. Thus, we also discuss the available capabilities with respect to the ones needed by the different use cases.
    - The phasing of new functionality along the 5G-TOURS phases and the 5G EVE platform releases. This also includes fundamental aspects, such as spectrum allocation.
    - The integration of the novel functionality in the available network architecture.
- The initial description of the development plans for the three innovations that will characterize the 5G-TOURS network deployment. In particular, we detail the baseline software components that will be leveraged for their implementation, and an initial evaluation of different software architecture options. These points will be further detailed in the subsequent releases of the work package deliverables.

The work performed by this Work Package "Network architecture and deployment" for the editing of this deliverable has been strictly coordinated with the one of Work Packages 4, 5 and 6, which focus on the vertical development of each test site respectively.

1 Introduction

Telecommunications networks are becoming more important every day as they are already a significant part of any society's infrastructure and play a fundamental role in the economic and wellness growth. Nowadays, millions of people throughout the world are using network-enabled services, produce a substantial amount of load in the providers' infrastructure.

The 5th Generation (5G) of the mobile telecommunications network that is currently in its early deployments made by the European operators, is expected to magnify the importance of telecommunications network in many aspects of our everyday life. In particular,5G is expected to holistically impact the way all the stakeholders and users are approaching the telecommunications networks [1], transitioning from a mere capacity growth to a complex ecosystem of service providers, operators and users that create, manage and use specifically tailored instances of the network that provide the required performance for each service. This new vision requires a radically new design of the network architecture that covers new frequency bands, new radio access technologies, and new core capabilities, as well as the overall optimization and coordination from the mobile radio to the backhaul and core network. Specifically, the system needs to exhibit the required flexibility to provide services that need very diverse requirements (e.g. minimum throughput or maximum latency [2]) on the same infrastructure, by implementing the *network slicing* paradigm.

Such a flexible architecture is paramount for the 5G-TOURS which aims to embody the different requirements coming from the verticals of the three trials site (the touristic city, the safe city and the mobility efficient city) into the same architecture. That is, verticals industries such as the ones included in the 5G-TOURS consortium will require very stringent requirements from the network, including immersive multimedia, e-health, smart transportation or robotics, which are generating very different types of traffic.

Of course, 5G-TOURS does not start from scratch, as it relies on:

- the standardization work coming from the latest releases of the most important Standard Development Organizations (SDOs) such as 3GPP and ETSI
- the work of the phase II 5GPPP projects, who investigated the integration of novel technologies into the baseline architecture
- the implementation of these architectures in the 5G EVE infrastructure, which provide the building blocks for the successful realization of the envisioned use cases [3].

Therefore, to deploy the envisaged use cases, 5G-TOURS will exploit the facilities currently being built within the 5G EVE project, which is one of the three European ICT-17 projects in charge of building end-to-end facilities to support a variety of vertical field trials. The 5G EVE facilities rely on pre-commercial trial frameworks and include 5G technologies such as millimeter Wave (mm-Wave), Massive Input Massive Output (MIMO), Small Cells, elements of Mobile Edge Computing (MEC), all orchestrated under an Software Defined Networking (SDN)/Network Function Virtualization (NFV) architecture supporting slicing capabilities. Leveraging the 5G EVE platform, 5G-TOURS will deploy highly innovative use cases around the themes of the touristic city, the safe city and the mobility-efficient city in the nodes of Turin, Rennes and Athens respectively.

On top of the existing 5G EVE facilities, 5G-TOURS may require specific functionalities hardware and software functionality which are beyond the current capabilities of the 5G EVE infrastructure. Hence, in this document, we discuss the baseline of the required 5G-TOURS network architecture that will vertebrate the overall network deployment of the project and the required additions. As such, the document is structured as follows: in Section 2 we describe the methodology that we will follow in the work package to take into account the use case requirements and steer the network design during the project lifetime. In section 3 we discuss the baseline 5G architecture used in the project, and discuss three fundamental additions that will be studied during the course of the work package: (i) the extension of the MANO the framework with Artificial Intelligence (AI) and Big Data Analytics, (ii) an enhanced broadcast support to provide high quality media services in the most efficient way, and (iii) an enhanced

Service Layer capable of translating service requirements into running network slices. Then, in Section 4, we discuss the current capabilities and the initial planned extension of the 5G EVE infrastructure in the three trial sites in detail: Turin (Section 4.1), Rennes (Section 4.2) and Athens (Section 4.3). In these sections, we describe the available infrastructure through the lenses of the use cases that are going to be implemented in each site. We also provide an initial deployment time planning for each of the trial site. Section 5 describe the implementation plans of the specific additions that will be included in the 5G-TOURS architecture (the AI-data analytics, the broadcast support and the service layer) plus an initial discussion on the user terminals. Finally, Section 6 concludes the document.

2 5G-TOURS Approach

The main steps of the project include (i) the design and deployment of an architecture that is based on the existing components of 5G EVE and Phase 2 projects, (ii) the implementation of solutions developed within 5G-TOURS using the 5G EVE architecture, and innovations from 5G-MoNArch and 5G-Xcast, (iii) the deployment of trials to evaluate the 5G-TOURS vertical solutions in each trial site. The overall philosophy of 5G-TOURS is to create a link between ICT-17 projects in order to implement the 13 use cases [3] on top of 5G EVE in three cities is described in Figure 1.

5G-TOURS will implement several novel use-cases that will be deployed over the three trial sites using the 5G EVE platform. These use cases have been grouped around the three trial sites of the *touristic city*, the *safe city* and the *mobility efficient city*. The *touristic city* aims at improving the touristic experience in a city by providing added value services and media applications at major touristic attractions to complement the tourists' visit. The *safe city* includes use cases aiming at enabling a person to have a safe trip (e.g. for touristic purposes). Finally, the *mobility efficient city* aims at improving the tourism and tourism-related experiences for people (e.g. driving through the city) with applications such as AI-based parking management, personalized evacuation procedures for emergency situations, and entertainment/educational experiences in smart busses.

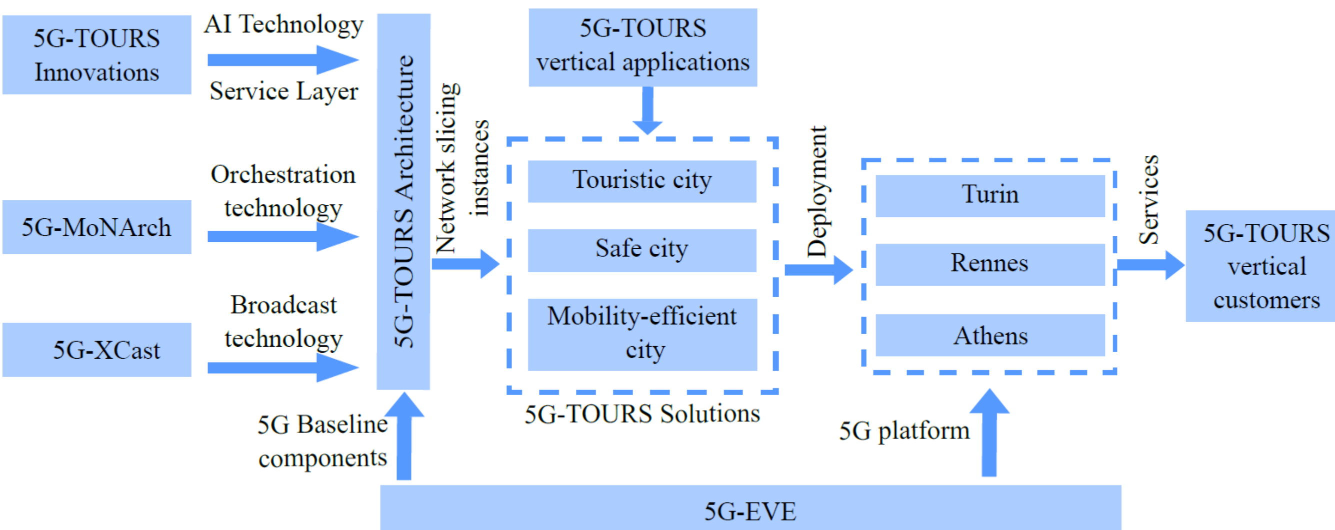

Figure 1: 5G-TOURS Approach

To support the aforementioned use cases 5G-TOURS will leverage existing solutions from Phase 2 projects such as the broadcast innovations from 5G-Xcast for the touristic city uses cases. More specifically, the solutions described in the 5G-Xcast deliverables D3.2 [4] on the Air interface and D3.3 [5] on the Radio Access Network (RAN) architecture will be used as a basis for the RAN solution. For the 5G Core broadcast solution, the deliverable D4.1 [6] on Mobile Core Network (CN) will be used as a basis. Depending on the 3GPP progress on broadcast solutions for the 5G Core (5GC) and the RAN side, 5G-TOURS will use part of the 3GPP solution and the 5G-Xcast solution. Similarly, the orchestration technology developed within 5G-MoNArch will be used across all trial sites and for all use cases. In particular, 5G-TOURS will rely on the concepts of elasticity and resiliency that have been proposed and detailed in 5G-MoNArch deliverables D3.2 [7] and D4.2 [8]. Also, the architectural work developed for 5G-MoNArch D2.3 [18] will be used at the basis of the work carried out by this work package.

On top of the Phase 2 project solutions, 5G-TOURS will deploy the following innovations from the network perspective:

- AI-based enhanced Management and Orchestration (MANO) solutions for slice management

- AI-based data analytics framework for autonomous and efficient management of the 5G-TOURS deployment
- Service layer to provide a friendly interface for vertical customers, based on 5G EVE's Application Program Interface (API)
- Broadcast support with novel algorithms in the 5G RAN and Core

To implement the aforementioned innovations, 5G-TOURS will adapt the solutions of Phase 2 projects (5G-MoNArch and 5G EVE) accordingly, in order to meet the requirements of the different use cases. Most importantly, innovations deployed within 5G-TOURS will be compliant with the 3GPP ongoing standards, in order to push their adaption in future commercial products. Finally, 5G-TOURS will leverage on its deployed network infrastructure to implement the use cases of the different trial sites. As such, 5G-TOURS will initiate the necessary network slices in order to provide the required network services. Furthermore, 5G-TOURS will implement vertical solutions (e.g. media applications, e-health services, Internet of Things) that use the network services to provide the required functionalities to the different use cases.

Regarding the deliverables of 5G-TOURS, an iterative process is in place, reflected over D3.x releases. In each iteration the following features will be discussed:

Inventory:

- Implemented functions
- Available infrastructure

Use-case mapping:

- List of use-cases
- Mapping of use-case specific functions to the most relevant network slices

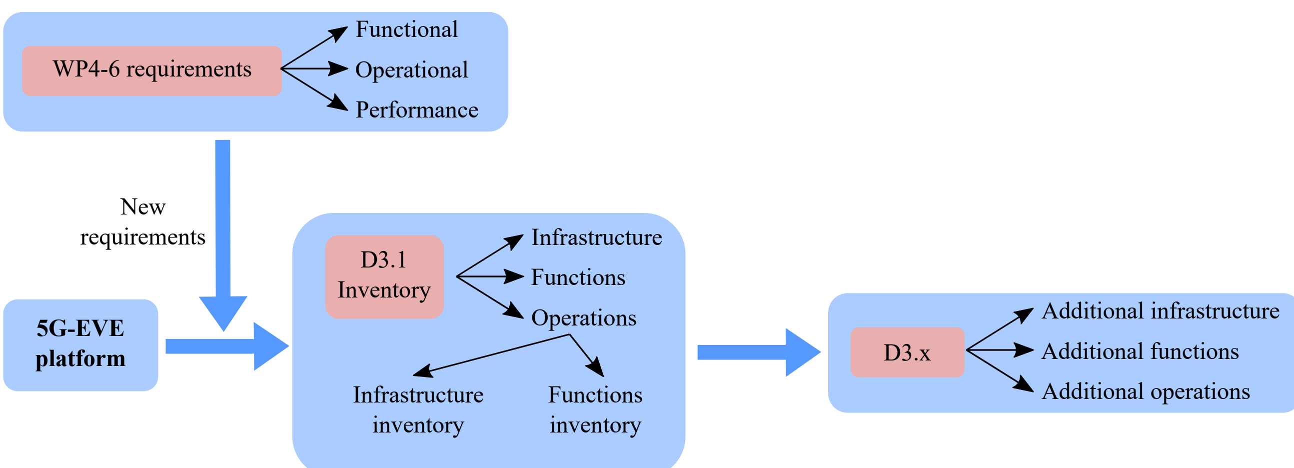

Figure 2: 5G-TOURS Architectural updates strategy

2.1 5G-TOURS phases

As discussed above, the 5G-TOURS trials will rely on the facilities provided by 5G EVE in three of its trial sites: Turin, Athens, and Rennes. These trial sites are interconnected with each other, which will be leveraged in the use cases that involve more than one site. Following the deployment plans for 5G EVE, the trials of 5G-TOURS will consider the following two phases:

- Phase I: A first phase that relies on deployments that cover a limited area in the city, where pre-commercial network equipment will be deployed for the specific purpose of 5G-TOURS, and possibly other 5G EVE trials. In these deployments, the network infrastructure will be used exclusively to run these trials.
- Phase II: A second phase, where it is expected that 5G equipment will be deployed for the commercial networks of the operators, and this commercial deployment can be leveraged to run some trials by instantiating specific network slices for 5G-TOURS that can co-exist with the commercial operation of the network without disrupting it. The final details on such network components (e.g., the kind and version of the deployed 5G Core or the used frequency bands) will be disclosed in future deliverables of this Work Package.

Note that the above two phases are complementary: while in the first phase we cannot achieve very large network scales but we can deploy 5G-TOURS specific implementations along with the pre-commercial network to evaluate advanced network functions and innovations, in the second phase we can cover much larger areas, and address use cases requiring large-scale deployments, but we are limited to use 5G commercial equipment and cannot introduce any kind of research prototype into the network infrastructure.

3 5G-TOURS Architecture and Technologies

The 5G-TOURS overall architecture will principally stem from the work performed by the main standardization fora, such as the 3rd Generation Partnership Project (3GPP) or the European Telecommunications Standards Institute (ETSI), enriched by some specific addition coming from 5GPPP Phase 2 project such as 5G Xcast (for the broadcast related aspects) and 5G MoNArch (for the AI-related ones). Importantly, the architecture of 5G-TOURS will lie on top of the 5G EVE platform, which has already been developed in three trial sites. In the following sections, we dissect the baseline technology that will be employed during the project.

First, we discuss the 5G-TOURS overall architecture (see Section 3.1), that builds on the individual test sites running in each of the three cities which, in turn, are based on a baseline 5G Architecture (see Section 3.2) which will be enhanced by the specific 5G-TOURS innovations. Hence, in Sections 3.3, 3.4, 3.5 and 3.6 we discuss the modules (see Figure 3) enhanced by 5G-TOURS and the related general concepts and predecessor projects where they come from.

3.1 Overall Architecture

The overall architecture of the 5G-TOURS will be split into intra-site and inter-site architecture. The former architecture will be site-specific, will be based on the 5G EVE base lines of the three different trial sites of 5G-TOURS (Turin, Rennes and Athens), and will present differences among those three trial sites. It will also include network orchestration components that will be specific to the respective site. The latter architecture will sit on top of the three intra-site architectures, and as such, it will be common among them, offering more centralized orchestration functionality among the different sites.

3.1.1 Intra-Site Architecture

3.1.1.1 Turin Site

The Turin site will implement the '*touristic city*' and will cover three museums (Palazzo Madama, Museum of Oriental Art and Museum of Modern Art), and their close surrounding areas (the Educational Lab (Edulab), Borgo Medievale and Museo Pietro Micca, Risorgimento Museum), and will be deployed on TIM's existing infrastructure in Turin headquarters [9]. In the RAN, Ericsson's Multiple Input Multiple Output (MIMO) antenna will be used, and Remote Radio Heads (RRHs) will connect to Baseband Units (BBUs) through enhanced Common Public Radio Interfaces (eCPRI). In the core network, Ericsson's 5G Evolved Packet Core (EPC) that supports 3GPP Release 15 in a non-standalone (NSA) mode will be used to provide network slicing functionality during phase I of the project, and will be upgraded to 5G Core during the project, depending on the operators' deployments and 5G availability. For orchestration at the core network Ericsson's MANO NFV Orchestration solution will be used initially. At a later stage, a new MANO solution will be developed. Finally, for broadcasting, Ericsson's Radio Solutions will be used during the initial phase, while novel broadcast solutions are planned for later stages of the project. More details about the Turin Site plans are provided in Section 4.1.

3.1.1.2 Rennes Site

The French site in Rennes will implement the '*safe city*', and will be split in three parts: (i) an indoors deployment in a hospital, (ii) an outdoors deployment in an area, and (iii) an Internet of Things (IoT) deployment for the use cases that involve sensors and massive Machine Type Communications (mMTC). Initially, the existing IoT infrastructure of B-COM (LoRa Network) will be used for the outdoors deployment. Later, an outdoors deployment in the area surrounding the Rennes University Hospital will be considered, based on the 5G network availability in the area considered, as well as the device availability from vendors. In the RAN, Nokia's AirScale solution [10] will be used, which includes base stations, active antennas, and a cloud RAN platform. In the core network, the Wireless Edge Factory (WEF) of B-COM, located in Rennes, will be used. On top of the physical deployment, there will be a MANO NFV solution from Nokia-FR, based on 5G EVE equipment located in Orange Paris. Specific details for the 5G-TOURS French site are provided in Section 4.2.

3.1.1.3 **Athens Site**

The Athens site will implement the *"mobility-efficient city"* which will initially cover an area in the Marousi region (in the suburbs of Athens), as well as an area in Athens International Airport (AIA). Later, the possibility of extending the 5G connectivity to cover a larger area around Marousi will be explored. In the RAN, Nokia-GR's AirScale solution [10] will be used, while in the core network Nokia's platforms (4G during phase 1 of the project and 5G from phase 2 onwards) and components will be used. OTE will also provide an additional solution for the core network, which will be based on its Athonet platform [11]. The physical equipment will be upgraded to 5G-capable equipment during the project. For the IoT uses cases addressed within the trial site of Athens, WINGS STARTLIT IoT platform (smart living platform powered by Artificial intelligence & robust IoT connectivity) will be primarily used, and Nokia-GR's IoT platform will be used complementary. ACTA's KPI measurement & validation platform will be used for accurate and effective testing of service and network KPI's, as discussed in Section 4. At a later stage of the project, novel orchestration solutions with be developed and deployed on top of Nokia-GR and OTE's physical infrastructure. Finally, MANO solutions will be provided by Nokia-GR, that will include CloudBand Network Director functionalities, as well as Application Management functionalities. A more detailed discussion on the specific Greek site facilities is provided in Section 4.3.

3.1.2 Inter-Site Architecture

The inter-site architecture of 5G-TOURS will reside on top of the site-specific architectures of the three trial sites, and will include enhanced orchestration functionalities, as well as additional functionalities not present in the intra-site architecture. Specifically, the following orchestration components will be deployed:

- Enhanced MANO
- AI modules
- Broadcast modules

Enhanced MANO will include algorithms for orchestrating the different resources and network functions among the different trial sites. Initially, the enhanced MANO component will be built on the MANO solution developed within 5G-MoNArch Phase II project (based on the *'resource elasticity'* concept of the 5G-MoNArch project) and will re-use the 5G EVE MANO solution. During the course of the project, it will be adapted to meet the requirements of the 5G-TOURS use cases. The AI modules will include algorithms developed during the 5G-TOURS project that will be responsible for the autonomous and efficient management and configuration of the network resources and functions. The AI decisions will then be fed to the enhanced MANO component to enable efficient resource management and network configuration.

As the 5G EVE baseline does not include support for broadcast functionality, novel broadcast solutions will be developed for the specific use cases (use cases 4, 5, possibly extended to 8 and 13 [3]), as a Point-to-Multipoint (PTM) service based on 5G-Xcast, using the 5G-Xcast User Plane Network Function (XUF) and 5G-Xcast Control Plane Network Function (XCF) . The XUF will be responsible for the retrieval and delivery of broadcast content, while the XCF will be responsible for session management and user authentication. The broadcast functionality will be developed in incremental steps. Initially, there will be a 5G NSA core with LTE enhance Multimedia Broadcast Multicast Service (eMBMS) RAN. At a later stage, a 5G Standalone core with LTE eMBMS RAN will be developed. At the last stage, a 5G Standalone core with 5G New Radio (NR) broadcast RAN will be deployed.

On top of the orchestration components, a service layer will be deployed. The service layer will be an intuitive interface where vertical customers will be able to set their requirements (e.g. number of devices supported, maximum latency allowed), and request services. Specifically, in order to provide an easy-to-use service to vertical users with different backgrounds, the service layer will provide a user-friendly interface, a service layer technology interface, and a network components interface. The service layer will be based on 5G EVE's API, and will be responsible for network slicing, virtualized function orchestration at the application layer, network slice monitoring, and network slice operation. An illustration of the overall architecture is shown in Figure 3.

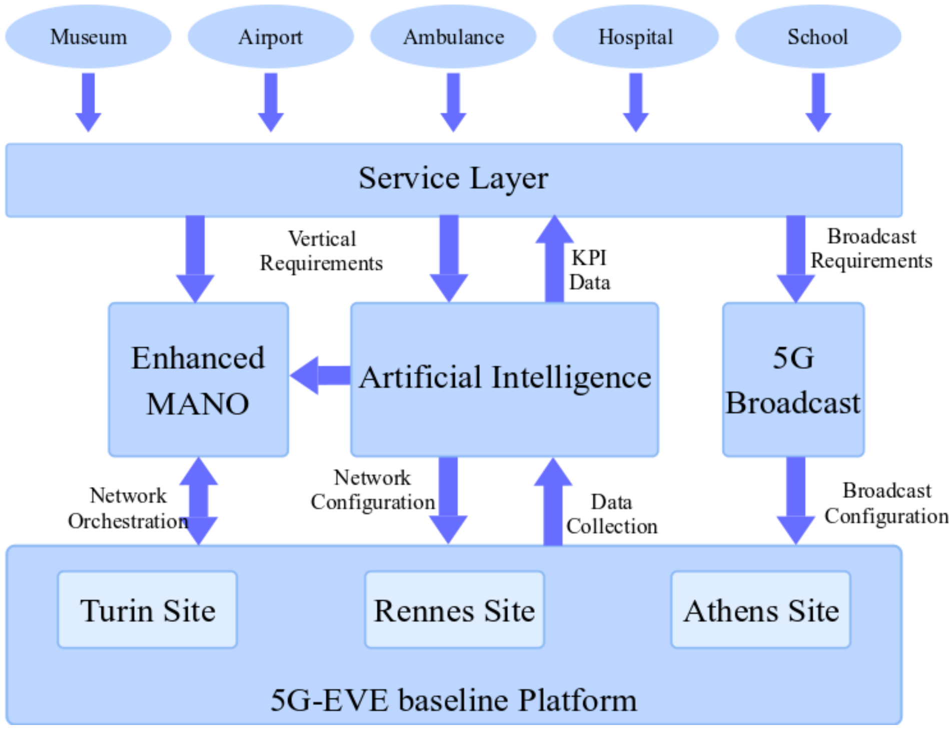

Figure 3: 5G-TOURS Overall Architecture

3.2 5G Baseline Platform

This sections provides an overview of the technology needed by 5G-TOURS to provide the innovative use cases described in [3], discussing the common standardized functions of general 5G platforms and its main features. Then, in Section 4, we will discuss the actual implementation planned for the each of the test sites.

5G implies major changes in implementation and deployment of networking infrastructure making the network "cloud enabled" and ready for to support new services to industries and private users. Architectural requirements for 5G network have been laid down since 2016 and then developed in Release 15 (5G phase 1) and Release 16 (5G phase 2). A 5G platform is constituted of wireless access, transport, cloud core and communications, network management and orchestration, as can be seen in Figure 4. Going into detail for each component:

- **5G Access:** RAN Compute and baseband, radio, and site solutions.
  NR to cover indoor hotspots, dense urban, urban and rural areas for usage scenarios eMBB (enhanced Mobile Broadband), mMTC (massive Machine Type Communications) and URLLC (Ultra-Reliable and Low Latency Communications)
- **5G Transport:** Fronthaul, backhaul, edge, core.
  Increased capacity, low latency and increased density for NR connectivity
- **5G Core:** Packet core unified data management & policy.
  Evolution from Non-Stand Alone (NSA) to Stand Alone (SA) Service Based Architecture (SBA), slicing

- **Management & Orchestration**
  Network management, automation and orchestration of nodes, networks and capabilities. Network slice provisioning, supervision, performance assurance through standard interfaces

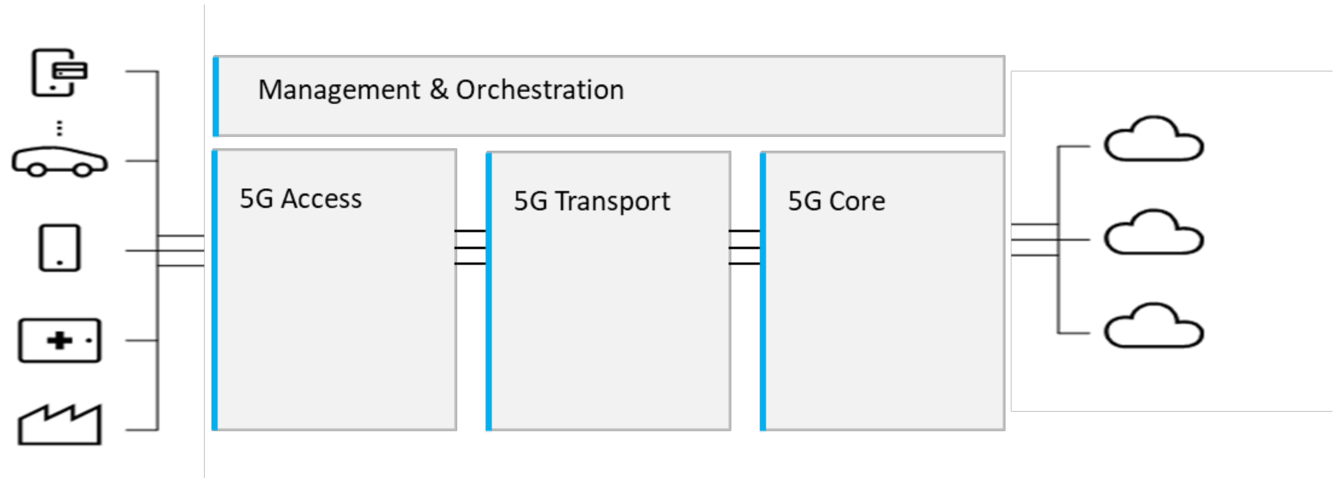

Figure 4: A 5G Baseline Platform

3.2.1 5G Access

One key component of 5G radio access is an innovative air interface, New Radio (NR), which is designed primarily to enable utilization of a larger portion of spectrum that spans on low, medium and high frequency bands, alongside flexible numerologies, in order to ensure both high traffic throughput and wide coverage. NR is specified in [14] to address the different types of services detailed by ITU IMT-2020 Focus Group in different deployment scenarios (indoor hotspots, dense urban, urban and rural areas) [12]:

- enhanced Mobile Broadband (eMBB)
- massive Machine Type Communications (mMTC)
- Ultra-Reliable and Low Latency Communications (URLLC)

Figure 5 provides an illustration of the application of the listed services and spectrum usage independent of deployment scenarios. All 5G-TOURS use cases can be mapped to one or more of those services and deployment scenarios.

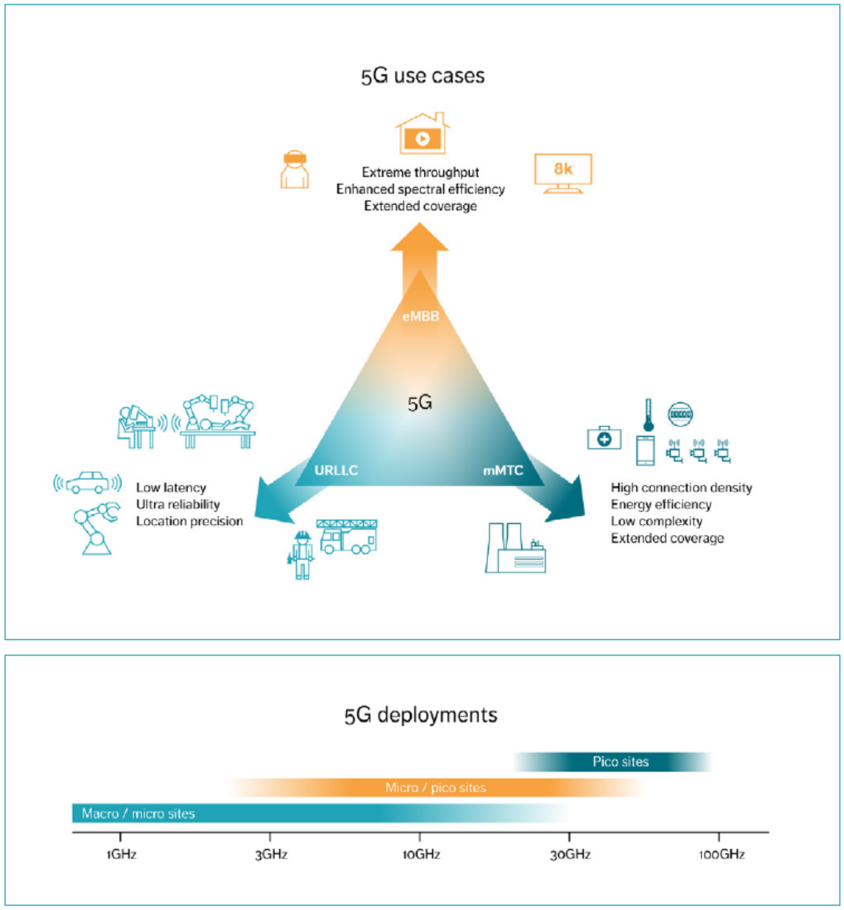

Figure 5: 5G use cases, spectrum and deployments (Source: Ericsson)

One of the design principles of 5G has been the support of high level of interworking with LTE to allow staggered inclusion of NR in existing LTE deployments (Figure 6). Such interworking incentivizes the support of dual-connectivity where, for example, a device maintains simultaneous connectivity to a dense high-frequency layer providing very high data rates, as well as to an overlaid lower-frequency LTE layer that provides ubiquitous connectivity.

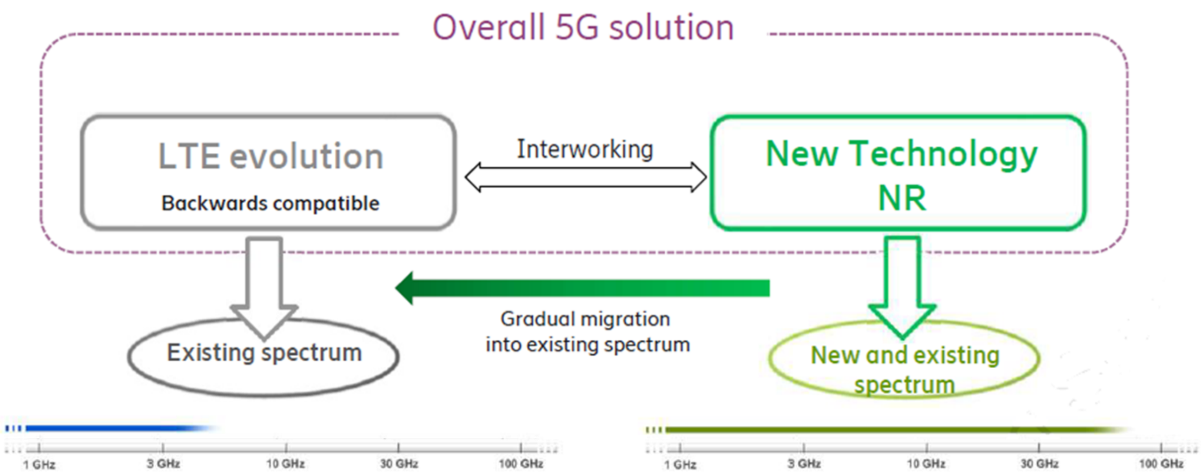

Figure 6: LTE and NR coexistence and evolution (source: Ericsson)

User plane (UP) aggregation between LTE and any new radio technology is another example of this high level interworking, and one of the main focus in 3GPP Release 16 [15]. It is important to note that, even though new radio access technologies require a new radio bearer, NR and LTE can be fully integrated from a system perspective, therefore NR can be deployed both as a stand-alone system – for industry applications, for example – and as a natural evolution of the existing wide area LTE network, as shown in Figure 7.

The key technology components to address so wide range of requirements in 5G radio access include:

- Modulation schemes: in addition to QPSK, 16QAM, 64QAM and 256QAM (already supported on LTE), NR introduces 1024QAM for high throughput applications and π/2-BPSK in Uplink (UL) to reduce peak to average power ratio.
- Channel coding: introduction of new coding/decoding, i.e. Low-Density Parity Check (LDPC) code for data channels and Polar code for control channels.
- Cyclic-Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM): CP-OFDM with a scalable numerology (subcarrier spacing, cyclic prefix) in both UL and Downlink (DL) up to at least 52.6GHz.
- Frame structure: NR frame structure supports Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) transmissions and operation in both licensed and unlicensed spectrum. It enables very low latency, fast Hybrid Automatic Repeat Request (HARQ) acknowledgements, dynamic TDD, coexistence with LTE, and transmissions of variable length (e.g. short duration for URLLC and long duration for eMBB).
- Advanced multi-antenna technologies: technologies such as massive MIMO and beamforming, with phased antenna arrays. NR employs different antenna solutions and techniques depending on which part of the spectrum is used for its operation.
- Ultra-lean design: NR has an ultra-lean design that minimizes always-on transmissions to enhance network energy efficiency and ensure forward compatibility with legacy mobile network radio access networks. In contrast to the setup in LTE, the reference signals in NR are transmitted only when necessary. The four main reference signals are the demodulation reference signal (DMRS), phase-tracking reference signal (PTRS), sounding reference signal (SRS), and channel-state information reference signal (CSI-RS). All reference signals are User Equipment (UE) specific.
- Access/backhaul integration: self-backhauling where access and (wireless) backhaul share the same technology and the same overall spectrum pool.

Flexibility, ultra-lean design and forward compatibility are the pillars based on which all the 5G NR physical layer technology are being designed and built. The high level of flexibility and scalability in 5G NR will enable it to meet the requirements of diverse use cases, including a wide range of carrier frequencies and deployment options. Its built-in forward compatibility will ensure that 5G NR can easily evolve to support any unforeseen requirements.

3.2.2 5G Transport

The transport domain delivers connectivity between remote sites and equipment/devices using either fiber or microwaves, depending on the field installation requirements.

The key characteristics for 5G transport are:

- Increased bandwidth: New 5G spectrum, better utilization of the available spectrum, and coordination features such as dual connectivity and carrier aggregation increase the bandwidth needs leading to a higher demand for capacity in the transport network both in fronthaul and backhaul segments. To cope with this need, 5G transport scales both in speed and number of interfaces and, for the fronthaul segment, it can benefit from different split in radio stack introduced by eCPRI specifications [57].
- Lower latency: low latency is critical for coordination functions over the NR interfaces in both non-standalone and stand-alone 5G deployments, as well as for certain 5G use cases such as critical IoT. Transport is key in meeting the new 5G requirements for enhanced performance and most efficient use of the radio access spectrum. Depending on the transport interface and services, the network must guarantee that the different requirements of maximum latency have to be satisfied by the transport network.
- Increased connections and network interfaces support: the introduction of RAN compute and different splits in the radio stack, with the radio functions (e.g. packet processing and radio control) pushed to the cloud create the need to transport traffic with different requirements. The transport network needs to support virtualization and Network Function (NF) distribution in different points of the network (e.g. cloud, edge) depending on the services to address. The new standard includes the support for Baseband Processing Functions (BPF) centralization with distances of up to 15-20km between the BPF and Radio Functions (RF), and the introduction of packet fronthaul, support for different requirements on different type of interfaces.
- End to end security and synchronization: 5G enhances security compared to 4G, especially in the areas of subscriber privacy, service based architecture and interconnection of security and integrity protection of the user plane [58]. The 5G transport network will ensure secure transport of a wider number of data traffic interfaces and network synchronization that is crucial especially for TDD-based radios, toward a large number of end point distributed over large areas. Security in 5G has many similarities with security in LTE, but the introduction of Service Based Architecture (SBA) on 5G pushes for protection at higher protocol layers (i.e. transport and application), in addition to protection of the communication between different core network entities at the internet protocol (IP) layer (typically by IPsec). Furthermore, synchronization with absolute precision of 1.5µs or less (depending on the radio technology and function used) is required.
- Slicing and service separation support: the shift from dominant mobile broadband to multiple services supported by network slicing drives the need to manage different Quality of Service (QoS) requirements in a dynamic wat. In addition to providing bulk connectivity for the operator's mobile network fronthaul and backhaul, the transport domain has to provide different types of customers requiring connectivity services, such as a Layer 2 or Layer 3 Virtual Private Networks (VPNs), each one with its own Service Level Agreements (SLA). Network slicing needs to ensure appropriate allocation, isolation and optimization of resources for every slice instance.

The 5G RAN technology adds new requirements to the bandwidth, latency, synchronization, security and resource allocation of transport networks that affect architectural choices in its design.

3.2.3 5G Core

To allow smooth migration from 4G to 5G and independent evolution of RAN and CN, 3GPP has foreseen different possible migration strategies [13] and different deployment options, shown in Figure 7.

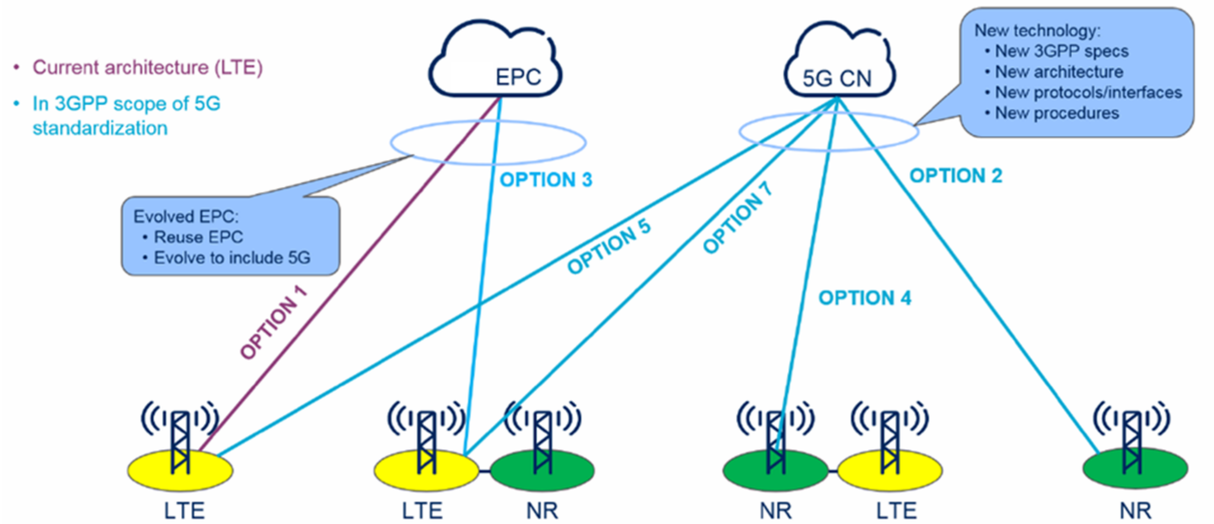

Figure 7: 5G RAN and CN deployment options

Options 2, 4, 5 and 7 are all related to the new 5G Core (5GC) technology, while options 1 and 3 relate to an upgraded EPC. Options 3, 4 and 7 are also sometimes referred to as Non-Standalone (NSA) RAN, and Option 2 as Stand-Alone RAN (SA). To benefit of the features of 5GC as described in [14] for 3GPP Release15 and in [15] for Release16, the SA deployment and 5G CN are required.

5G CN is based on the so-called SBA where architectural elements or NFs[1], through standardized APIs, offer services to other NFs or other "consumers". SBA is made possible by the separation of User Plane (UP) and Control Plane (CP) that can be deployed, scaled and dislocated in a completely independent way from one another (e.g. Control and User Plane Separation – CUPS, specified by 3GPP on [16]). SBA enables virtualized deployment where NFs can be fully distributed, redundant and scalable.

The specific features of 5GC are:

- Local hosting of services and Edge Computing: 5G is designed to support diverse services with different data traffic profiles and models. Local hosting of services is provided through the Edge Computing capability., i.e. the possibility for an operator and/or a 3rd party to execute the services close to the UE's access point of attachment. This reduces the end-to-end latency and the load on the transport network. Edge computing is enabled by the SBA deployment where NFs can be deployed anywhere in the network.
- Network slicing: A network slice is a set of elements of the network specialized in the provisioning of a certain type of services, providing isolation from the rest of the operator NFs. Network slicing is a major characteristic of the 5G system. Based on the business scenario, the operator can decide how many network slices to deploy and what functions/features to share across multiple slices. For a given slice, its characteristics are either "pre-defined" in the 3GPP Standard or are operator-defined. There are three types of "pre-defined" slices: type 1 is dedicated to the support of eMBB, type 2 is for URLLC and type 3 is for mIoT support. "Pre-defined" slices allow inter-operability with reduced coordination among operators. Usage of network slices allows to expose network capabilities to third parties providing a third party the possibility to:

[1] Network Function Virtualization was initially defined by ETSI in 2012 [52] as "*the way that network operators architect networks by evolving standard IT virtualisation technology to consolidate many network equipment types onto industry standard high volume servers, switches and storage, which could be located in Datacentres, Network Nodes and in the end user premises*". With the introduction of 5G networks, virtualized NFs have been recognized as a key enabler for Core Network evolution [14].

  - customize a dedicated network slice for diverse use cases,
  - manage a trusted application in a Service Hosting Environment,
  - improve user experience,
  - efficiently utilize backhaul and application resources.
- Unified Access Control: It defines deployment scenarios, subscriber profiles, and available services , based on operator policies, to allow UE access in case of network congestion. The network can restrict the UE access on a per-access category basis.
- Policy framework and QoS support: A policy framework is supported for session, access and mobility control, QoS and charging enforcement, as well as policy provisioning in the UE. The system defines a flow based QoS framework with or without QoS dedicated signaling. For the option without any specific QoS signaling flows, the standardized packet marking is applied, which informs the QoS enforcement functions what QoS level to provide. The option with QoS dedicated negotiation offers more flexibility and QoS support with finer granularity. Also, a new QoS type is introduced (Reflective QoS), where the UE requests the same QoS rules for the uplink traffic as the ones it received for the downlink. In this mode, symmetric QoS differentiation over downlink and uplink is supported with minimal control plane signaling.

3.2.4 5G Management and Orchestration

The network management and orchestration architecture for 3GPP Release16 is described in [17] where the management services and their management capabilities accessible by management service consumers via standardized service interfaces are defined, while management entities are organized in Management Functions (MnF). Management entities evolve from ordering explicit configurations (e.g. configuring a router or a server) to distributing policies, KPIs and target goals that each subsystem optimizes autonomously and locally.

The 3GPP management system is capable of consuming services from NFV MANO interfaces provided by NFV Orchestrator, Virtual Network Function (VNF) Manager and Virtualized Infrastructure Manager (VIM) to automate and orchestrate a range of lifecycle management processes, and coordinate complex dynamic systems of application, cloud, transport and access resources. The 5G management and orchestration system for the mobile network that includes network slices, follows the aforementioned network and network slice management model, sub-network and network slice subnet management model, and network function management model.

The aim of network orchestration is to simplify the operations of the mobile network. The increasing complexity calls for powerful, reliable and flexible ways of simplifying the design, test, launch and maintenance of a wide range of communication services. Automation can offer a solution to these requirements.

5G management benefits from management data analytics services to support a wide variety of service requirements and improve networks performance and efficiency. The management data analytics utilize the network management data collected from the network (e.g. service, slicing and/or network functions related data) and make the corresponding analytics based on the collected information providing prediction insights that can be applied automatically to adapt and fine-tune the network performance in real-time, in order to deliver the best end-user experience.

3.3 Enhanced Management and Orchestration

For the enhanced MANO, *two new components* are going to be developed within the 5G-TOURS project:

- The AI module, that will manage the network resources (more details on this aspect are provided in Section 3.4, while the implementation plans are presented in Section 5.2)
- Broadcasting, that will be developed as a PTM service, and will be based on 5G-Xcast (more details available in Sections 3.5 and 5.3)

The MANO will take the information available from the physical infrastructure and the service's requirements from the verticals (through the Service Layer) and using the new AI module for evaluating the resources, it will execute the deployment. Some elements from 5G-MoNArch and 5G EVE are going to be re-used, and in the future, they will be extended and adapted for the 5G-TOURS project requirements.

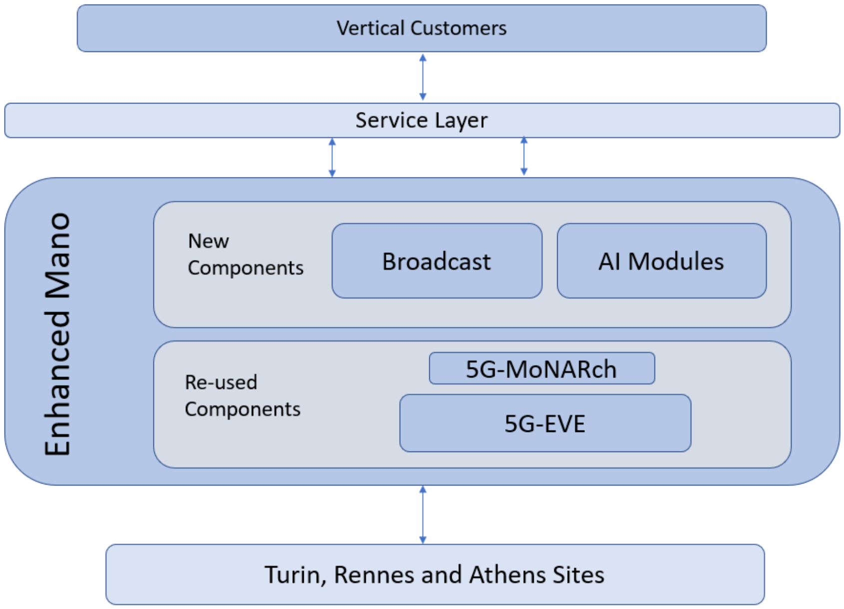

Figure 8: 5G-TOURS Initial MANO architecture

3.3.1 5G-MoNArch

The 5G-MoNArch architecture is structured in 4 layers, as shown in Figure 9 5G MoNArch high-level final overall architecture [18]:

- Network layer
- Controller layer
- Management & Orchestration layer
- Service layer

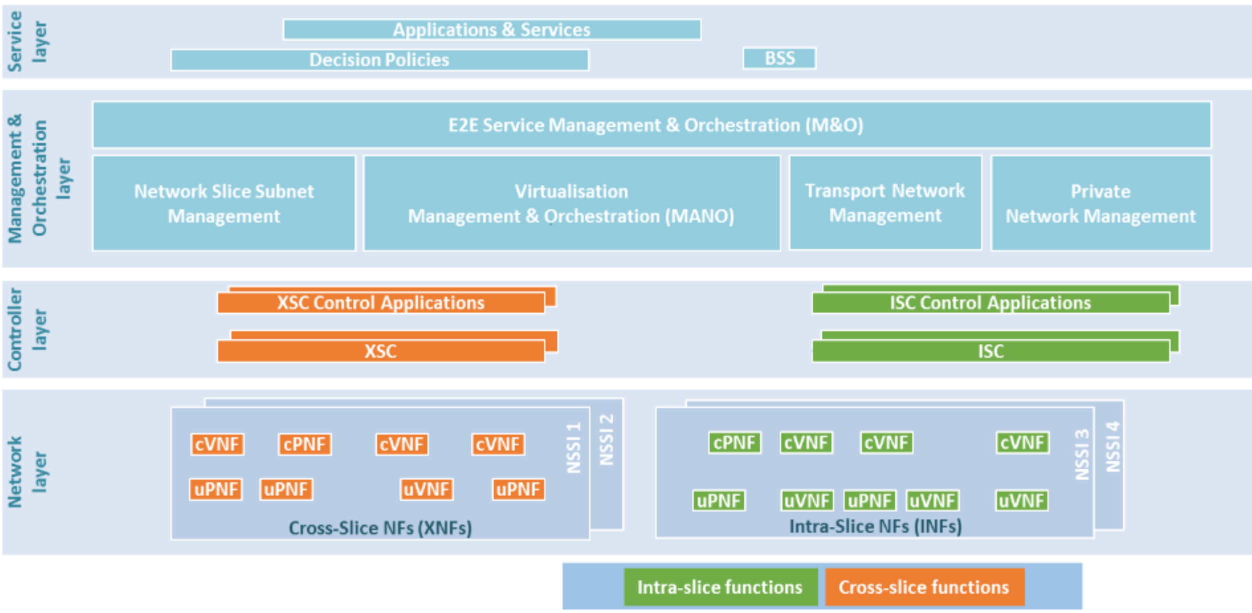

Figure 9 5G MoNArch high-level final overall architecture [18]

The Controller Layer: extends the functionalities to mobile networks, and provides the following controller types:

- Cross-Slice Controller (XSC): The logic applied to the controlled NFs is made by one of the possible multiple applications hosted on top of the controller.
- Intra-Slice Controller (ISC): The applications (that can be from several vendors) creates the control logic and then communicate with the ISC using the northbound interface (NBI).

The Network Layer: contains the Network Slice Subnet Instances (NSSI), which comprises the NF of a specific network domain. Several Network Slice Instances (NSIs) can share the same NSSI which can be formed by a Cross-Slice NF or ad Intra-Slice NF. This service-based representation allows for flexible and extensible interactions between NFs.

The Management & Orchestration layer: is formed by the Management and Orchestration functions from different network, technology, and administration domains, such as:

- 3GPP public mobile network management
- ETSI NFV
- MANO
- ETSI MEC functions
- Management functions of Transport Network and non-public enterprise networks.

This layer contains the E2E Management and Orchestration sublayer hosting the Network Slice Management Function (NSMF) and Communication Service Management Function (CSMF) that manage network slices and communications services respectively. Regarding the MANO, virtual machines and virtualization containers are supported.

The Virtualized Infrastructure Manager includes a Container Instance Management Function and a VMI Management Function. NFV orchestrator has capabilities for dispatching functionality for selecting between VM-related or container-related MANO functions. Finally, this layer is also capable of accommodating network slice subnet management domain.

The Service Layer: is formed by the Business Support Systems, Policy and Decision functions and external entities' applications and services.

5G-MoNArch Innovations:

The innovations developed within 5G-MoNArch that will also be used in 5G-TOURS are the following:

- Cross-domain management and slice control to allow coordination across domains and slices:

This functionality improves the efficiency of the system with dynamic resources allocation.

- Experiment-driven optimization, to take advantage of the experimental results to design high performance algorithms:

For the next generation of mobile networks, this is one of the more important elements. The experiment-driven optimization is possible through measurement campaigns, which feed the modelling procedure and model the behavior of the VNF independently of network, storage and computational requirements. These models helps managing the resources and cloud infrastructure.

- Cloud-enabled protocol, for added flexibility in the virtualized functions' orchestration:

All the network elements (edge and core nodes in different locations) are united in a big "telco cloud". 5G-MoNArch implements a flexible execution platform that builds on MANO and NFV as enablers for flexible function allocation.

- Security and resilience:

Resilience provides the capability to make a reliable operation of two major network components. With a combined notion of a reliable operation of both the telco cloud and the RAN, it is the time percentage of the provided error-free service that counts. Regarding security, a detailed security analysis of all the involved networks elements is performed.

- Elasticity:

With the term elasticity we refer to the capability of dynamic and automatic adaptation of the network to the changes that occur in it, or to the changes in the demand for resources and services. In 5G-TOURS resources and services are scaled up and down, and placed appropriately, in the sense that the requirements imposed by the verticals in terms of KPIs are met with an efficient resource utilization.

3.3.2 5G EVE

5G EVE's [19] goal is to be able to implement and test different 5G infrastructures in Europe. In 5G-TOURS, this can be used to interconnect the sites (Turin, Rennes and Athens), by designing and implementing site interworking and multi-slicing/orchestration mechanisms.

5G EVE's framework currently supports a number of Orchestrators, VNF Managers and Managements tools, as well as several Cloud Platforms (Nokia ALCM, OSM R4, Ericsson OSS, Openstack, Nokia Cloud, Ericsson Executive Environment). As such, it is a unique selling point of the 5G EVE end-to-end facility, which aims at providing a unified and integrated experimentation platform spanning heterogeneous sites, where diverse 5G capabilities and tools are deployed. Therefore, it is a combination of coordination features for the seamless orchestration and execution of vertical use case experiments over heterogeneous infrastructures. Its design and implementation are performed from scratch, trying to enhance, combine and integrate existing solutions for multi-site orchestration where possible, catalogue NFV network services, VNFs and network slices, and monitor network and service performances. Figure 10: 5G-TOURS MANO interaction strategy shows the preliminary interworking framework architecture and high-level functional split, as well as its logical positioning with respect to the 5G EVE experiment portal and the four site facilities. In particular, the interworking framework sits between the experiment portal, that is the frontend by the 5G EVE platform and the site facilities, where the vertical use case experiments will be deployed for testing and validation of 5G and service specific KPIs.

The two main reference points exposed and provided by the 5G EVE interworking framework are:

- the Interworking API exposed at the northbound towards the 5G EVE experiment portal,
- the adaptation and abstraction interface at the southbound for providing a common and unified access to the individual site facilities services and APIs.

The Interworking API can be considered as a collection of primitives that aims at exposing a common interface and model for end-to-end Network Services and slices provisioning the support of the vertical use case experiments. It is important to highlight that the interworking API is not only a provisioning interface. Rather, it is conceived to expose additional features for the operation of the vertical use case experiments, including runtime configuration of the network services and slice elements (e.g. VNFs), and monitoring of network and service performance metrics in support of the validation of the targeted KPIs within each experiment.

On the other hand, the Adaptation layer, aims to abstract the heterogeneous capabilities and APIs exposed by the 5G EVE site facilities, mostly focusing on orchestration and control features in this preliminary interworking framework definition. Therefore, it exposes a set of common internal APIs and models to the interworking framework components for accessing per-site management, control, orchestration and monitoring services, and translating them into site-specific APIs and models. In particular, the common APIs and models provided by the adaptation layer are intended to provide transparent access to those site features and services required to fulfil the vertical oriented technical requirements. For each of these required per-site features and services, the adaptation layer is equipped with specific drivers, providing the required translation from the common interface to the site-specific APIs.

3.3.3 Outlook

As discussed in Section 3.1, the different 5G-TOURS site will have different MANOs, as follows:

- Turin: Ericsson MANO
- Athens: Nokia MANO
- Rennes: Nokia MANO

Therefore, the 5G TOURS MANO will have several interfaces, functions and methods to communicate with all of them.

A short example of the flow is as follows:

- The Service Layer sends a request to the enhanced MANO.
- The enhanced MANO checks the request information and evaluates the availability of the needed resources for that operation in the destination site, communicating with that site's MANO.
- The enhanced MANO adapts the request information to the destination MANO format and starts the operation.
- After finishing, the enhanced MANO reports the results to the Service Layer.

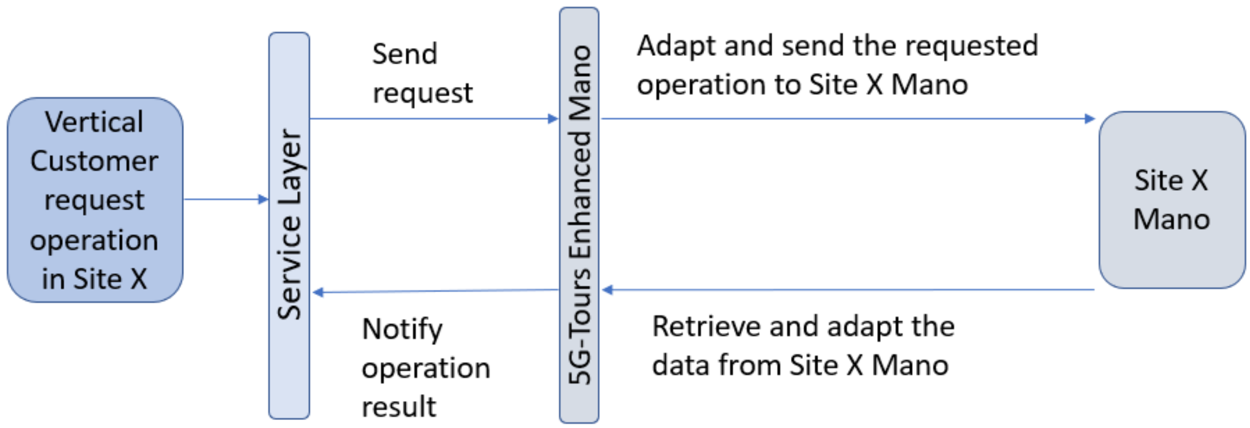

Figure 10: 5G-TOURS MANO interaction strategy

The design and development of the enhanced MANO solution will take into account the aspects introduced by 5G-MoNArch and 5G Xcast, and will be integrated into the 5G-TOURS Service Layer as discussed in Section 3.6.

3.4 AI-based Data Analytics

When dealing with large-scale deployments such as those addressed by 5G-TOURS trials, specific mechanisms that take automated decisions on the management and configuration of the network shall be devised to perform the so-called autonomous management of the network.

Thus, besides the design specific VNF, one of the most challenging tasks to be accomplished is network management, as discussed in Section 3.3. We have to transition from a static operation support system/business support system (OSS / BSS), to a new hierarchy of elements that deal with a very complex ecosystem of tenants, network slices, and services, each one with different requirements [20]. Therefore, 5G networks needs an orchestration framework capable of performing intelligent service and resource management, as follows:

Resource orchestration: among the task that have to be performed in this context, is the assignment of the needed resources to each tenant and slice, their proper configuration (i.e., spectrum) independently of the "semantic" of the deployed VNFs.

Service orchestration: this task needs to understand the service needed by the tenant and translate it into VNFs. Also, the chaining and relation among VNFs needs to be provided.

Hence, performing operations such as deciding whether a VNF shall be shared across slices or across tenants, their location in a possibly highly heterogeneous cloud infrastructure, or the number of allocated CPU cores are just a few examples of the MANO layer responsibilities. Therefore, designing an efficient multi-service, multi-slice, and multi-tenant MANO layer entails challenges on both architectural and algorithmic levels. We claim that, an optimized network resource utilization, while providing desired SLA under 5G network slicing, can only be attained if very precise AI solutions are deployed in the network. By allowing this, a cost-efficient network management and orchestration can be achieved, avoiding high overprovisioning or under-provisioning that cause excessive expenditures or service outages, respectively.

However, due to the high number of input parameters involved in large-scale deployments, devising algorithms that account for all parameters and potential situations would be very complex, and machine learning techniques appear as the natural choice to this end. Therefore, in 5G-TOURS we will design and implement an AI-based Data Analytics framework that allows for an autonomous and more efficient management of the 5G-TOURS deployment.

This framework will be aligned with the standardization efforts recently started at ETSI in the Experiential Networked Intelligence (ENI) [24] group on AI-based solutions, at 3GPP SA2 on Network Data Analytics Function (NWDAF) [17], and at 3GPP SA5 on Management Data Analytics Service (MDAS) [22] and Intent Driven Management Service [25]. In the remaining of this section we provide an overview of these seminal activities.

3.4.1 3GPP Activities

3GPP envisions data analytics as one of the fundamental enablers for 5G and beyond 5G Networks. The work that has been carried out for Release 16 and will further be enhanced for Release 17 [23] defines reference information flows and several use cases for the usage of Data Analytics in the network. The key network function in this respect is NWDAF, a 5G Core NF that performs several tasks in the data-driven lifecycle management of the network. The operation is exemplified in Figure 11 and discussed below.

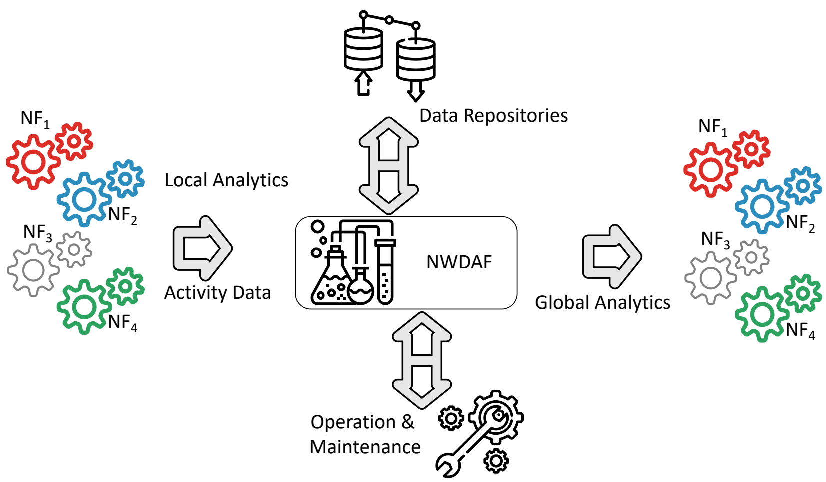

Figure 11: 3GPP network automation strategies

NWDAF is used for data collection and data analytics in centralized way. An NWDAF may be used for analytics for one or more network slices. Other NFs and the network Operation and Maintenance (OAM) decide how to use the data analytics provided by the NWDAF to improve the network performance. Some of the envisioned use cases include:

- QoS management
- Traffic handling
- Customized mobility management
- Edge computing
- IoT assistance
- Load balancing
- Security

Currently, 3GPP is debating about an event-driven solution for the problem, in which different element subscribe to the NWDAF to receive refined data analytics.

3.4.2 ETSI ENI Activities

In response to the industry demand for AI-driven intelligent networks, ETSI has created the ENI workgroup. ENI's goal is to improve operator's experience and add value to the telco provided services, by assisting in decision making to deliver operational expenditure (OPEX) reduction, and to enable 5G deployment with automation and intelligence. In particular, ENI aims to define an architecture that uses AI techniques and context-aware, metadatadriven policies, to adjust service configuration and control based on changes in user needs, environmental conditions, and business goals, according to the "observe-orient-decide-act" control loop model.

Network slicing is indeed the best use cases envisioned by 5G, which can serve as a prime example to demonstrate the ENI's architecture. By assisting the MANO (as shown in Figure 12), it is especially useful to improve the operator's benefits, especially around VNF's computational resources efficiency, while preserving the user requested SLA.

The telco industry's evolution towards standardization of AI-assisted networks, requires various industry consensus, including grammar and syntax for service policy and associated Domain Specific Language (DSL), as well as data ingestion format, to foster the ability to interact with the broad variety of tools used for management and monitoring. A *normalized* format is required to also address the difficulty of harmonizing the state of the divergent infrastructure, due to the use of silo specific tools (e.g., per compute, network, and storage) and the variety of "assisted systems", each with different capabilities and different exposed APIs, as well as varying degrees of ability to interact with the AI system, like ENI. ENI is thus defining architecture components such as data ingestion and normalization, to provide a common base for ENI's inter-modular interaction, as well as to transform the external assisted system (e.g., a 3GPP/5G implementation) inputs to a format that is understood by ENI.

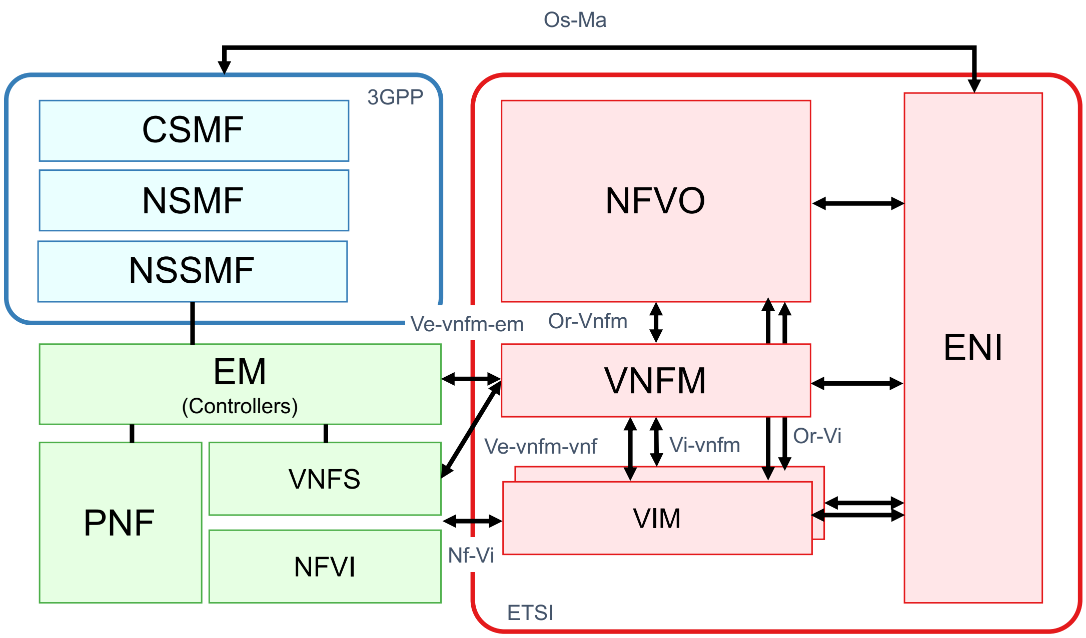

Figure 12: Joint ETSI – 3GPP management and orchestration architecture [18]

3.4.3 Outlook

The AI-based Data Analytics framework implemented by 5G-TOURS will thus follow the modularized system architecture of ETSI ENI [24] (for the implementation details see Section 5.2), which comprises of the following modules: (i) *Policy Management module*, which provides decisions to ensure that the operator's goals and regulator's policies are met, (ii) *Context Awareness module*, which describes the state and environment; for example, an operator business may prevent a specific type of a network slice in a given location, (iii) *Situational Awareness module*, which enables the understanding of how information, events, and commands may impact the next state, actions and ability to meet its operational goals, (iv) *Cognition Management module*, which operates at the higher level and allows to consult and meet the end-to-end goals, and (v) *Knowledge Management module*, which is used to represent information, differentiating between known facts, axioms, and inferences.

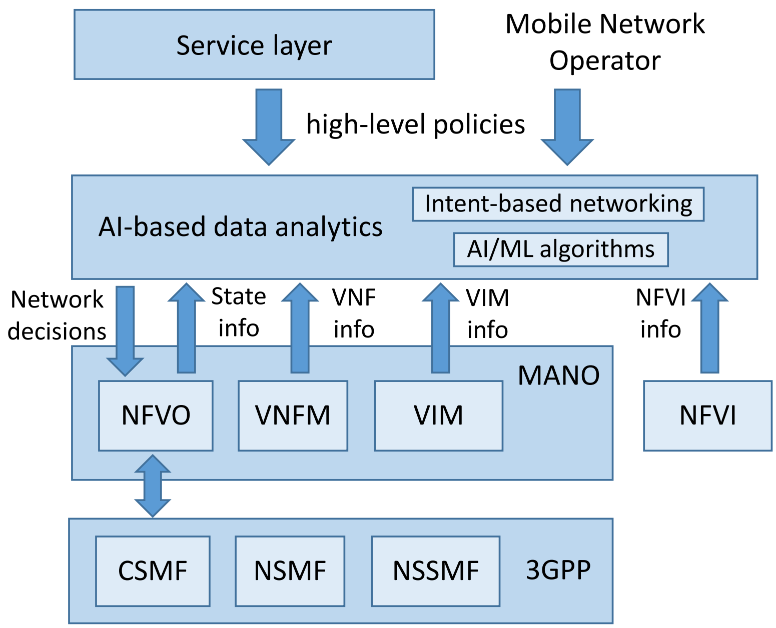

Figure 13: 5G-TOURS Data Analytics approach

The interfaces of the 5G-TOURS AI-based data analytics framework are depicted in Figure 13. The current NFV Infrastructure (NFVI) information provides the knowledge on the computational resources' capabilities (e.g. type of CPU, memory, data plane and accelerators) and availability (e.g. status and utilization level). Building on such information and running the AI-based algorithms, the framework can then influence and optimize placement decisions made by the VIM, while ensuring that 3GPP policies, resources allocation and SLAs are adhered to. Moreover, by using this information, resource utilization can be further optimized by (i) enabling higher density for a given set of workloads under the associated SLA, (ii) anticipating and reacting to changing loads in different slices and assisting the VIM to avoid resource conflicts, and/or (iii) timely triggering of up/down scaling, or in/out scaling of associated resources. More information about the implementation strategy followed by 5G-TOURS are discussed in Section 5.2.

Devising a network slicing framework requires novel algorithms to manage the infrastructure resources and sharing them between the different slices, while guaranteeing that the requirements of each slice will be met. This applies throughout the following network functions:

- Admission Control is in charge of deciding whether upcoming network slice requests can be admitted in the system or not and is enacted to ensure that the requirements of the admitted slices are satisfied.
- Network (re)-orchestration allocates the available computational resources to the admitted slices in the most efficient way possible, fulfilling the demands of each slice, while avoiding computational outages.
- Resource Management manages the sharing of the radio and computational resources between network slices, ensuring that the potentially stringent requirements of all the slices (e.g., latency and throughput) are met.

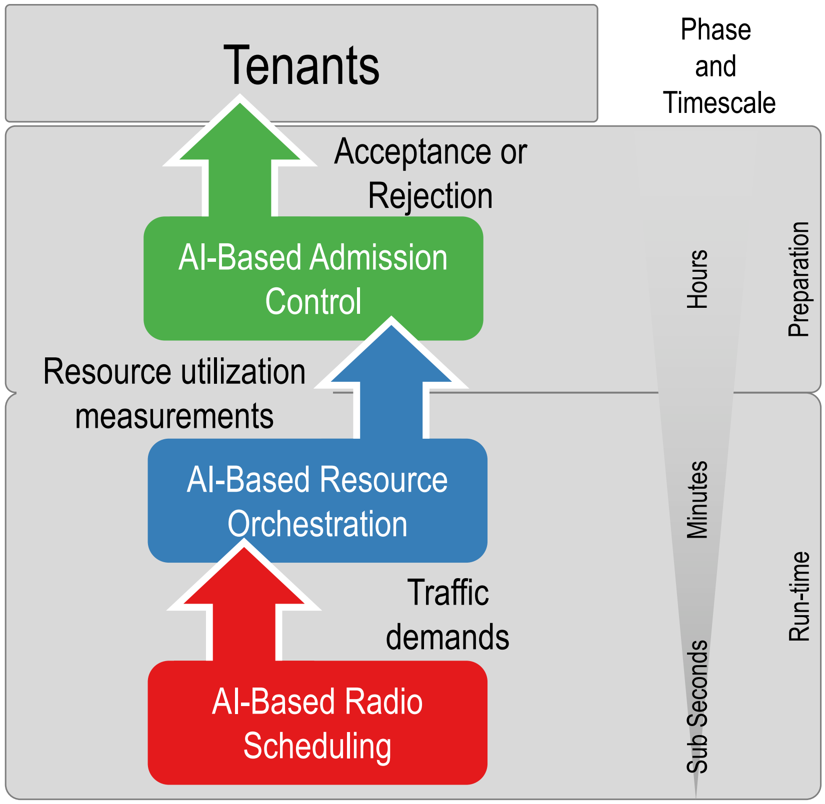

Figure 14: Applications of AI

Figure 14 shows the framework that may be used to empower network slicing with data analytics. This framework gathers components to deal with each of the above functions. These components involve different phases of the "Network Slice Lifecycle Management", consisting of four main steps that have to be addressed: (i) preparation; (ii) instantiation, configuration and activation; (iii) run-time, and (iv) de-commissioning. These phases make up the deployment of network slices (including admission control), their re-orchestration (allocating resources to slices), and operation (including resource management).

In order to cope with the complexity and scale of the deployment while providing a simple interface to manage and operate the network, the AI-based data analytics framework of 5G-TOURS will adopt an *intent-based approach*. With this approach, the policies coming from the vertical customer (though the service layer) and the mobile network operator can simply indicate their 'business intents', declaring high-level service policies rather than specifying detailed networking mechanisms. Then, leveraging AI and Machine Learning (ML) techniques, the network will understand such policies and continuously align to them, using context and analytics to constantly learn and adapt to changing needs and conditions. The powerful abstraction level offered by such an intent-based interface allows to specify end-to-end service composition policies by taking advantage of some kind of formalism that employs this paradigm to orchestrate end-to-end service chains deployed across heterogeneous SDN/NFV domains [25]. 5G-TOURS aims to provide an implementation of this concept, paying particular attention to the specific needs of the vertical customers involved in the project.

3.5 Broadcast Support

5G covers all the technologies introduced in cellular services after Release 14. The first 5G version, Release 15, introduced disruptive additions into the Air Interface (New Radio or NR), RAN (gNB) and Core (SBA). However, NR does not support PtM communications, since no Study Item was approved in Release 15 targeting multicast/broadcast, due to time constraints in 3GPP. Nonetheless, there are very high chances of approving a Study Item that supports a NR-based multicast in Release 17. This is in line with the already approved "Architectural enhancements for 5G multicast-broadcast services" or 5MBS [26]. The goal of this Study Item is to include multicast capabilities inside the 5G Core to natively support Vehicle to Everything (V2X), IoT and Broadcast use cases and applications deployed in an SBA-based environment and leverage from 5G improvements.

In 4G, the solution for Mobile Broadcast is called enhanced Multicast Broadcast Multimedia Services (eMBMS), also known as LTE Broadcast. It is designed as an all-in-one solution, extending the 4G EPC to provide broadcast services. Inside 3GPP, this technology was iterated and improved with new features on each Release, keeping the backwards compatibility with previous versions. While initially targeting terrestrial broadcast as the main use case, different services wanted to leverage the broadcast capabilities in the cellular architecture, such as Mission Critical, V2X or IoT. However, the initial versions of eMBMS did not fulfil the requirements of those verticals, so future revisions of eMBMS added new features and modes to accommodate their needs. Derived from this, eMBMS features can be classified into Mobile Network Operator (MNO)-approach and broadcaster-approach. More background information about eMBMS can be found in Annex A.

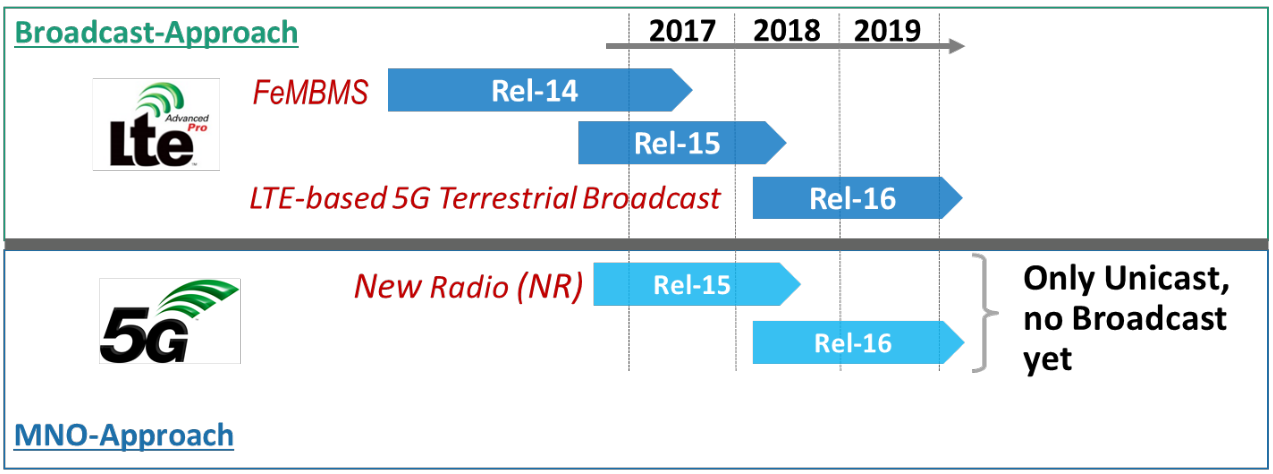

Figure 15: Broadcast approach along 3GPP releases

The latest commercial feature of the MNO-approach is Multicast operation on Demand (MooD). MooD is a set of procedures in eMBMS and EPC that allows the dynamic switching of transmissions from broadcast to unicast and vice versa. A new function, MooD Manager, is added to the Broadcast Multicast Service Centre (BM-SC). If the content can be broadcasted on demand, the MooD-eligible UEs regularly send the consumption reporting messages to the consumption reporting server(s). The MooD Manager (i.e., Analytics) regularly pulls the information from the consumption report server(s) to identify the number of users consuming a certain content. When an audience size reaches a certain threshold, MooD Manager triggers an eMBMS session (with the required Service Announcement) containing the popular content and notifies all the UE consuming the content via unicast to switch to the eMBMS transmission. MooD also includes procedures for the shutoff of eMBMS transmissions when they are no longer popular, with the required notifications to handover the users back to unicast. This feature is already deployed in Australia by Telstra, with Ericsson and Qualcomm equipment, for sports content for Samsung Galaxy devices S8 and S9 using a dedicated application [27].

On the other hand, for the Broadcaster-approach, there are still ways to perform a 5G Broadcast transmission. A Work Item for a revised version of enhanced Television (enTV) is on-going in Release 16, known as "5G LTE-Based eMBMS" or FeMBMS [28]. The main features of enTV are shown in Figure 16. Additional changes to the air interface in order to improve the reception will be included, such as Cell Acquisition Subframe (CAS) improvements and new numerologies. However, no changes are planned at core network. As a reminder, this is still using LTE Core Network, RAN and Air Interface. Notable trials in Europe of FeMBMS include [29] and [30].

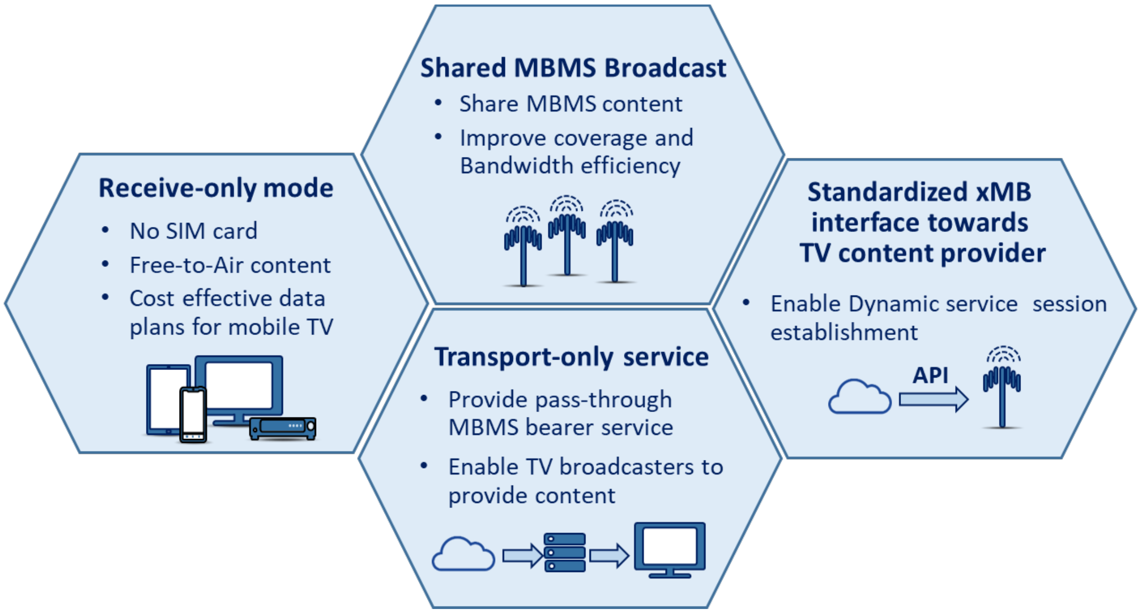

Figure 16: Summary of Release 14 eMBMS features

3.5.1 5G-Xcast

The "Broadcast and Multicast Communications Enablers for the Fifth Generation of Wireless Systems", or 5G-Xcast project [31], was proposed in order to overcome the gap in mobile broadcast solution based on NR and 5GC. The project run from July 2017 till July 2019. The main objectives of 5G-Xcast were:

- to develop broadcast and multicast capabilities for the standalone 5G NR and 5G Core Network.
- to design a 5G converged network architecture combining fixed, mobile and terrestrial networks to dynamically and seamlessly switch between unicast, multicast and broadcast modes or use them in parallel.

5G-Xcast has been fundamental towards the vision of a converged 5G infrastructure for fixed and mobile access to audio-visual media content, including terrestrial broadcast. The project took a holistic approach to harmonize the media delivery among the three considered types of networks and provided an optimized and seamless media user experience.

Figure 17 illustrates a seamless experience to users as they move between locations served by networks of different capabilities. For example, in the case of a user with a mobile device, they may start in the home (labelled as '1' in the figure) using multicast/unicast on a fixed broadband network before moving outside ('2'), where there may be a reliance on the mobile network to deliver broadcast and unicast data. A simultaneous delivery over available mobile network channels (multilink) is triggered to achieve the desired Quality of Experience (QoE). Finally, the user moves to another outdoor location ('3'), such as a rural environment with a sparser mobile network deployment with less capacity available. Here, a broadcast TV network is used to deliver broadcast content to the mobile device, supplemented by interactive services delivered over the mobile broadband network. Figure 18 shows the hybrid broadcast service use case of 5G-Xcast [32].

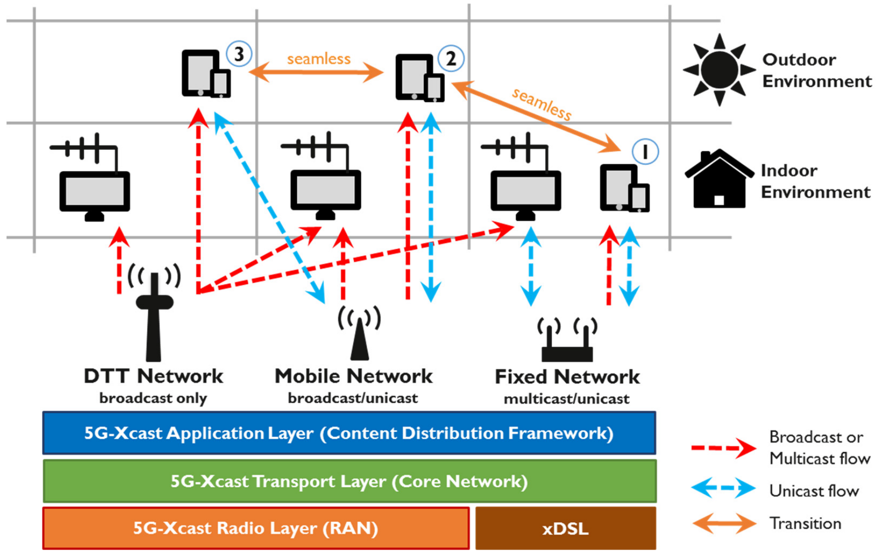

Figure 17. An example of one user moving between three different environments each of which has different combinations of networks available.

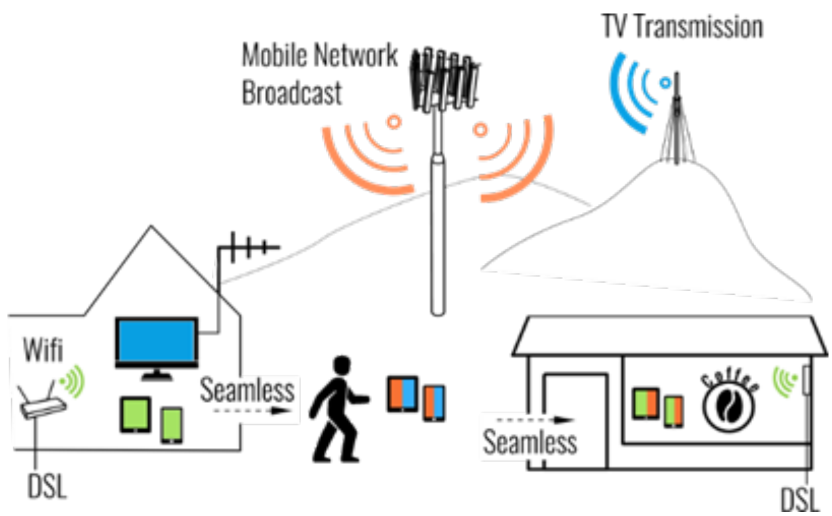

Figure 18. 5G-Xcast hybrid broadcast service use case: combinations of networks and technologies give a seamless experience as the user moves between different locations.

5G-Xcast conceived multicast/broadcast PTM transmissions as an essential delivery tool for optimal system performance. The paradigm shift proposed by 5G-Xcast for 5G Broadcast is that PTM transmissions should be built-in features integrated into the overall 5G system architecture [33], keeping as many commonalities as possible with unicast Point-to-Point (PTP) in order to maximize compatibility and interoperability, and enable dynamic seamless switching between different modes of operations, as well as their parallel usage. The integration of PTP and PTM modes under one common framework is essential to exploit network and spectrum resources in an efficient and economic manner, e.g. a common framework ensures that the use of PTP and PTM modes can be managed transparently within the network, leading to a simplified and unified service design across various access networks. Additionally, a common framework fosters that all network and user equipment support the PTM delivery feature. The fact that specific hardware is required for LTE Broadcast, at both terminal and network sides, is probably the main barrier that has held up investment in the technology.

This approach will also enable the deployment of standalone 5G broadcast networks for the distribution of radio and TV broadcast services. Furthermore, by adopting a unified approach for PTP and PTM media delivery, it will also simplify the use of broadcast and make it transparent to content providers in a straightforward and scalable manner, for both dynamic and pre-positioned media delivery scenarios.

As shown in Figure 19, 5G-Xcast has defined multicast/broadcast components for the 5G system, distinguishing between those elements that are radio network-related (radio layer, RAN), network-aware (transport layer, core network), and network-agnostic (application layer, converged content distribution framework).

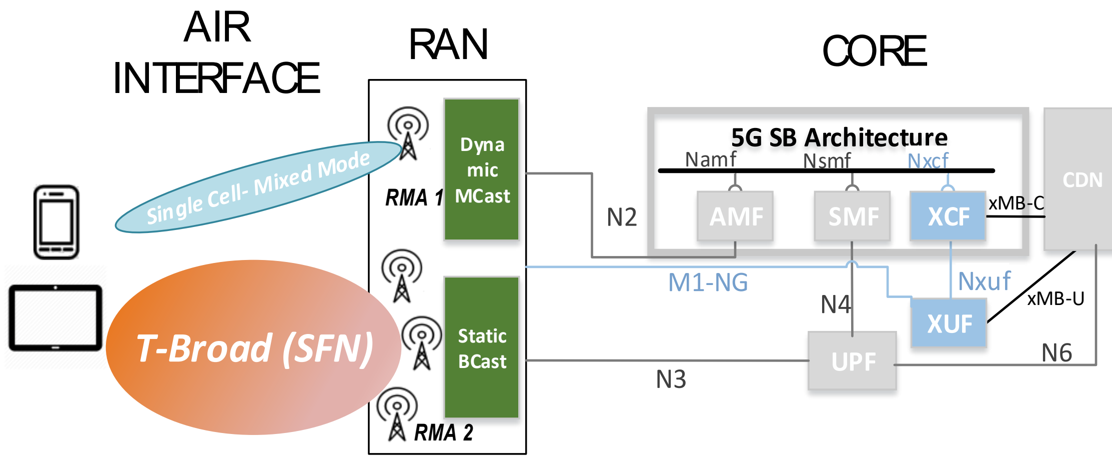

Figure 19: Summary of 5G-Xcast architecture based on its outcomes.

3.5.2 5G-Xcast Air Interface

Two specific 5G PTM technologies are proposed, in order to fulfil the different 3GPP requirements needed for broadcast and multicast, as well as those derived from the 5G-Xcast use cases defined in [32]. These technologies are the Mixed Mode and the Terrestrial Broadcast Mode. 5G-Xcast partners have been contributing to the 3GPP Release 16 discussions in order to detect missing functionalities that are needed to fulfil the agreed PTM requirements.

The 5G-Xcast Mixed Mode enables a dynamic and seamless switching between PTP and PTM transmissions, both in the downlink and the uplink. This solution is envisaged for the different verticals of the 5G-Xcast project, i.e. media and entertainment, automotive, IoT and public warning, and is oriented to address the particularities of MNOs. It reuses the NR Release 15 air interface specification as much as possible to ensure the maximum compatibility with PTP. However, some modifications are included, such as the discovery of the scheduling information to a group of users, which is enabled by the introduction of a Group Radio Network Identifier (G-RNTI), and a multiple cell coordination that is enabled by forcing the same cell scrambling sequence to the neighboring gNB. Negative numerologies as well as the concept of mini slots are also included to support Single Frequency Networks (SFNs) with larger coverage areas.

The 5G-Xcast Terrestrial Broadcast Mode, which is 5G PTM mode oriented to Broadcast Network Operators, enables the reception of the service to users without uplink capabilities, i.e. being a downlink-only mode. The key design principle is the reuse of the existing 5G-NR design for Mixed-Mode operation with the necessary extensions to deliver Terrestrial Broadcast services. This includes enabling transmission over small, medium and large coverage areas, including from Low-Power Low-Tower (LPLT) to High-Power High-Tower (HPHT) stations. To make these possible, different configurations are enabled to operate Multi-Frequency Network (MFN) and SFN deployments. In particular, the necessity to cope with large delay spread (in HPHT MFN due to natural echoes, and in HPHT SFN due to large inter-site distance) imposes important changes in the air-interface design. To allow very large Inter-Site Distances (ISDs) in SFNs, as required by the 3GPP requirements, very narrow carrier spacing (more than those provided in the Mixed Mode), new cyclic-prefix values and reference signals are included in NR. In addition, special attention is given to the LTE CAS, taking into account new design possibilities in NR.

3.5.3 5G-Xcast RAN Architecture

As explained in Section 3.2.1, the 5G RAN is formed by a collection of gNBs. In 5G-Xcast, the design principle fully leverages the functionality split of the gNB into Centralized Unit and Distributed Unit. Two different PtM modes were proposed: Dynamic multicast as a radio resource optimization, and static broadcast as a service. To enable both aspects, a new concept, known as Radio Multicast Area (RMA), was introduced. RMA is a subset of cells that are transmitting multicast/broadcast content in a synchronized way, forming an SFN. Users moving inside the RMA would not experience service interruption, similarly to eMBMS. However, in eMBMS it is the BM-SC residing at the Core that launches the SFNs, while in 5G-Xcast that decision resides on the RAN, based on the number of users and their geographic location. The cells belonging to the RMA can be changed, adding or removing them on-the-fly depending on the audience conditions.

Inside the gNB architecture, two new entities were introduced to enable the RMA, called gNB-CU Multicast Function (gNB-CU-MC) and the DU Multicast Function (DU-MCF). Their role is to fulfil the SFN requirements, i.e. common scheduling and radio parameters, and compensate for possible delays. A new revision of the synchronization protocol used in eMBMS (SYNC) has been designed for 5G-Xcast, called RAN-SYNC [34], where the synchronization encapsulation happens at RAN instead of the Core.

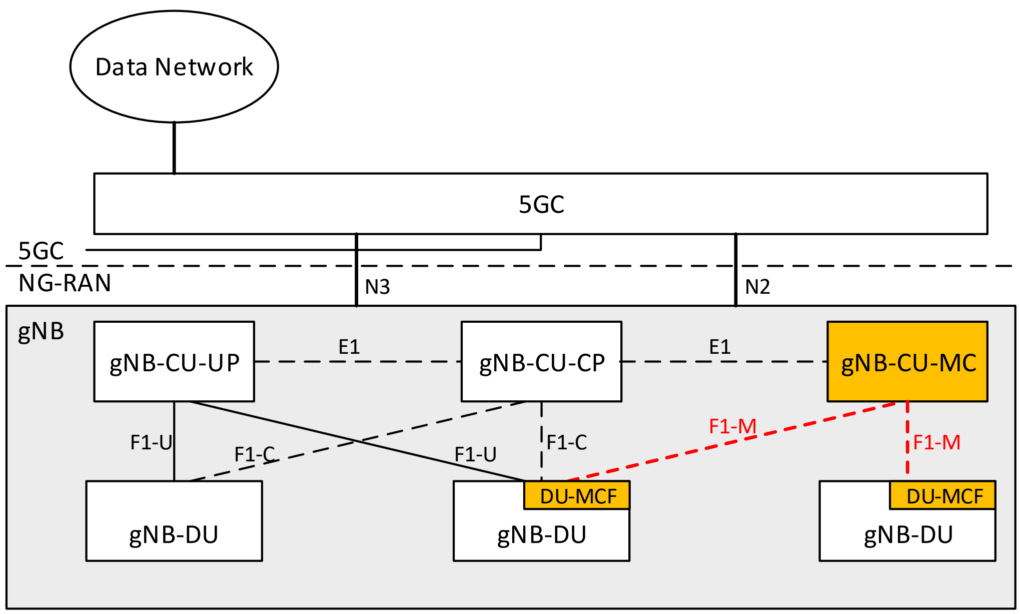

Figure 20: 5G-Xcast RAN Architecture, showcasing the gNB-CU Multicast Function and the DU Multicast Function

3.5.4 5G-Xcast Core Network

In order to provide broadcast capabilities to the 5G Core, 5G-Xcast devised two additional NFs, one at User Plane and the other at Control Plane, called Xcast User Function (XUF) and Xcast Control Function (XCF) respectively. As their name implies, XCF is located at the control part of the architecture, while XUF resides on the data plane. In more detail:

- XUF is tasked with the delivery or retrieval of content from the content provider, apply FLUTE packetization to the data and Application Layer – Forward Error Correction (AL-FEC) protection. The output is multicast IP packets towards the User Plane Function (UPF) or the RAN.

- XCF controls the authentication and authorization of external content providers, the creation, management and termination of services and sessions, and the status notification. Additionally, XCF manages the network resources used for broadcast services and their geographical location, the AL-FEC configuration, and the IP multicast anchor point. It also provides service announcement, reports for consumption and file repair and the dynamic switching from unicast to multicast/broadcast. The interaction between the XCF and other NFs is performed via the SBA.

To accommodate both static broadcast services and transparent multicast transmission modes, two different architectures are possible:

- Architecture 1, where the XUF feeds multicast data into the UPF. The design philosophy behind this solution is to leave the lowest imprint possible over the PTP architecture of 5G. Most of the existing procedures for PTP are reused, so terminals having a 5G modem can work under this architecture.
- Architecture 2, where the XUF forwards broadcast data into the RAN. This is an evolution of eMBMS where the MBMS Gateway (MBMS-GW) sends the data to the involved cells using the M1 interface. In a similar way, the XUF sends data to the involved cells using M1-NG, a new interface designed in 5G-Xcast.

A core solution was also devised to support Non-3GPP Access. The document [6] covers how to perform Layer-3 convergence for fixed and mobile networks.

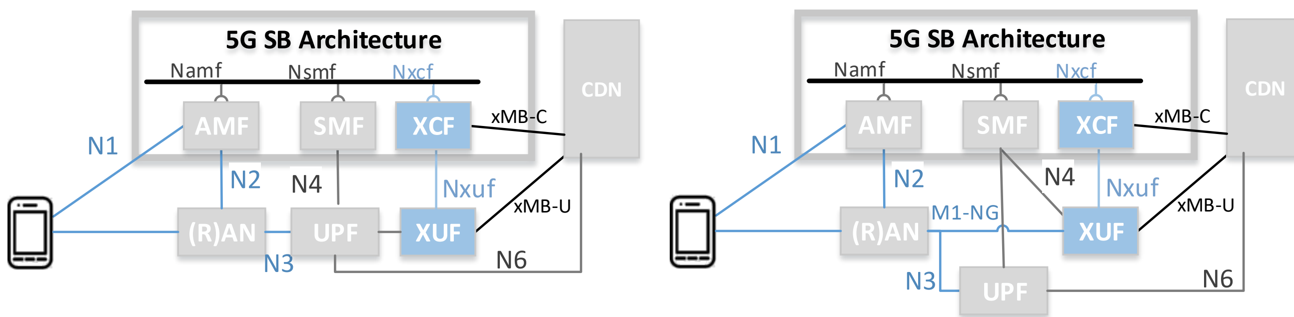

Figure 21: Both possible architecture deployments in 5G-Xcast

3.5.5 Outlook

Since 5G does not consider multicast/broadcast communications, 5G-TOURS will leverage the NFs designed in 5G-Xcast to provide this functionality. In detail, the XUF and XCF as shown in Figure 19 will be implemented during the project and the possible feasibility of integration for the 5G-EVE inter-site platform will be investigated.

3.6 5G-TOURS Service Layer

In order to meet the needs of the vertical customers of 5G-TOURS, the project will design a Service Layer that provides them with a suitable interface. This interface will allow the vertical customers to request and operate network services in a user-friendly manner.

Multiple functionalities are required to implement this interface. Firstly, the Service Layer will implement a mechanism to design, instantiate and manage network slices. This mechanism will allow the customer to express its functional and performance-related requirements. Secondly, the Service Layer will communicate with the enhanced MANO described in Section 3.3 to implement the network slice requested by the customer. This connection with the MANO system will also let the Service Layer display a catalogue of available services and VNFs to the customer.

The Service Layer will also send the customer requirements to the AI-based analytics module described in Section 3.4, using an appropriate high-level formalism, so that the AI module can interact with the MANO module to optimize the resource allocation and ensure that the requirements are met. It will also display the monitoring data gathered by the analytics module so that the customer can verify that its requirements are met.

The design of this Service Layer will re-use the APIs from the 5G EVE project whenever possible, adapting them to the specific needs of 5G-TOURS verticals. In addition, components from 5GPPP projects 5G-Transformer (5GT) [35] and SLICENET [36] are also considered for inclusion and will be described in this Section. The design will also be aligned with the incipient efforts on Exposure Governance Management Function (EGMF) [17] at 3GPP, where some 5G-TOURS partners are involved.

3.6.1 Architecture

With regards to the NFV-MANO architecture (see Figure 22), the 5G-TOURS Service Layer can be thought of as a part of the OSS/BSS module that sits on top of the NFV Orchestrator (NFVO) module. In the 5G-TOURS architecture, the NFVO role is played by the enhanced MANO module. The service layer also interacts with other components, such as the analytics framework and broadcast module that can be modeled as element management systems.

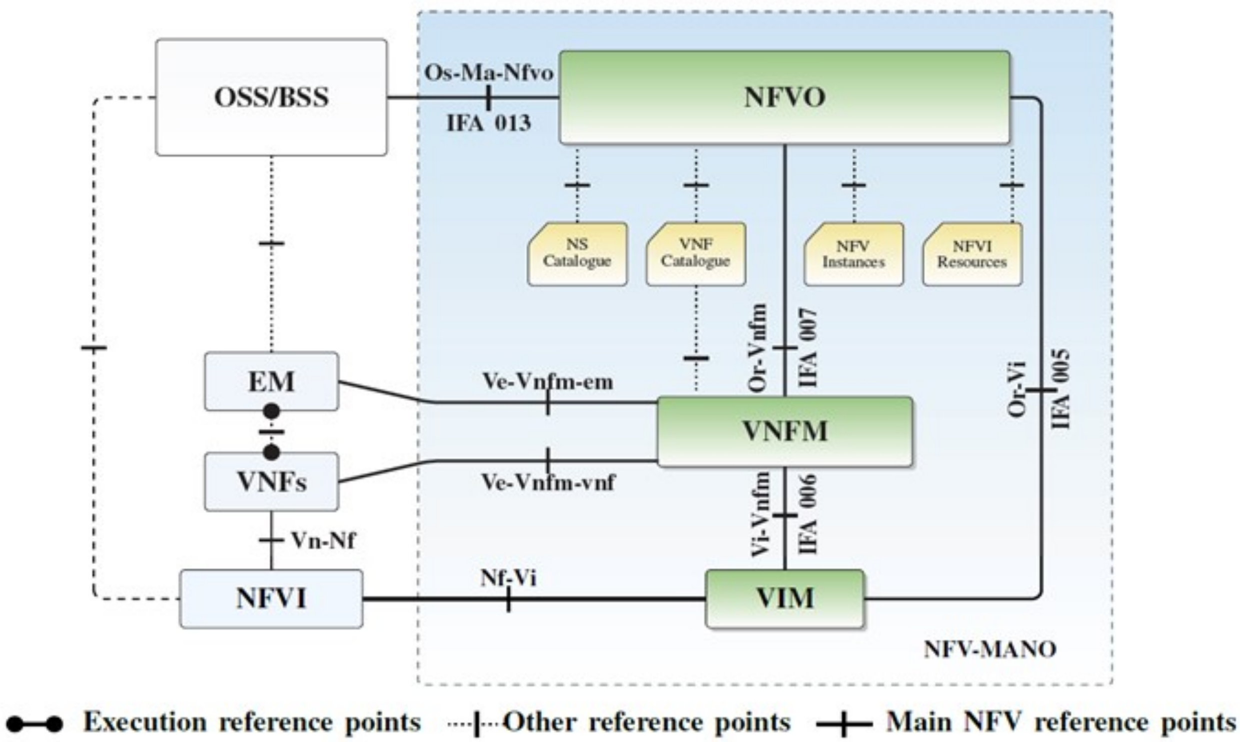

Figure 22: ETSI NFV architecture

With regards to the Network Slicing functions defined by TR 28.801 [37] , there are two possibilities to consider when designing the Service Layer:

- We consider the CSMF, NSMF and Network Slice Subnet Management Function (NSSMF) to be part of the Service Layer, and thus expose an API to the vertical extending the concepts of network slice to support the notion of Vertical Service. This extension adds Network Services like video streaming to network slices in order to better match the usual needs of the vertical customers (See Figure 23).
- We consider only the NSMF and NSSMF to be part of the Service Layer. In that case, we expose the NSMF API to the vertical's CSMF and provide only a network slice to the vertical. This dedicated slice will be

fully managed by the vertical. In this case, the Northbound API offered by the Service Layer should be based on the one defined in TS 28.531 [38] (Figure 24).

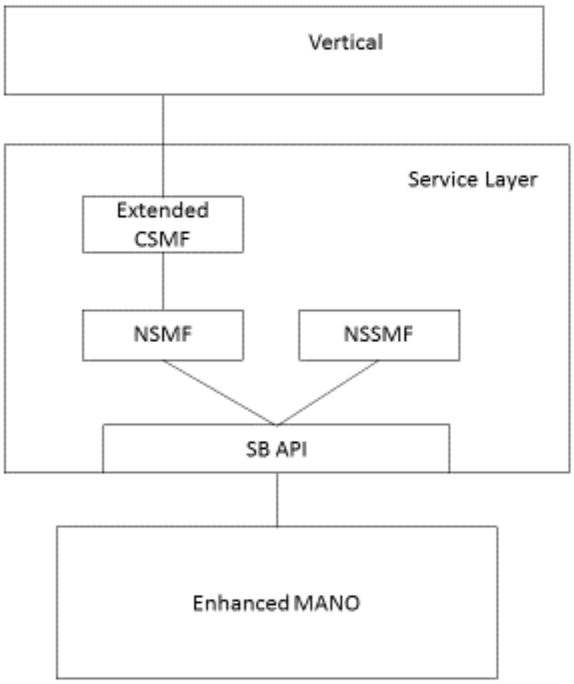

Figure 23: Service Layer NS Architecture (Option 1)

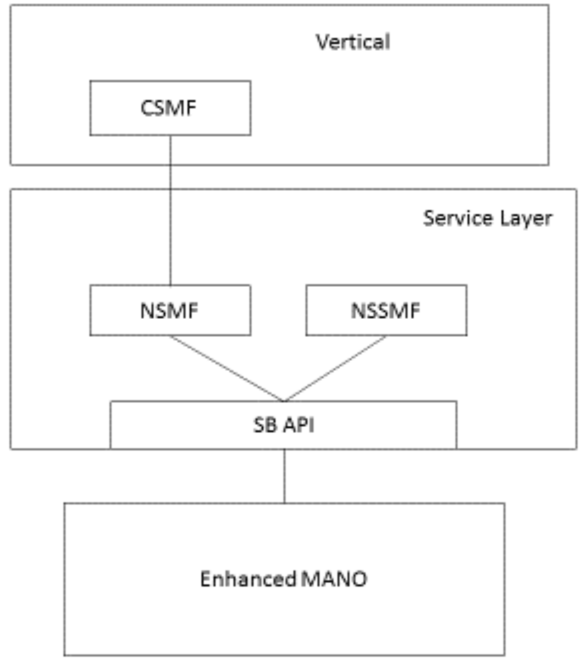

Figure 24: Service Layer NS Architecture (Option 2)

With regards to the 5G EVE architecture, the Service Layer maps directly to the Experiment Portal (Figure 25).

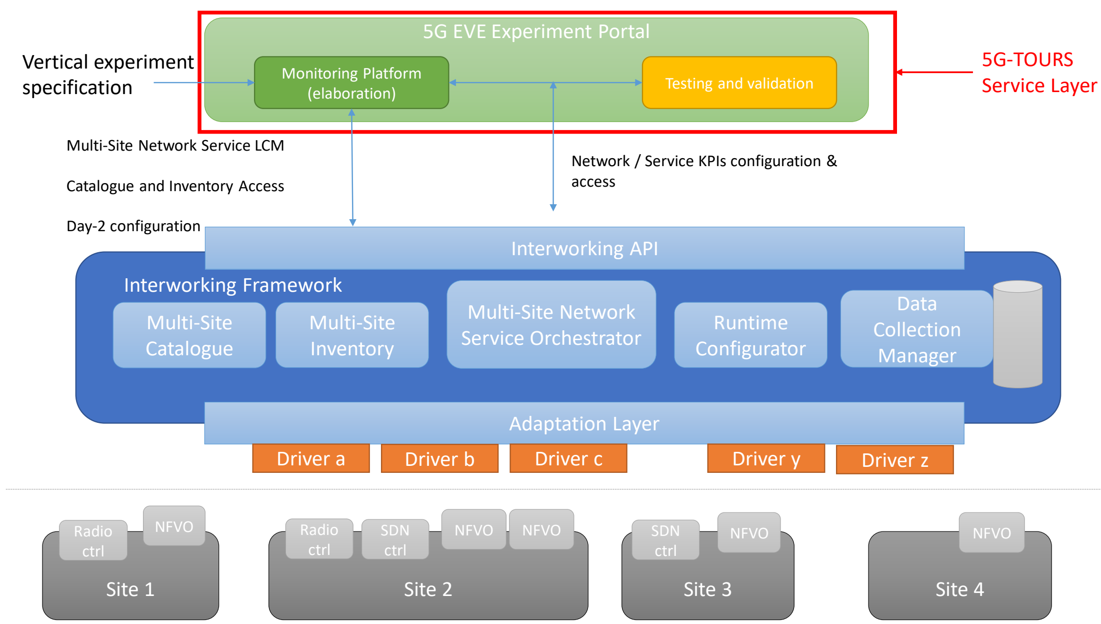

Figure 25: Interworking Framework architecture as defined in D3.1 from 5G EVE

3.6.2 Service Layer Technology

3.6.2.1 Network slice blueprint and lifecycle management

The core of the Service Layer is a mechanism that allows the vertical customer to define a network slice and manage its lifecycle. This includes multiple aspects:

- *Slice definition*: the customer should be able to define a network slice including the services and the operational requirements such as capacity, reliability or security level, based on a Vertical Slice Blueprint (VSB) that provides an easy starting point. The mechanism should also provide a catalogue of low-level blueprints to the customer and allow them to build their own network slice blueprints if none of the available ones match their needs.
- *Slice creation*: once the customer has defined a network slice, the Service Layer will translate the description of the slice into Network Slice descriptors (NSD) and send them to the MANO system.
- *Slice monitoring*: the customer should be able to access monitoring information about the deployed slice to check that the required KPIs are met.
- *Slice management*: based on this information, the customer will be able to decide whether they want to increase or decrease the capacity of their slice and create new ones.
- *Slice deletion*: once the customer no longer needs a slice, they should be able to delete it from the 5G-TOURS system.

The 5GT Vertical Slicer (5GT-VS) component from the 5G-Transformer project is a good baseline to implement this blueprint and network slice management system. Another option would be the mechanism discussed in the SLICENET project architecture [39].

3.6.3 5G-Transformer Vertical Slicer

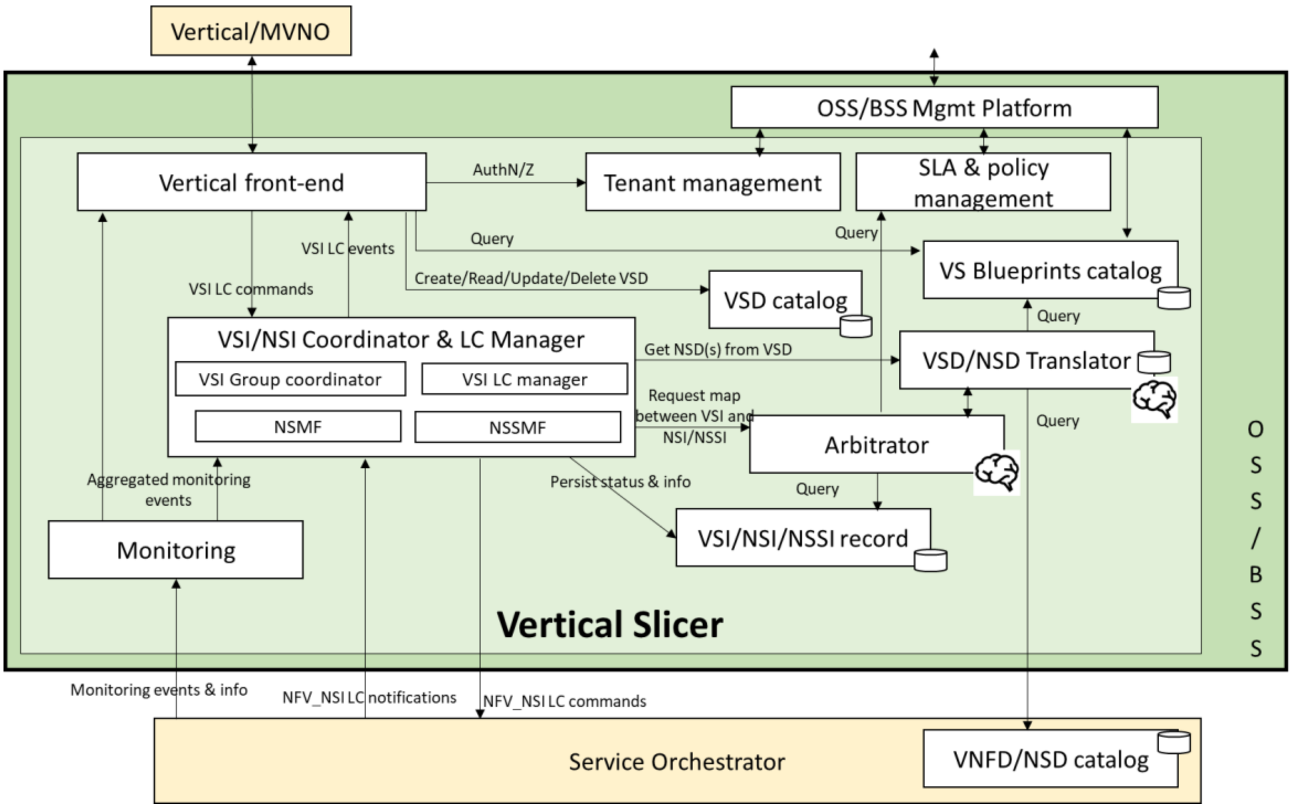

Figure 26: Vertical Slicer as defined in D3.3 by 5G-Transformer

As described in [40], the 5GT Vertical Slicer (5GT-VS) provides the vertical customer with a set of VSBs. This high-level mechanism abstracts the implementation details of the network slices in the 5GT system and allows the vertical customer to focus on the functional definition of its service and its performance requirements. The 5GT-VS also offers a set of basic services as building blocks, which the vertical customer can combine to create a vertical service.

Once the customer has filled the VSB with its requirements, it becomes a Vertical Service Descriptor (VSD). Based on this VSD, a component of the 5GT-VS named "VSD/NSD Translator" translates the VSD into slice-related requirements and decides which network services will be used to implement the VSD requested by the customer. These network services are described as graphs of VNFs using ETSI Network Service Descriptors.

The slicer then decides whether the requested VSB can be implemented through existing slices, or if a new one should be created. This decision is based on the resources already allocated for the vertical customer and the ones requested for the new service. It is also based on the expected security level of the service which may require the complete isolation of the service in a dedicated network slice.

The next component of the 5GT-VS is the "Vertical Slice Instance (VSI)/NSI Coordinator and Lifecycle Manager". It is responsible for managing the VSIs (i.e. the instantiation of a VSD) and NSIs from creation to deletion. This module coordinates multiple sub-modules:

- *The VSI Lifecycle Manager*: this module is responsible for managing the lifecycle of each VSI and the associated finite state machine. It also maintains the mapping between a VSI and the NSIs that implement it and performs accounting of vertical service resource consumption per VSI.

- *The Network Slice Manager Function (NSMF)*: this module keeps tracks of the available VNFs and Physical Layer Functions (PNFs) available in the NSDs exposed by the Orchestrator, and uses that information to assess whether a VSI can be implemented within an NSI. The NSMF also keeps records of all the network slice requirements (e.g. number of CPU, storage) per NSI, and sends this information to the Arbitrator to calculate the deployment flavors of the NFV.
- *The Network Slice Subnet Manager Function (NSSMF)*: the NSSMF plays the same role as the NSMF but for network slice subnets.

3.6.4 SLICENET Architecture

SLICENET is a 5G-PPP research project which focuses on the management of network slicing using cognitive techniques and AI. Its aim is to build a network slicing framework based on the following principles:

- *Network slicing*: the framework enables the verticals to build flexible and customized network slices to address their specific needs. One important feature of SLICENET is that it allows the creation of multi-provider network slices.
- *One-Stop API*: the framework provides a single-entry point for verticals that abstracts the underlying architecture based on the information provided by the aggregated NSIs and NSSIs. This one-stop API also provides slice blueprints to simplify the work of the verticals when requesting a slice.
- *Plug & Play*: the SLICENET frameworks allows both the slice provider and slice customer to customize the NF deployed in a slice to better match their performance and functional requirements. The plug & play concept also eases the deployment of multi-provider slices by increasing the interoperability among the providers.
- *Cognition*: given the very high complexity of a multi-provider environment, the management and orchestration of the slices will need to be automated. The SLICENET framework uses ML algorithms based on Monitor-Analyze-Plan-Execute (MAPE) loops to optimize the operation of all the components of the slices.
- *Cross-Plane Orchestration*: The cross-plane orchestration provides orchestration abstractions in two dimensions. On one hand, vertically, each layer hides the complexity of its implementation from the upper layer through an orchestrator. On the other hand, horizontal orchestration allows the SLICENET to coordinate across multiple domains inside a given layer.

Based on these principles, the high-level SLICENET architecture was designed as shown in Figure 27. Overall the Management Plane and its Management Layers seem to fulfil the requirements of the 5G-TOURS Service Layer with the AI-based analytics and Multi-Site Orchestrator (MSO) as well. However, the functional split between the SLICENET components is much less clear than that of the 5G-Transformer components. The various layers are also more tightly integrated compared to 5G-Transformer. This would probably make the reuse the SLICENET components in 5G-TOURS more complex, compared to the more modular components from 5G-Transformer and 5G EVE.

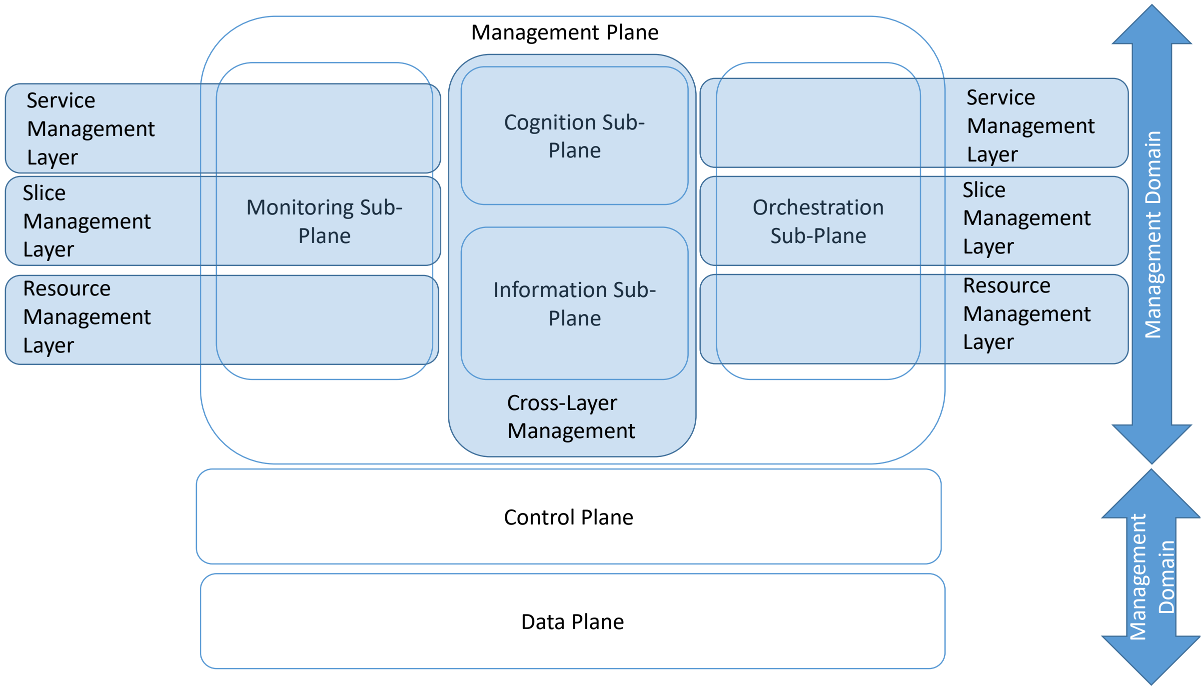

Figure 27 SLICENET "Level 0" architecture

3.6.4.1 SLA Management

In addition to the above, the Service Layer should allow the customer to define an SLA for the slice. The Service Layer will then translate the SLA into a formal requirement and send it to the AI-based analytics module described in Section 3.4. In order to do this, the Service Layer will need to include a formal language designed to express the performance requirements of the vertical customers, such as those presented in [41] or [42].

The analytics module expects to receive the SLA as a set of high-level performance requirements called Intents. An early example of this can be found in [25]. In essence, Intent-based networking means that the Service Layer should only communicate with the analytics module without using any information on the underlying systems. Then, the analytics module would be in charge of ensuring that these Intents are fully respected at all times.

The 5GT Vertical Slicer already includes a basic mechanism to communicate performance requirements to the Orchestrator. This means that the NSD sent by the Vertical Slicer to the Orchestrator includes scaling increments for each of the network slice. These increments define the steps which can be used by the Orchestrator to scale the services up or down in terms of CPU, RAM, etc. The most straightforward way of implementing SLA management would be to extend it to send both scaling increments to the MANO module, as well as intents to the analytics module. These two modules can then interact to choose the correct scale for the VNF included in the network slice and ensure that the requirements are met. The scaling should be dynamic based on the actual resource usage and reported to the Service Layer in real time.

3.6.5 Outlook

Based on the above analysis of the 5G-Transformer and SLICENET architectures, it appears that both projects provide components suitable to form the basis of the 5G TOURS Service Layer. However, 5G-Transformercompo-nents seem easier to integrate in the 5G EVE architecture, which will be used as a starting point for 5G-TOURS. As such, our first approach will be to start with the 5G-Transformercomponents, most notably the 5GT Vertical Slicer, to implement the 5G-TOURS Service layer. SLICENET components will only be considered if the use 5G-Transformercomponents proves impossible.

4 5G-TOURS Trial Platforms

This section describes the details of the different 5G-TOURS trial platforms, namely the touristic city (Section 4.1), the safe city (Section 4.2) and the mobility-efficient city (Section 4.3). The three subsections follow a similar approach, describing the current state of the art in the thee trial site (mostly the artifacts made available by 5G EVE), and discuss the possible planned extensions required to support the 5G-TOURS use cases. The figures reported for each of the test sites are aggregated ones, that will be further refined in the subsequent releases of the Work Package documents.

In the following table, we describe the 5G EVE main milestones concerning vertical.

Milestone	Milestone name	Timing
MS4	Participant vertical industries requirements documented	Q4 2018
MS5	Initial access to participating vertical industries for non-interworking use cases. Participating vertical industries start deploying their applications in some site facilities.	Q2 2019
MS7	External vertical industries and core applications requirements documented.	Q4 2019
MS8	First release of the 5G end to end facility. The 5G end to end facility starts being used by vertical industries.	Q1 2020
MS9	Second release of the 5G end to end facility. All APIs, web portal, and interworking capabilities of the 5G end to end facility are fully operational. Pilots start	Q3 2020
MS10	Third release of the 5G end to end facility. Feedback vertical industries is implemented. Access to external vertical industries.	Q4 2020

Based on the above, the integration of 5G-TOURS, according to its phases (Section 2.1) can start immediately. In the following subsections, we discuss thus the Phase 1 for the three cities, while the full description of the Phase 2 will be provided in the subsequent versions of the WP deliverables.

4.1 Touristic City

4.1.1 Phase 1 network deployment

The phase 1 network deployment in the touristic city of Turin will largely rely on the available infrastructure from 5G EVE for the verticals trials.

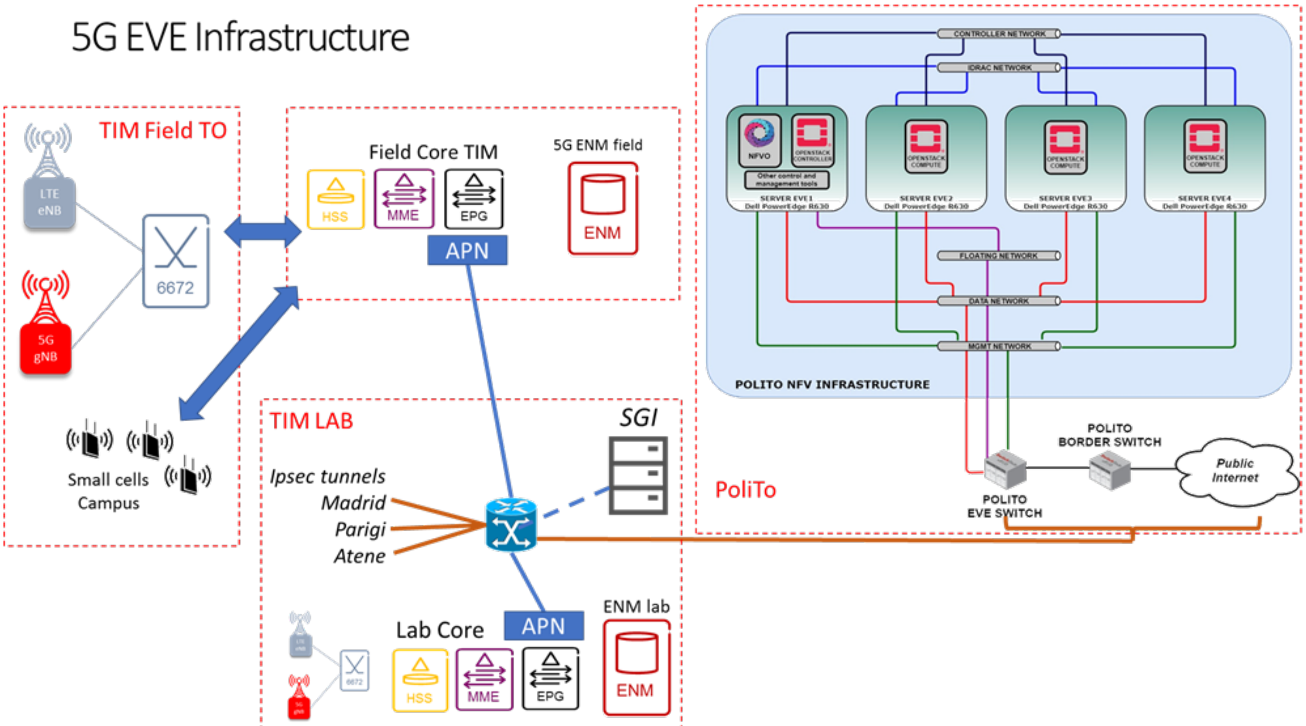

Figure 28: State of the art of the 5G EVE Infrastructure

The 5G EVE site facility in Turin leverages on initiatives to experimentally evaluate and develop the 5G system that have been started by some partners of the project. The 5G site facility is constituted by live and laboratory-based experimental environments for the evaluations of the 5G features. It relies mostly on 5G equipment provided by Ericsson as part of 5G trials in Turin. The infrastructure consists in 5G RAN (with NSA nodes), fronthaul and backhaul and open source tools for the management and orchestration of the NFV infrastructure. Various networks gateways offered by TIM interconnect the various edge/peripheral locations to core datacenter sites, other 5G EVE site facilities and external public cloud services if needed. The 5G EVE platform will be available to 5G-TOURS starting from 2020. Nevertheless, after the first year of project the state-of-art of the Italian infrastructure either already deployed or planned is depicted in Figure 28. An extensive description of the infrastructure components can be found in Section 4.1.2, and summarized below:

TIM LAB

- Equipped with Prisma UE emulator (to analyze the effect of traffic and terminals)
- Equipped with a full radio chain (RAN and Core) for testing.

TIM Field Turin (outdoor)

Currently, a RAN NR 15.0 has been deployed in the trial area (approximately between the main Turin railway station and Politecnico di Torino). The NSA architecture also includes an LTE layer (Figure 30). Furthermore,

- a Field Core is available,
- OneM2M platform is available to collect urban sensors data to be provided to verticals,

- the possibility that trial users could access the 5G EVE network infrastructure via specific and private Access Point Name (APN) is currently under discussion (links in blue in Figure 28)

PoliTo (Politecnico di Torino, Figure 29)

- 4 servers Dell Power Edge R630, running Open Stack,
- Orchestrator based on an implementation of OSM

The four servers are interconnected through a Gb/s switch (EVE switch in the figure), while a 10 Gb/s switch guarantees outer connectivity.

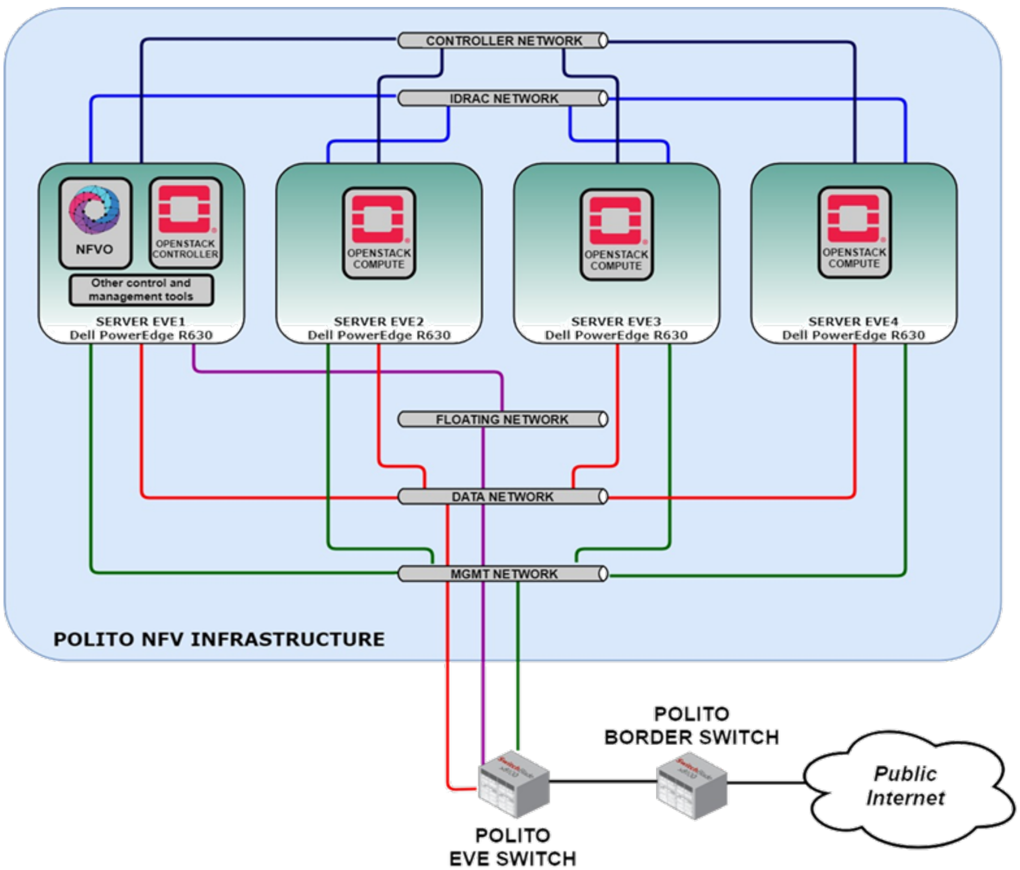

Figure 29: Close-up of the Polito NFV Infrastructure

Frequency bands

As stated in [44], the Italian site facility will use different frequencies, i.e. LTE frequencies on bands already in use by TIM (800 MHz, 1800 MHz and 2600 MHz), and new frequencies on B42 (3500 MHz) and B43 (3600-3800 MHz). The deployment and usage of these frequencies will be defined based on the results of the official frequency auction for 5G under finalization by the Ministry of Economic Development in Italy.

The above description represents a snapshot at M2 of 5G-TOURS of the on-going network setup development within 5G EVE framework and may change in the future. The network deployed for 5G-TOURS will be expanded according to the use cases definition and taking into account the availability of network equipment and terminals.

The network infrastructure will be extended in four subsequent phases, and it will include the indoor coverage and the outdoor coverage of the close surrounding areas of the following premises (see Figure 30):

- Palazzo Madama,
- Modern Art Museum (GAM)

- Edulab
- Auditorium RAI "Arturo Toscanini"

At the time of writing of this document, further coverages are currently under discussion:

- Borgo Medioevale
- Museo Pietro Micca

In the following sections, the above extensions will be identified as extension 1.

As in the TIM field 5G EVE infrastructure, the above premises will be covered by LTE layers and 5G NR NSA when available and will be interconnected with the other parts of the infrastructure. The use of Ericsson *dot* technology as indoor access points is an option, and it will be analyzed and studied in the developing of the project, as well as the details of the terminals and types of terminals to be used in those premises.

Figure 30: State-of-art and evolution of the 5G EVE outdoor TIM coverage area (with the locations of the two sites "Y"), the 4 premises considered by 5G-TOURS and the 2 (in grey) under discussion

In addition, the objective of use case 4 "High quality video services distribution" is the distribution of audio-visual (A/V) content and services to a potentially unlimited number of users, by automatically switching to the multicast/broadcast service. First, an MNO-centric approach (low-tower, low-power) will be implemented, where the content is transmitted via the cellular network in a mixed mode approach using LTE eMBMS and multicast/broadcast and unicast resources are utilized. More specifically eMBMS requires dedicated radio frames and, unless Release 14 terminals are used, unicast and broadcast cannot be multiplexed together. In order to use eMBMS, a percentage of unicast radio resources must be reserved. Subsequently, a second option will be considered, where a broadcaster's infrastructure with HPHT topology will be used to transmit receive-only content to all users at once. The above extensions will be identified as extension 3 in the following sections.

5G-TOURS activities regarding novel orchestrator solutions will constitute another extension of 5G EVE platform, which will be identified as extension 4 in the following sections.

4.1.2 Phase 1 network equipment

The Ericsson solutions is based on 3GPP Release 15 5G NSA infrastructure. The NSA architecture provides connectivity for combined LTE and NR systems, where LTE provides the control plane function while LTE and NR are used for User Plane. This 5G deployment is supported in the Ericsson Radio System and EPC solutions that are detailed in term of equipment and functions in the next paragraphs.

4.1.2.1 Radio Equipment

Ericsson radio system provides many solutions for Access Network, such as macro, street macro, micro, and indoor radios. The radios are based on state-of-the-art multi-standard technology and can operate in GSM, WCDMA, LTE, and 5G mode using FDD, TDD, as well as supplementary downlinks.

Radios are designed to be installed in cabinets, close to the antennas, or fully integrated into the antennas as Antenna Integrated Radio (AIR) units. They can be rail, wall, ceiling or pole mounted. The rail system, incorporating Ericsson's unique one-bolt installation, provides tremendous flexibility and speed, and resolves many site challenges faced by operators.

Ericsson's 5G NR RAN is part of Ericsson Radio System and a vital component of 5G Platform. NR RAN is built for multiple bands and for the RAN Compute portfolio, that consists of today's and future basebands, new radio processors, and other future products supporting NSA, as well as SA deployments. NR RAN can be remotely installed on existing Ericsson Radio System radios and enables 5G use cases implementation such as broadband and media everywhere, smart vehicles and transport, critical service and infrastructure control, critical control of remote devices, human machine interaction and sensors networks.

At current state, the equipment used to implement the NSA RAN solution in 5G EVE are:

- Ericsson NR AIR 6488 (B43)
- LTE Radio (22xx series)

As a general model of E2E solution the setup can be summarized as follows (Figure 31):

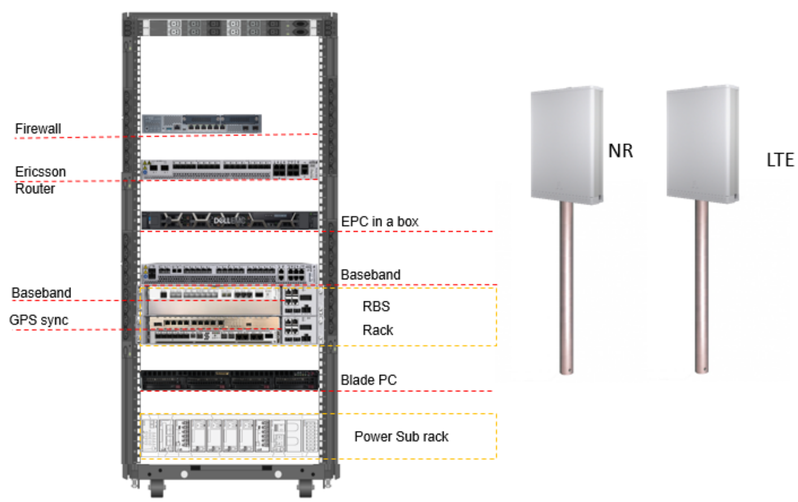

Figure 31: 5G NR general scheme

Used bands and radio models could change during the project, both due to 5G EVE changes in the solution implementation and/or for specific additional equipment needed to implement 5G-TOURS specific requirement (e.g. coverage extension to support identified use cases).

4.1.2.2 Software and Cloud Infrastructure

In Ericsson Radio System the software for radio access networks enables the smooth evolution to 5G through manageable steps in coexistence with LTE, based on components of multiple technologies, in a way that ensures flexibility and high performances. Current technologies include massive MIMO, Cellular IoT, Gigabit LTE, Machine Learning, Ericsson Spectrum Sharing, Licensed Assisted Access, 5G plug-ins and others – everything from small cells to mega-city deployments of Centralized RAN.

Ericsson Cloud Core network establishes reliable connectivity, determines the quality of service and enforces it through policy and control of traffic and applications. It supports updates to 5G Core featuring network slicing and cloud-native core network deployments.

The 5G EPC supports the NSA 5G NR delivering end-to-end 5G use cases and operates independently of access type. The 5G EVE core network supports 3GPP Option 3 (NSA), where NR devices are anchored in an LTE cell. The 5G EPC network element functionalities are implemented on virtual machines running in a blade server. In detail, the following modules are implemented:

- Virtual Mobility Management Entity (vMME)
- Virtual Evolved Packet Gateway (vEPG)
- Virtual User Data Consolidation (vUDC) (virtual Centralized User Database (vCUDB), virtual Home Subscriber Server (vHSS-FE))
- Serving Gateway (SGW)
- Packet Gateway (PGW)

Ericsson's Cellular IoT solution leverages 4G LTE and 5G NR capabilities in the four segments:

- Massive IoT (MIoT): It provides cellular connectivity to low complexity IoT devices based on Narrowband IoT (NB-IoT) and Category M (CAT-M) technologies.
- Broadband IoT: It adopts the capabilities of mobile broadband connectivity, providing much higher data rates and lower latencies than MIoT
- Critical IoT: It addresses extreme low latencies and ultra-high reliability connectivity requirements, powered by 5G NR
- Industrial Automation IoT: It is tailored for advanced industrial automation applications of global manufacturers

In the framework of 5G EVE project, IoT solutions have been deployed in the safety and environment applications such as [43]:

- Management of critical issues related to urban mobility in the corridor between Politecnico and the Porta Susa railway station.
- Monitoring the flow of people to or from the Politecnico and station, identifying the type of mobility used (pedestrian, bus, bike etc.).
- Introducing sensors that allow communication with the users (e.g., beacons) and putting them in communication with the users in the train, at the station, in the Politecnico and in the outdoors.

5G-TOURS will leverage on 5G EVE infrastructure to develop the new IoT identified uses cases.

4.1.2.3 5G-TOURS Planned infrastructure extension

At current state, the equipment needs for 5G-TOURS has two strong dependencies:

- Use case definition and detailed requirement
- 5G EVE project

So far, four main areas of development are considered from network perspective:

- Ensure 4G/5G connectivity in all trial location (indoor and outdoor).
- Capture bandwidth and latency requirements of all use cases as differentiators of 5G technologies.

- Implement a broadcast functionality, such as Ericsson LTE eMBMS (low-tower, low-power) and/or TV broadcast service (high tower, high power) solutions.
- Implement an orchestrator solution to implement slicing in the most effective way.

The above topics will be further analyzed in detail and shared with the 5G EVE project to ensure a proper network infrastructure development to capture trial requirements to be addressed by network components and needed functions.

Currently, RAN software is running on radio and baseband hardware platforms. To facilitate the growing diversity of use cases with the best possible network quality, the RAN processing platform of the future needs to support a greater deployment flexibility than what regular baseband equipment can offer. For instance, availability, cost, and quality of transport connections will have a large influence on what the best processing architecture for an operator is.

5G-TOURS evolution could embrace these concepts and consequently require more flexibility in the RAN (Phase 2). In this direction, Ericsson introduces the new “RAN Compute” in Ericsson Radio System that consists of today’s and future basebands, new radio processors, and other future products.

4.1.3 Phase 1 network KPI verification

Regarding extension 1 all the locations included in the below table will have to be covered. Regarding extension 2 the KPIs reported in Table 1, based on the current requirements, have to be satisfied by the 5G EVE testing platform (completed with the relevant extensions). Regarding extension 3, use case 4 calls for a data rate of $\geq$ 25 Mbps to be delivered via traditional PTP cellular connections, and PTM broadcast solutions by LTE eMBMS (low-tower, low-power) and/or TV broadcast service (high tower, high power). The additional PTM broadcast solutions coverage will have to enable the service delivery to the locations present in Table 1. Finally, regarding extension 4, the orchestrator will have to create, deliver and manage all the necessary slices to guarantee the service requirements for all use cases.

The use cases related to the touristic city of Turin will demonstrate the 5G technology benefits to citizens and tourists as they aim at improving the touristic experience in a city by providing visitors with (i) added value services within the visited touristic attractions, and (ii) media applications to complement their visit. More specifically, some use cases are centered on a museum, providing Augmented Reality (AR)/ Virtual Reality (VR) applications, as well as robots that serve as guides and allow for remote visits. Other use cases address media distribution and production, to provide visitors with digital content to complement their visit and produce live events to further improve the visitors’ experience. The lists of use cases and their technical requirements [3] at this stage are listed in the following table:

Use-case	Name	Customer	Location	Slice	Preliminary Technical Requirements				
					density	speed	throughput	latency	reliability
Use-case 1	Augmented tourism experience	City museums, municipalities or any touristic service provider	Palazzo Madama and its surroundings, Edulab, Modern Art Gallery (GAM), and possibly Museo Pietro Micca and Borgo Medievale	eMBB, mMTC	TBD (~tens per 1km^2)	-	200 Mbps DL and ≥ 20 Mbps UL per device	≤ 15ms E2E	99.999%
Use case 2	Telepresence	Museums	Palazzo Madama, Edulab, GAM, and possibly Museo Pietro Micca and Borgo Medievale	URLLC, eMBB	-	-	10 Mbps DL and 10- 20 Mbps UL	≤ 10 ms (bidirectional mode)	99.9999%
Use case 3	Robot-assisted museum guide and monitoring	Museums, (also hospitals, shopping malls, airports, etc.)	Palazzo Madama, and possibly GAM	URLLC, eMBB	-	-	10 Mbps DL and 10- 20 Mbps UL	≤ 10 ms (bidirectional mode)	99.9999%
Use case 4	High quality video services distribution	City museums, municipalities	Palazzo Madama and its surroundings, Turin city (~15 km^2) depending on infrastructure	eMBB	-	-	≥ 25 Mbps	≤ 10 ms (bidirectional) N/A for PTM mode	99.9999%
Use case 5	Remote and distributed video production	Media companies	Palazzo Madama and its surroundings, the RAI Auditorium "Arturo Toscanini" and location(s) in Turin TBD	eMBB, URLLC	-	-	≥ 25 Mbps (for each video)	≤ 10 ms (bidirectional mode)	99.9999%

Table 1- Touristic city phase 1 use-case requirements

The above technical requirements have to be satisfied by the testing platform. The envisioned 5G EVE capabilities are shown in Figure 32 [43]. The generic 4G and 5G capabilities are depicted along with the technical requirements of the co-located 5G EVE use case "5a – Smart Cities".

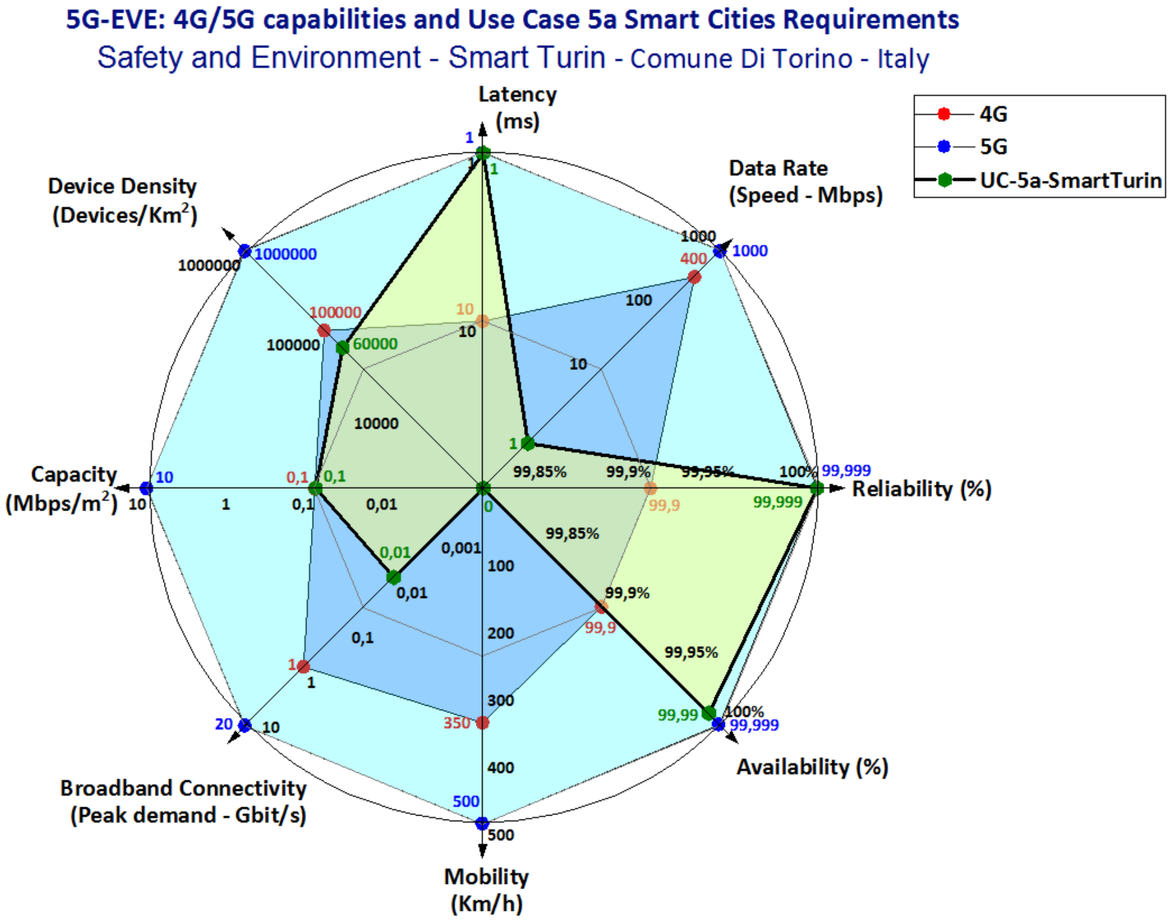

Figure 32 5G EVE network capabilities comparison with 5G-TOURS UC requirements

It can be noted that, in general, the 5G-TOURS requirements appear to be more demanding, at least in terms of throughput and reliability. Regarding the throughput requirements, which are particularly demanding for use case 1, a possible improvement could be obtained through an extension of the 5G EVE network with additional nodes (specifically for the indoors deployment). Regarding the required reliability, as values exceed those of the above figure, use cases 2-5 have to wait for the 5G networks to evolve further, e.g., by hardware redundancy, channel coding, additional nodes, or try to reduce this particular requirement. In 5G-TOURS, the most suitable solution will be investigated.

4.2 Safe City

4.2.1 Phase 1 network deployment

4.2.1.1 5G EVE planned functions

During the first year of 5G EVE, partners implemented the first site facilities and contributed to the first use case integration and onboarding according to the roadmap exposed in Section 2.1.

Documents in [43] and [44] describe the 5G EVE French site facility and planning. The French site facility is composed of a cluster of 4 nodes located in different cities. Its main feature is that it rests on two main pillars:

- The first pillar comprises a pre-commercial Nokia 4G/5G E2E network facility, composed of pre-commercial 5G platform based on open-source and inner-source products developed by Nokia Mobile Networks Business Unit (so-called “NOKIA pre-commercial platform” or Internal Friendly User Network (IFUN)) located in Paris-Saclay.
- The second pillar is mostly based on open source building blocks and distributed on several facilities interconnected by VPN, namely:
    - Plug’in platform located in Châtillon-Paris (operated by Orange): This innovative 5G platform proposes a whole framework for developing 5G components;
    - Flexible Netlab platform located in Rennes (operated by BCOM): It is a multi-tenancy dedicated environment, taking benefit from some key corporate resources, such as a private cloud infrastructure;
    - Open5Glab playground located in Sophia Antipolis (operated by Eurecom);
    - NOKIA research platform: This is a research platform based on open-source and inner-source developed in Nokia Bell Labs that relies on specific and local resources (edge and central). RAN and CORE are deployed on different platforms operated by an end-to-end service orchestration.

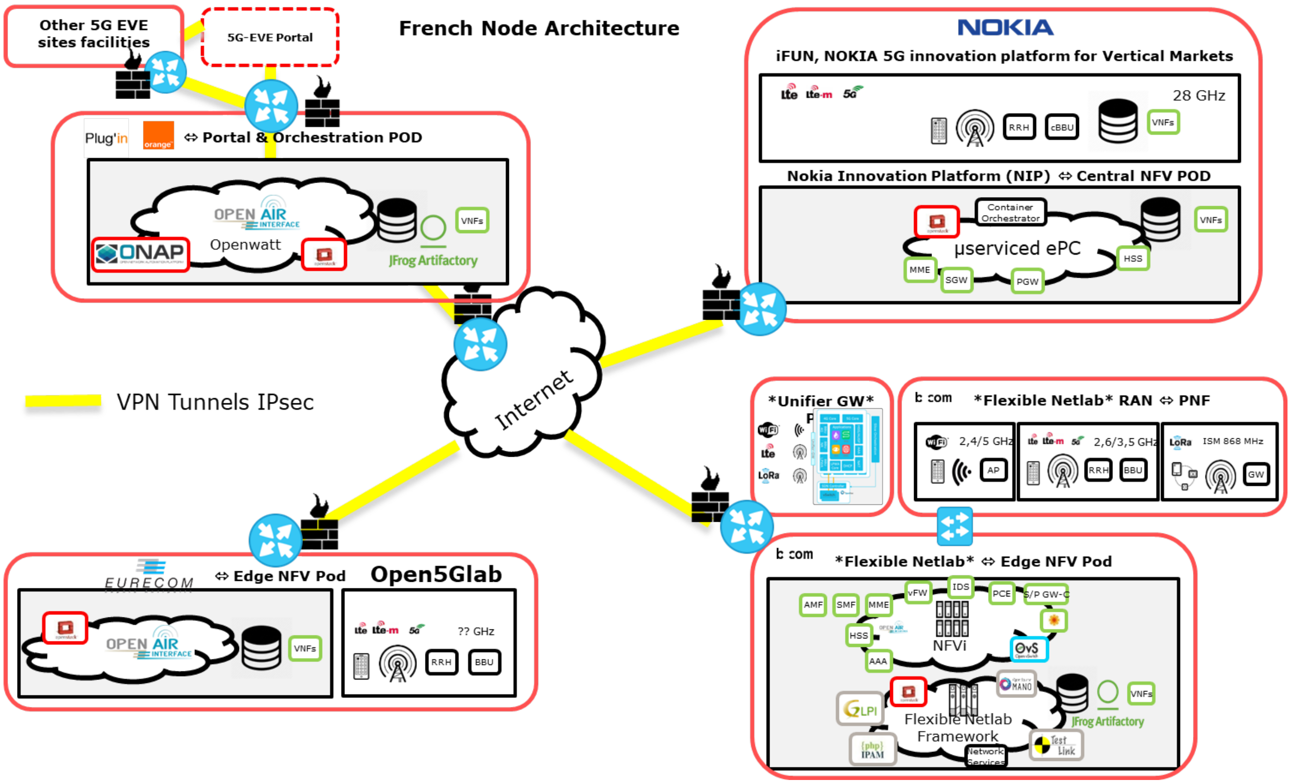

Figure 33: 5G EVE French node architecture

The four sites provide their own hardware/software resources and are viewed as cloud edge nodes being able to host the first two 5G EVE use-cases. The four sites are interconnected via L2/L3 VPN tunnels IPsec and managed via an Open Networking Automation Platform (ONAP) based orchestrator located in Chatillon and connected via its North interface to the project portal.

The telecom functions supported by EVE are reported in Table 2.

Table 2 -5G EVE end-to-end capabilities roadmap

Capabilities	Features	2019/MAY	2020/JAN	2020/JUL	2021/JAN
5G Services	**Enhanced MBB (eMBB)**	**Y**	**Y**	**Y**	**Y**
	URLLC (URLLC)	(Pre-sched)	Y(Rel-15)	Y(Rel15)	Y(Rel-16)
	Massive IoT (mMTC)	Y (LTE-M+NB-IoT)	Y (LTE-M+NB-IoT)	Y (LTE-M+NB-IoT)	Y(Rel-16)
5G Architecture Options	**Option-1 (Legacy)**	**Y**	**Y**	**Y**	**Y**
	Rel15-GNR + EPC in NSA mode		Y	Y	Y

	Rel15-5GNR + Rel15-5GC in SA mode			Y	Y
	Rel16-5GNR + Rel16-5GCore (in NSA & SA modes)				Y
5G Access Features	Flexible Numerology		Y	Y	Y
	Massive MIMO	Y	Y	Y	Y
	Multi-User MIMO		Y	Y	Y
	RAN Virtualization			Y	Y
	Latency Reduction	Y (pre-scheduling)	Y(Rel-15)	Y(Rel15)	Y(Rel-16)
Core Network	**vEPC supporting 5G**	**Y**	**Y**	**Y**	**Y**
	5GC			Y	Y
	CUPS	Y	Y	Y	Y
	SBA			Y	Y
	Interworking with LTE			Y	Y
Slicing	Network Slicing (std 5G Services: eMBB, URLLC, mMTC)		Y	Y	Y
	Service Slicing (cloud orchestration level)			Y	Y

	Multi-site Slicing			Y	Y
Virtualization	NFVi support	Y	Y	Y	Y
	SDN control		TBD	Y	Y
	Vertical Virtualized Application deployment support	Y	Y	Y	Y
Edge Computing	3GPP Edge Computing		Y	Y	Y
	ETSI MEC		(optional)	(optional)	(optional)

4.2.1.2 **5G-TOURS planned additional functions**

In this section, we discuss the planned network function deployment to support the use cases requirements as described by [3]. To support these use cases, we need to use the 5G EVE platform that provides a complete stack for declaring verticals and services as shown in [43] that will have to be respected, meaning:

- new vertical such as hospital will declare its experiment blueprints at 5G EVE portal,
- these blueprints will be interpreted inside the interworking layer and deployed over the French pilot,
- the French pilot is based on ONAP, therefore ONAP will have to deploy the experiment over the various involved locations (Nokia Paris Saclay, B<>Com, Rennes hospital).

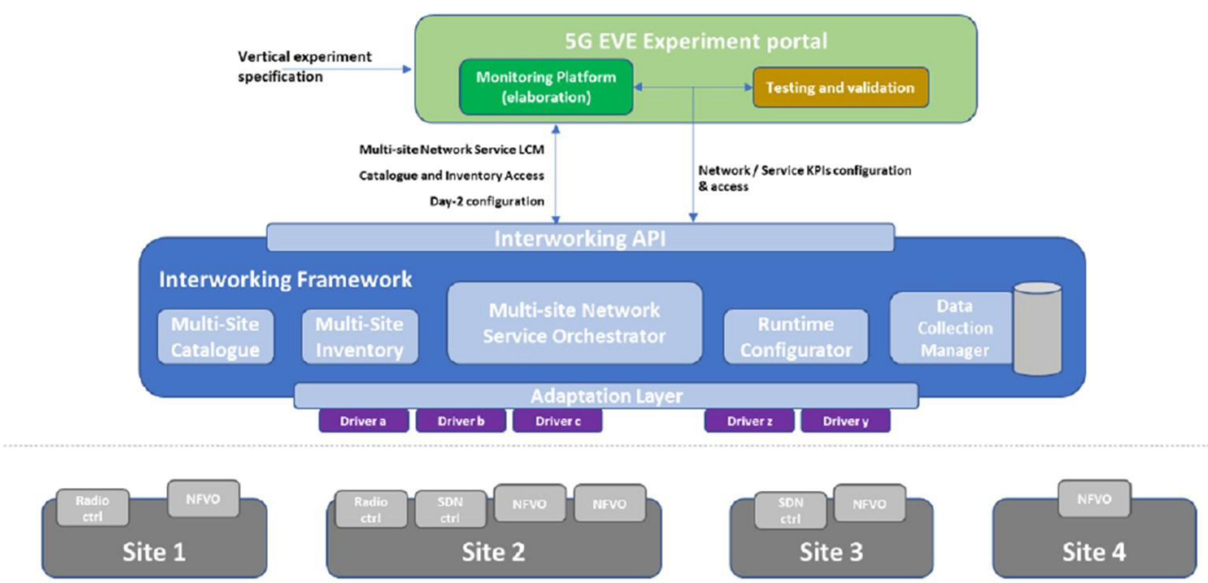

Figure 34: Interworking Framework architecture as defined in D3.1 from 5G EVE

Based on the above, the following actions need to be performed:

- New actors declaration
- New resources declaration
- New blueprint definition
- Testing

This integration within 5G EVE stack needs to be completed as 5G EVE progresses. More details on these points are also available in the 5G-TOURS Service Layer description (see Sections 3.6 and 5.4).

4.2.2 Phase 1 Network Equipment

4.2.2.1 Generalities

The network coverage is depicted in Figure 35. The left picture depicts the outdoor coverage using both external and B-Com areas (phase 1), and Rennes (phase 2), while the right picture illustrates the indoor coverage within the Rennes hospital. Two frequencies will be used, at 2.6GHz and 26GHz, pending authorization from the French regulation authority.

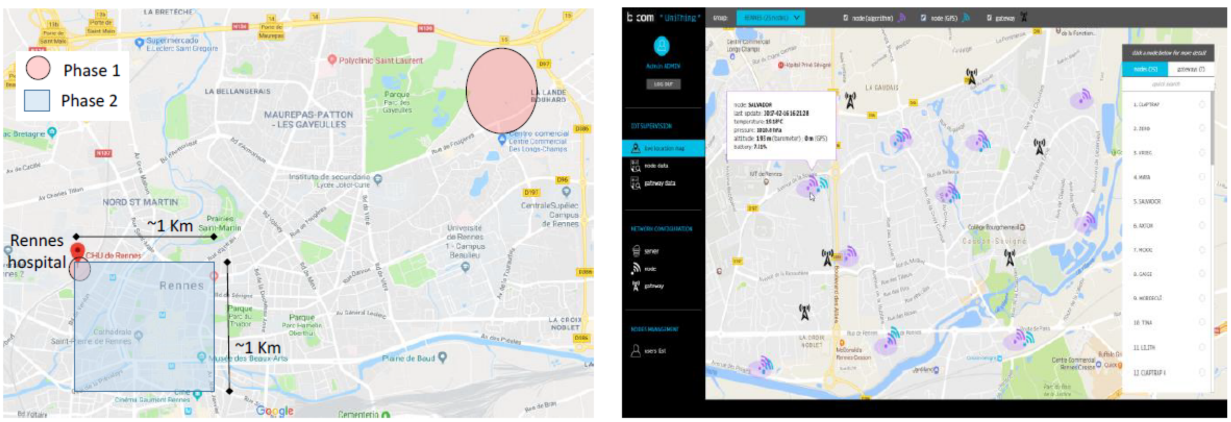

Figure 35: 5G EVE coverage in Rennes

The required infrastructure deployment[2] are listed below.

Equipment	Requirement
Base stations	• Small cells indoor at Rennes hospital • Outdoor at BCom & TDF • Outdoor city (phase 2)
Terminal devices	• Few mobile terminals • 10s of sensors
Area covered	• BCom office (0,5 km^2) • Rennes Hospital and surroundings (200m x 200m) • Rennes city (phase 2) •
End-user equipment	• E-health products • AR glasses (5)

[2] NB: Equipment related to telecom vendors are highlighted in blue.

	• Wearables (10) • Patches (10)
End-users	• Hospital staff • Simulated patients
Network equipment	• Release 15 and evolutions
Type of coverage	• Indoor • Outdoor

Table 3- Safe city phase 1 infrastructure requirements

The general considerations for the integration can be summarized as follows:

- New radio sites must be added (Rennes hospital, BCom, TDF),
- New connectivity resources need to be added between new and old sites,
- New computing resources must be added on those sites (Rennes hospital) or added to existing sites (Bcom, Nokia Paris Saclay, Orange).
- It is also clear that new telecom functions must be added (e.g. localized UPF).

Different architectural options are considered with:

- separation of User Plane and Control Plane functions to optimize traffic throughput
- co-hosting applications
- support of 5G NSA

Some additions to the 5G EVE baseline platform have to be done, as listed below:

- Addition of new radio sites,
- Addition of new transport and compute resources,
- Addition of new telecom functions,
- Integration within the 5G EVE service stack.

4.2.2.2 Radio Equipment

Currently, the precise details on the radio equipment that will be used in the two trials location (BCom & TDF and Rennes Hospital) cannot be disclosed. However, there are ongoing discussions regarding the details of the deployment in the Rennes Hospital, where Nokia Airscale small cells will be used. The frequency and the power used by this deployment will also be defined in the subsequent deliverables of this Work Package, as they depend on commercial availability and the Nokia product line roadmap.

4.2.2.3 Transport resources

We expect the need to interconnect the following sites:

- Rennes hospital to BCom
- Rennes hospital to Nokia Paris Saclay
- Rennes hospital to Orange

These connections are supposed to be VPN over Internet. Actual requirements will be decided in due course, and will depend on the:

- actual application requirements,
- deployment options in terms of User Plane Function (UPF) and Control Plane Function (CPF).

Note that BCom and Orange are already connected, as well as Nokia Paris Saclay and Orange (both of them through the 5G EVE infrastructure).

4.2.2.4 Software and cloud resources

The following places need to provide computational resources:

- Rennes Hospital
    - for supporting local functions
    - hosted within or nearby the hospital premises
- B-com
    - for supporting CORE functions
    - hosted in Flexible Netlab
- Nokia Paris Saclay
    - for supporting CORE and SERVICE orchestration
    - hosted in Nokia Innovation Platform

- CORE CPF functions to be deployed in BCom (Wireless Edge Factory), Nokia (Nokia Innovation Platform) or Orange (Plug'In),

- CORE UPF functions to be deployed in Rennes hospital.

4.2.3 Phase 1 KPI verification

This section describes how expected requirements will be covered.

Use-case	Name	Customer	Location	Slice	Preliminary Technical Requirements					Completion
					density	speed	through-put	latency	reliabil-ity	
Use case 6	Remote health moni-toring and emergency situation noti-fication	Hospital: wearables & patches for health moni-toring	Hospital + Bcom.TDF (phase 1), Rennes (phase 2)	mMTC, URLLC	Several devices / m2	-	-	<10ms	>99.99%	Partial: com-plete tests in Rennes Hospi-tal, partial in Bcom/TDF
Use case 7	Teleguidance for diagnos-tics and inter-vention sup-port	Hospital: re-mote treat-ment & diag-nosis, smart glasses	Hospital (phase 1), Rennes (phase 2)	URLLC, eMBB	-	>100km/h	>2Gbps	<10ms	>99.99%	Partial: static tests in Rennes Hospital
Use case 8	Wireless op-erating room	Hospital: AR & cobotics assisted sur-gery, smart glasses	Hospital	URLLC, eMBB	>10Gbps, latency < 5ms, reli-ability > 99.99%	-	>10Gbps	<5ms	>99.99%	Possible
Use case 9	Optimal am-bulance rout-ing	Hospital	Hospital (phase 1), Rennes (phase 2)	mMTC		>100km/h				Partial: static tests in Rennes Hospital (park-ing)

Table 4- Safe city phase 1 use-case requirements completion

As can be seen, the main limitations of phase 1 are due to:

- incomplete coverage (phase 2 will provide completion),
- limited number and type of slices.

4.3 Mobility-efficient City

4.3.1 Phase 1 network deployment

The phase 1 network deployment in the mobility-efficient city will largely rely on the 5G EVE Greek site infrastructure. In this section, a more detailed description of 5G EVE planned functions is given (according 5G EVE roadmap), along with an introduction of preliminary add-on specific for 5G-TOURS.

4.3.1.1 5G EVE Planned functions

The Greek 5G EVE site infrastructure will cover a region of northern Athens, around the R&D site of the Greek National Telecommunication Organization (OTE). The OTE site serves as a testing ground for services, equipment, and new features prior to their commercial release (including [pre-] 5G equipment), while it also maintains a connection to the commercial 4G+ network of OTE. The existing equipment and network functionality consist of Nokia technologies, which will be progressively extended to support 5G during the lifetime of the project. The architecture of the 5G EVE OTE-NOKIA GR platform that will be used during the 5G-TOURS project is the following (exemplified in Figure 36):

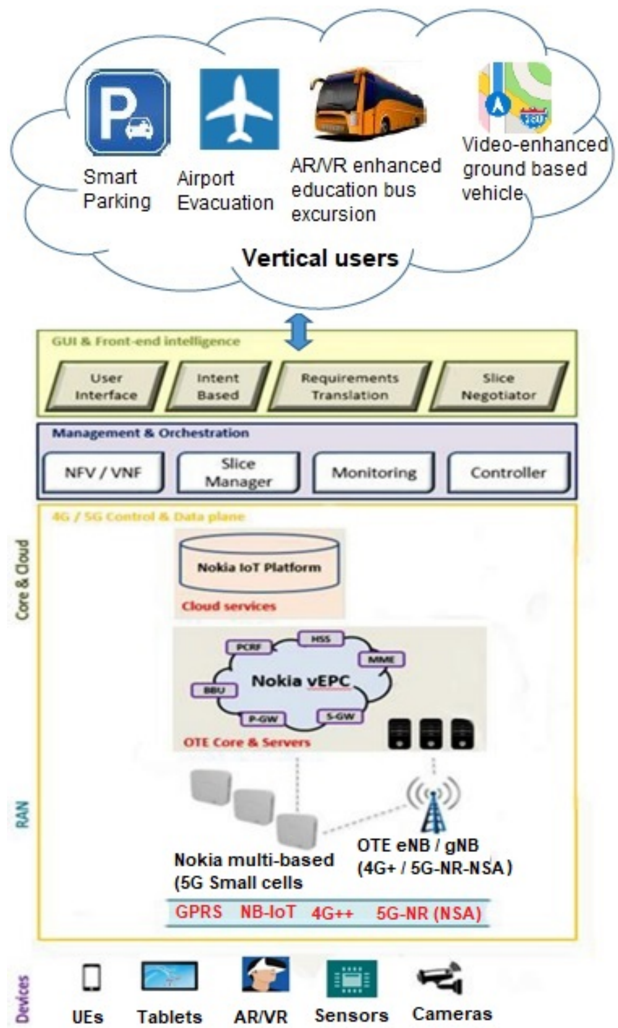

Figure 36: Architecture of the 5G EVE OTE-NOKIA GR platform

4.3.1.2 5G EVE extended functions

OTE, in conjunction with Nokia GR are responsible for preparing and upgrading the 5G EVE Greek site infrastructure to cover the area of Athens International Airport (AIA) at the Spata area of Attica, in order to be able to handle the four 5G oriented vertical use-cases Figure 36, namely:

- Use case 10 – Smart airport parking management
- Use case 11 – Video-enhanced ground-based moving vehicles
- Use case 12 – Emergency airport evacuation
- Use case 13 – Excursion on an Augmented Reality (AR)/Virtual Reality (VR)-enhanced bus

Note that the airport deployment covers a substantially large area (around 5 Km^2), as it needs to cover not only the airport building, but also the outer area for some of the use cases. The current deployment covers about 0.5 Km^2 and is expected to increase substantially with the roll-out of commercial 5G deployments, allowing for transportation-related use cases. The areas covered by these deployments are depicted in Figure 37.

Figure 37: Coverage area at the AIA (left) and in Psalidi (Northern Athens, right)

For the implementation of the four use cases the following deployments are considered:
<u>UC10:</u> NOKIA GR will install antennas (5G Multi-band small cells) to cover approximately 3-5 Km^2. NOKIA GR will also install antennas (5G Multi-band small cells) to cover the internal area with 5G network. AIA will offer the facilities (parking, building, servers, etc.). The existing 5G EVE 4G/5G facility of OTE will be used (Nokia vEPC), with connection to OTE's core network. For about 100 parking spots, a corresponding number of sensors and chipsets will be installed by WINGS and Sequans.

<u>UC11:</u> Two follow-me cars will be used by AIA. Cameras and 5G routers will be installed on the cars by AIA and Samsung. Instead of IP cameras, Samsung mobile phones can be used. In cases of emergency, online video streaming has to be sent via a server of AIA to the police, ambulances and fire brigade operational centers. Coverage will be needed for an area of ~3 Km^2. Reliable connection is needed for all the Use Case area. Web based live video streaming is also needed.

<u>UC12:</u> The demo area for the UC11 is approximately 300 – 400 m^2. Mobile smart phones or tablets will be used for receiving evacuation instructions. SIM cards or eSIMS will be provided by OTE.

<u>UC13:</u> Concerning the UC13 for a number of 20-25 students, a corresponding number of AR/VRs devices (headsets) and tablets will be provided by Samsung. Also, a corresponding number of SIMs will be provided by OTE. Outdoor/indoor 5G coverage is also needed. The bus route will also be considered (scenario A: moving bus). Education will be covered in an AIA internal area (scenario B).

The current 5G EVE Greek site facilities are being updated during the fourth quarter of 2019 to Release 15. New antennas (indoor/outdoor), as well as the corresponding equipment will be installed at the AIA area in order to support the 5G-TOURS use cases for the project lifecycle.

4.3.2 Phase 1 network equipment

This section describes the 5G EVE planned infrastructure, as well as preliminary additional 5G-TOURS infrastructure.

The equipment deployed via 5G EVE implementation will consist of Nokia platforms and components for the RAN and core networks, as well as management and orchestration functionality. Additionally, for the core network, OTE will provide an alternative solution based on Athonet.

For the purposes of 5G-TOURS, new antennas (indoor/outdoor), as well as the corresponding equipment will be installed at the AIA area, in order to support the relevant use cases of the project. The orchestration solutions developed by 5G-TOURS will be used in the second phase of the project. For the IoT equipment, STARLIT (WINGS' IoT platform) will be primarily used, while Nokia's IoT platform will complement the required functionality when needed. Below, we describe the equipment that will be available during the first phase of the project in the Athens site, which will be updated further during the progress of the project.

4.3.2.1 Radio Equipment

Currently 5G EVE's infrastructure consists of Release 14 radio. Based on 5G EVE's roadmap upgrade to 5G is planned within November 2019. Nokia Airscale is a radio access network with the hardware and software to prepare the way for the IoT and 5G future. Nokia Airscale Radio Access includes the following elements:

- Nokia AirScale Base Station comprising single, dual and triple band radio units, and indoor/outdoor system modules
- Nokia AirScale Active Antennas (Compact Active Antennas, as well as massive MIMO Adaptive Antennas)
- Nokia Airscale Cloud RAN
- Nokia Airscale WiFi

It is also noted that with AirScale, it is possible to deploy 5G service on existing LTE bands, as well as new bands, such as millimeter Wave (mmWave). An indicative AirScale radio access deployment is illustrated in Figure 38. Depending on the use case and the transmitted power needs, AirScale is able to support either LTE or 5G interfaces.

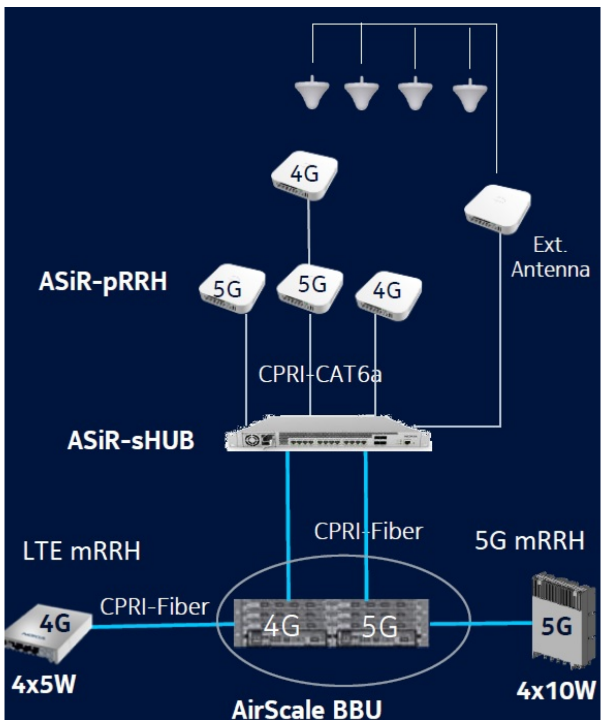

Figure 38: Nokia AirScale Radio Access Elements

4.3.2.2 Software and Cloud Infrastructure

The Software and Cloud Infrastructure consists of Release 14 Mobility Management in Cloud Architecture (CMM), Cloud Mobility Gateway (CMG) which provides access in subscriber user plane (5G upgrade is to be finalized by November 2019), and the CLI administration/configuration interface to CMM. The CMM VNF is a virtualization of the Mobility Management Entity (MME and Serving GPRS Support Node (SGSN) network functions. Functional behavior the same as with non-virtualized nodes. CMM VNF is composed of multiple internal components (VNFCs).

4.3.2.3 Network Connectivity

The Nokia IoT platform interoperates with network equipment from a variety of network vendors, and is agnostic of the network connectivity, supporting a variety of technologies, including 3G, 4G/LTE, and Wi-Fi. A number of low-power wide area network (LPWAN) connectivity interfaces are also available, including NB-IoT (licensed) and LoRA (unlicensed).

4.3.2.4 5G-TOURS Planned Infrastructure Extension

The mobility efficient city involves indicative use cases that span all three basic service types (eMBB, mMTC, URLLC), as well as combinations of them. These use cases will rely on a common basic network infrastructure, comprising of a RAN solution, a transport solution, and a Cloud Packet Core (vEPC and/v5GS) with components compatible to the MANO ETSI architecture, in order to support network management, orchestration, virtualization and slicing in accordance to the needs of each use case.

To reliably support all use cases that will be showcased in the Athens node, the infrastructure must offer slicing mechanisms, which in turn may entail different RAN requirements, e.g. different number of base stations/antennas, different type of antennas (indoor, outdoor), or different scheduling and resource allocation mechanisms. These (and many more) open issues will be shaped to comply with the technical aspects and requirements of the diverse use cases.

Mobility-efficient city trial will be built on Nokia's cutting-edge products. Nokia Airscale radio access solution enables support for NSA 5G NR technology, making it possible to deploy 5G service on existing LTE bands, as well as new bands, such as mmWave. It includes Nokia AirScale Base Station, Nokia Air-Scale Active Antennas (Compact Active Antennas, as well as massive MIMO Adaptive Antennas) and Nokia Airscale Cloud RAN. Based on current estimations three NSA 5G indoor/outdoor antennas are needed to fulfill the requirements of 5G-TOURS' use cases that will be implemented in three buildings at AIA, as shown in Figure 39. Figure 39indicates the area of airport that will be used for the Athens' use cases, and the areas marked with black indicate the buildings that will be used for the implementation of the use case. Nokia's CloudBand Network Director & Application Manager, which is a Nokia solution for MANO and NFV management, will be also used. For the purpose of Virtualized Infrastructure Manager (VIM), Nokia's Cloudband infrastructure software will be used, built on OpenStack. This solution can virtualize and manage computational, storage, and network resources. It also enables VNFs to run, and ensures that they meet strict robustness, performance, and security requirements. Concerning specific network functions, Nokia's Cloud Mobility Management / Cloud Mobility Gateway, will be used. This solution includes edge-cloud capabilities, enabling cloud RAN. The solution comprises compact size hardware, real-time and low latency optimized infrastructure software, and pluggable acceleration modules enabled by specific processing acceleration technologies. Furthermore, virtual EPC will be also available by OTE's Athonet platform, which provides a complete software-based mobile EPC that includes an HSS, Voice-over-LTE (VoLTE), and LTE Broadcast (eMBMS). This mobile core solution can be deployed in fully virtualized environments (NFV), enterprise data centers or standard off-the-shelf servers.
Furthermore, Nokia IoT platform will be upgraded to support traffic via a 5G network within December 2019.

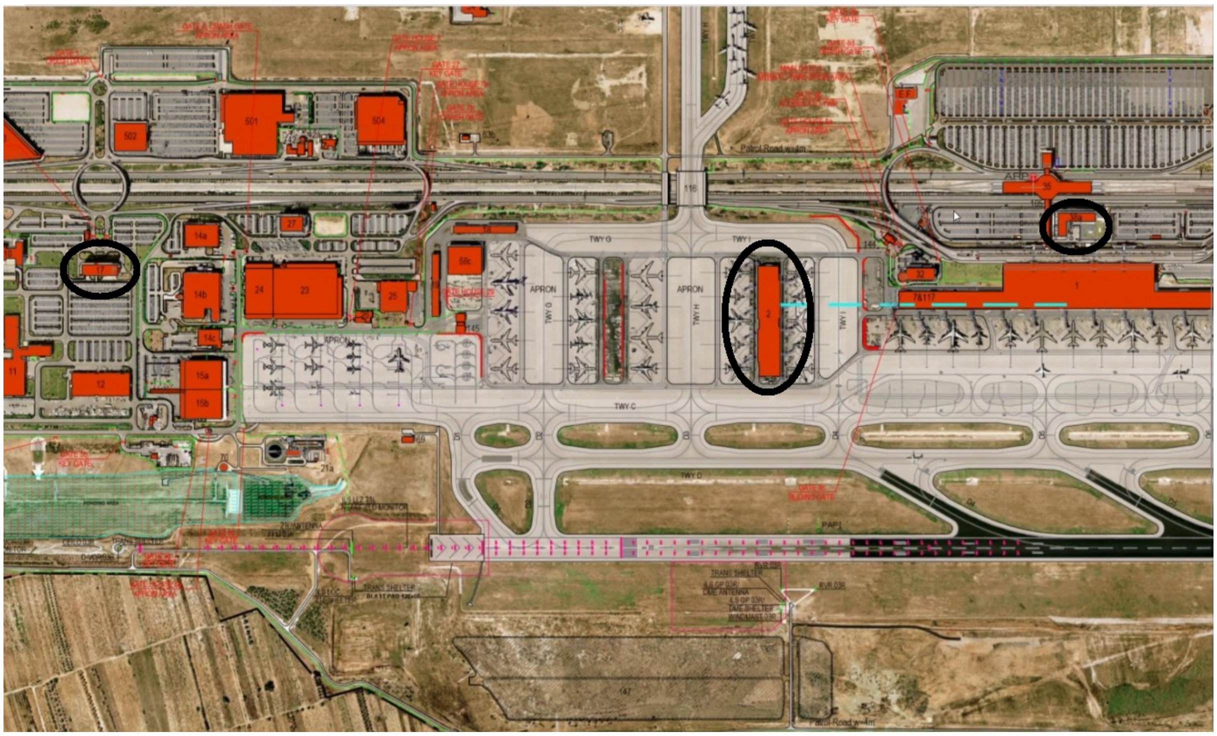

Figure 39: RAN coverage of AIA (top view)

The aforementioned infrastructure will support the Athens' node use cases, and is expected to satisfy the indicative system requirements summarized in Table 5.

Use Case Name	Slice Type	Preliminary Technical Requirements				
		density	speed	throughput	la-tency	reliabil-ity
Use case 10 Smart airport parking management	MTC/ mMTC	~ 100 devices that will cover the entire demo area	Low to moderate	Low data rate per device	< 1 sec	>99.99%
Use case 11 Video-enhanced ground-based moving vehicles	eMBB	Few tens of video sources	<= 100 km/h	25 Mbps in uplink	<10ms	>99.99%
Use case 12 Emergency airport evacuation	URLLC	Several users per m2	low	few Mbps in D/L	<10ms	>99.99%
Use case 13 Excursion on an AR/VR-enhanced bus	eMBB	-	<= 100 km/h	500 Mbps	<10ms	> 99.99%

Table 5- Mobility-efficient city use cases system requirements

All the values are aligned with the ones reported in [3]. For UC12 in particular, a location accuracy in the order of 1 meter is also expected.

4.3.3 Phase 1 network KPI verification

Accurate and effective testing, for service and network KPI measurement and validation, will be introduced, in order to verify the expected level of network quality in 5G EVE, as well as 5G-TOURS. ACTA's KPI validation platform (KVaP) via the use of network probes, positioned in key interface parts of the end-to-end network, will accumulate appropriate parameter metrics at various points of the live network. The measurements will be transmitted and stored to a cloud server for further processing. These measurements relate to latency, reliability, data rates, and other measurements, that are essential in validating the network KPIs. Furthermore, the large amount of data will be analyzed and presented in a user-friendly format, in order to identify possible weak points and undertake corrective actions for network optimization and performance improvement. The last two pointes eventually lead to improved end-user experience and service acceptance.

5 5G-TOURS Implementation plans

In this section we describe how specific software modules that will populate the 5G-TOURS software ecosystem will be implemented, also according to the specific timeline discussed in Section 4.

5.1 Enhanced Management and Orchestration

In order to accommodate the demands of the specific use cases envisaged in 5G-TOURS, an enhanced network slice management and orchestration (MANO) framework will be designed, developed and validated in order to deliver the heterogeneous requirements of the different applications, in a most efficient manner, as described in Section 3.3 of this deliverable. The 5G-TOURS enhanced MANO will be implemented with OSM [45] leveraging on the MANO solution developed by the 5G-MoNArch, and will interoperate with the underlying 5G platform, by exploiting the standardized interfaces provided by the equipment to this end and on the MANO framework of 5G EVE, which is also based on OSM for some of its sites. As a matter of fact, 5G-MoNArch based its implementation of the Touristic City Testbed upon an OSM platform [46]. Other solutions such Cloudify [47] and Open Network Automation Platform (ONAP) [48]could also be investigated and validated. Cloudify, which is a single open source, end-to-end platform designed to transform network services and applications, connect branches, deploy and manage multi-access edge and IoT devices, break down silos and deliver all services on-demand – automatically, at scale, could be used to manage resources on the edge. On the other hand, ONAP provides a unified operating framework for vendor-agnostic, policy-driven service design, implementation, analytics and lifecycle management for large-scale workloads and services, such as 5G, BBS, Cross domain and Cross layer VPN (CCVPN), vCPE, VoLTE, and more. With ONAP, network operators can synchronously orchestrate physical and virtual network functions. This approach allows operators to leverage existing network investments; at the same time, ONAP's openness and ubiquitous acceptance in major networks will accelerate the development of a vibrant VNF ecosystem.

In order to orchestrate a network slice that meets the requirements of the 5G-TOURS vertical customers, orchestration algorithms, like those devised by the 5G-MoNArch project [49] will be used, after being enhanced and adapted to the 5G-TOURS specific environment and requirements. These algorithms select the most appropriate location (physical infrastructure elements) for the different VNFs instantiated for a network slice, including the ones corresponding to application layer functions. The infrastructure can encompass MEC capabilities. The algorithms take as input from the underlying infrastructure the resource availability in the different nodes of the network and interact with the AI-based data analytics module to reach optimal decisions. Based on the output of the orchestration algorithm, the end-to-end service orchestrator instantiates the network slice as follows:

- Issues the corresponding requests to the SDN Controller to instantiate connections between the different network nodes,
- Requests the Virtualized Infrastructure Manager (VIM) to reserve the virtual resources at the different network nodes,
- Commands the Virtual Network Function Manager (VNFM) to instantiate the VNFs, and
- Configures the Physical Network Functions (PNFs) and VNFs.

The enhanced Management and Orchestration framework which will be developed in 5G-TOURS will benefit from the resource elasticity concept of 5G-MoNArch [49] (inherent and elaborated also in various network management research and development activities, as well as in the context of cloud infrastructures). Elasticity is an essential feature of a system, in order to respond to changes in the traffic demand, e.g., due to changing patterns and mobility Elasticity mechanisms adapt the resource allocation to load changes, in an automatic manner (and also by potentially exploiting artificial intelligence mechanisms), such that at each point in time the available resources match the demand as closely and efficiently as possible. This implies that, for a relatively small variation in the amount of resources available, the operation of the service should not be disrupted. The focus is on the elasticity of computational resources in addition to the communications resources. Such a feature is highly desirable for the 5G-TOURS use cases (health, mobility, content-related), based on eMBB, as it can help to minimize the cost of the required network deployment, thus contributing to meet the economic KPIs identified in the scope of 5G-TOURS project.

Elasticity in 5G-TOURS will be addressed from an orchestration scope as follows: (i) orchestration-driven elasticity achieved by the flexible placement of VNFs, and (ii) slice-aware elasticity via cross-slice resource provisioning mechanisms. Providing orchestration-driven elasticity means increasing the orchestrator's flexibility with respect to VNF placement decisions. This aspect impacts also the need for end-to-end cross-slice optimization, as provided by the slice-aware elasticity. That is, multiple network slices deployed on a common infrastructure can be jointly orchestrated and controlled in an efficient way while guaranteeing slice isolation and resource allocation per slice's SLA. Note that these two elasticity dimensions are not mutually independent; on the contrary, they can be combined to boost performance.

As mentioned above, in the design of an elastic management and resource orchestration solution we envision a very prominent role for AI, as a tool to enhance the performance of elasticity algorithms. Some examples of performance boosting capabilities that could be provided by AI techniques are the following:

- Learning and profiling the computational utilization patterns of VNFs, thus relating performance and resource availability,
- Traffic prediction models for proactive resource allocation and relocation,
- Optimized VNF migration mechanisms for orchestration using multiple resource utilization data (CPU, RAM, storage, bandwidth), and
- Optimized elastic resource provisioning to network slices based on data analytics.

In summary, powerful mechanisms will be developed for the management and orchestration, in order to deliver the services with utmost efficiency for 5G.

5.2 AI-based Data Analytics

When dealing with large-scale deployments such as those addressed by 5G-TOURS trials, intelligent automated mechanisms for decision making are needed to support the network management processes. This includes the orchestration of a range of lifecycle management processes as well as the coordination of complex systems of applications, cloud, transport and access resources. Moreover, verticals may also need certain knowledge for the proper tuning/shaping of their services.

Regarding the network management decisions, due to the high number of input parameters involved in large-scale deployments, devising algorithms that optimize, in real-time, taking into account all the potential parameters is complex. The application of machine learning techniques is a straightforward choice to this end. The 5G-TOURS AI-based Data Analytics framework will be able to leverage on past knowledge in order to forecast: (a) the requirements of services given the capabilities of the network in real-time; (b) efficient, with respect to the resource consumption, ways of satisfying the demand / coping with requirements; (c) propose explicit configurations, (d) enforce policies in the network or a subsystem, (e) optimize each subsystem autonomously, (f) adapt and tune the network performance in real-time and (g) detect potential security issues that may arise in the network.

Regarding the vertical part (supporting health, mobility, safety, and, ultimately, further touristic related operations) there is need for machine learning mechanisms, e.g., when/where to offer service features, taking into account the network capabilities. In the light of the above 5G-TOURS will cover both requirements identified above, through the AI-based Data Analytics component/framework which will follow the modularized system architecture of ETSI ENI as mentioned in Section 3.4 of this deliverable. The Service layer will interact with the intent-based interfaces developed already within 5G EVE, which will be enhanced and used for enabling the specification of service requirements through high level terms. So, the AI-based Data Analytics will be affected by requirements at some point delivered through the intent based mechanisms. A more detailed view can be found in Figure 40 below:

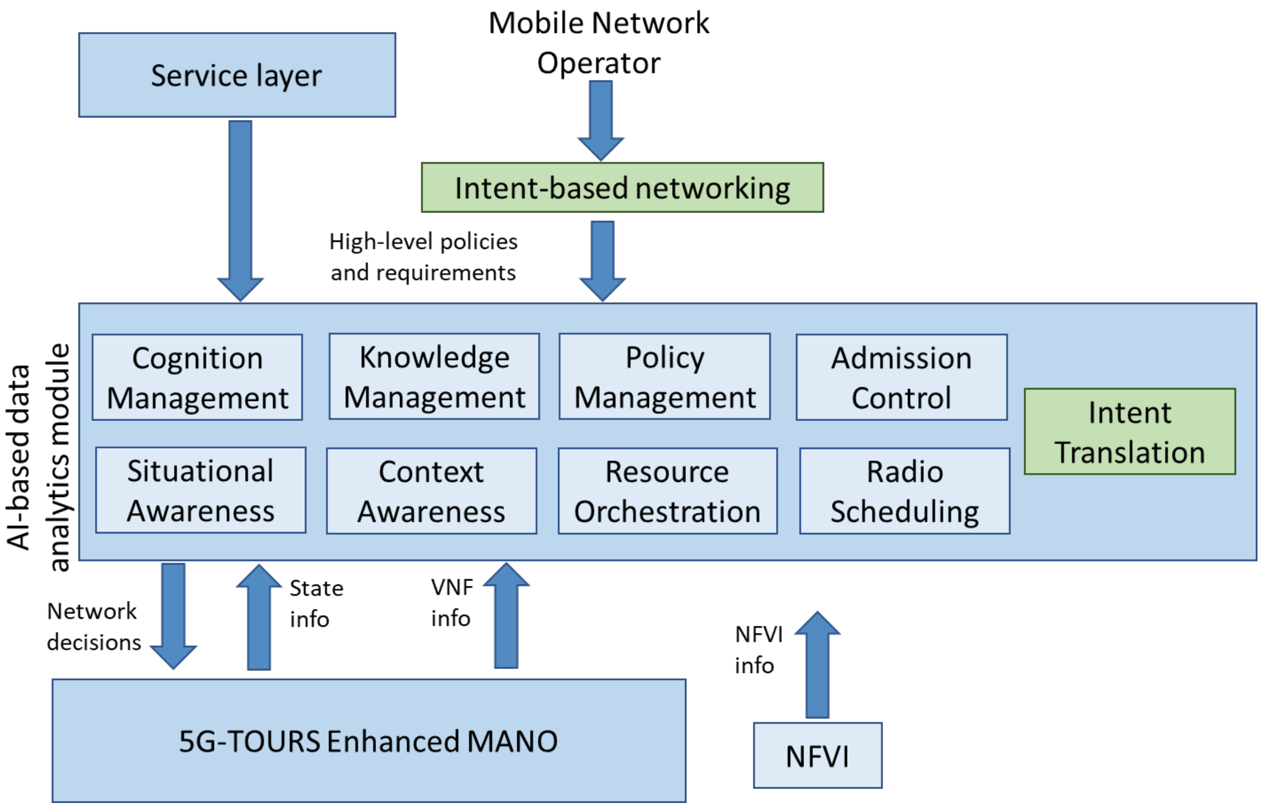

Figure 40: Initial Implementation strategies for the Ai-Based Data Analytics framework in 5G-TOURS

In summary, 5G-TOURS aims to provide a concrete implementation of data analytics module, paying particular attention to the specific needs of the vertical customers involved in the project, and as well to those of the network operator.

5.3 Broadcast Support

The broadcast capability is enabled in Turin site, the support follows a stepwise approach in the deployment of a system that enables broadcast capability. Each step provides additional capabilities as well the involvement of more evolved equipment's.

The first step is to integrate the LTE Broadcast components with existing commercial devices and software into 5G EVE testbed as a baseline as shown in Figure 41. Ericsson provides the LTE system including both EPC and RAN (AIR6488 base stations) that supports broadcast. Expway provides the terminals as well as the core network equipment's to enable broadcast. The terminals could be the commercial Bittium or Samsung phones having Expway's middleware installed. The broadcast core network equipment's (the BM-SC and MBMS-GW) provided by Expway are integrated into Ericsson's LTE system. All components will be deployed at Turin node managed by Telecom Italia.

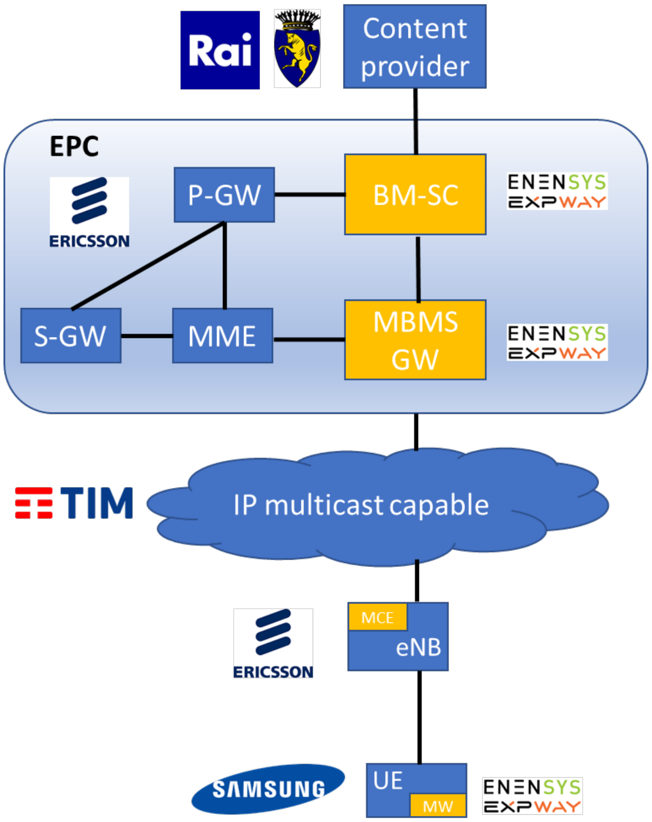

Figure 41: 5G-TOURS baseline broadcast architecture in Turin

The second step is to evolve the Turin node to the 5G NSA (Non-Standalone Architecture) implementation with Option 3X where the LTE EPC connects to both LTE RAN supporting eMBMS and 5G-NR RAN as shown in Figure 42 The 5G NSA Option 3X allows the terminals to benefit from 5G NR in normal operations while switching to LTE broadcast if they consume a popular content as defined in the use cases [3].

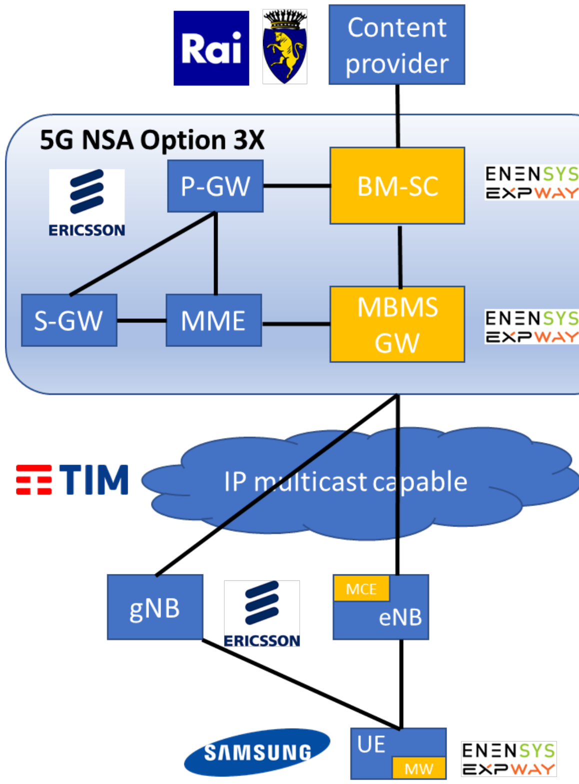

Figure 42: 5G-TOURS 5G NSA Option 3X

The third step is to evolve the testbed to 5G Standalone Core where the 5GC connects to both LTE eMBMS RAN and 5G NR RAN. Since this step involves the 5GC supporting broadcast, the broadcast network functions (NF) developed in 5G-Xcast project will be implemented and integrated into the 5GC. The development and implementation of the 5G broadcast NFs shall follow the standardization evolution in 3GPP.

The fourth and final step is to evolve the testbed in a full 5G system supporting broadcast in both 5GC and 5G NR Broadcast RAN prototype.

The first two steps are feasible during the project lifetime. These two steps are the target to achieve at the end of the project. The third step depends on the standardization evolution or progress in 3GPP, especially whether broadcast is enabled in Release 17. In addition, this step depends also on the development plan of the 5GC in Turin site. The fourth step can be considered as a possibility for a Proof of Concept if broadcast is fully enabled in 5G including both core network and RAN during the project execution.

5.4 5G-TOURS Service Layer

As discussed in Section 3.6, the implementation of the Service Layer should start with an assessment of the current state of the software in terms of feature completeness and stability. Then, the first extension should be the SLA management framework, as it will require the most development. This extension includes the following steps:

- Designing the API to send intents to the AI-based analytics module.
- Choosing a formalism for the clients to express their SLAs at the northbound API.
- Writing the mechanism that translates the northbound SLA into a set of intents matched to the performance increments specified in the slice NSD sent to the Orchestrator.
- Extending the GUI to support SLA specification in the design of a network slice

The next step will be to extend or replace the monitoring module to make use of the KPI gathering capabilities of the new analytics module. At this stage, a decision should also be made on whether a monitoring GUI is required, or whether the monitoring information should only be provided to the customer though the northbound API. In this case, the Service Layer needs to provide KPI monitoring to the vertical customers, so that they can check whether their requirements are met and analyze the performance of their service. These KPI will be gathered by the analytics framework and displayed in the Service Layer GUI. They will also be made available through the northbound API of the Service Layer.

Both 5G EVE [50] and the 5G-Transformer Vertical Slicer use the publish/subscribe mechanism for their monitoring operations, thus it would make sense for the analytics module to use the same paradigm. This would allow for the integration of the monitoring module in the Service Layer in the two following ways (Figure 43):

- Replace the monitoring module of the Vertical Slicer with the one from the analytics module, and plug that directly to the monitoring system of the 5G EVE Interworking Framework through and *ad hoc* translation layer,
- Keep the Vertical Slicer monitoring module and add the analytics module as a middleware between that and the Interworking Framework. This leaves more flexibility to store backups of the collected data or configure what data the customer is allowed to retrieve.

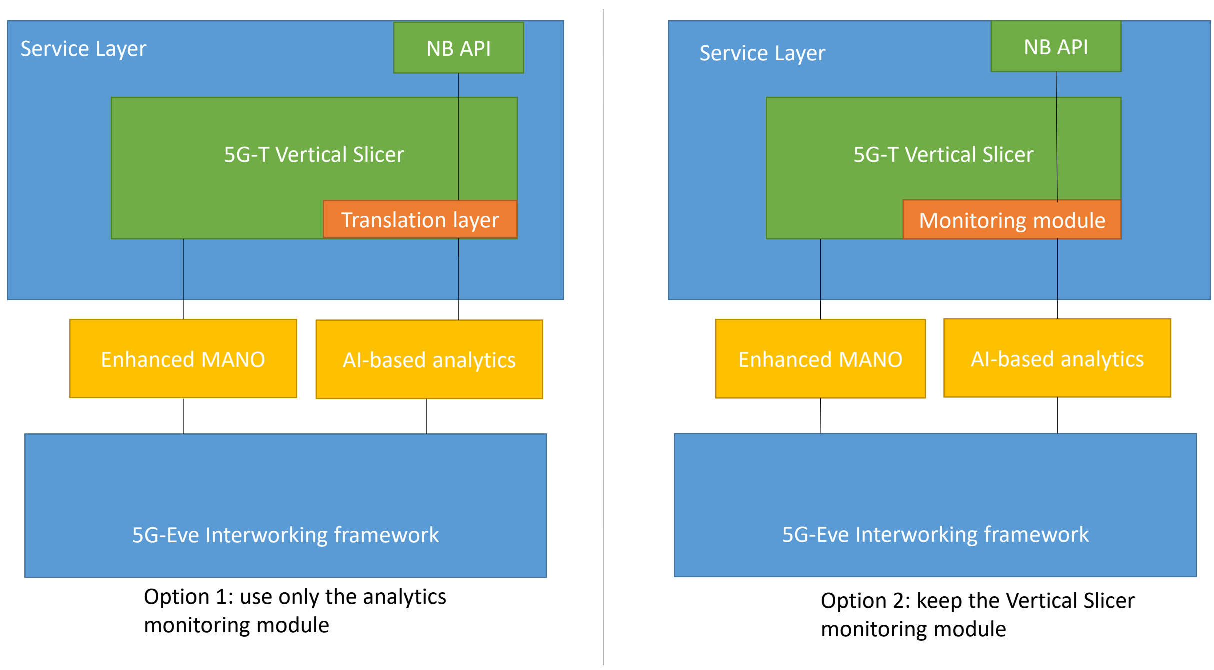

Figure 43: Options to implement the monitoring guide

5.4.1.1 Northbound Web-based GUI

All the functionalities offered by the Service Layer should be accessible either through the GUI or through a northbound API offered to the OSS/BSS system of the customer. For the GUI implementation, we can reuse the Network Slice Manager GUI from the 5G-Transformer project.

The Network Slice Management will require extensions to allow the customer to define their SLAs in a standardized manner when they define a slice. If the option of displaying the monitoring information gathered by the analytics framework is chosen, a dedicated GUI like Grafana [51] should be added to the Service Layer.

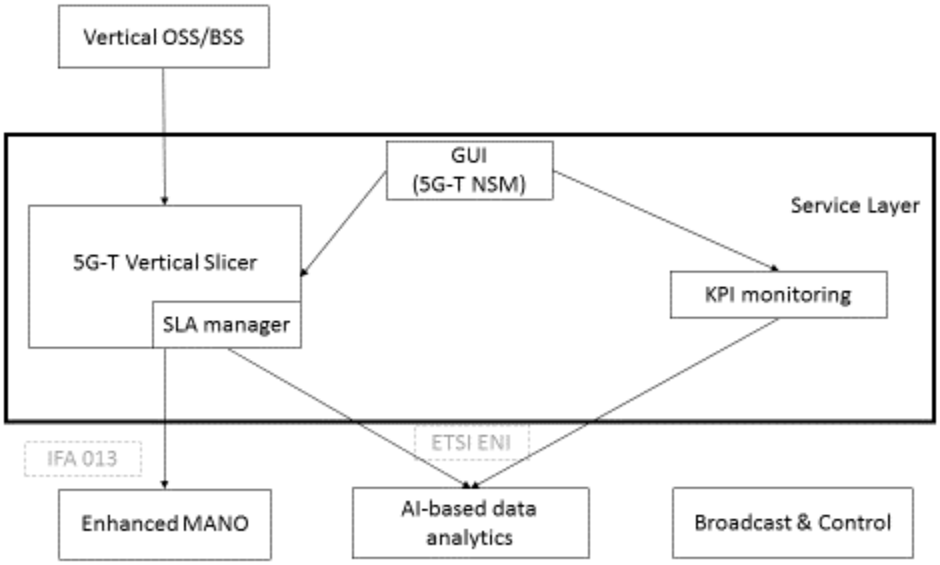

Figure 44: Initial 5G-TOURS Service Layer Architecture

5.4.1.2 Interface with network component

The Service Layer shall interact with the rest of the network, as summarized below:

- The Service Layer will interface with the enhanced MANO system through an interface based on the IFA 013 [52] standard. This standard interface will be augmented, if required, to fulfill all the requirements of 5G-TOURS.
- The Service Layer will interface with the analytics module using an interface based on ETSI ENI [24]. It may be required to design an extension of the standard specifically for intent-based networking.

5.5 End Devices

Different devices will be considered for the different use cases. In particular, although 5G promise is to have a single flexible network to serve the variety of uses cases, from the terminal standpoint, it is expected that each use case will lead to a dedicated optimized device. In short, it is not expected that a modem designed to support eMBB type of services could efficiently serve the mMTC type of use case. Similarly, neither eMBB modem nor mMTC one could efficiently support URLLC type of services.

Another important point is to distinguish the end-user terminal from the modem. The cellular modem is part of the end-user device and is in charge of providing the cellular connectivity pipe. All the rest is to support other function of the device, such as the screen, host CPU, audio interface, camera, sensors, keyboard if any, etc. Therefore, in context of the project, it is expected to have (or mimic) three types of modem, that could empower various types of end-user devices.

5.5.1 eMBB and URLLC modems and devices

In order to support the use cases that are based on eMBB slices, Samsung will provide a number of Samsung Galaxy Note 10 [53] devices running Android 9.0 (Pie) version, with the following characteristics. In terms of the CPU, the provided devices will feature a 64-bit Octa-core processor with 2x2.7 GHz Mongoose M4 cores, 2x2.4 GHz Cortex-A75 cores and 4x1.9 GHz Cortex-A55, with a Mali-g76 MP12 GPU. Furthermore, the provided devices will feature

8GB of RAM memory. In terms of the connectivity characteristics, the provided devices will be LTE Cat.20 capable, with enhanced 4x4 MIMO capabilities, and will support up to 2 Gbps of download and up to 150 Mbps of upload speed. Furthermore, they will be capable of NSA 5G connectivity at sub-6Ghz bands and mmWave bands.

For the use cases that include video transmission and reception, the provided devices will feature a main camera at the back of the phone that supports (i) 12 MP resolution and 27mm wide lenses for an aperture of f/1.5-2.4, (ii) 12 MP resolution and 52mm wide lenses for an aperture of f/2.1, and (iii) 16 MP resolution and 12mm wide lenses for an aperture of f/2.2. In terms of video capabilities, the provided devices will be able to support the following settings:

	Pixel Density	FPS Rate
Setting 1	2160	30/60
Setting 2	1080	30/60/240
Setting 3	720	960

For video playback, the provided devices will feature a dynamic AMOLED touchscreen with the support of 16M colors, at the size of 6.3 inches. The supported resolution will be 1080x2280 pixels (i.e. ~ 401 pixel-per-inch density). The audio interface will include stereo speakers, as well as a 3.5mm audio jack capable of 32-bit/384kHz audio with active noise cancellation.

In terms of sensors, the provided devices will include a fingerprint sensor placed underneath the display, accelerometer, gyroscope, proximity sensor, barometer and compass. For audio processing, the devices will feature the Bixby natural language and dictation sensor. Finally, the devices will include a non-removable Li-Ion battery of 3500 mAh capacity, with a fast battery charging capability at 25 Watts.

5.5.2 mMTC modems and devices

The mMTC side of the 5G triangle is served by LTE cat-M and NB-IoT evolutions, as defined by 3GPP. It is not expected that the ecosystem will define a new waveform, based on NR to serve the low end of MTC.

As a result, SEQ will provide samples of LTE Cat-M and NB-IoT modems, with advance instrumentation features to support the mMTC use cases. To scale up the deployment, it is expected that site owner or use case responsible will get additional devices on the shelves.

At this stage, it is not clear what the support of Cat-M and NB-IoT is from the infrastructure standpoint. A possible system on chip on which could be developed a mMTC device is Sequans Monarch family of solution.

Monarch is a single-chip LTE Cat M1/NB1 solution designed specifically for NB-IoT applications, including sensors, wearables, and other low data, low power M2M and IoT devices. Monarch complies with the ultra-low-power and reduced complexity feature requirements of the 3GPP mMTC, that defines narrowband, low data rate LTE technology for MTC. Monarch achieves a very high level of integration whereby baseband, RF transceiver, power management, and RAM memory are integrated into a tiny 6.5 x 8.5 mm package, running Sequans carrier-proven LTE protocol stack, a lightweight M2M (LWM2M) client for over-the-air device management, and a rich set of AT commands.

Using the Monarch SiP integrated module, reception from 700MHz to 2.2GHz can be supported. It must be noted that it is not expected that mMTC will be deployed in higher frequency ranges due to the more challenging link budget, especially for buried objects (like meters, indoor sensors etc.). The use of this module provide several advantages, as discussed next.

Monarch is ideal for adding Cat-M1 and/or NB1 LTE connectivity to narrowband, low data rate M2M and IoT devices, including utility meters, industrial sensors, health and fitness bands, asset trackers, and numerous additional devices for smart home, smart city, and wearable applications.

Developing an end-user device prototype directly based on a chipset or a module requires long development and integration time, with design of dedicated hardware boards. For easier end-user prototype, it may be safer to consider ready to use modules or pre-integrated solutions. The GM01Q-STMOD expansion board is an example of such a pre-integrated solution. It could provide cellular LTE-M and NB-IoT connectivity to any STM32 DISCOVERY kit.

Figure 45: STMOD extension board [54]

The use of such boards would mean that the end-user device is developed in a STM32-like environment, which is perfectly suited to sensor types of devices. Another option could be based on Pycom [55] or Nimbelink [56] already pre-integrated devices. These platforms allow quick development using Arduino or Rasberry Pi boards.

6 Conclusion

In this document the baseline network architecture that will be employed by the 5G-TOURS projects was presented, with particular focus on the several fundamental aspects that will be tackled throughout the project duration. More specifically, the following points were presented and discussed:

- The interactions towards other work packages of the project, and especially the ones related to the use cases implementation, will require a very high level of coordination to ensure the fulfilling of the specific requirements of each use case.
- The description of the baseline architecture of 5G-TOURS, that will blend together the available 5G EVE infrastructure with the technology coming from the 5G-Xcast and 5G-MoNArch projects. The objective is to go beyond the state of the art and impact the relevant SDOs, such as 3GPP and ETSI.
- The specific modules that have to be included to efficiently support the 5G-TOURS use cases, and their initial implementation plans. Namely, the 5G-TOURS partners will focus mostly on the following three areas:
    i. AI based data analytics extension of the MANO,
    ii. efficient broadcasting,
    iii. an extended Service Layer.
- The specific details on the trial site development. In this document, we provided a detailed description of the available artifacts in each site, and the planned extensions (both hardware and software) required to meet the KPIs set by the use cases.

In the following deliverables of the work package we expect to provide more details on other relevant aspects, such as the definition of additional reference point in the architecture, in order to host the additional 5G-TOURS modules. Furthermore, we expect to provide more details on the concrete modules' implementation.

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Annex A – eMBMS Background

The ability to perform Point-to-Multipoint (PTM) transmissions is key for some use cases inside 5G-TOURS. The main advantage of PTM transmissions at transport side is the scalability, since an unlimited number of users can receive the demanded service. 3GPP has included the possibility to do multicast and broadcast transmissions since 3G, in a system called Multimedia Broadcast Multicast Service (MBMS). The first iteration of the system was a commercial failure for many reasons, including the need for specific terminals and the limited capacity offered by 3G. In future releases, MBMS has received many improvements, with the most notable one being the migration to 4G, in a revised version called enhanced MBMS (eMBMS) in Release 9, while keeping backwards compatibility with previous iterations.

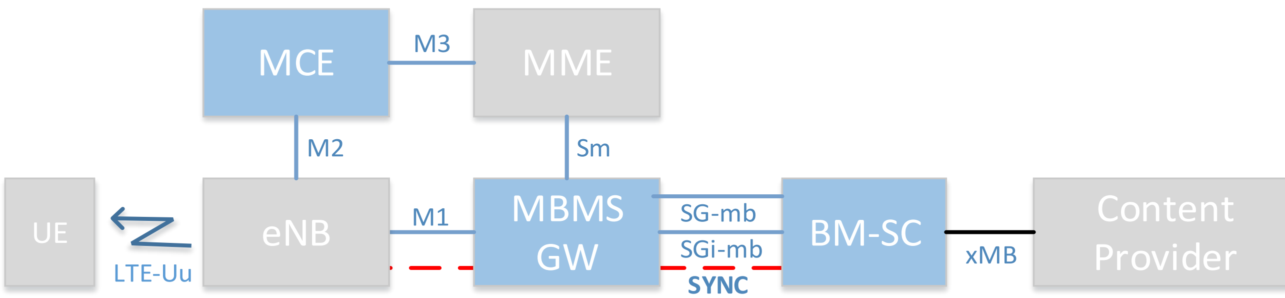

Figure 46: eMBMS architecture in LTE. Added blocks over the Point-to-Point Core are highlighted in blue.

eMBMS is characterized by being a full solution as an add-on over the EPC, to offer broadcast services, including additional entities, interfaces, waveforms and protocols into the LTE Core and RAN. In detail, eMBMS adds the following to the Core Network:

- MBMS Gateway (MBMS-GW.): Propagates the incoming data towards the RAN, using multicast over M1 interface. Involved eNB must join the multicast group in order to receive the broadcast data to be radiated. At the Control Plane, it exchanges signalling for establishing the eMBMS bearer.
- Multi-cell/Multicast Coordination Entity (MCE): This entity controls the Radio Resource Allocation and the decision of the transmission mode used by an eMBMS service. Additionally, the MCE chooses the Air Interface parameters and commands the eNBs to launch the MBMS transmission, monitoring any error by the eNBs.
- Broadcast Multicast Service Centre (BM-SC): Entry point of the multimedia content into the transport network. It is tasked with the management of the eMBMS sessions and bearers, provides service announcement, forward error correction, encryption and synchronization. The encapsulated multimedia stream is forwarded to the MBMS-GW.

Regarding the Air Interface, eMBMS defines a new transmission mode named Multicast Broadcast Single Frequency Network (MBSFN). A group of eNB (i.e. 4G base stations) who have joined the multicast group are transmitting the same data, with the same radio parameters, at the same time, creating a Single Frequency Network (SFN). The main advantages of an SFN are the increased coverage and the stable reception quality across the cell area. However, the waveform must adhere to the SFN requirements: a new type of subframe, MBSFN subframe, is introduced inside the LTE Air Interface, and the associated physical channel, Physical Multicast Channel (PMCH). For these MBSFN subframes, unicast radio resources must be reserved, ranging from 10% up to 60% resource allocation of the whole LTE frame. Inside this subframe only PMCH data (i.e eMBMS data) can be multiplexed, thus it is not possible to map unicast data into MBSFN subframes, even if there is no multimedia data available to be broadcasted. Another limitation is the mandatory addition of unicast control part even in 60% eMBMS allocation schemes, adding overhead to the broadcast transmission. Other changes to the physical layer include longer cyclic prefix and dedicated reference signals for PMCH.

New transport and logical channels to support broadcast are introduced at the higher layers of the RAN. The logical channels include the Multicast Control Channel (MCCH) and the Multicast Transport Channel (MTCH). MCCH carries acquisition information for the UE to tune in a certain eMBMS service, as well as all the services available in the cell, and is periodically transmitted in the PMCH (the scheduling period is customizable). The MTCH carries the eMBMS data of one or more services and forwards data to the PMCH. The added transport channel is the Multicast Channel (MCH) which is tasked with scheduling all the services coming from the MTCH according to MME signalling.

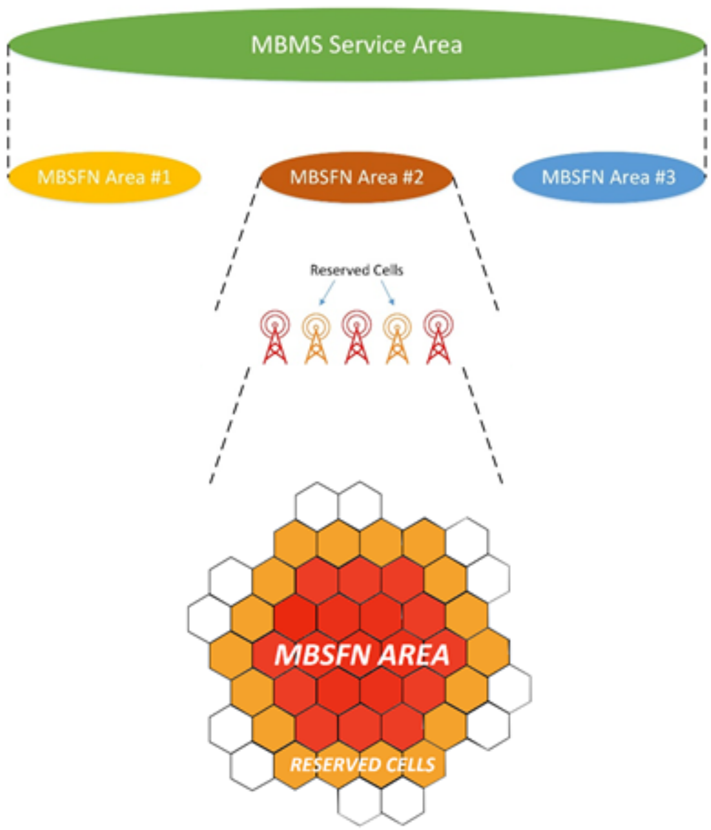

Figure 47: Relationship between MBMS Service Area, MBSFN Area and Reserved Cells.

eMBMS introduces several new concepts in order to manage the provision of broadcast services:

- MBMS Service Area: geographic area where the broadcaster or mobile operator wants to provide a service, using MBMS bearers. MBMS Service Area is composed of 1 or more MBSFN areas. Each MBMS Service Area is uniquely identified by a Service Area Identifier (SAI).
- MBSFN Area: a group of synchronized cells forming an SFN. single cell can belong to several MBSFN areas.
- Reserved Cells: At the edge of the MBSFN area the QoS cannot be guaranteed, so the operator can choose not to transmit the control part of the eMBMS signal. These cells without control information are called Reserved Cells. This disallows new users to tune into the eMBMS transmission, but keeps the service continuity of the audience moving into a reserved cell.

EVOLUTION OF eMBMS AND enTV

The initial version of eMBMS was included in Release 9, and future Releases kept adding new functionalities on top of the existing architecture, with a big overhaul in Release 14. Two noteworthy additions are the Multicast operation on Demand (MooD), and the Single Cell Point-to-Multipoint (SC-PTM). SC-PTM is an alternative delivery mode to MBSFN, using a new set of logical channels that are mapped into the Physical Downlink Shared Channel (PDSCH) instead of PMCH, allowing the multiplexing of unicast data with broadcast, but losing the ability to perform SFN. On the other hand, MooD monitors the number of users watching a given service, and when a given audience threshold is reached, the EPC automatically launches a MBMS session with the consumed content and notifies the users to switch to broadcast.

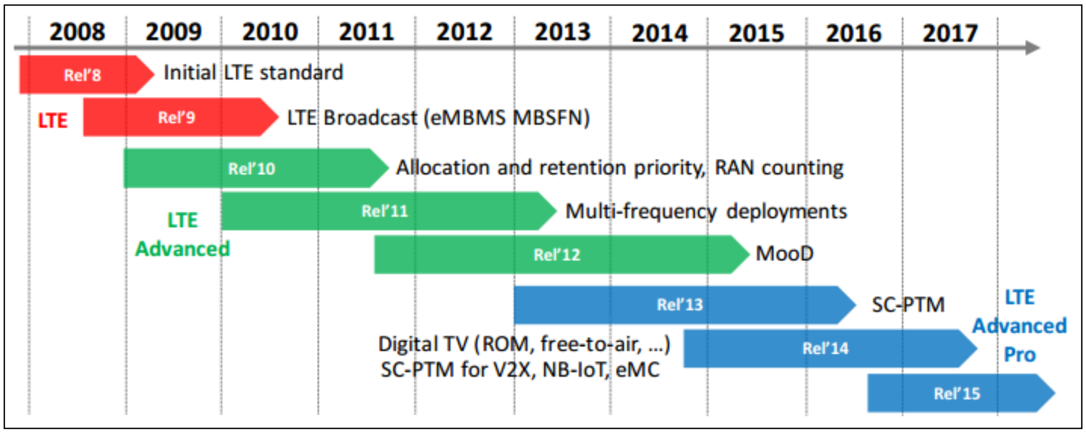

Figure 48. Timeline of the eMBMS evolution.

Release 14 brought big changes to eMBMS: the enhanced Television Services (enTV). Motivated by broadcasters, enTV incorporates changes from Core Network to Air Interface to adapt eMBMS into an attractive choice for Terrestrial Broadcast using existing infrastructure. Regarding the Air Interface, new numerologies supporting diverse subcarrier separation and larger distance between transmitters were added, so existing broadcaster infrastructure could be used for enTV. Additionally, up to 100% resource allocation from an LTE carrier can now be mapped to eMBMS transmissions, increasing the capacity. To support this, a new type of subframe, called feMBMS subframe, without the unicast control part, is now included. This new subframe type includes a Cell Aquisition Subframe (CAS) to let terminals tune to the signal quickly. Finally, in case there is no MBMS data available at PMCH, unicast data can now be multiplexed in MBMS subframes.

At the Core Network, the following new features are introduced:

- Receive-Only-Mode (ROM), in which SIM-less devices can tune in to enTV transmissions without being registered with the network,
- Transport or transparent delivery mode, where the multimedia content from the service provider is just forwarded as it is, without any transcoding,
- A standardized, RESTful interface called xMB to expose BM-SC capabilities to trusted 3rd parties, so sessions can be created remotely,
- Signaling support for shared broadcast transmissions under one LTE carrier.

Annex B – Resource Elasticity Background

We are currently observing the softwarization of communication networks, where network functions are translated from monolithic equipment to programs that run in a shared group of computing, storage and communication resources. While it is clear that almost any software improves flexibility (for example, the ability to create instances of more servers to cope with the growing traffic demand), in order to cope with the stringent requirements imposed by the network services, a complete redesign of the communications protocol stack, instead of a mere translation of hardware functions into software, is needed. This has been the case beyond the concept of resource elasticity, which has been at the basis of the 5G-MoNArch project.

Specifically, the 5G-MoNArch project defined network resource elasticity along three dimensions as follows:

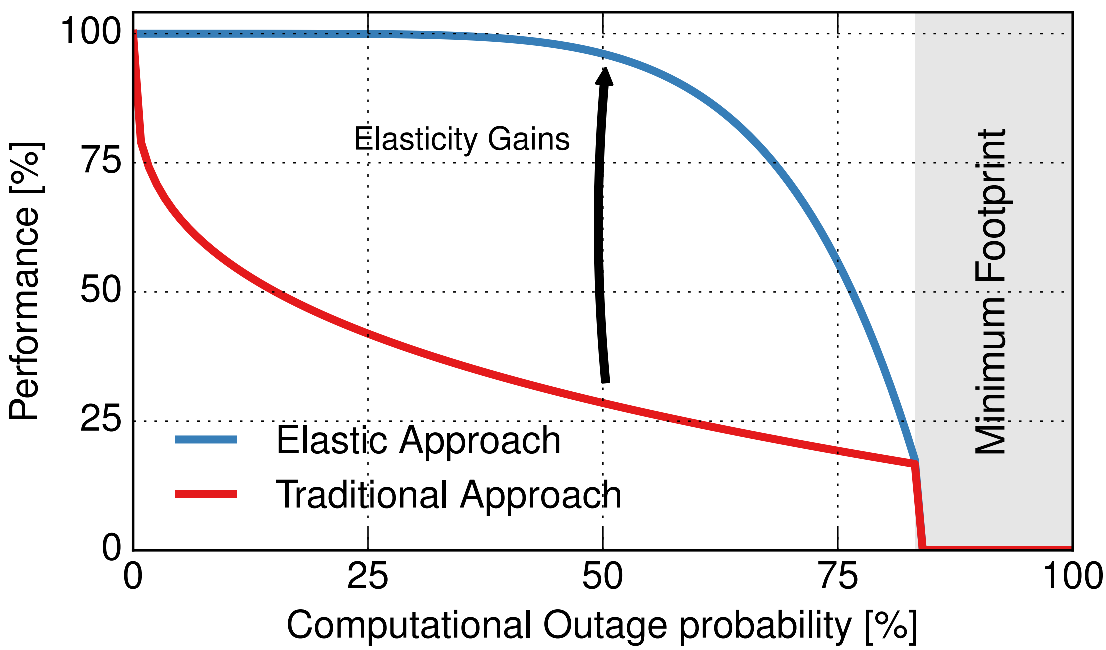

Figure 49. Computational elasticity.

Computational elasticity: Figure 49 depicts an example of Computational Elasticity. A traditional network function usually stays in the top left corner: with full resources it will get full performance. However, in a softwarized network, in which resources (such as CPU) are dynamically orchestrated and are more likely to fail causing computational outage probability. Therefore, in 5G MoNArch different algorithms that deal with this principle were investigated. As resource elasticity mostly deal with CPU resources, the project focused mostly on those functions that consume most CPU such as frame encoding and decoding.

Slice Aware elasticity: a Network Slice may be orchestrated across very heterogeneous kind of resources, ranging from edge deployments that are used for ensuring low latency to centralized resources, that maximize resource pooling and hence cost savings. So, "slice aware" orchestration algorithms were designed to dynamically adapt the orchestration of a single network slice across the available resources, optimizing the resource utilization while maintaining the required QoS.

Orchestration aware elasticity: while hosting several network slices on the same infrastructure, the objective for a network operator is to optimize the resource required to run them. As slices are likely to have fluctuations (see Figure 50), Orchestration aware orchestration algorithms takes advantage of this and adapt the resource assignment to each slice in order to have an optimized resource utilization across slices.

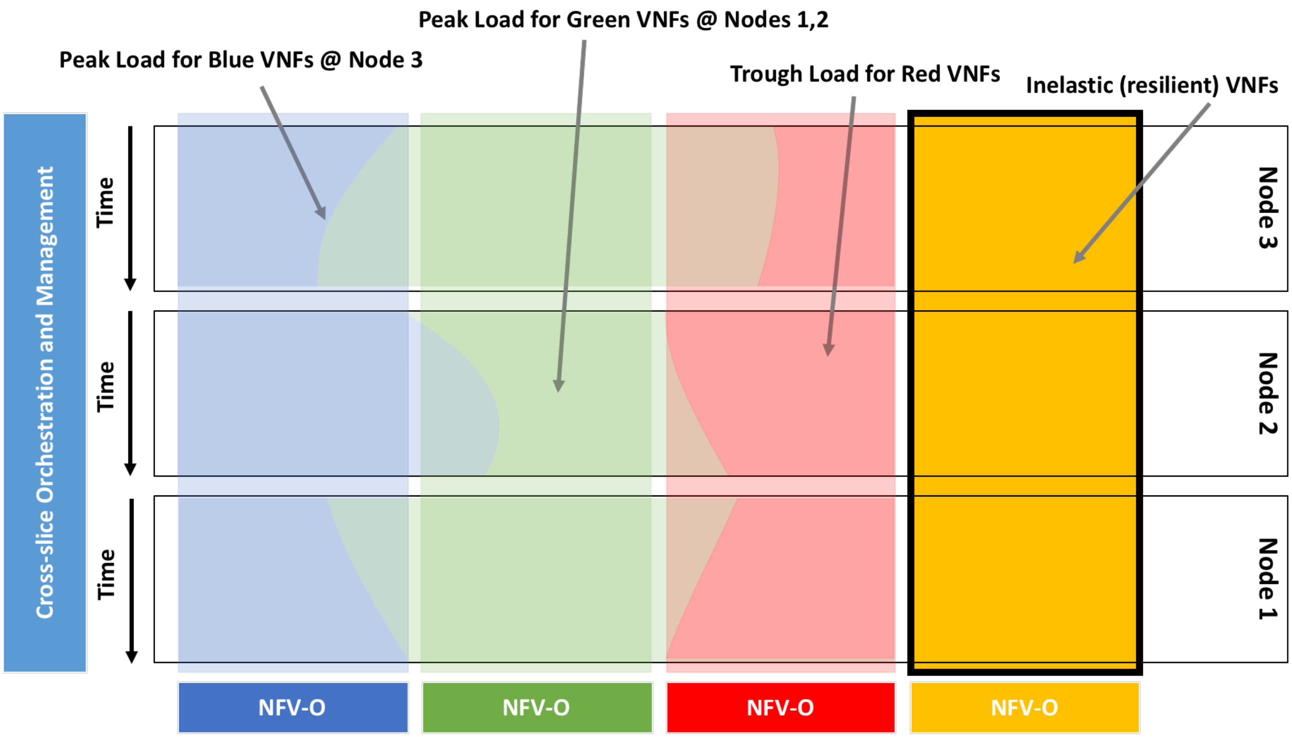

Figure 50. Orchestration driven and Slice driven elasticity.

All the above mechanisms are described in depth in [8], together with the architectural implications of these choices.