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Abstract

This report provides a comprehensive list of quantitative and qualitative requirements for the 5G NORMA architecture, including security and functional requirements. Based on these requirements, key technology enablers are described which are necessary for a 5G architecture. In order to integrate these technologies, the preliminary 5G NORMA reference architecture is introduced. It is detailed through four distinct views which relate the two main functional requirements, i.e. mobile network multi-tenancy, and multi-service and context-aware adaptation and allocation of mobile network functions, with the key technology enablers Software-defined mobile network control, adaptive composition and allocation of network functions, and joint optimization of mobile access and core. Using these four different views, the architecture is discussed and its requirements are further detailed. Finally, this report provides a detailed description of the validation process of the 5G NORMA architecture design.

Keywords

Mobile network architecture, functional requirements, security requirements, software defined mobile network, functional decomposition, joint optimization of mobile access and core, evaluation and validation process

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List of Acronyms and Abbreviations

Acronym	Description
3GPP	Third Generation Partnership Project
5G NORMA	Novel Radio Multiservice Network Adaptive Architecture
A-CPI	Application-Controller Plane Interface
AI	Air Interface
API	Application Programming Interface
BB	Building Block
BS	Base Station
BSS	Business Support System
CAPEX	Capital Expenditure
CME	Central Management Entity
cMTC	Critical Machine Type Communication
CNE	Core Network Element
CoMP	Cooperative Multipoint
CRAN	Centralized Radio Access Network
D2D	Device-to-Device
D-CPI	Data-Controller Plane Interface
DPI	Deep Packet Inspection
DSP	Digital Signal Processor
E2E	End-to-End
EC	European Commission
EM	Element Management
eNB	Enhanced Node B
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FE	Functional Element
FPGA	Field Programmable Gate Array
GUI	Graphical User Interface
GWCN	Gateway Core Network
H2020	Horizon 2020
HSS	Home Subscriber Server
HT	Horizontal Topic
IaaS	Infrastructure as a Service
ICT	Information and Communication Technologies
IE	Information Element

IMS	IP-based Multimedia Services
iNC	iJOIN Network Controller
InP	Infrastructure Provider
iRPU	iJOIN Radio Processing Unit
iSC	iJOIN Small Cell
KPI	Key Performance Indicator
MAC	Medium Access Control
MANO	Management and Orchestration
MANO-F	Management and Orchestration Function
MBB	Massive Broadband
MCS	Modulation and Coding Scheme
MME	Mobility Management Entity
mMTC	Massive Machine Type Communication
MOCN	Multi Operator Core Network
MSC	Message Sequence Chart
MTC	Machine Type Communication
NaaS	Network as a Service
NEM	Network Element Manager
NF	Network Function
NF-FG	Network Function Forwarding Graph
NFV	Network Function Virtualization
NFVI	Network Function Virtualization Infrastructure
NFVO	Network Function Virtualization Orchestrator
NGMN	Next Generation Mobile Networks Alliance
ONF	Open Network Foundation
OPEX	Operational Expenditure
OS	Operating System
OSS	Operation Support System
OTT	Over The Top
PA	Power Amplifier
PCRF	Policy and Charging Rules Function
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PDU	Packet Data Unit
P-GW	Packet Gateway
PLMN	Public Land Mobile Network
PoC	Proof of Concept

QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RANaaS	RAN as a Service
RAT	Radio Access Technology
RG	Requirement Group
RISC	Reduced Instruction Set Computer
RLC	Radio Link Control
RNE	Radio Network Element
RNM	Radio Node Management
RRC	Radio Resource Control
SBI	Southbound Interface
SDMC	Software Defined Mobile Network Control
SDMC+O	Software Defined Mobile Network Control and Orchestration
SDN	Software Defined Networking
S-GW	Serving Gateway
SoC	System on Chip
SON	Self-Organising Networks
TeC	Technology Components
UDN	Ultra-Dense Network
UE	User Equipment
V2X	Vehicle-to-Anything
veNB	Virtual eNB
VIM	Virtualized Infrastructure Manager
VM	Virtual Machine
VN	Virtual Network
VMNO	Virtual Mobile Network Operator
VNF	Virtual Network Function
VNFM	Virtual Network Function Manager
WAN	Wide Area Network
WP	Work Package

Definitions

Slice	A network slice (instance) is a collection of (mobile) network function instances including their required resources necessary to operate an end-to-end (self-contained) logical mobile network.
5G NORMA protocol	The protocol to convey information over a reference point. Information and concrete protocol characteristics are reference point dependent.
Controller	A network function in the control layer that dynamically influences the behaviour of a set of network function instances through their fast reconfiguration.
Function chain	A function chain (in the context of network functions) refers to a directed graph that describes how individual network functions are logically interconnected.
Infrastructure provider	The business entity providing physical and virtual network resources like memory, compute, storage or networking to service provider(s) (cf. section 5.1.2).
Interface/Reference point	A reference point is the point of connectivity between two network functions within the function chain. It unambiguously identifies the characteristics of that interconnection.
Manager	A function of the management and orchestration layer that manages specific aspects of network function instances like life cycle or configuration.
Network function	A physical or virtual function (type) in the control or data layer.
Orchestrator	The orchestrators generate a suitable function chain in a network slice that provides the service requested by the tenant.
Policy	A policy is a (set of) rule(s) to guide the orchestrators' decisions.
Library	A database holding software resources like virtual network functions, MANO functions or network services, including their descriptions to enable orchestration (cf. section 5.1.3).
Service	A component of the portfolio of choices offered by service providers to a user, i.e., a functionality offered to a user. The user can be an end-user, an enterprise or a tenant. Examples are voice, messaging, broadband internet or machine type communication.
Service provider	The business entity providing service(s) to its tenant(s) by utilizing resources from infrastructure provider(s).
Service template	The service template describes the service properties, e.g. the end-to-end latency it demands, and a suitable function chain that implements this service.
Tenant	The business entity requesting and using a service from a service provider.

1 Introduction

1.1 Background and Scope

5G NORMA aims at designing a novel 5G mobile network architecture which provides a higher degree of flexibility in order to accommodate use cases which are going to be relevant for 5G mobile network deployments. Since it is not possible to foresee all future use cases with probably diverging requirements, the architecture must be sufficiently flexible to integrate and adapt to these use cases. The increased level of flexibility is achieved through "multi-service and context-aware adaptation of network functions" and "mobile network multi-tenancy" enabled by novel concepts of "adaptive (de)composition and allocation of mobile network functions", "software-defined mobile network control", as well as "joint optimization of mobile access and core network functions."

The 5G NORMA architecture and therefore the scope of this document covers mobile access and mobile core functionalities. In order to understand the needs for further improvement of mobile network architectures, we first explore the state of the art in Section 2. This state of the art analysis defines the scope of our work which builds upon the results provided by the projects EU FP7 iJOIN and EU FP7 METIS. 5G NORMA builds upon the architectural definitions in 3GPP including radio access and core network entities. Furthermore, the scope includes the novel area of software defined networking and network function virtualization.

The definition of the architecture relies mainly on the definition of requirements which may be expressed in quantitative and qualitative terms. An overview of the underlying requirements of the architecture is provided in Section 3 taking into account relevant scenarios and use cases, qualitative requirements such as flexibility, security requirements, and functional requirements.

Building upon these requirements, key technology enablers are defined which must be supported and integrated by the mobile network architecture. In the case of the 5G NORMA architecture, these are software defined mobile network control and orchestration, adaptive composition and allocation of mobile network functions, and joint optimization of mobile access and core, as further described in Section 4. These key enablers are then integrated into the 5G NORMA architecture and can be considered from different angles, or architecture views, which are detailed in Section 5.

Finally, this document introduces and details the architecture design validation in Section 6. The validation concept details the approach and main objectives of the validation process, which needs to address both quantitative and qualitative metrics. We further define different means of validation including demonstrators, simulations, and analytical tools. Finally, the document provides an overview of evaluation scenarios.

1.2 Key Contributions

The key contributions of this document include the definition of architecture requirements which are used to design the 5G NORMA mobile network architecture. This includes quantitative and qualitative requirements, which are important to integrate the expected diversity of use cases and services in the future 5G mobile network.

We further introduce the first, preliminary 5G NORMA mobile network architecture and four distinct views on the architecture. These different views reflect different aspects of a mobile network and reveal different important interaction and functionality of the mobile network architecture. These different views are applied throughout the project in order to develop and optimize functionality.

Finally, the document provides a detailed validation concept which does not solely focus on individual use cases but it provides a holistic view by means of overarching scenarios integrating multiple use cases.

2 State of the Art and Related Work in Progress

While 5G NORMA aims to design a new architecture based on novel concepts, some of the enabling technologies upon which it relies have received substantial attention so far. In the following, we review the main contributions that have been performed by standardization bodies, other projects and academic literature recently. All these contributions can be largely classified into three different topic areas: (i) mobile network architecture, (ii) Software Defined Networking (SDN), and (iii) Network Function Virtualization (NFV).

Two of the precursor projects of 5G NORMA, namely EU FP7 METIS and EU FP7 iJOIN, have devoted significant efforts to devise novel architectures that enable some of the features pursued by 5G NORMA. These are considered as starting points by 5G NORMA, which will build on the results of these previous projects and extend them to build an architecture that comprises some of the building blocks coming from both projects and extend them to design a comprehensive architecture. Some additional contributions to the definition of mobile architectures have also been provided by standards or similar organizations, such as the Next Generation Mobile Networks Alliance (NGMN) and the Third Generation Partnership Project (3GPP). NGMN has defined a set of requirements and high-level design criteria, which were already used as guidelines by 5G NORMA for the definition of relevant requirements and use cases in [18]. It is worth mentioning that many of the 5G NORMA partners are actively involved in NGMN. Furthermore, 5G NORMA has a clear plan to provide input to Third Generation Partnership Project (3GPP) as well despite the fact that 3GPP focuses rather on near-term development.

As for SDN, the work undergoing at Open Network Foundation (ONF) has many similarities with the Software Defined Mobile Network Control (SDMC) concept proposed by 5G NORMA. Indeed, new ONF extensions aim to use the spirit of SDN to provide flexibility in the implementation of mobile network functions (NFs) other than routing and forwarding, which is precisely the goal of 5G NORMA. The 5G NORMA and ONF efforts are parallel activities in terms of timing, and a number of partners involved in 5G NORMA are actually pushing the same ideas at ONF. This provides a very good framework to place 5G NORMA results in standards and thus maximising their impact.

Finally, the European Telecommunications Standards Institute (ETSI) has defined a NFV architecture which is a key enabler for the flexible function (de)composition and allocation concept of 5G NORMA. 5G NORMA plans to define an architecture as close as possible to ETSI NFV.

2.1 Mobile Network Architecture

2.1.1 NGMN

In February 2015, NGMN has published a 5G White Paper [2]. Therein, NGMN describes its vision of the 5G business environment expected to emerge in 2020 and the following decade. It identifies demands and business needs of the envisioned services and analyses how technology and architecture can meet these requirements.

2.1.1.1 Requirements on 5 G networks and enabling technologies

In [2], the identified 5G requirements have been compared to the capabilities of a baseline 4G system according to 3GPP Release 12. This comparison has shown the need for improvements in three main areas:

- 4G network capabilities cannot meet the demands of future services. Many user and system performance parameters, e.g. data rate, minimum end-to-end latency and connection density, need to improve substantially.
- Today's networks lack operational sustainability. The 4G core network architecture consists of many dedicated network entities, making the network architecture complex and difficult to scale and manage. On the other hand, many operations and maintenance processes still require manual work and site visits. 5G shall lower the operational costs, both in terms of procedural, organizational, and administrative effort and of energy consumptions.
- Greater flexibility and business agility are essential to enable new business models.

NGMN has spotted several ongoing technology trends that will contribute to achieve these improvements. Figure 2-1 illustrates these trends and how they relate to the three main areas, mentioned above.

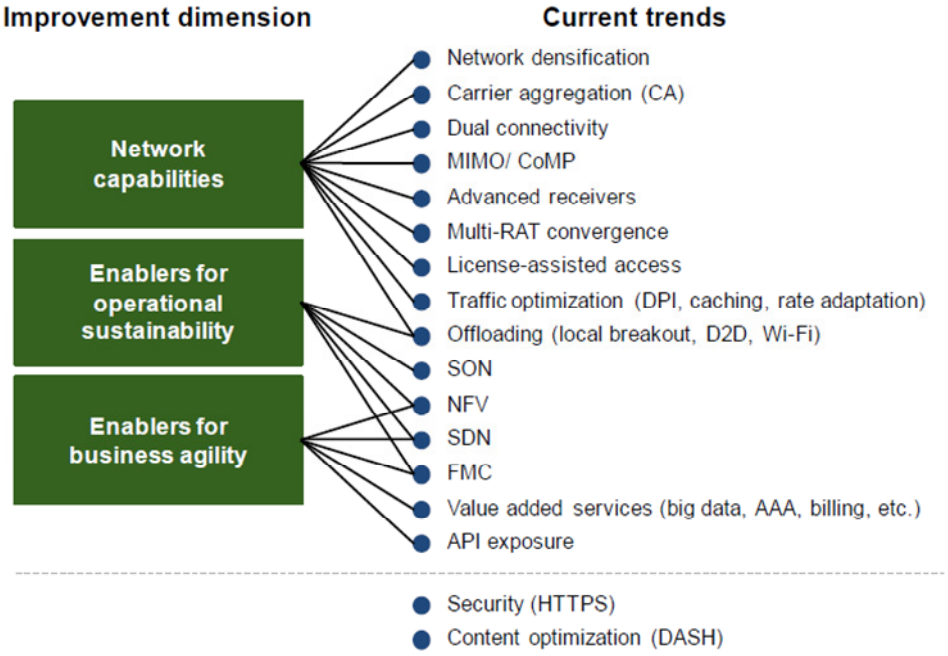


Figure 2-1: Technology trends identified by NGMN [2]

NGMN has collected a list of technology building blocks and analysed their benefits and maturity. This list can be found in the annex of [2]. From the perspective of 5G NORMA, several technology building blocks are particularly interesting:

- Flexible split of radio access network (RAN) functions among network nodes
- Software Defined Networking
- Smart Edge Node (a node, e.g. a base station, that can actively carry out some of the core network functionalities or additional services such as caching)
- Virtualization of the mobile core network

- Virtualized Cloud-RAN (C-RAN)
- Enhanced multi-operator network sharing
- Enhanced multi-radio access technology (RAT) coordination
- Context-aware and user centered network

Apparently, all these technologies are in line with 5G NORMA's innovative enablers adaptive (de)composition and allocation of mobile NFs, SDMC, and joint optimization of mobile access and core NFs. These technologies are further in line with 5G NORMA's innovative functionalities mobile network multi-tenancy, and multi-service- and context-aware adaptation of NFs. They all relate to NFV and SDN, and according to Figure 2-1, they are expected to improve operational sustainability and business agility.

2.1.1.2 Network Slicing

In the analysis of business demands and service requirements, it has turned out that services may have significantly different requirements on the network. To meet these requirements and still exploit the benefits of a common network infrastructure, NGMN promotes the concept of network slicing: According to NGMN, a "network slice (5G slice) supports the communication service of a particular connection type with a specific way of handling the C-and U-plane for this service. To this end, a 5G slice is composed of a collection of 5G network functions and specific RAT settings that are combined together for the specific use case or business model" [2]. Therefore, a network slice is a dedicated, logical network for a single tenant or a specific application. It is understood as end-to-end network, covering NFs running in software on central or edge cloud nodes as well as dedicated radio nodes, the transport network between nodes, and possibly the 5G devices used by the customers. The service provided by a network slice is specifically adapted to the demands of the tenant or the application, which implies that C- and U-plane for this service are handled in a specific way. Ideally, a network slice contains all necessary functionality for this service but avoids all other functionality, thereby minimizing its internal complexity.

Slices are mutually isolated, e.g. access to data carried or stored within another slice is not permitted. Nevertheless, since slices are dedicated logical, not dedicated physical networks, multiple slices can share the same infrastructure resources and the same physical NF. This will improve the utilization of the infrastructure equipment, reduce energy costs and thus improve the operational sustainability of the network equipment. Alternatively, infrastructure resources can also be assigned to a dedicated slice for exclusive usage, when needed by the application or requested by a tenant, e.g., in the case of mission-critical communications.

2.1.1.3 Architecture

NGMN's proposed 5G architecture uses the structural separation of hardware and software achieved by NFV methods and the programmability enabled through SDN concepts to offer tenant- or application-specific network slices on a shared infrastructure. This architecture is shown in Figure 2-2.

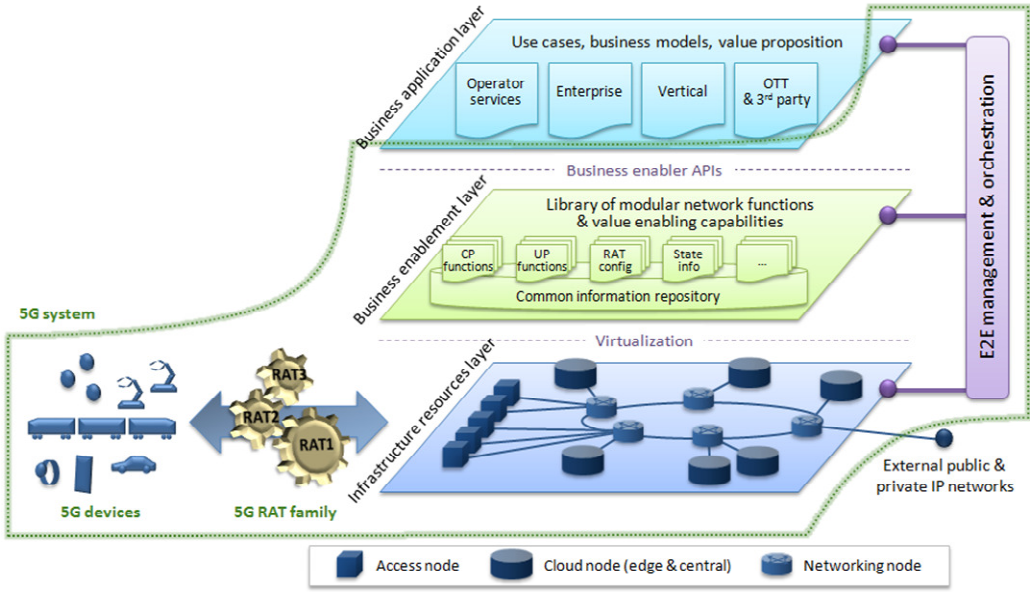


Figure 2-2: NGMN 5G architecture [2]

The NGMN 5G architecture comprises three layers and a management entity:

- The infrastructure resources layer comprises all physical network resources of a fixed-mobile converged network, i.e. cloud nodes, networking nodes together with their associated links, access nodes and 5G devices. The cloud nodes offer processing, networking as well as storage capabilities and can be located in the center as well as on the edge of the network. The 5G devices comprise terminal devices as well as data forwarding devices, e.g. relays, hubs, or routers. It is expected that these devices and their capabilities are also configurable. The physical resources are exposed to the business enablement layer and can be accessed and configured by the management and orchestration entity.
- The business enablement layer deals with the functions that are executed on the physical resources provided by the infrastructure layer. It comprises a library of functions required within a network, including functions realized by software modules that can be retrieved from the repository to the desired location, and related configuration parameters. Selection of the appropriate functions for a particular service, their arrangement and configuration is done dynamically by the end-to-end (E2E) management and orchestration entity.
- The business application layer consists of specific applications or services of the mobile network operator or tenant. On this layer, network slices can be created by the E2E management and orchestration entity, and applications can be mapped to network slices.
- The E2E management and orchestration entity configures all three layers according to demands of the requested service or business model and supervises them during runtime. This includes defining the network slices, chaining the relevant modular NFs and mapping them onto the infrastructure equipment. It also includes resource management and scaling the capacity of functions and managing their geographic distribution. NGMN expects that this entity will build on technologies designed in the framework of by NFV, SDN, or self-organising networks (SON) concepts.

2.1.2 EU FP7 iJOIN

The EU FP7 project iJOIN[1] has been a collaborative project which finished in April 2015. The scope of this project was limited to small-cell networks where small-cells are connected through heterogeneous backhaul to the core network. An essential part of this project was the quantitative and qualitative analysis of the impact of non-ideal backhaul technology on the deployment and performance of small-cell networks. In particular, the objective has been to investigate the applicability of partial RAN centralisation as well as the use of commodity hardware to process RAN functionality.

Due to the project size, iJOIN was strongly focusing on particular technologies, e.g. iJOIN proposed an evolutionary path for 3GPP LTE and did not introduce novel LTE functionality but rather applied and extended existing functions. This is in strong contrast to 5G NORMA which aims for a clean-slate approach which may break with the existing 3GPP LTE architecture. iJOIN further focused on the RAN and did not consider core NFs, compared to 5G NORMA which considers both mobile core and RAN functions. Furthermore, iJOIN assumed digital signal processor (DSP) based processing platforms at radio access points and commodity hardware based processing platforms at the central processor [3]. Finally, similar to 5G NORMA, iJOIN investigated SDN based network control in order to optimize jointly radio access and backhaul network operation [4][5].

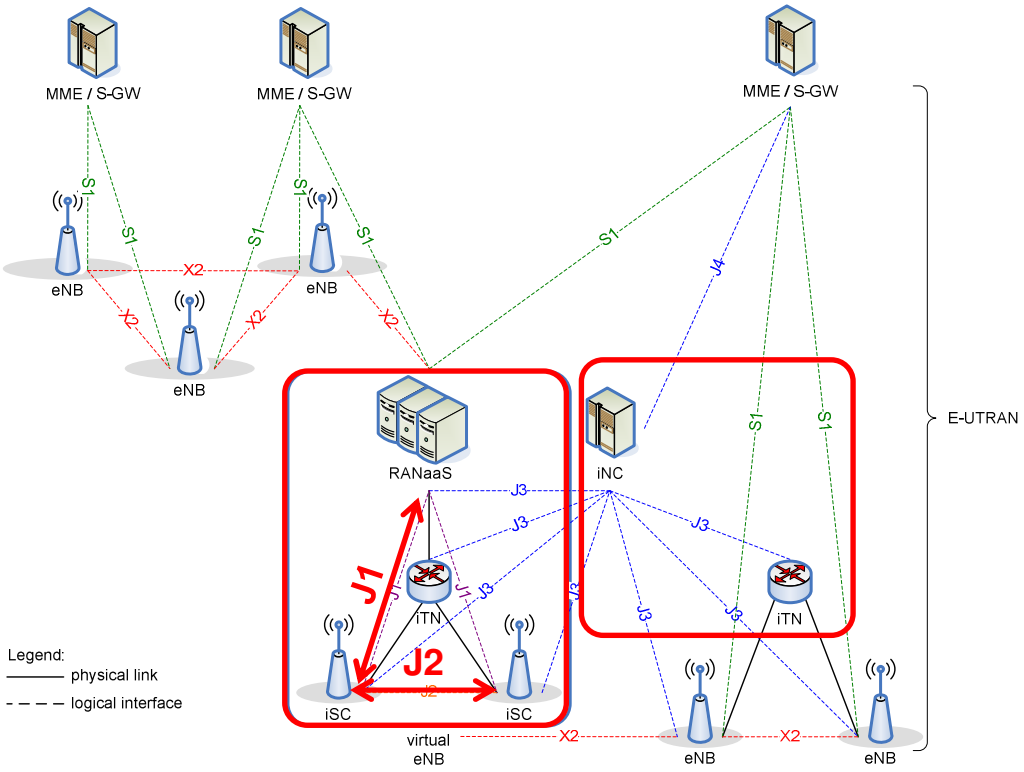
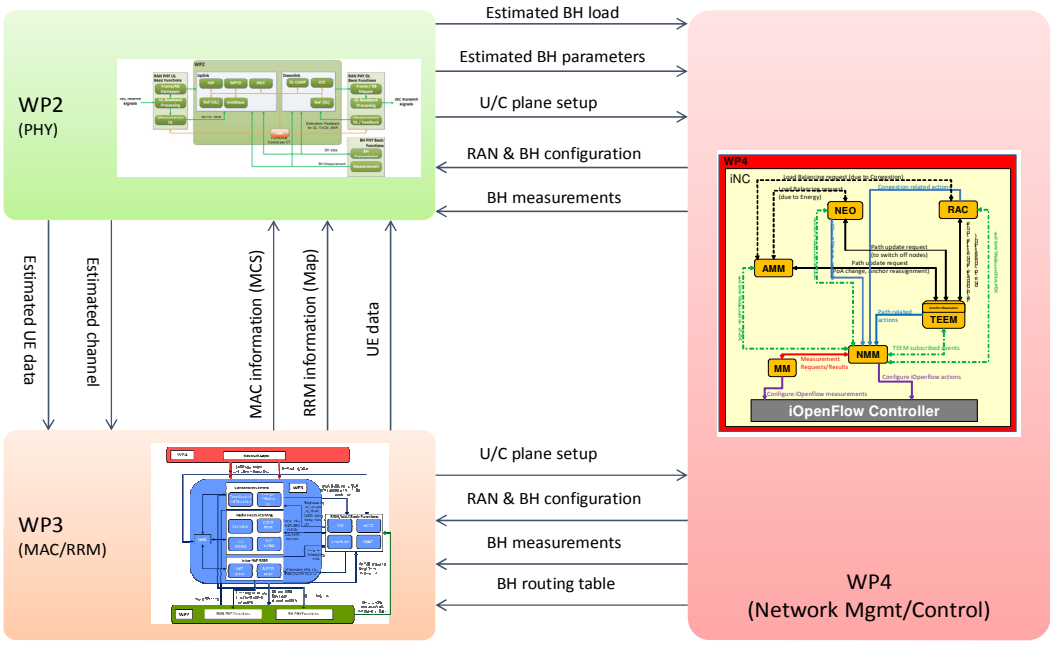


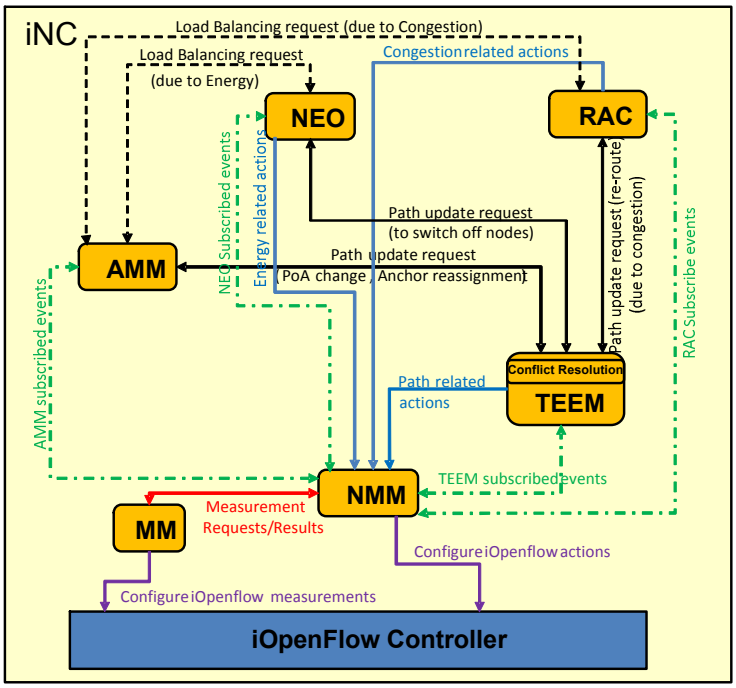
Figure 2-3: Logical architecture as proposed by EU FP7 iJOIN

[1] http://www.ict-ijoin.eu

The first main architecture result is shown in Figure 2-3 which is the logical architecture as proposed by iJOIN [5]. The proposed architecture did not break with the 3GPP LTE architecture but rather introduced two interfaces, J1 and J2, which allow for a seamless integration of the iJOIN technologies. Existing interfaces, i.e. S1 and X2, were not modified in order to maintain legacy compliance.



a) Functional architecture



b) iJOIN Network Controller

Figure 2-4: Functional architecture as proposed by EU FP7 iJOIN

Figure 2-4b) details the components of the iJOIN Network Controller (iNC) which is based on the SDN concept and allows for joint optimization of mobile access network and backhaul network operation [7][8][9]. The main purpose of the functional architecture has been to identify the main components which are relevant for the partial centralization of small-cells over heterogeneous backhaul, to describe the interaction of these components, and to derive the necessary control and management mechanisms.

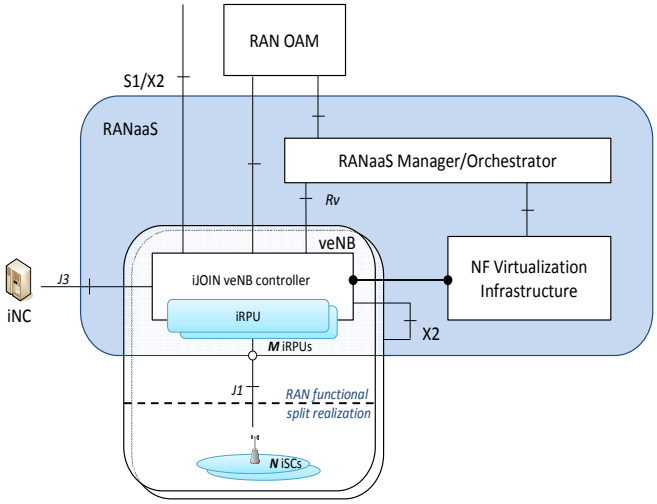


Figure 2-5: RANaaS platform as proposed by EU FP7 iJOIN

Finally, the iJOIN project derived a detailed proposal for the centralized platform, which was named RAN as a service (RANaaS) platform. The concept is illustrated in Figure 2-5 and the main component of this concept is the virtual eNodeB (veNB) which is composed of physical radio access points (here: iJOIN Small Cells, iSCs) and iJOIN radio processing units (iRPUs), and controlled by a veNB controller. The veNB allows for encapsulating the processing divided across remote and central site while maintaining standardized interfaces (e.g. X2) towards other veNB or eNB, as well as the core network (e.g. S1). In [4] and [5], this concept is further detailed and compared with the ETSI NFV architecture.

2.1.3 EU FP7 METIS

The EU FP7 project METIS[2] [29] presents its architecture description from different viewpoints as well. First, a functional architecture is presented that may lay a foundation for development of first novel 5G NFs. It is based on functional decomposition of most relevant 5G technology components. The logical orchestration and control architecture depicts the realization of flexibility, scalability and service orientation needed to fulfil diverse 5G requirements. Finally, a third viewpoint reveals deployment aspects and function placement options for 5G.

2.1.3.1 Functional Architecture

Figure 2-6 illustrates the main building blocks (BBs) of the functional architecture identified by METIS. Each main BB can be hierarchically split into a number of sub-BBs. These sub-BBs can be “common BBs,” containing functionalities required for more than one Horizontal Topic (HT) concept, and “HT-specific BBs,” which are essential for enabling a single HT concept. In

[2] http://www.metis2020.com

order to make system and architecture development more clearly arranged the METIS architecture integrated 5 less complex sub concepts that are denoted as “Horizontal Topics”. Each sub-BB is finally described through a set of more fine granular Functional Elements (FEs) with each FE performing an inherently consistent logical task. FEs have been derived by functional decomposition of prioritized technology components (TeCs) developed in METIS [10]. Notably, a TeC comprises a specific methodology, algorithm, module or protocol enabling certain system features and contributing to the fulfillment of specific technical requirements. It has also to be noted that METIS is primarily focusing on the RAN part, so not all components required to operate a 5G system are covered.

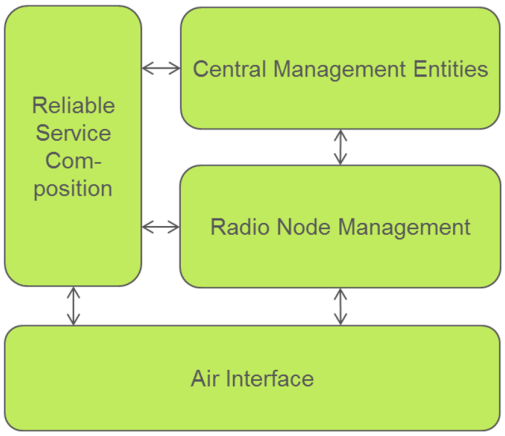


Figure 2-6: Main building blocks of METIS 5G architecture.

The functional architecture can be decomposed into:

- **Central Management Entities** (CMEs), containing BBs that cover network overarching functionalities which are not specific for certain HTs and use cases or scenarios. Typical examples are Context Management and Spectrum Management. These BBs are usually more centrally arranged. However, depending on the use case, a partially distributed realization might be possible, as well.
- **Radio Node Management** (RNM) containing BBs that provide radio functionalities that usually affect more than one radio node and that are not HT-specific. Exemplary functions are Long-/Short-Term Radio Resource & Interference Management, Mobility Management, Radio Node Clustering & (De-) Activation, and D2D Device Discovery & Mode Selection. In principle those functions will be deployed at medium network layers (e.g., at dedicated Cloud-RAN nodes [6]). The interface requirements between FEs that are mapped to those BBs (especially the air interface sub-BBs) have strong impact on the function placement.
- **Air Interface** (AI) including BBs that are directly related to air interface functionalities of radio nodes and devices. It comprises HT-specific as well as common BBs. Examples are AI enablers for ultra-dense networks (UDNs) or for different types of machine type communication (MTC) applications.
- **Reliable Service Composition** represents a central C-Plane functionality with interfaces to all other main BBs. It is used for availability evaluation and provisioning of ultra-reliable radio links which can be applied for novel service types requiring extremely high reliabilities in message data transfer or extreme low latencies, e.g., industrial environments, eHealth, or V2X (vehicle-to-anything) communication.

2.1.3.2 Logical Orchestration & Control Architecture

The METIS 5G architecture development was driven by three key aspects: flexibility, scalability, and service-oriented management. The envisioned logical orchestration & control architecture (see Figure 2-7) is based on usage of upcoming architectural trends, such as SDN and NFV. It will provide the necessary flexibility for realizing efficient integration and cooperation of FEs according to the individual service needs as well as future evolution of existing cellular and wireless networks [11][12][2].

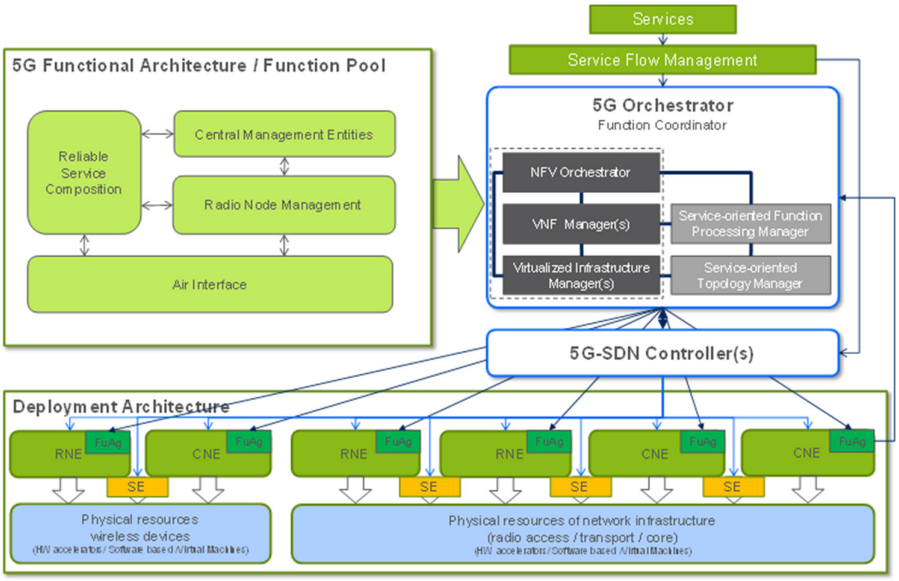


Figure 2-7: Logical orchestration & control architecture of METIS 5G system

NFs derived from FEs are flexibly deployed and instantiated by the 5G Orchestrator, which consists of NFV Orchestrator, Virtual NF (VNF) Manager and Virtualized Infrastructure Manager [13] as well as their extensions Service-oriented Function Processing Manager and Service-oriented Topology Manager. It is responsible for managing all VNFs of the 5G network including radio, core and service layer by mapping logical topologies of C-/U-Planes to physical resources in the deployment architecture dependent on corresponding logical topologies for each service.

The Service Flow Management analyses the customer-demanded services and outlining their requirements for data flows through the network infrastructure. These requirements are communicated to 5G Orchestrator and 5G-SDN Controller. Radio Network Elements (RNEs) and Core Network Elements (CNEs) in the orchestration & control architecture are logical nodes that are specified having in mind the possibility to be implemented on different software and hardware platforms (both virtualized and non-virtualized). The 5G Orchestrator is interfacing with RNEs and CNEs via the Function Agent (FuAg) by which it performs the configuration according to service requirements, also known as service orchestration.

It is expected that, increasingly, the hardware platforms designed to run RNEs are capable of supporting NFV to a certain extent, but especially low-cost equipment – such as small cell nodes– will probably be realized without or still limited NFV capabilities due to cost reasons. In contrast to that, CNE-related computing platforms allow fully flexible deployment of NFs based on virtualization concepts, which is already happening today in 4G systems [14].

The 5G-SDN Controller sets up the service chain on the physical network infrastructure taking into account the configurations orchestrated by the 5G Orchestrator. The 5G-SDN Controller (implementation as VNF is also possible) then constructs the U-Plane processing for the data flow, i.e., it builds up the connections for the service chain of CNEs and RNEs in the physical

network. The flexibility is restricted by limitations of physical network elements, but also by pre-coded accelerators implemented in certain nodes, e.g., hard-coded physical layer procedures in order to minimize processing delay and energy consumption.

2.1.3.3 Deployment Architecture

Figure 2-8 shows the METIS E2E reference network that is used when functional placement within the network topology is discussed. This reference network shows how the different types of sites are located along the access, aggregation and core networks within a typical telecom operator network.

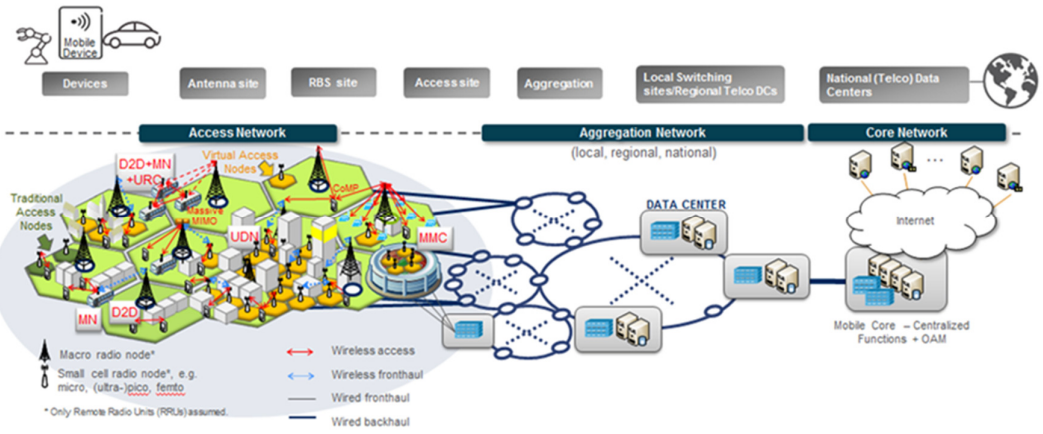


Figure 2-8: METIS E2E reference network

The model includes devices, e.g., terminals and D2D groups, antenna sites, e.g., small cells, relay nodes, cluster nodes, as well as radio base station (RBS) sites. In addition, data centers with data processing and storage capabilities at access, aggregation, and core level are depicted.

In principle, NFs can be deployed at all those sites in a flexible architecture, but finally, it strongly depends on the underlying service and use case requirements. In order to enable flexibility in positioning within the network topology two types of NFs are distinguished:

- **Synchronous NFs** for which processing is time-synchronous to the 5G AI (slots/frames). They typically require high throughput on the interfaces, which scales with traffic load, overall radio bandwidth, and number of antennas.
- **Asynchronous NFs** for which processing is time-asynchronous to the 5G AI (slots/frames). They typically require low throughput on the interfaces, and the processing requirements scale with the number of users, but not with the overall traffic load.

2.1.4 3GPP

In 3GPP, flexibility in RAN is supported by the concept of a capacity broker for RAN sharing, which was introduced in 3GPP System Architecture Working Group 1 (SA1) [15]. A RAN provider, such as Infrastructure Provider (InP), provides on-demand resource allocation through the capacity broker. Specifically, the InP can share via signalling a particular and unused portion of the capacity for a specific period of time with a virtual mobile network operator (VMNO). Interestingly, the capacity broker performs admission control to optimise the resource management for multi-tenancy sharing operations.

3GPP SA 5 targets the extended legacy network management architecture in order to accommodate network sharing based-on long term contractual agreements [16]. Using the Type-5 interface, the InP facilitates resource sharing to contend VMNOs through the InP network manager system. The Type 5 interface is established upon an agreement between mobile operators to

provide connectivity among the network manager systems across different organizations. Then, the InP forwards monitoring information to the sharing operator-network manager through the management system. Monitoring performance information is conveyed through (i) Type 2 interface or Itf-N between the management system and network element manager, (ii) Type 1 interface or Itf-B between the Shared RAN Domain Manager and an eNodeB.

Additionally, beyond the original RAN sharing concepts, 3GPP has defined two distinct architectures in 3GPP SA2 as documented in [17]:

- **Multi-Operator Core Network (MOCN),** where each operator has its own Evolved Packet Core (EPC) providing a functional split between the core network and RAN. While the eNBs are shared, different core network elements, each belonging to a different operator, are deployed and connected to the eNBs, i.e. Mobility Management Entity (MME) and Serving Gateway (S-GW), using a separate S1 interface. This directly enables customization such as load balancing policies which are provided within each operator's core network, service differentiation, and interworking with legacy networks.
- **Gateway Core Network (GWCN),** where also the MME is shared between operators. This scheme enables cost savings compared to MOCN, but at the expense of reduced flexibility.

The described schemes are illustrated in Figure 2-9. MOCN provides more flexibility and both schemes MOCN and GWCN are completely transparent to the user equipment (UE).

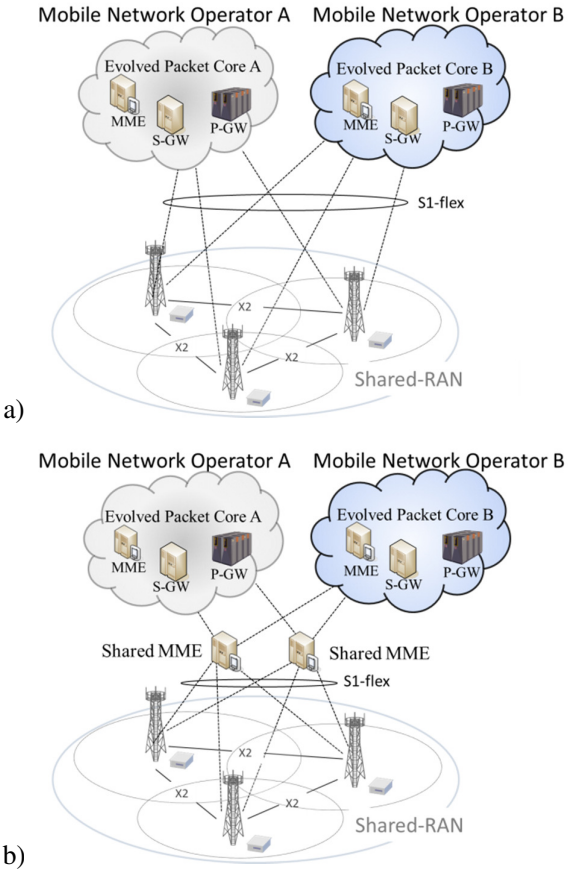


Figure 2-9: 3GPP architectures for network sharing; (a) MOCN, (b) GWCN

A UE distinguishes up to six different mobile operators that share the RAN infrastructure based on broadcast information, namely Public Land Mobile Network (PLMN) identifier. The UE is able to obtain connectivity or perform a handover regardless of the underlying RAN sharing

arrangement. The S1 interface allows eNBs to exchange PLMN-ids with MMEs in order to properly assist the selection of the corresponding core network, while the X2 interface just supports a PLMN-id exchange amongst neighboring eNBs for the handover process.

2.2 Software Defined Networking and Open Network Foundation

The Open Networking Foundation[3] is an organization funded by major actors in the networking industries that focuses its activities on fostering the standardization and the adoption of the SDN paradigm [30].

The goal envisioned by SDN (and hence by ONF [31]) is providing open interfaces for simplifying the development of novel software that is used to control the network. The SDN approach hence is to enable a software-based programmability of NFs, resources, and, as a consequence, of overall network capabilities. Among the functionalities targeted by an SDN architecture is not only the control of the forwarding functions, but also deep packet inspection and modification.

The key idea behind SDN is the decoupling of control plane from data plane. The network intelligence is then located in the Controller node, a centralized entity that takes care of managing the underlying network infrastructure that is, in turn, seen as an abstract resource.

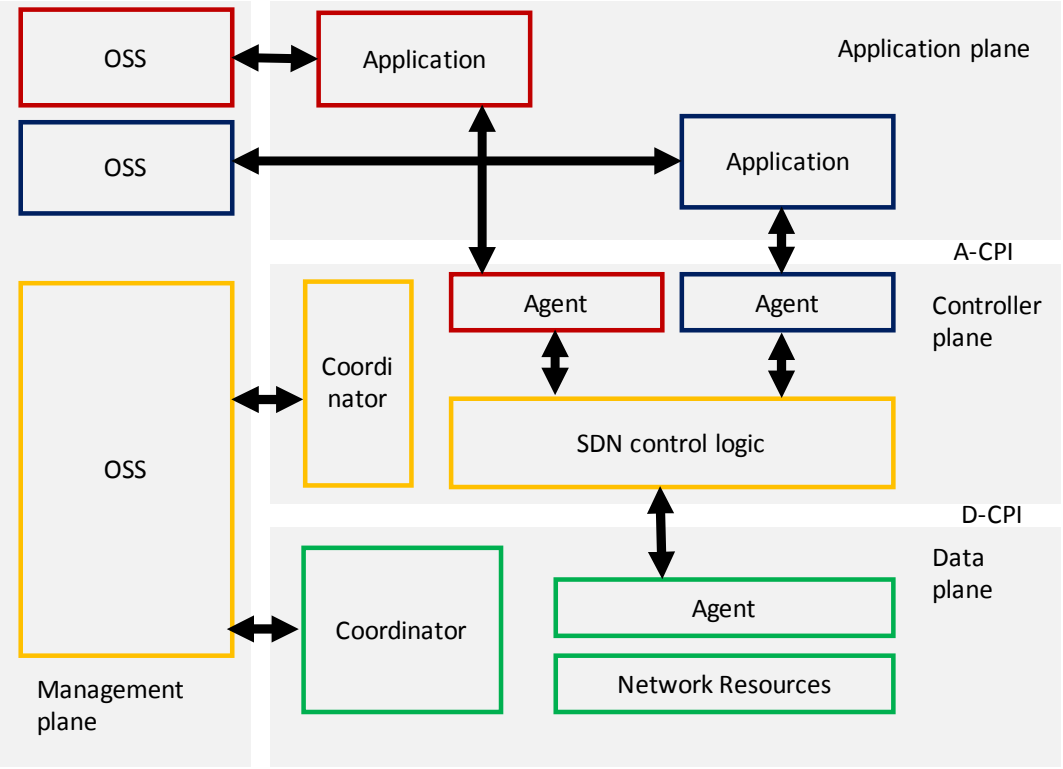


Figure 2-10 ONF-SDN Architecture

[3] https://www.opennetworking.org

The resulting architecture is depicted in Figure 2-10. It allows a very high level of customization as all the NFs and their automation is managed through software. As a result, SDN-enabled networks feature high flexibility and scalability, allowing a rapid adaptability of networks to rapidly changing requirement.

2.2.1.1 Requirements

The main requirements supported by the ONF through the SDN paradigm are:

- Support for interoperability based upon open SDN controller plane interfaces;
- Independence from the characteristics of SDN controller distribution;
- Scalability and support for recursion to encompass all feasible SDN controller architectures;
- Applicability to, and simplified and unified configuration of, a wide range of data plane resources;
- Policy and security boundaries related to information sharing and trust;
- Support for management interfaces, across which resources and policies may be established, as well as other more traditional management functions; and
- Co-existence with existing business and operations support systems, and other administrative or control technology domains.

These requirements are met through the definition of programmable NFs managed by a centralized control service. NFs and services embrace the full OSI stack and can be either physical or virtual. Finally, the SDN architecture also takes into account the co-existence with legacy non-SDN technologies, to mitigate the issues during the transition to a software-defined approach.

2.2.1.2 Layering

The SDN architecture proposed by the ONF includes three layers:

- The Data Plane: the set of network entities that expose their capabilities to the Controller Plane using the data-controller plane interface (D-CPI, or Southbound interface).
- The Controller Plane: the entity in charge of translating the applications requirements into a set of fine-granular commands to the network infrastructure. At the same time, feedback about the current network infrastructure status is provided to the applications. Applications use the application-controller plane interface (A-CPI, often called Northbound Interface). Among the additional functionalities that SDN may implement there is the orchestration of competing applications demanding for limited network resources.
- The Application Plane: the entity hosting the SDN-capable applications which communicate their requirements to the Controller Plane through the A-CPI (Northbound Interface).

The view of certain resources offered to the upper layer is customized by agents, i.e., network infrastructure in the case of Data Plane, virtualized network infrastructure for the Controller Plane.

2.2.1.3 Research Trends

Current research trends follow three main directions:

- North: the interface between the SDN-capable application and the Controller layer is undergoing a definition process.
- South: as new RATs emerge, the D-CPI interface has to be updated
- East/West: the coordination with legacy network controller is paramount to guarantee a smooth transition to the SDN paradigm.
- SDMC (as pursued by 5G NORMA): extension of the SDN paradigm to mobile NFs.

2.3 ETSI Network Functions Virtualization

High flexibility is achieved, and thus cost saving for network operators, when network virtualization is applied to network services and network functions (NFs). Network function virtualization (NFV) decouples software NFs, such as S-GW, P-GW, MME, from proprietary hardware appliances to transform them into building blocks that can be flexibly combined to build communication services. Different network operators (tenants) can deploy customized network services with different virtual NFs on a common infrastructure, thus realizing network sharing.

A network service is defined as a composition of network functions and defined by its functional and behavioural specification. VNFs can be chained with other VNFs and/or Physical Network Functions (PNFs) to realize a network service. The NF Forwarding Graph (NFFG) describes the topology of the network service or a portion of the Network Service by referencing VNFs and PNFs and (virtual) links that connect them [34].

An end-to-end network service (e.g. mobile voice/data, Internet access, a virtual private network) can be described by one or multiple NF Forwarding Graph(s) of interconnected Network Functions and end points. The end points correspond to devices, applications, and/or physical server applications. A 5G network slice instance as described in Section 2.1.1 implements the functions necessary to operate the end-to-end network service [33].

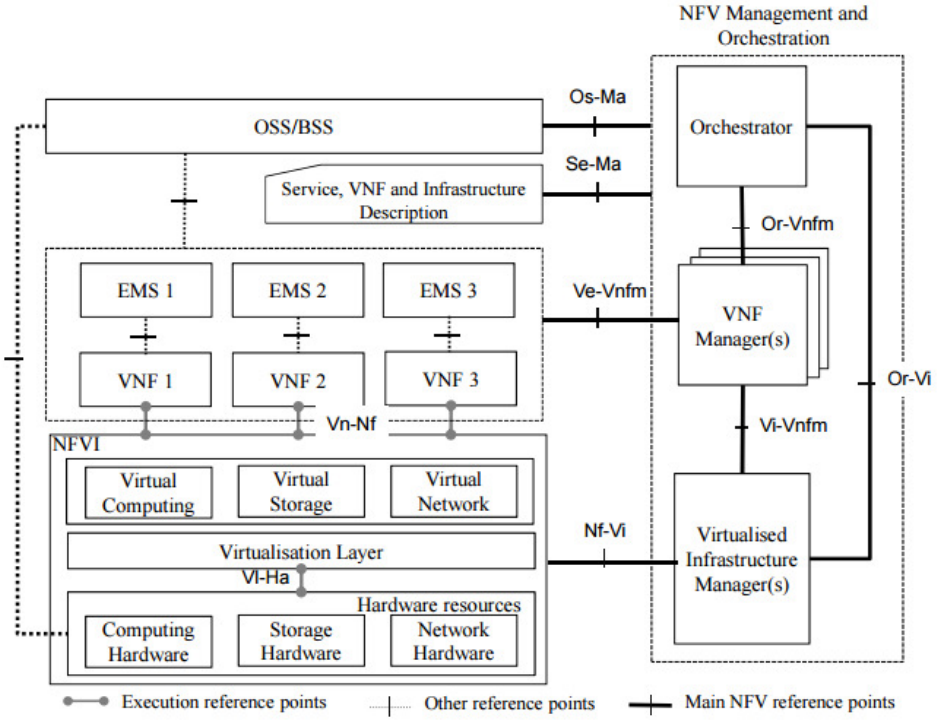


Figure 2-11: ETSI NFV MANO architecture[4]

The NFV MANO architectural framework represented in Figure 2-11 shows the individual functional blocks. Multiple functional blocks may be merged and the reference point amongst them can be internalized. Each of the functional blocks has a well-defined set of responsibilities

[4] http://www.etsi.org/technologies-clusters/technologies/nfv

and operates on well-defined entities, using management and orchestration as applicable within the functional block, as well as leveraging services offered by other functional blocks. In the NFV MANO architectural framework different NFV MANO functional blocks are identified: (i) Virtualised Infrastructure Manager (VIM), (ii) NFV Orchestrator (NFVO), (iii) VNF Manager (VNFM). Additionally, we have Element Management (EM), Virtualized Network Function (VNF), Operation and Business Support System (OSS and BSS), NFV Infrastructure (NFVI), which share reference points with NFV MANO. While the MANO functional blocks are responsible for VNF and network service lifecycle management and orchestration, OSS and EMS perform classical network management tasks, such as, FCAPS management (fault, configuration, accounting, performance, security).

3 Requirements on the 5G Mobile Network Architecture

This section details the requirements that need to be fulfilled by the 5G mobile network architecture. In particular, we discuss a) scenarios and business models that need to be supported by the architecture; b) requirements on flexibility, scalability, and context-awareness; c) security requirements, and d) finally, requirements on the mobile network functionality that must be enabled.

3.1 Scenarios and Business Models

The future mobile networks should support creation of new business models without having an architectural impact. Hereafter we present business requirement from a mobile network operator centric view.

Mobile network operators must address two distinct streams of market requirements. In the first stream, as a service provider, the mobile network operator need to address customer, enterprise, and vertical. The networks need to support concurrently a diverse set of services and their related vast range of technical requirements. As shown in NORMA deliverable D2.1 [18] and highlighted in Figure 3-1, the set of services considered for 5G implies three main dimensions of service requirements which drive the network development:

- Massive Broadband (MBB),
- Critical machine type communication (cMTC), and
- Massive machine type communication (mMTC).

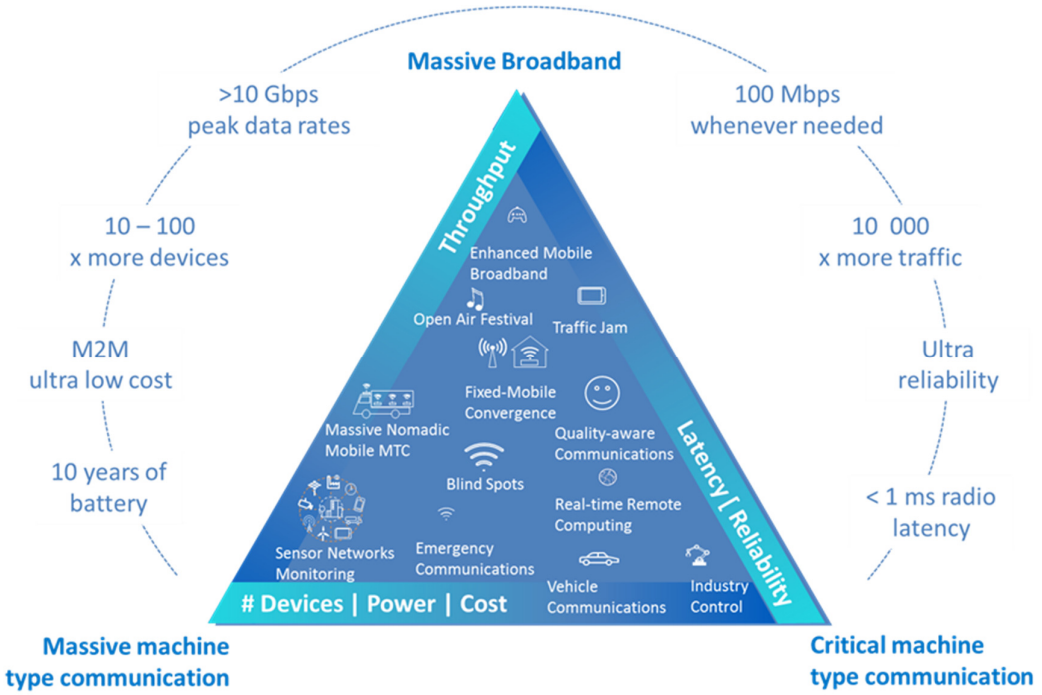


Figure 3-1: Service drivers for 5G mobile network development

The second market stream is defined by the need for the network to support new business models where third parties will use assets of the network for their own offerings to their users. In these new business relationships, the network operators need to adapt their network to provide Infrastructure as a service, Network as a Service or Platform as a Service.

In order to ensure that the proposed network architecture is able to address this diverse set of market requirements, 5G NORMA focuses on scenarios which combine different use cases and requirements. For that purpose, two main scenarios were defined in [18] and will be used throughout the project to develop and evaluate novel technologies. In particular, one scenario focuses on multi-service provisioning in order to demonstrate how different service requirements can be integrated into a single architecture.

Furthermore, 5G NORMA addresses the diverse requirements through its innovative enablers which are further detailed in Section 4.1, most notably Software Defined Mobile Network Control, adaptive composition and allocation of network functions, and joint optimization of mobile access and core. In the context of virtualization, mobile network operators need to adapt their network deployment to a new business model of infrastructure as a service (IaaS), Platform as a Service (PaaS) or network as a service (NaaS). To better cope with the requirements of new business models with third parties, the deployment of the network must be flexible and adapted to a tenant's demands on quantitative requirements such as quality of experience (QoE) but also functional requirements. In order to address these requirements, the second 5G NORMA scenario addresses multi-tenancy support to demonstrate how different tenants can be integrated into a single mobile network.

In summary, the two scenarios defined in [18] provide the means to address the market requirements in term of 5G services and new business models during the design of the 5G network architecture within 5G NORMA.

3.2 Flexibility, Scalability, and Context-Awareness

The future mobile network architecture should satisfy a set of requirements as indicated in the previous section. Based on these requirements, the 5G architecture is expected to support

- Flexibility supporting arbitrary services with sometimes contradictory network requirements, to be future proof and to avoid the need for designing a specific architecture per service;
- Flexibility for introducing new and future technologies and concepts to improve network efficiencies, network and service performance.
- Flexibility to support multiple business purposes, including sharing the network assets with third parties (tenants) by deploying e.g. Network as a Service
- Scalability to support an ever increasing amount of data and growing number of connected devices (mobile and fixed devices, sensors). The network needs to adapt to the traffic fluctuations depending on time, on location, on services and on context.
- Context-awareness to adapt network to the service(s) in real-time. Using information from environment and user such as location, time, user identity and profile should help for efficiently provisioning the service, managing mobility and network resource. Context awareness is useful for the placement of NFs inside the cloud network by taking into consideration physical deployment constraints and limitations.
- multiple services at the same time on a single infrastructure, to avoid the need to deploy multiple network infrastructures within the same geographic area; and
- Ability to support heterogeneous deployments such as ultra-dense and macro-cellular networks, indoors and outdoors deployment, as well as different transport network characteristics. This shall avoid the need for adapting the deployment to the architecture's capabilities and its limitations, which may prove to be very stringent under certain physical deployment constraints.

As a result of above requirements, the major challenge, which is tackled by 5G NORMA, is the fact that a single architectural network instantiation may not be sufficient anymore. Instead, leveraging the NFV and SDN concepts, the network is then sliced into many dedicated end-to-end virtual networks, each handling a business case while sharing the same physical network infrastructure. Then diverse instantiations of adapted function chains, each of them contained in its own slice may be used instead of a single functional architecture which must fit all purposes. However, each individual, applicable function chain needs to be verified and potentially may interact with each other. Therefore, the right balance between additional architectural overhead to provide the required flexibility, and the benefits of flexibility, context-aware adaptation, and adaptability must be identified.

Beside the previously mentioned requirements, [18] derived specific requirements based on a representative set of use cases that can be envisioned today, and that are integrated in a perspective architecture based on network slicing and functional decomposition. These more specific requirements have been abstracted into eleven requirement groups (RGs) [18], which are listed in the following:

- Fast network reconfiguration within a network slice;
- Fast network reconfiguration between network slices;
- Device duality;
- Separation and prioritization of resources on a common infrastructure;
- Multi-connectivity in access and non-access part of the 5G system;
- Massive scalability of protocol NFs;
- Highly efficient transmission & processing;
- QoE/QoS awareness;
- Adaptability to transport network capabilities;
- Low latency support; and
- Security.

5G NORMA uses these requirement groups to develop and later evaluate novel technologies as well as the design of the architecture. This evaluation will be done both qualitatively and quantitatively. More details on the evaluation concept are given in Section 6.

3.3 Security Requirements

The basic requirement with respect to security has been stated in [18] as follows: "The network must be designed in a way that allows to secure the network, its users and their traffic effectively against cyber-attacks, and may provide flexible security mechanisms that can be tailored to the needs of the different use cases that are supported." In [18], this is mentioned as a design principle which implies that the 5G NORMA architecture design shall be done in a way that satisfies this requirement.

Moreover, [18] also comprises a number of security requirements, described in the context of the 5G NORMA use cases. These are rather general "black-box requirements" that do not make assumptions about the network architecture and the way how the network works. Beside [18], there are various other sources of requirements. For example, we can assume that the LTE security features [19] are likely to be required also in 5G systems. Moreover, a number of potential security features have been discussed in 3GPP, but have not been adopted yet and are described in [20]. Organizations such as the NGMN Alliance have already stated security requirements on top of the security provided by LTE [2].

However, the focus of this section is rather on the specific approach taken by 5G NORMA. In particular, we focus on security requirements for the specific architectural concepts and enabling technologies adopted by the project, such as NFV, SDN, multi-tenancy and network slicing. In the following, we list the security requirements we have identified so far:

Tenant isolation: Ensure that tenants are restricted to their assigned resources and cannot attack other tenants by stealing their resources, modifying their resources, or modifying or reading any content held by these resources. This includes isolating tenant domains also from the resource provider domain in a way that a tenant cannot break into this domain but can only interact with it according to well specified, secure procedures. Tenant isolation must not only consider the legal interfaces, but also the threat of information leaking via side channels. For example a VM may be assigned some memory for its use, and in this memory there may be still data visible from a previous user of this memory.

Note that the tenant isolation mechanisms are typically under control of the infrastructure provider, who must be trusted not to compromise network security by failing to provide the isolation. Even more, a tenant cannot be "isolated" from the infrastructure provider. We assume suitable security cannot be provided in case of a malicious infrastructure provider.

Secure Software Defined Mobile Network Control: When the control software of the network is no longer a static, monolithic block but consists of various dynamically created and possibly heterogeneous control applications that access networking resources via an SDN controller, sound application-authentication and -authorisation mechanisms must be implemented by this SDN controller. This may also require distinguishing different application roles and respective permission classes for the different control-operations the SDN controller provides to applications. In case of applications of different tenants accessing the same SDN controller, e.g. an SDN controller provided by a networking infrastructure provider, this requirement becomes a specific instance of the tenant isolation requirement above.

Physical VNF separation: It is required to prevent attacks between VNFs running on the same hardware entity via exploits of vulnerabilities in virtualization software, which are likely to exist in spite of all virtualization platform security measures. Hence, means must be provided that allow physical separation of VNFs without sacrificing the principle of flexible and efficient resource allocation. Such means will not only support physical tenant isolation, but will also allow the setup of different security zones within the domain of a single tenant.

Flexible security: In order to support multiple services with different requirements, possibly implemented within separated, dedicated network slices, security procedures must be available that allow for adapting to the specific needs of a service or network slice. This flexibility may relate to the way the user plane is protected, or how end user devices are authenticated and authorized to use a service or slice. However, while protection of service- or slice-specific resources may be adaptable, protection mechanisms required by the network against malicious or erroneous tenant behaviour are indispensable and must not be subject to "bidding down" attacks. In the same way, the underlying network infrastructure must always be soundly protected against any malicious or erroneous behaviour of end user devices.

Support of reactive security controls: Assuming that network implementations will not be flawless and thus be vulnerable to cyber-attacks, it is required that the architecture allows the dynamic use of reactive security controls, i.e. means to detect possible security breaches and to react on them accordingly in an automatic way. This may include security monitoring mechanisms, software integrity protection mechanisms for VNFs, anomaly detection, intrusion detection and prevention mechanisms including deep packet inspection. Apparently, security mechanisms such as monitoring may in turn become target of cyber-attacks, e.g. against end user privacy, and must be protected accordingly.

Security orchestration: Assuming a dynamic network structure, also the protection mechanisms and the security controls will need to be rather dynamic, flexible, and autonomous. In order to ensure the effectiveness and efficiency of the overall security concept, suitable security orchestration functions are required.

Reliable fallback: In the context where vastly increased use of software-defined capabilities feeds evolution of network flexibility towards the realisation of 5G, reliable baseline hardware capabilities are required as a fallback in order deal with, e.g., the increased security vulnerability associated with software being hacked. Further investigation of the detailed demarcation of what should remain in hardware versus what can be implemented in software is therefore needed. Based on preliminary studies, the following requirements can be stated:

- Support of "forced" reset or reboot, or "kill-switch", in the case that a device or network element is detected as significantly and damagingly malfunctioning. This may be due to error, malicious behaviour, or if a device or network element is detected as having been compromised from a security perspective.
- It may be needed to formulate a robust E2E communication including means to perform hardware resets in order to avoid compromised hardware. This might be seen as a rudimentary but robust "slice" implemented in hardware. However, if the integrity of such a "slice" in hardware is compromised, then it is far more difficult to perform countermeasures. This is therefore to be weighed against the benefits of implementing some aspects of such a capability in software.

3.4 Operational Requirements for 5G Architecture

This section details the functional requirements which are imposed on the 5G architecture and which are derived from the previous discussion. There are two major functional requirements which have been mentioned before and are further detailed in the following, i.e. mobile network multi-tenancy, and multi-service and context-aware adaptation and allocation of NFs.

3.4.1 Mobile Network Multi-Tenancy

Supporting multi-tenancy in mobile networks is one of the major challenge addressed by the 5G NORMA architecture design. It is accomplished by network slices with customized capabilities. Specifically, the network slices must consider third party business requirements, service level agreement (SLA) policies, and service adaptation. To perform network slicing operations, we have identified the following functional requirements:

- Network resources such as communication, storage, processing, and function resources are sliced based on different service requirements (see Section 5.1 for a comprehensive definition of "network resources"). This will be performed using a pool of resources, which are reserved for a given slice to achieve particular performance goals. Thus, a resource optimization mechanism is required to optimally allocate resources optimizing metrics such as spectral efficiency or network energy consumption.
- Different resource management policies are defined per network slice. In particular, each slice can require different QoS levels which are fulfilled by means of particular NF chains, function configurations, scheduling policies, etc., which are deployed ad-hoc for that particular slice. The rationale behind is that a proper customization of a network slice appropriately accommodates specific application requirements.
- Distinct tenant requests can result in different profits. The prioritization of a multi-tenancy system is very important to enable new business models where the infrastructure provider has the role of mediator. In such case, based on the resource availability, the main objective of the infrastructure provider, i.e., the admission controller, is to admit multi-tenant requests in order to optimize the global revenue. This will result in potential unfairness, which must be properly handled.
- Vertical market players must be supported by the architecture. A vertical market player is usually focused on meeting the needs of a specific industry without owning network infrastructure. Therefore, an API to enable verticals to directly communicate with the infrastructure provider is required, which must take security issues into account. This interface needs to be properly designed as it opens competition and enables new business models.
- An important requirement is represented by the operational and capital expenditures (OPEX and CAPEX) reduction. Shared utilisation of resources and network equipment, e.g., to accommodate and balance tenants' capacity requests, helps to realize multiplexing gains and reducing costs significantly.

3.4.2 Multi-Service and Context-Aware Adaptation and Allocation of Mobile Network Functions

In order to achieve the 5G NORMA objective of proposing multi-service mobile network architecture, the following functional requirements on multi-service and context-aware adaptation should be fulfilled:

- **Flexible vertical-specific or even service-specific detection of traffic should be supported**. Different services may require different service detection methods, e.g. IP-based Multimedia Services (IMS) and other operator-provided services may be detected via control plane signalling, while Over-the-Top (OTT) or Internet services may require user plane traffic monitoring to allow for detecting specific application flows. Service detection function should be designed sufficiently flexible and extensible to enable different service detection methods for any foreseeable service.
- **Service specific and context-aware derivation of service requirements should be supported**. The QoE and QoS, mobility, security and other requirements can be derived dynamically based on detected services as well as network context. For instance, mobility management requirements may be identified according to UE type and class, UE mobility pattern, the detected service characteristics in terms of reliability and continuity and RAT capabilities. QoE and QoS requirements may be derived based on dynamic policies as well as real-time user plane traffic monitoring.
- **Adaptation of NFs to enable service and in-service differentiation should be supported**. The NF selection, placement, and configuration can be adapted based on the derived requirements of the detected service to enable service and in-service differentiation. The NFs may be centrally located at the central cloud for the detected services having relaxed latency requirements, while NW functions may be placed at the edge of the network for detected services requiring low latencies. For instance, multi-

connectivity functionality may be configured to increase the connectivity capacity for MBB services, or it could be configured to provide redundant connectivity, e.g. for cMTC services. As another example, the scheduling function can be configured differently according to user classes in terms of mobility status, multi-RAT capability and detected service types, e.g. mMTC, cMTC, or MBB.

- **Context aware NF adaptation and allocation should be supported**. The NF selection, placement, and configuration for the detected service can adapt to the deployed physical architecture such as available antenna sites, equipment housing, and transport network capacity and latency. For instance, when a user leaves the area covered by an edge cloud[5] and enters the area of another edge cloud, the mobility function may determine how the NFs are executed, on the original cloud, another edge cloud, or another central cloud. A reallocation should take into account UE location, network conditions and context, as well as QoS and QoE.
- **Dynamic network monitoring functions should be supported**. Continuous monitoring will enable service- and context-aware NF adaptation. For instance, they might provide monitoring of available network resources for more efficient mobility and multipath control, and real-time monitoring of user traffic flows to enable application-specific and context-aware QoE/QoS management and dynamic routing control. Furthermore, it might provide monitoring of processing and radio resource allocation schemes, e.g., for better slice management and verification/planning of the performance of slices. Vitally, they might also assist the detection of security-related vulnerabilities or violations. Network signalling due to dynamic monitoring and reporting should be minimized in order to increase resource usage efficiency.

4 5G NORMA Key Enablers and Reference Architecture

This section describes the three innovative key enablers which are in the focus of 5G NORMA, namely software defined mobile network control, adaptive composition and allocation of mobile NFs, and joint optimization of mobile access and core. These key enablers have been identified in order to fulfill the previously introduced requirements on the 5G NORMA architecture. Hence, at the end of this section, we introduce the 5G NORMA reference architecture which is further detailed in Section 5.

4.1 Key Innovations and Enablers

In the following, we detail the three 5G NORMA key innovations which take into account the requirements described before and detailed in [18]. Later, we introduce the 5G NORMA reference architecture which provides the required architectural framework for these key innovations. The reference architecture is further detailed in Section 5. Section 6 will address the validation of the reference architecture, aiming at the evaluation whether and how efficiently the aforementioned requirements are fulfilled.

[5] Section 5 provides a definition of edge and central cloud. In general, it distinguishes cloud-computing data centers located close to the radio access points (edge cloud) and those located close to the core network (central cloud). Edge cloud, central cloud, and bare metal (non-virtualized hardware) are referred to as network domains.

4.1.1 Software Defined Mobile Network Control and Orchestration

In order to enable a **flexible** network management and operation, we follow a **software-defined** approach to design the mobile network architecture. Indeed, the SDN functionality has recently gained a lot of popularity as a new approach to build networks as detailed in Section 2.2. Along the lines of SDN, 5G NORMA's architecture incorporates the Software-defined Mobile Network Control and Orchestration (SDMC+O) concept which includes functions relevant for radio access and mobile core network. While the Orchestration part is explained in the next section, in the following we expose the concept behind SDMC.

The SDMC+O approach that we propose resembles SDN in that we split mobile network functionality into (i) those functions that are being 'controlled'; and (ii) those functions that 'control' the overall network and are executed at the controller. However, our SDMC+O concept is specifically devised to control mobile network functionality, and 'controlled' functions are not limited to data plane functions but also control plane functions, both of which can be placed arbitrarily in the edge cloud or the central cloud.

To implement the SDMC+O paradigm, where wireless functionality is controlled by external software located in the controller, it is essential to specify an interface between the controller and the mobile NFs that (i) is standardized and supported by all deployed equipment, and (ii) provides sufficient flexibility to obtain the desired behavior of the network by reprogramming the behaviour of 'control' functions only. In this way, SDMC+O effectively provides network programmability capabilities allowing third parties, i.e. virtual operators and vertical market players such as OTT providers or V2X operators, to request network resources on-demand.

Indeed, the control of wireless networks comprises many functions including, among others, channel selection, scheduling, modulation and coding scheme (MCS) selection, and power control. With a software-defined approach, all these functions could be performed by a programmable central control, which provides very important benefits for the operation of the mobile network. The key advantages resulting from incorporating the proposed approach include the following:

- **Flexibility**: A current problem for mobile network operators is the high amount of capital and operational expenditures of their networks independent of the actual traffic load and service usage, and thus the earning for products they sell to customers. By means of our SDMC+O approach, operators would be able to fit the network to their needs by simply re-programming the controller and thus reducing costs, while being able to scale-up and down virtual functions, also enhancing reliability.
- **Programmability**: Allowing third parties to acquire network resource on-demand satisfying their individual SLAs. In addition, programmability can enhance the user perceived QoE by customizing the network resource accordingly.
- **Unified management**: Adopting a logically centralized control unifies heterogeneous network technologies and provides an efficient network control of heterogeneously deployed networks, reflecting evolving traffic demands, enhancing mobility management and considering dynamic radio characteristics.
- **Simplified operation of the wireless network**: With SDMC, network operators only need to control a set of central entities (namely, the controllers) that control the entire network, which possibly includes heterogeneous radio technologies.
- **Enabling new services**: By modifying the behaviour of applications that run on top of the SDMC controller's northbound interface, many new services that were not included in the initial architecture design can be enabled by modifying the network behavior and adapting its capabilities for the introduction of new services within few hours instead of weeks [21].

- **Performance**: By adapting the functions such as scheduling or channel selection to the specific needs of the applications or the scenario, significant performance gains can be achieved. For instance, the controller has a global view of the network, which allows for optimizing the resource allocation and scheduling across multiple base stations (BSs).
- **Inter-slice resource control**: Following the network slice concept, SDMC allows to provision resources for different slices by allocation of a network slice with associated network capacity, a particular split of the control/user-plane and the virtual NFs. Additionally, SDMC also allows for dynamically sharing resources between different slices through inter-slice resource control.

Finally, as an analysis of the pros and cons of the SDMC+O approach, it is important to note that with the benefits of such software-defined approaches also come additional risks and management requirements. For instance, SDN introduces additional interfaces and increases the complexity of the control software which may lead to higher vulnerabilities. They may also require management of the attribution of resources, e.g., processing capabilities, to communication paths, e.g., forming network slices. Such a flexibly configurable network has inherent capabilities and benefits thanks to being able to dynamically attribute resources in physical equipment to communication links: Exemplary advantages are to ensure that the geographical and logical location of processing resource to realise associated network elements matches the locations of traffic loads and traffic paths which optimally minimise communications latency in 5G applications.

4.1.2 Adaptive Composition and Allocation of Mobile Network Functions

The key idea behind 5G NORMA to support service flexibility is to decompose the mobile NFs, including access and core functions, which are usually associated to a network element and adaptively allocate them to the edge cloud or central cloud, depending on:

- the specific service and its requirements, e.g., bandwidth and latency;
- the transport network capabilities, e.g., available network capacity and latency.

The adaptive composition and allocation of NFs further enables several advantages:

- If service requirements and backhaul capacity are sufficient to allow for centralizing the functionality in the central cloud, better scalability and pooling gains can be obtained from moving major parts of the functionality to the cloud.
- If services have specific requirements that require moving part of the functionality to the access, or backhaul constraints do not allow for fully centralizing mobile network functionality, then gains can be obtained by using a fully or partially distributed configuration. Achievable benefits can for example be lower latencies, enabling autonomous operation of edge clouds, or offloading the backhaul and the central cloud.
- There is no need to define a single general purpose function per task, e.g., forward error correction, link adaptation, or scheduling, that is suitable for all physical deployments and services, but instead multiple different functions may exist (or versions), each one optimized to its specific deployment scenario and services supported. Hence, this optimization may allow for providing multiple lightweight and stripped down versions of a function compared to a single complex multi-purpose function.

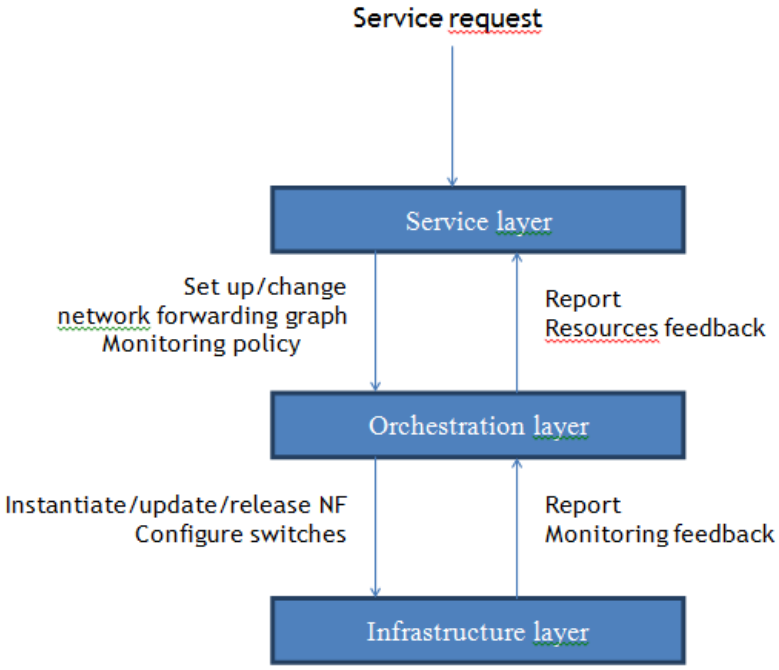


Figure 4-1: Layers for function (de)composition and (re)allocation

Figure 4-1 introduces a synoptic scheme of the layers that should be supported in 5G NORMA in order to be able to compose and allocate the functions following the service requirements. In the following, the individual tasks necessary to satisfy service requirements are further detailed.

In order to be able to implement the required flexibility and dynamicity, 5G NORMA architecture must enable the definition of the QoS/QoE service requirements. In fact, different services may have different traffic characteristic, which calls for different mechanisms for service requirement definition. It is further needed to build a service graph which expresses the requested service at the application layer in terms of the required set of abstracted network and capability functions that should be chained with their logical connectivity. Here, the abstracted network and capabilities functions might be either atomic NFs with specific functionality such as deep packet inspection (DPI), routing, and scheduling, or compound NF blocks which are composed of several atomic NF such as MME, control parental, or a physical layer function.

The service graph of different services could be done via an offline operation which stores user, service, application, operator and even context specific policies on QoS or QoE. The service graph is then translated into NFs (instantiable types) with the required infrastructure resources, e.g. computing, connectivity, and storage, and delivered to the orchestrator. The different instantiable NFs are stored in a database. The allocation of the NFs is driven by the optimisation of metrics such as latency, QoE, resource utilization, and energy efficiency. It will further be dependent on the spatial and temporal characteristics as well as traffic fluctuations in the mobile network. For instance, in the case of latency-critical services, functions may be allocated close to the radio access point to minimize delay, while they may be allocated in the central cloud for other services to improve efficiency.

In order to optimize the network resource utilisation, continuous monitoring of the QoS and QoE levels for each service flow is required. Specifically, a hierarchical monitoring system is beneficial. For example, it will often be useful to have (vastly simplified) monitoring implemented at different processing points in the network with possibly limited resources, perhaps even in terminals. Some misbehaviours may only be detectable at particular locations, such as in the user terminal. Larger, more capable and knowledgeable monitoring systems can feed infor-

mation, instructions or constraints to the less-capable monitoring system at the point where the misbehaviour is likely to happen, which includes some human input, e.g., from the operator. Such capability is also consistent with data being divided into and only accessible in different domains, which will likely be the case in the heterogeneous 5G network scenarios that seem probable to prevail. For instance, the top-level monitoring might not be allowed to have access to information from a different domain in a heterogeneous network (HetNet), but can send instructions to monitoring in that different domain such that the monitoring can be done locally and reported to the top-level entity in a way that doesn't violate information exchange constraints, e.g., privacy and data protection.

4.1.3 Joint Optimization of Mobile Access and Core

The third major 5G NORMA key enabler is the joint optimisation of mobile access and core. This aims to overcome the drawback of static allocation or distribution of mobile access and core NFs into specified infrastructure entities or network elements. Thus, all data forwarding and data processing functions across mobile access and core may be considered jointly in facilitating flexible and optimal network slicing while fulfilling service and architecture requirements stated in Section 3.

5G networks need to support new use cases, network deployment scenarios, and business models in addition to those of current mobile broadband access and IP connectivity. It is therefore expected that the 5G network architecture should allow for: (i) flexible structuring or restructuring of the network with support of various RATs and inter-RAT interworking between 5G and legacy technologies; and (ii) flexible capability to segregate mobility management from service control, i.e. packet forwarding and processing, across different mobility control areas or administrative domains. It is practically required to distinguish functions that are executed closer to the access point on bare metal or edge cloud, and those functions which are executed more centrally in the central cloud. So far, there exists a logical split between radio access and core network which basically enables an independent evolution of both, it allows for integrating different RATs, and it enables multi-vendor interoperability. These characteristics should be maintained by the 5G NORMA architecture.

5G NORMA investigates possibilities and proposes novel concepts for cross-function or cross-layer optimization including bare-metal, edge cloud, and central cloud. This includes, e.g., possible joint optimization of typical mobile access and mobile core functionality.

A key technology to enable the joint optimization across different domains is SDMC+O and the smart functional decomposition of NFs as described in the previous sub-section. This alleviates a problem that is experienced in current standards where static function splits are too restrictive for supporting novel services or services with very divergent requirements efficiently. Flexible on-demand mobility of functional blocks may become a pre-requisite for 5G networks to cope with diverse and challenging services that may emerge in the future.

The joint optimization across different network domains herein focuses on the following areas:

- Providing on-demand adaptive NFs dedicated and optimized for specific services;
- Providing optimized QoS and QoE support with flexible aggregated service flow, i.e., enhanced bearer service model, in-service-flow QoS differentiation and multi-connectivity;
- Providing enhanced support for NFV, network slicing, and multi-tenancy; and
- Providing enhanced support for mobility, load-balancing, and resource management.

4.2 Reference Architecture and its Views

In this section, we describe the reference architecture from a high level point of view. Specifically, this section introduces the four different views of the 5G NORMA reference architecture.

The particular details of the architecture design will be explained in Section 5 on the basis of this section.

Figure 4-2 depicts our general approach to describe the 5G architecture. Two main fields have been identified, i.e., the 5G NORMA key innovations which were introduced in Section 4.1, and four different views which serve as the mean for looking at the 5G architecture from different perspectives, representing different aspects of and concepts for the same architecture.

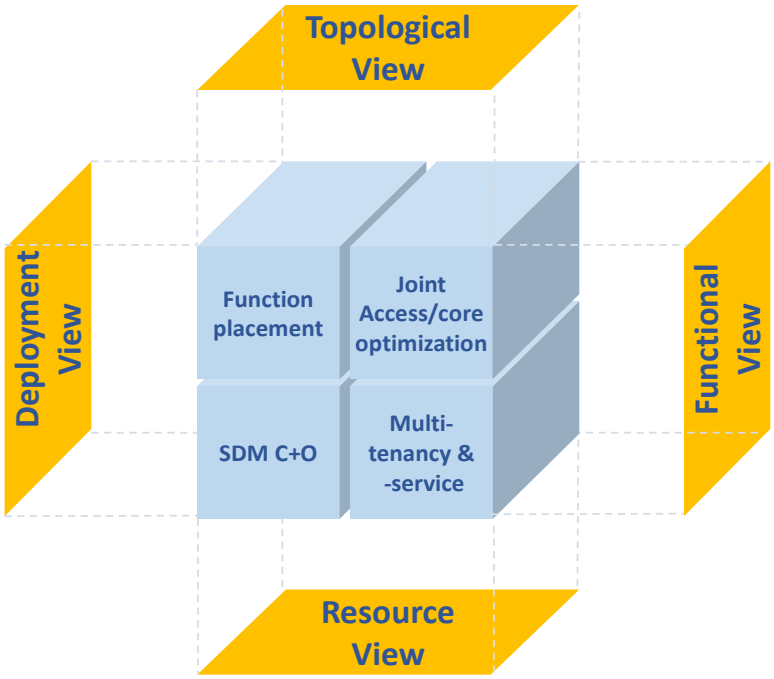


Figure 4-2: The four architecture views as considered by 5G NORMA

The motivation to make use of these different views has been the need of representing properly all characteristics that the new 5G architecture introduces. In presentations of previous mobile architecture approaches such as LTE, mainly a single figure representing the logical connections is used. This is enough for legacy technologies but in 5G we have identified new arising characteristics that need to be captured as well such as:

Functional blocks and interfaces, which is the typical way of representing network architectures.

Flexible allocation of functional blocks to different network entities, i.e. the virtualization of NFs leads to dynamic deployments in which functions may be located in different places. This flexibility on the NF placement shall be captured properly.

Communication, processing, storage, and memory resources that the functional and physical blocks make use of, i.e., in traditional networks, dedicated devices host specific network functionalities. In NFV, resources are virtualized. Furthermore, the flexible mapping of NF blocks to an execution environment leads to repositories that store these function blocks, including a description that enables their orchestration. Service templates, which are also stored in repositories, further describe how to chain these function blocks to implement the respective services.

Topological interconnection of the different blocks. In traditional network architectures, the topology of the network is basically represented by the functional architecture. By contrast in 5G networks, the functional blocks and the different locations are loosely coupled. This leads to

the necessity of representing the topological structure of the different physical resources, regardless of the functional building blocks that may be executed in the different places.

In order to capture these four characteristics properly, we have depicted the architecture by means of four different views, each of them focusing on one characteristic. The views and their scope are briefly described in the following:

Functional view: The functional view captures the functional blocks and the functional interfaces regardless of each function block's location within the network and regardless of the resources used. This is a purely logical view of the architecture.

Deployment view: The deployment view depicts the different possible locations of functional blocks. This also includes the possibility that a functional block may be deployed in different locations, which has to be represented also properly. In the same way, network slices may also be represented in this view as part of a certain network deployment.

Resource view: The resource view captures the resources that the different network components make use of. This includes physical and virtual resources, along with repositories for NF and service templates.

Topology view: The topology view captures the topology of the network. This differs from the functional view in that the topology depicts the way in which physical respectively virtualized network resources are interconnected (including networking, processing, storage, and memory), while the functional view depicts the interconnections between functional blocks. The topology view includes the notion of distance respectively latency, which in 5G NORMA determines the main difference between edge and central cloud. It may also depict bandwidth of transport media between distinct instances of resources in contrast to the deployment view that shows only the generalized class of resources such as edge and central cloud.

5 5G NORMA Architectural Views

5.1 Resource View

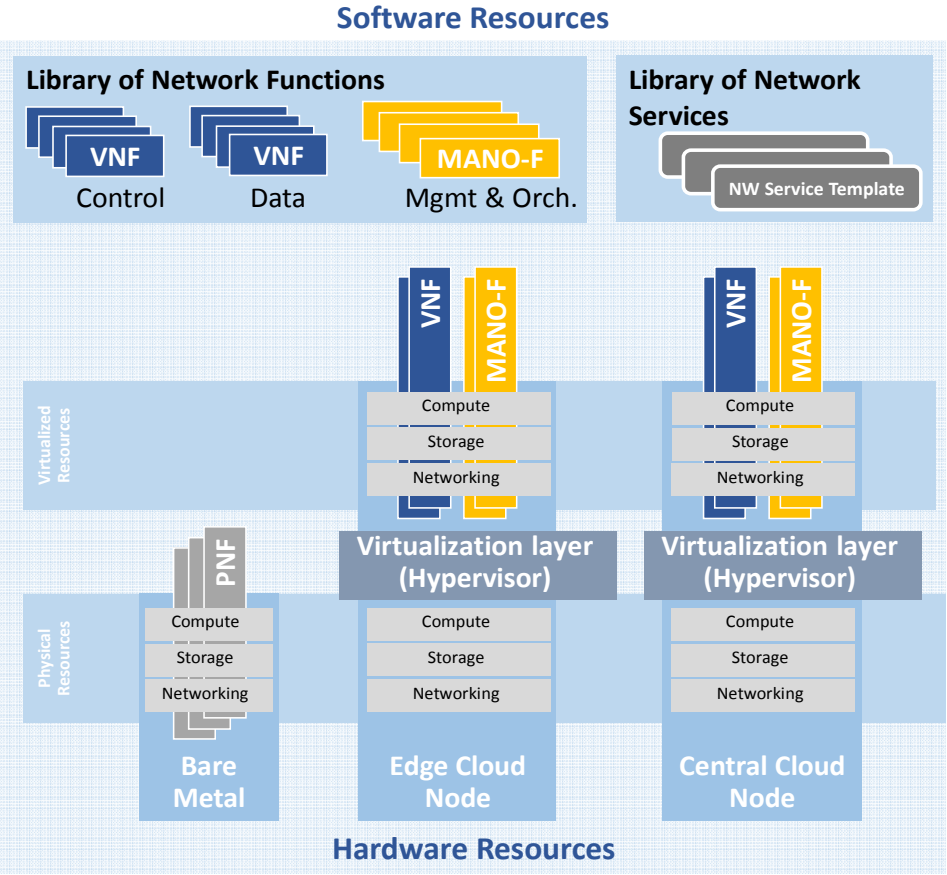


Figure 5-1: 5G NORMA resource view

This section details the resources view of the 5G NORMA architecture as illustrated in Figure 5-1. This view encompasses the comprehensive set of resources available to network management and orchestration entities in order to compose mobile network instances for different use cases and tenants. Therefore, the different categories of infrastructure resources considered in 5G NORMA are described. This includes general purpose physical and virtual resources, i.e. networking, storage, computing, and memory, as well as dedicated physical NFs and elements, referred to as "bare-metal" or "embedded." Furthermore, template and blueprint libraries for NFs and network services are described.

5.1.1 Deployment Types

As shown in Figure 5-1, 5G NORMA distinguishes three deployment types which determine, among others, the classes of network resources which are considered. These three deployment types are [32]

1. **Central Cloud Node**: The central cloud comprises one or more centrally located data centers hosting a significantly large collection of processing, storage, networking, and other fundamental computing resources where the tenant is able to deploy and run arbi-

trary software, which can include operating systems and applications. Typically, only a few of them are found in a nationwide operator network.

2. **Edge Cloud Node**: The edge cloud comprises a small, locally located, i.e. close to or at the radio site, collection of processing, storage, networking, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. Typically, the number of edge clouds is at least one order of magnitude higher than the number of central cloud instances. Particularly, they are expected to be deployed in rather densely populated metropolitan, urban, and sub-urban areas. While adhering to NFV principles, the edge cloud exhibits greater heterogeneity than the central cloud in terms of utilized hardware and hypervisors, geographical deployment, and topological structure. Both central and edge cloud provide virtualized resources in order to execute virtualized network functions (VNFs), and management and orchestration functions (MANO-Fs).
3. **Bare metal**: On bare metal nodes, PNFs are executed. PNFs are NFs that exhibit a tight coupling between hardware and software systems. In fact, software and hardware of a PNF cannot be decoupled at all, in many cases software is even highly embedded in the hardware. 5G NORMA orchestration functions have to pay particular attention for PNFs which may be added to or removed from a network service (see Section 2.3 for a definition) referred to as NF forwarding graph (NF-FG). However, lifecycle management operations, such as scaling in and out, are applicable only in a very limited way to PNFs.

5.1.2 Hardware Resources

The hardware infrastructure resources considered in 5G NORMA include both general purpose and specialized hardware that comprise memory, compute, storage, networking, and other fundamental capabilities. These hardware resources can be available in either virtualized or non-virtualized, i.e. bare-metal, manner. 5G NORMA differentiates four categories:

1. **Hardware based on x86 architecture**: This includes standard server hardware based on the x86 Intel instruction set architecture. It is characterized by simple portability of executable software, mostly only minor or even no adaptations are required.
2. **Hardware based on non-x86 architecture**: This category includes server hardware based on other architectures than standard x86 instruction set architectures, such as reduced instruction set computer (RISC) and ARM. Executable software is not easily portable from x86 to other server architectures.
3. **Programmable, purpose-built hardware**: Programmable, purpose-built hardware exhibits a tight coupling between hardware and software systems. In fact, sometimes software and hardware of a programmable purpose-built hardware cannot be decoupled at all, in many cases software is even highly embedded in the hardware. Examples of this category include systems based on DSPs, field programmable gate arrays (FPGAs), or mobile radio base station chipsets, e.g., available from Texas Instruments, Freescale, and Cavium. Usually, DSPs and mobile radio base station chipsets are programmable. However, they work with a completely different instruction set than commonly used x86 processors. Moreover, different kinds of hardware accelerators are particularly well suited to processing functions in mobile radio, e.g. FFT, channel decoding etc.
4. **Non-programmable, purpose-built hardware**: Non-programmable, purpose-built hardware is built for a dedicated processing function and exhibits very limited (or no) configurability. Examples include RF components of mobile radio base stations. In some cases, purpose-built hardware can be shared by multiple tenants, e.g. two operators using separate carriers amplified on a shared power amplifier (PA) and transmitted from the same antenna. Virtualization techniques cannot be used within this hardware category.

The outlined major hardware categories correlate with the deployment types as outlined in Figure 5-1, i.e., bare metal, edge cloud, and central cloud. While the first two hardware categories are more likely to be found in edge and central cloud nodes, the latter two categories usually host physical NFs, i.e., they exhibit a closer coupling between hardware and software systems. Nevertheless, edge clouds, due to their proximity to the radio site, can also comprise a significant amount of purpose-built, dedicated hardware systems.

Generally, certain functions can be provided on different hardware types, hence the function can be re-located. However, it is inefficient to move binary files from one hardware type to another. Similarly, dependencies can also occur in cloud environments, e.g., a binary can be bound to a particular guest operating system (OS) version of the virtual machine (VM). After upgrading the OS, a new version of the binary is required as well. Again, this limits the portability of binaries. However, the possibility to run multiple guest OSs, and multiple versions of a guest OS, is easily available in a cloud environment and therefore increasing flexibility. However, this increases overhead in the network management and orchestration domain as well.

In terms of administrative domains, hardware resources are typically part of the infrastructure domain, which may be defined by different criteria (e.g. by organization, by type of resource such as networking, compute and storage as in traditional data center environments, by geographical location, etc.), and multiple Infrastructure Domains may co-exist. An infrastructure domain may provide infrastructure to a single or multiple *tenant domain(s)*. The infrastructure domain is application-agnostic and thus has no insight of what is executed within a VNF.

5.1.3 Business Logic Software Resources

The second part of infrastructure resources considered in 5G NORMA are application software resources, i.e., software executing the business logic of a mobile network. For example, templates for VNFs, such as mobility management, IP anchoring, or authentication, are contained in this category. Any software utilized for providing Infrastructure-as-a-Service (IaaS) or Platform-as-a-Service (PaaS), such as host OS data center servers or hypervisor software, is not included in this category. 5G NORMA separates two major sub-categories:

1. **Library of network functions**: The library of NFs represents the repository of all executable VNF packages including the necessary blueprint and metadata, such as resource requirements, supported interfaces, and reference points as well as orchestration and configuration parameters. It thus supports the creation and management of a VNF, i.e. VNF descriptors, software images, and metadata files, via interfaces exposed to other management and orchestration entities. For example, slice orchestrator and NF manager can query the library for finding and retrieving a VNF package to support different operations (both entities are explained in further detail in Section 5.2). Tenants can either access a “default” library or have individual, customized libraries. Furthermore, each tenant keeps a record of currently operating NF instances, their configuration, as well as a lifecycle management statistics in an “online” instance directory.
2. **Library of (network) service templates**: The library of (network) services represents the repository of all executable network services including the necessary blueprints and metadata such as QoS parameters. A network service template refers to the set of VNF that should be chained to implement the network service, e.g. VoiP, IMS. The service orchestrator has access to this library through interfaces to create more complex service requested either by the end –user or the service provider. A service template could contain: network service descriptors, link descriptors, connectivity descriptors. Same for NFs, each tenant keeps a record of currently operating network service instances, their configuration, and included NFs.

The administration right of these two libraries depends on the business model: IaaS, NaaS, classical telco operator, or service provider. The relationship between all these entities will be analyzed in Work Package 2 (WP2) of 5G NORMA. Typically a tenant domain may use infrastructure from a single or multiple infrastructure domains. The service provider could own and man-

ages its infrastructure, supporting a tenant or a vertical or a third player via specific SLA contract.

5.2 Functional View

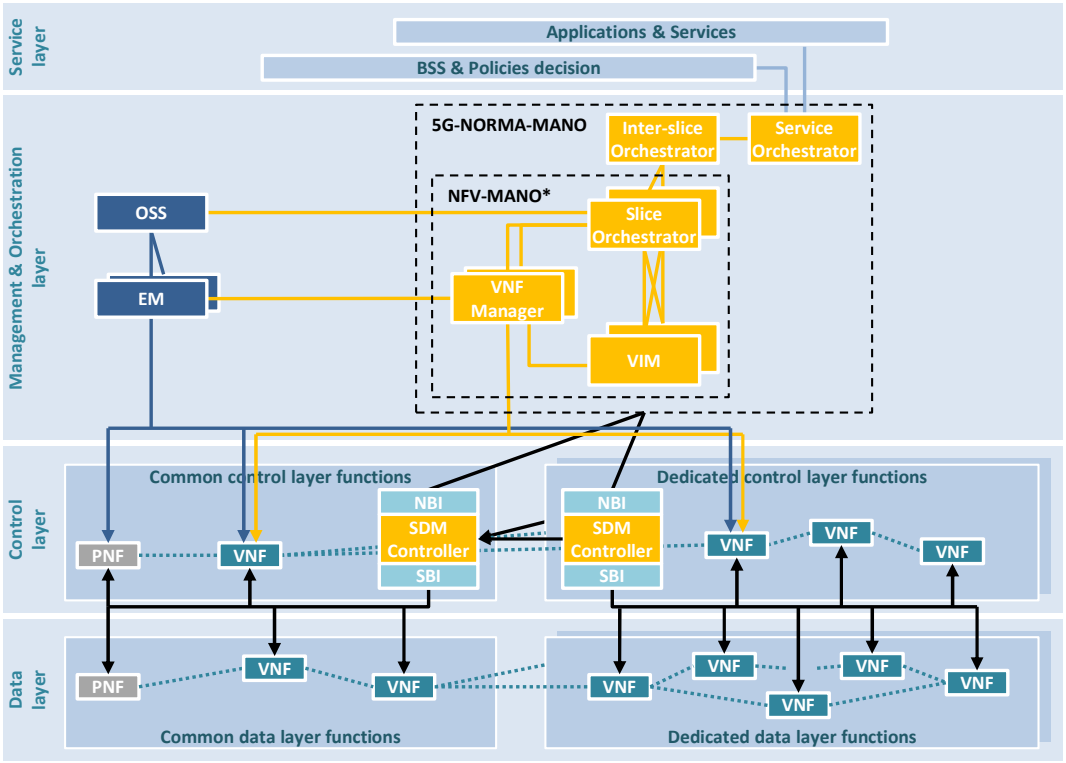


Figure 5-2: Preliminary 5G NORMA functional reference architecture

The typical way to show a network architecture is to show its functional architecture, i.e. to show its logical functional blocks with their belonging to the different layers and their logical interconnections. The preliminary **5G NORMA functional reference architecture** is depicted in Figure 5-2. This is a meta-architecture in that it manages and orchestrates E2E network slice instances as shown in Figure 5-2. Therefore, only MANO functions are shown concretely, while control and data layer are both shown with abstract VNFs and PNFs only. These functions are going to be defined in detailed by 5G NORMA work packages 4 and 5 in the further course of the project. An example is the SDM controller (SDMC) in the control layer, which, within its exclusive regime of control, connects via its southbound interface (SBI) to all PNFs and VNFs in its exclusive regime and northbound to the 5G NORMA-MANO architecture.

The overall 5G NORMA functional architecture includes the following MANO functions: VIM, VNF Manager and the Slice Orchestrator correspond to the ETSI NFV-MANO architecture [22] as indicated by the dashed frame labelled NFV-MANO* around these three functions in Figure 5-2. These functions will be extended and concretized by 5G NORMA compared to ETSI which is indicated by an asterisk. For example, the Slice Orchestrator (called NFV Orchestrator in ETSI-NFV) interfaces with further new 5G NORMA MANO functions, namely the Inter-slice Orchestrator and the Service Orchestrator. Together, these five functions are the core part of the 5G NORMA-MANO architecture. The OSS and EM are legacy functions and present already in today's non-virtualized and non-cloudified networks, but extended to become VNF-aware and to interface with Slice Orchestrator and VNF Manager, respectively. In the following, each 5G NORMA MANO function is explained in more detail.

The **Service Orchestrator** is owned and operated by the tenant or the service provider. One of its primary task is *service function chaining*, i.e., a service creation request is mapped to a set of network services (service chain), including the mapping of service-level requirements such as service level agreements and key quality indicators to a suitable network slice configuration. Its output is a service instance that provides the requested service. It decides whether the service instance can run in an already existing network slice through simple reconfiguration, or whether a service chain needs to be added, either by amending service chains of an existing network slice or by creating a new slice to hold the new service chain. Its work is automated by means of business and policy decisions.

The **Inter-slice Orchestrator** is owned and operated by the service provider. It has a comprehensive view of the subset's resource requirements and overall resources of according infrastructure providers. It handles the dynamic provisioning of the slices and *manages the resource sharing (physical and virtualized resources) among slices*, i.e., scaling up a slice may need another one to scale down. It executes policies decision to solve conflicting requirements between slices for sharing (virtual) resources and links, e.g. rules based on different slices' priority policies. Based on its coordination decision it triggers the Slice Orchestrator for creating, updating or releasing the slice. It provides the input parameters and rules to the Slice Orchestrator for virtual resource orchestration. In case where some slices, possibly belonging to distinct tenants, share some VNF and/or PNFs, i.e., the common control and data layer functions, it coordinates the allocation of such resources among slices and tenants during their life cycle. A tenant who wants to optimize the resources among all the slices it owns may want to operate an Inter-slice Orchestrator on its own besides the one operated by his service provider. If and how this may be supported will be the outcome of the upcoming design iterations.

The **Slice Orchestrator** is owned and operated by the service provider that operates the slice for the tenant which is not precluding that tenant and service provider may be the same. There is one instance per slice. It includes all functionality of the ETSI NFV Orchestrator, namely it optimally *(re)allocates NFs* in its slice (cf. deployment view) and performs *lifecycle management of its slice*, i.e., it binds together all VNFs' life-cycle management via their respective VNF Managers.

The **VNF Manager** is owned and operated by the service provider. There are multiple instances per slice. The number of VNF Manager instances scales with the number of VNF vendors and VNF instances, as a vendor's VNF Manager typically only operates VNFs of the same vendor and a single VNF Manager manages typically only up to a certain maximum number of VNF instances at a time. The VNF Manager performs lifecycle management for the VNFs it manages.

The **Virtual Infrastructure Manager (VIM)** is owned and operated by the infrastructure provider. It has the full knowledge about all physical resources under its control. On request of the Slice Orchestrator it allocates or releases the requested amount of virtual resources, i.e., processing, storage, networking, and returns the remaining resources to the requesting Slice Orchestrator for (re)allocating its VNFs. 5G NORMA foresees a many-to-many relationship with Slice Orchestrator to support network slices spanning infrastructure units owned and operated by different infrastructure owner as well as sharing a single infrastructure unit by different service providers.

The **VIM Agent** (not shown in Figure 5-2) is introduced by 5G NORMA to support large infrastructures spanning multiple physical locations, even complete countries. The VIM Agent manages a part of the overall infrastructure of its operator and typically runs within that part of the infrastructure. It acts on behalf of the VIM. It is optional and can be logically subsumed under the VIM and is therefore not depicted in the above figure.

At least the Inter-slice Orchestrator, possibly also the Slice Orchestrator, require knowledge about the available infrastructure resources to fulfil their tasks. This knowledge is only fully available to the infrastructure provider respectively the VIM that he operates because detailed knowledge about available infrastructure resources is considered a business secret. The simple

solution is to consider infrastructure operator and service operator to be owned by the same business entity, so that such resource knowledge can be considered to be available to the (Inter-) Slice Orchestrator. This approach implies that a network slice cannot span infrastructures owned and operated by different businesses but always must be owned by a single business.

For a general solution that mitigates this problem, it needs to be determined if and what kind of abstraction of resources is sufficient for successful operation of the (Inter-)Slice Orchestrators and whether such an abstraction sufficiently prohibits the service operator from inferring back to the full available resources of an infrastructure provider. For example, the SLA between infrastructure provider and service operator may already detail sufficiently well what class of resources can be provided, e.g., if an there is edge cloud (or only a central cloud) and what are the latency and bandwidth range towards the antenna sites potentially available to the service provider. If such an abstraction can be found, a further interface is added between VIM and Inter-Slice Orchestrator to retrieve the needed information as well as conversely for the VIM to update the Inter-Slice Orchestrator about changes. Likewise, the VIM to Slice Orchestrator interface may be augmented. Alternatively, the Slice Orchestrator may get that information via the Inter-Slice Orchestrator.

The **Operations Support System (OSS)**, with help of the **EM,** does the *setup of all NFs* that have been instantiated beforehand. After creation respectively instantiation, the respective EM instance performs FCAPS (fault, configuration, accounting, performance, security) management for both PNF and VNF (blue edges). The number of EM instances scales with the number of PNF vendors and PNF instances, the same way how VNF Managers scale with VNF vendors and instances. VNF Managers add to the whole setup process only functionality introduced by virtualization. A future evolution of the 5G NORMA functional architecture may therefore merge EM and VNF Manager into a single new MANO-F called Network Element Manager (NEM).

For clarity of presentation, Figure 5-2 only shows a few edges between EM and VNF Manager and their PNFs and VNFs. Actually all PNFs and VNFs in both control and data layers are setup and consequently all are connected to their EM, and all VNFs additionally are connected to their VNF Manager. For the same reason, the edges are overlaid into what seems to be a multicast-like communication between EM and all NFs, but is typically a unicast communication. The arrow heads are added to signify that NFs do not communicate among each other over this interface.

The **SDM Controller** is a key function of the 5G NORMA architecture. It is assumed to have an SDM controller instance per network slice. It controls all of the network slice's dedicated PNFs and VNFs, indicated by black edges from its southbound interface (SBI) to all NFs (same rationale for overlaid edges and arrow heads as for the EM to NF interface, i.e. neither multicast nor inter-NF communication). The SDM Controller allows for the reconfiguration in the order of tens of milliseconds, to dynamically influence and optimize the performance of its network slice within the given amount of resources assigned to its network slice, i.e. at the time of the last (re)orchestration. On the other hand, the (re-)configuration done by EMs only occurs after (re-)instantiation and can be considered to take place at a different time scale (rater seldom, with extents in the order of several seconds).

Following the SDN spirit, the SDM Controller also exposes a Northbound Interface (NBI) towards the 5G NORMA-MANO functions, whose scope is two-fold. The 5G NORMA-MANO to SDM Controller direction is used to define all the QoE / QoS constraints that have to be fulfilled for a given traffic identifier, that may range to a single flow to an entire network slice. The granularity of this API (that goes beyond the simple NF re-configuration) will be determined during the project, but we can provide some examples of its envisioned operation. For instance, the UL/DL scheduler can be dynamically configured by the SDM Controller to provide the needed QoE-related KPIs to HD Video Users flows, while maintaining resources for Best Effort user flows. The network capacity may be another KPI that the SDM Controller must fulfill, taking decisions about NF reconfiguration and routing.

In the case that the given QoE/QoS targets of the service(s) provided by its network slice cannot be met, the SDM Controller may request re-orchestration. For that purpose, it uses the SDM Controller to 5G NORMA-MANO functions direction of the NBI to trigger a re-instantiation request (both of computational capabilities or shared resources such as frequencies or other shared NF). Details on which MANO function(s) to interface with need to be figured out during the course of the project.

During the project, details of the NBI API as well as the entities that may access the NBI, i.e., who may run control applications on top of this API, including how to expose the NBI to tenants, need to be determined, and will be included into later revisions of the 5G NORMA functional architecture.

For efficiency reasons or due to the characteristics of a NF, as well as to transparently support multi-service for a single user terminal, it may be necessary to share some PNFs and VNFs among multiple network slices. For these **common network functions**, a separate SDM Controller is introduced. The SDM Controllers of all network slices that share the common NFs connect to the SDM Controller responsible for common NFs via their eastbound/westbound interfaces. This SDM Controller coordinates access of all the SDM Controllers of all the network slices that use its common NFs as part of their E2E network slices. It resolves potential conflicting requests.

Every instance of a NF instance, dedicated as well as common, including the SDM Controller, is owned and operated by exactly one service provider. While dedicated NF instances are used by exactly one network slice, a single instance of a common NF is used by multiple network slices, possibly owned by different service providers. A single E2E slice may use common NFs of different common NF owners, i.e., a single slice may span a single chain of dedicated NFs (those of the slice owner) and multiple chains of common NFs, each owned by a certain service provider, including itself.

In the 5G NORMA functional view discussed so far, both control layer and data layer are represented in an abstract way, using VNF and PNF instead of concrete functional block names. The motivation is that the concrete functional architecture in these two layers depends on the service and deployment, i.e. are not the same in all cases like the MANO layer functions but may vary. These functions will be instantiated on demand, adapted to both service and deployment, by the 5G NORMA-MANO functions, and after instantiation will be setup and configured by OSS and EM in the same way as today's non-virtualized mobile NFs.

Nevertheless, to exemplify the approach of 5G NORMA and its relation to the 3GPP LTE architecture, Figure 5-3 depicts an exemplary control and data layer using the functional grouping of LTE. Just the most basic and exemplary LTE functional blocks eNB, MME, HSS, PCRF, S-GW, and P-GW are shown. Each functional block is composed of a number of quasi atomic functions; in case of the LTE data plane for example the Medium Access Control (MAC) and Radio Link Control (RLC) in the data layer and Radio Resource Control (RRC) in the control layer, all defined within the eNB functional block. Small coloured squares indicate this composition of functional blocks by smaller atomic functions.

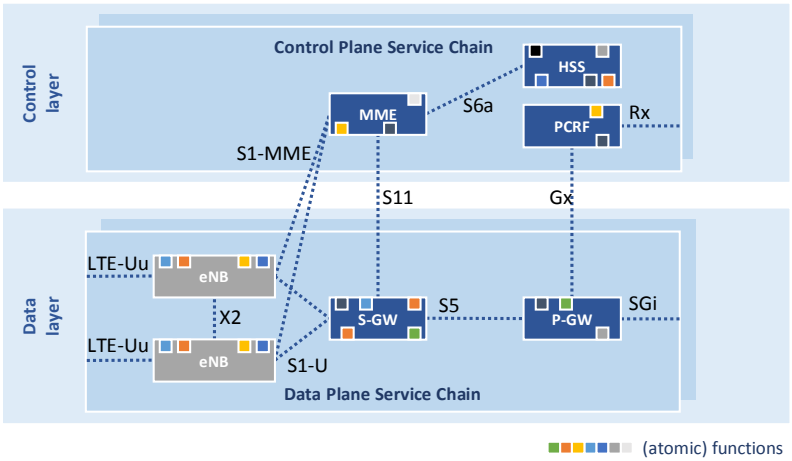


Figure 5-3: Example control and data layer employing LTE-like functional blocks

The **grouping of (atomic) functions into functional blocks** is listed in [23] and called therein hosting of functions, as LTE functional blocks at the same time may correspond to a distinct physical network node. 3GPP standardizes functions and interfaces. The grouping of functions into functional blocks is implicitly predefined by the interface definitions, respectively the protocol elements defined for each of these interfaces. For example, both RLC and Packet Data Convergence Protocol (PDCP) must reside in the eNB. LTE does not support to have RLC in the eNB and PDCP in the S-GW, because the S1-U interface only transports IP packets over GTP-U and not PDCP Packet Data Units (PDUs) unless proprietary extensions are used. This is needed to exchange PDCP PDUs between the PDCP function within the S-GW and the RLC function within the eNB functional block.

In contrast to the LTE functional architecture, 5G NORMA strives for smaller functional blocks as well as more flexible grouping of atomic functions into functional blocks. Accordingly, a 5G NORMA interface connecting functional blocks needs to be more flexible. For example, a 5G NORMA interface may define a basic set of information elements (IEs) and primitives and additional sets of IEs and primitives depending on the reference point, i.e. the two atomic functions that the specific 5G NORMA interface instance interconnects. Standardised IE sets and primitives are needed where function blocks of different vendors are chained and need to interoperate, while chaining of a single vendor's functions may also be proprietary. Nevertheless, the standardized basic set of IEs, primitives, and the base protocol that is run between functional blocks to convey the information, may be reused. Details will be defined in upcoming 5G NORMA architecture reports and be refined with each of the three planned design iterations planned during the project runtime.

5.3 Deployment View

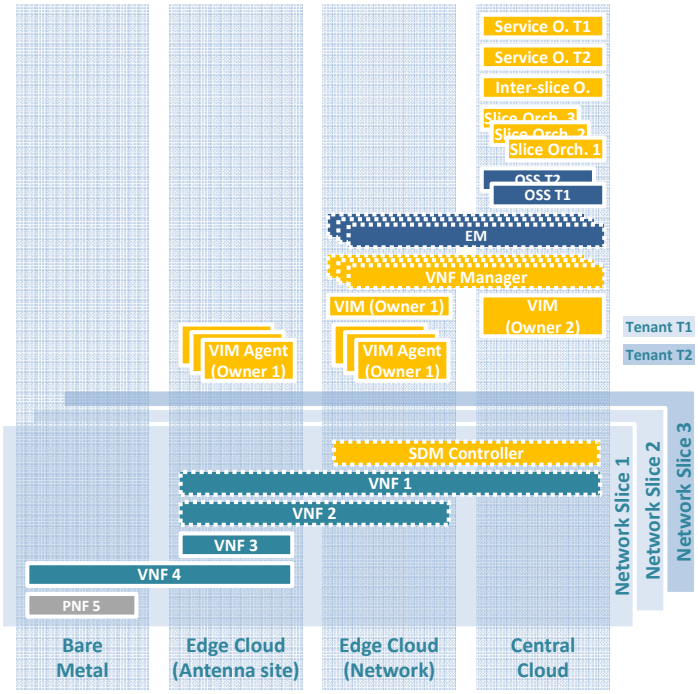


Figure 5-4: Example MANO deployment view

The deployment view is illustrated in Figure 5-4 and it shows the mapping of functional blocks to different resource classes. The example shown in the figure distinguishes four different resource classes: bare metal, edge cloud co-located at the antenna site, edge cloud within the (access) network and central cloud. It is still an abstract representation in that it does not show the concrete instances of functional blocks and resources but only the mapping of a type of functional block such as a mobility anchor to a type of resource class such as edge cloud or central cloud. A dashed box covering multiple resources in Figure 5-4 indicates that this functional block may be allocated to either one of these resources. A solid box covering multiple resources indicates that this functional block spans these multiple resources, i.e., its atomic functions are mapped to one of the resources. The deployment view neither shows interfaces nor mapping of functions to layers.

The example shown in Figure 5-4 depicts a single service operator utilizing resources from two infrastructure owners Owner 1 and Owner 2 and providing services to two different tenants T1 and T2. Infrastructure Owner 1 provides antenna sites and network with bare metal and two classes of edge clouds, one with co-located with the antenna sites providing minimal latency towards the user terminals and edge clouds within the (access) network. He uses VIM Agents to scale its logical VIM entity to manage its large distributed infrastructure. Infrastructure Owner 2 operates the central cloud only and does not use VIM Agents. Tenant T1 uses two slices to implement its services while tenant T2 only uses one slice for all its services. There is one Service Orchestrator per tenant (operated by the tenant itself) and one Slice Orchestrator per slice plus a single Inter-slice Orchestrator operated by the service provider.

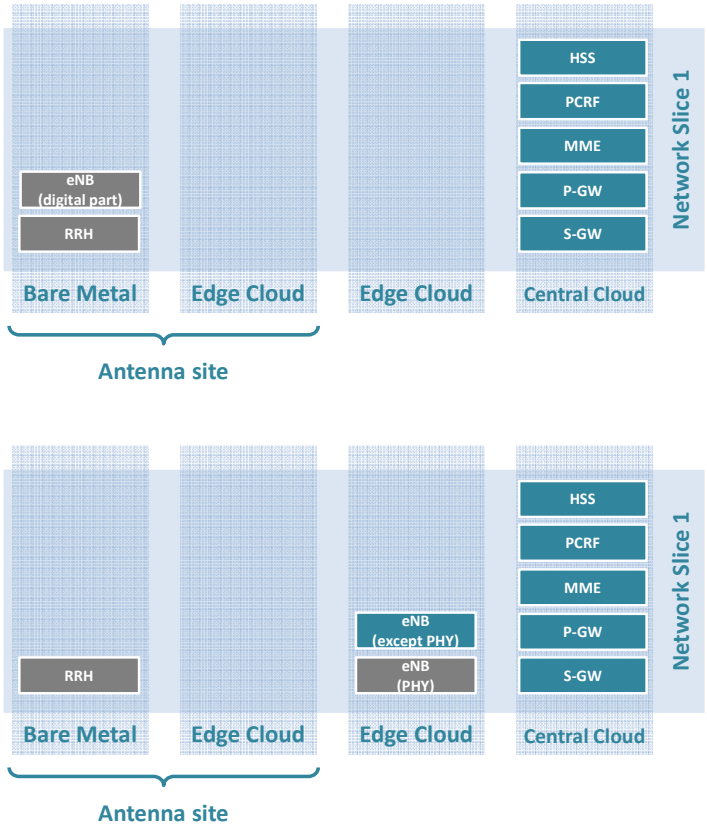


Figure 5-5: Fully distributed RAN (top) and cloudified CRAN (bottom) deployment

Figure 5-5 depicts the classical fully distributed RAN and centralized core deployment of the LTE control and data layer functional architecture shown in Figure 5-3 in the previous subsection, as well as a more recent "cloudified", i.e., (at least) partly virtualized, centralized RAN (CRAN) deployment. In the classical fully distributed RAN deployment, eNB run on dedicated hardware. Mixed signal and analogue eNB processing is separated from the digital eNB processing into so-called Remote Radio Heads (RRH). All eNB processing is located at (or near) the antennas, while all EPC related processing is executed centrally. In contrast, the cloudified CRAN deployment moves all digital eNB processing from the antenna site to the edge cloud within the (access) network (cf. following subsection). Processing is partly virtualized to become VNFs, executed on general purpose hardware, while other parts, here all physical layer processing, are implemented as PNFs executed on special purpose hardware (for efficiency reasons).

5.4 Topological and Physical View

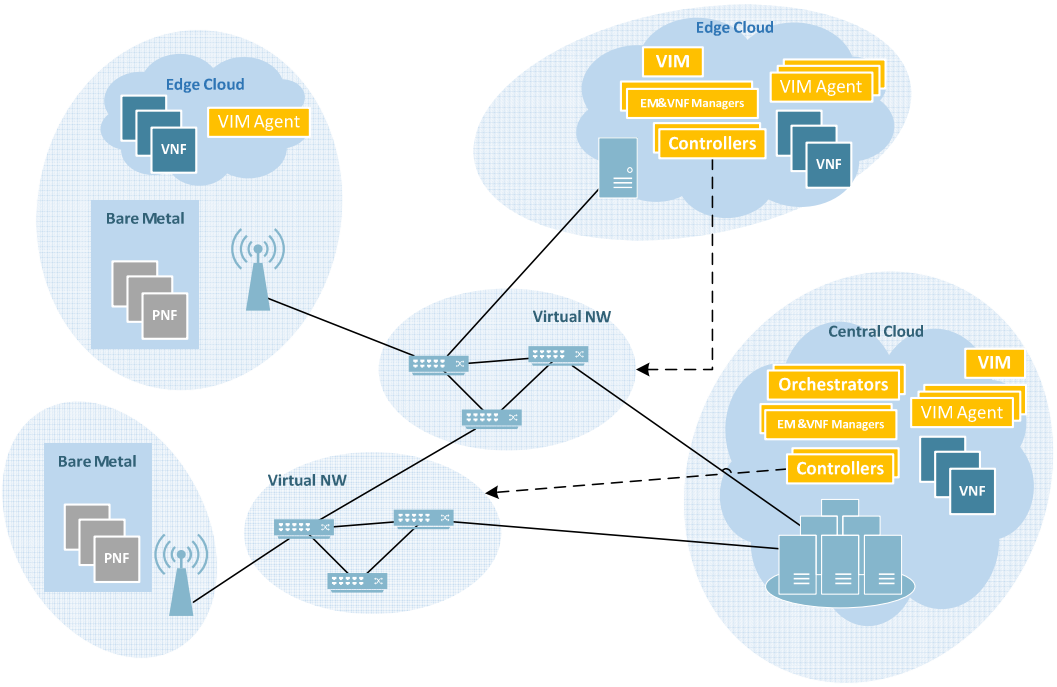


Figure 5-6: 5G NORMA topology view on architecture

As explained in Section 5.1.1 above, the central cloud comprises typically multiple data centers which may be several 100 km apart. These data centers are connected among each other by a wide area network (WAN). The WAN also connects the data centers of the central cloud to the data centers of the edge cloud, which is also illustrated in Figure 5-6 which links topology considerations with the previous considerations on the functional and deployment view.

Physically, this WAN is based on optical fibres with capacities of 10 Gbps and higher. Its topology can differ significantly according to the needs and preferences of the network operator: It may have multiple hierarchy levels, e.g. long haul links on a high level that interconnect regional and metropolitan networks on the underlying level. On each of these hierarchy levels, star, ring, tree or chain topologies may be deployed. Redundancy must be foreseen in the WAN, because otherwise a router or link failure might affect a huge number of terminals. It should be noted that usually this WAN will not be available for exclusive use by 5G networks. Typically, it is shared between fixed and mobile services with the larger portion originating from fixed services.

The edge cloud is located, as pointed out in Section 5.1.1, in the vicinity of the antenna sites. The dominant requirements for the fronthaul connectivity between an edge cloud data center and the radio access point at the antenna site are low latency and high capacity. In the case of centralizing radio access protocol layers, latency should be less than 100 – 200 µs [24][25]. Therefore, the distance between edge cloud and antenna site should not exceed a few 10km and a dedicated point-to-point connection should be used. For efficiency reasons, multiplexing (wave or time division multiplexing) [26] several of these connections onto a single fibre are necessary. The suitability of Ethernet switching requires further studies as it introduces additional delay and delay jitter [24]. The required speed of the fronthaul connection depends on the implemented fronthaul split, the properties of the radio signal that shall be transmitted over the air interface, in particular on the signal bandwidth and on the number of antennas. It is typically

in the range of 1 – 10 Gbps per antenna. Redundancy is usually not required, as a link failure will affect only few cells and thus a limited number of terminals.

Aside the centralization of major parts of the radio access protocol processing, also dedicated base stations, either macro or small cells, can be installed at the antenna site. The backhaul of such base stations is usually based on optical fibres. Micro wave links are cheaper to build than optical fibres but the achievable capacity of micro wave links is significantly lower. Therefore, they are suitable only for backhauling sites with few cells and low data rates on the air interface, i.e. mostly single small cells. The necessary data rate of the backhaul connection is determined mainly by the rate of data plane traffic passing through a base station. The acceptable latency of backhaul connections depends on the requested radio functionality, e.g. when cooperative multipoint transmission and reception (CoMP) shall be applied, latencies must be significantly lower than without CoMP [35][36]. Redundancy mechanisms are not required for the backhaul for the same reason as in the case of fronthaul.

6 Architecture Design Validation

6.1 Approach and Motivation

The objective of architecture design validation is to guide a two step architecture design iteration and thereby to finally provide a proof concept (PoC) of the 5G NORMA key innovations. It is illustrated in more detail in Figure 6-1. The assessment will be based on evaluation metrics to be elaborated based on the use case and scenario definitions in [18] (see also Figure 6-1). The use case definitions include a use case mapping to functional requirement groups, an assignment of quantitative key performance indicators (KPIs), and identification of "soft" KPIs. Scenarios combine groups of use cases so that the feasibility of an adaptive multi-service, multi-tenant network can be tested in a practical environment. These definitions compiled in [18] also build the basis for work WPs 4 and 5 of 5G NORMA as well as for the simulation and demonstrator framework and a socio-economic analysis that includes business and market aspects.

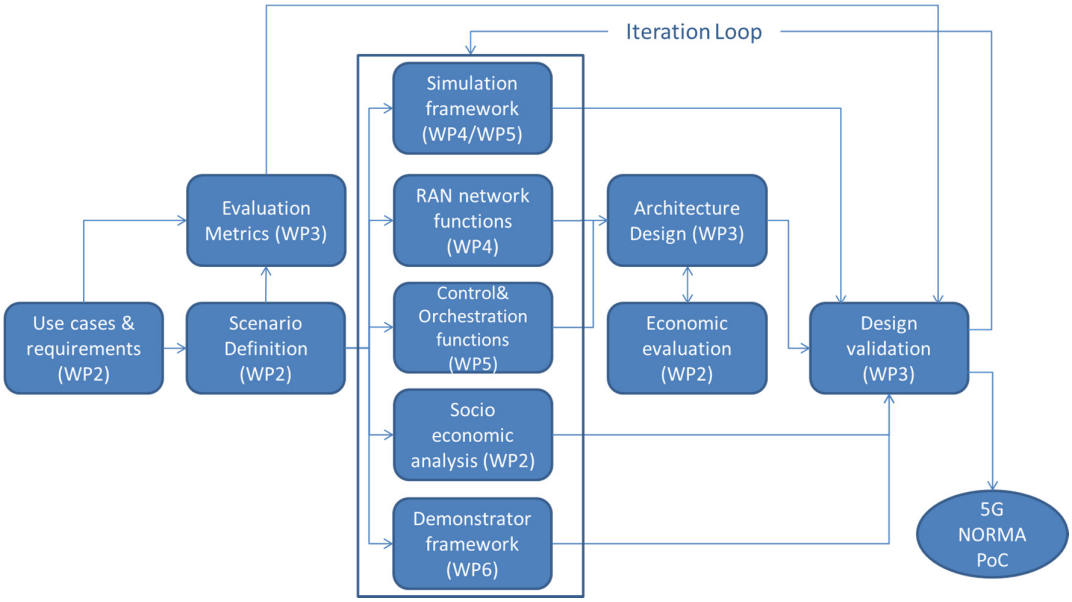


Figure 6-1: Architecture design and design validation within 5G NORMA

Architecture design stands synonymic for integration of NFs into an overall system. In that sense, architecture design will provide a reference architecture including all functional entities and interfaces needed for proper operation of the overall system in a top-down approach. This reference architecture defines the network structure with functional entities as placeholders and interactions between them. The architecture design will be mainly fed by work in the technical groups including RAN NFs (WP4) as well as control and orchestrations functions (WP5) where WP4 and WP5 investigate the internals of functional entities (bottom-up approach). Architecture design will also consider economical aspects, e.g., optimized and adequate transport networks between clouds and clouds and antenna sites.

In the first step, the design validation will define scenarios covering all important requirements and applications (see Section 6.4). Based on technical work in WP4 and WP5, architecture options applicable to these scenarios will be identified. Architecture options in that sense may include options for placement of management and orchestration functions, alternative structures for transport networks (backhaul / fronthaul) or alternative instantiations of functions chaining within logical slices.

Proper coordination of the simulation and demonstrator framework with respect to design validation will enable the quantitative evaluation of the fulfilment of quantitative KPIs whereas the adherence of functional requirements will have to be assessed qualitatively. In addition, protocol verification and protocol overhead analysis will help identifying gaps and defining a starting point for the second iteration step. In addition, design validation will help to understand pros and cons of different architecture options for the different use cases and scenarios.

6.2 Evaluation Criteria

As highlighted in Figure 6-1, the design validation process will get input from several other project activities. Based on the reference architecture and the architecture design work, we will integrate information from function templates of WP4 and WP5 and show exemplarily how to apply the 5G NORMA architecture options to example scenarios in [18]. Most important evaluation criteria are available and based on use case and requirement descriptions from WP2 but some KPIs may have to be supplemented. More concrete use case and scenario specific requirements have to be compiled into evaluation metrics including

- adherence of functional requirements;
- quantitative KPIs such as achievable latency, user throughput, cell throughput, network coverage, and terminal density;
- qualitative KPIs such as sufficient flexibility, manageable network complexity, sustainable standardisation effort, and scalability in particular for centrally arranged management functions; and
- support of scenario specific applications under defined environment and traffic conditions.

Hence, use case and scenario definitions provide the basis for the qualitative and quantitative evaluation and assessment of 5G NORMA key innovations. The assessment of functional system properties can be supported by proper protocol verification whereas the assessment of network performance will be enabled by coordination of the simulation and demonstrator frameworks. Some of the quantitative KPIs, e.g. cell and user throughput, can be checked by estimates or by inclusion of performance results from external resources. Further to the previously mentioned requirements, the evaluation of the 5G NORMA architecture must validate

- operational requirements such as feasibility of multi-tenant network sharing, proper definition of roles, and system manageability as well as interworking with legacy systems;
- security requirements which have been described in Section 3.3.

In particular, the identification of operational requirements will need input from the economic evaluation process which is further detailed in Section 6.3.

6.3 Evaluation Concept

This section describes different concepts and approaches which are applied by 5G NORMA to evaluate its architecture. The following description only provides an overview and will be detailed in later reports which pay more focus on architecture evaluation. Furthermore, these concepts integrate into the design validation process shown in Figure 6-1.

6.3.1 PoC Demonstrators

An integral part of the validation process are PoC demonstrators. PoC demonstrators show that a certain concept or approach is technically feasible and can be implemented with reasonable efforts. 5G NORMA selected three different PoC demonstrators which demonstrate the feasibility of function (de)composition and (re)allocation, and of the SDMC approach. In the following, all demonstrators are briefly introduced.

1. **Software demo**: The first demonstrator is a software demonstrator which shows the feasibility of function decomposition and (re)allocation. In particular, it focuses on the placement of interference coordination functions and the corresponding throughput performance improvement over legacy mobile networks. The demonstrated technology allows for adapting the RAN frame design based on the actual service. In this demonstrator, two representative services were chosen, i.e. video streaming and automotive event-driven safety services. It is of particular interest for heterogeneous networks (HetNets) with dense small-cell deployments where traffic patterns are fluctuating significantly and offer sufficient diversity gains. The demonstrator will feature a 3D-GUI (graphical user interface) and it is going to use a real-time mobile network emulator.
2. **Hardware demo**: The second demo is a hardware demo which also focuses on the function composition and relocation of VNF. In particular the demo focuses on the placement of the P-GW adaptive to the corresponding latency requirements. In order to demonstrate this, the current EPC components are moved to the eNB where the complete data layer is processed in a system on chip (SoC). Depending on the latency requirements, the U-Plane processing can be assigned either centrally or at the eNB.
3. **SDMC demo**: The third demo focuses on mobility management and how the SDMC approach can control it. In particular, the demo uses a SDN-capable infrastructure. It implements an OpenFlow controller suitable for an operator's mobile network. It can further provide a topology view, path computation, path management, and IPv6 support. The demo is used to show how quickly new network services can be implemented or modified using the SDMC approach.

6.3.2 Economic Evaluation

The economic evaluation is a three stage process. Prior to this, a preliminary round of activity will identify the areas where the initial 5G NORMA architecture is likely to provide cost savings for selected 5G services over alternative implementations not using NFV and SDN based concepts. To do this, the economic evaluation will require information on the initial architecture concepts as detailed in Sections 4 and 5. After this preliminary assessment, the economic assessment will consider both costs and revenues including revenues from new services and business models.

We expect that cost savings may come through economies of scale due to the ability to serve a much wider array of services on the 5G NORMA architecture than on current legacy network infrastructures, dynamic spectrum and network sharing through the multi-tenancy capabilities and more efficient use of spectrum and network resources through the context, QoS, and QoE aware functionalities in the network. The three evaluation stages are as follows:

1. The first evaluation stage will assess the operator business case for the first fully specified 5G NORMA architecture. 5G NORMA WPs 3, 4, and 5 will specify the detailed

equipment lists and connectivity requirements for this architecture which will enable modelling of the operator costs. Our approach will be to start from the baseline of the architecture needed to supply massive mobile communications services and an estimate of the potential revenues. We will then consider the impact of adding additional services and applications to serve other use cases. At all times we will consider costs and revenues relative to those of the legacy 4G network. We will also evaluate additional societal benefits not captured in ordinary consumer revenues. This may feed into public policy in areas where the private economic case may be negative, but the public case considering both private economic and societal benefits may be positive.

2. The results of the first stage will allow to define an "economically feasible" network architecture which would be financially viable for operators taking into account equipment and connectivity needs of this architecture. We expect a limited number of options to be investigated which are evaluated regarding their economic and societal costs and benefits.
3. In the third stage, we will refine our analysis to evaluate potential updates of the 5G NORMA architecture providing.

6.3.3 Protocol Verification

Message sequence charts (MSC) [27] depict information exchanges over time between involved entities in a clear and concise way. MSCs are therefore a good means to validate the 5G NORMA architecture against the set of functional requirements respectively the set of functional features derived from these requirements.

For example, consider the case that the 5G NORMA architecture needs to reconfigure a network slice in the case of resource failure or resource scarcity. In this example, a set of MSCs will show the whole process, starting from the specific trigger condition, e.g. performance measurement report indicating unmet QoS targets, and ending with reconfigured or re-orchestrated function chains in control and data layer, respectively, of the affected network slices. Recording the complete information flow between entities together with their processing steps and temporal ordering may disclose missing information, ambiguous information, unsatisfied processing preconditions, or race conditions. It provides therefore a validation of the completeness and correctness of the 5G NORMA architecture design.

6.3.4 Protocol Overhead Analysis

In addition to simulations and PoC demonstrators, theoretical methods have been used extensively to analyse and evaluate the performance of communication systems [28]. The focus of such mathematical analyses is usually on specific subsystems or well-defined and constrained system aspects. A system as a whole is usually too complex for a mathematical analysis and thus it can be assessed only through simulations. In other words, while only simulations can provide a top-down analysis of a system as a whole, mathematical tools can complement this with a bottom-up analysis of specific details or subsystems. Hence, theoretical and mathematical tools will be used to validate 5G NORMA concepts and as detailed in the following.

6.3.4.1 Adaptive (re)allocation of network functions

The adaptive (re)allocation of NFs strives for greater flexibility for the placement of NFs. While this will allow to reduce latencies, it will require more flexible interfaces with higher protocol overhead. From the current perspective, the following KPI could be estimated by analytical means:

- minimum achievable latency in typical latency-critical usage scenarios,
- protocol overhead of the correspondingly flexible interfaces, and
- pooling/multiplexing gains in case of more centralized function allocation.

6.3.4.2 SDN-based mobility management

SDN-based mobility management considers the mobility of terminal devices as well as the mobility of function blocks. As input for making mobility-related decisions, the SDMC has to collect measurement information that reflects the current connectivity situation of a mobile terminal or the current load situation of a NF. When such a decision has been made, the execution of a terminal handover or NF reallocation implies two kinds of data transfer. First, state information has to be transferred from the source to the target location. In the case of terminal handover, this comprises the UE context. In the case of NFs, this could comprise function states as well as source code, function-specific driver software and other data. Second, the traffic of ongoing connections to a terminal that has been handed over or through a re-allocated NF has to be forwarded from the source to the target location.

It is expected that two aspects of mobility management schemes can be evaluated via numerical analysis:

- Based on exemplary typical network deployment scenarios, the traffic load that is generated by collecting the necessary measurements will be quantified. This depends not only on the frequency and size of measurement messages, but also on the positioning of the SDMC and the network connectivity between measurement source and SDMC.
- The amount of data to be transferred during the execution of a terminal handover respectively a function re-allocation shall be determined. It is expected that in the case of terminal handover, the mechanism for traffic forwarding will have the highest influence. In the case of function mobility, the frequency of such re-allocations respectively the reasons for triggering a re-allocation and the amount of state information that has to be forwarded will have the highest impact.

6.4 Evaluation Scenarios

In Section 6.2, most important evaluation criteria have been compiled. Quantitative evaluation will be done by protocol analysis, system level simulations, demonstrations and economic modelling. Whereas demonstrators allow for inclusion of hardware properties system level simulations allow investigations with realistic traffic assumptions and number of devices. Another complementary evaluation can be done by economic modelling of bigger parts of an operator network. Despite the view on the evaluation scenarios is different, in order to attain consistent results among these different activities it is very important to have a common playground. In the following use cases and scenarios defined in [18] are analysed with respect to their relevance for inclusion into PoC evalutions.

Besides detailed description of considered applications and simulation models the example scenarios described in [18] Annex C are providing coexistence of use cases as needed for our PoC. In Table 6-1 the importance of requirement groups for selected use cases is taken from [18]. An assignment of 5G NORMA use cases to example scenarios (C1-C3) shows that with the assigned and hence selected uses cases (marked in bold) all RGs can be sufficiently validated. Whereas C1 and C3 enable testing of multi-tenant architectures C2 and C3 in addition enable testing of multi-service capabilities of the proposed architecture options.

Table 6-1 : Importance of requirement groups for the selected use cases

Requirement Groups	Example Scenario											
		C2/C3		**C1**		**C3**	**C2**	**C1**				**C3**
	Use Cases											
	Industry control	**Mobile broadband**	Emergency communications	**Vehicle communications**	Sensor Networks Monitoring	**Traffic Jam**	**Real-time remote computing**	**Massive nomadic/mobile MTC**	Quality-aware communications	Fixed-Mobile Convergence	Blind Spots	**Open Air Festival**
RG#1: Fast NW reconfig. within a slice	H	**M**	L	**M**	L	**H**	**H**	**M**	L	M	M	**M**
RG#2: Fast NW reconfig. between slices	M	**L**	L	**M**	L	**M**	**L**	**L**	L	M	M	**M**
RG#3: Device duality	L	**L**	H	**H**	M	**L**	**L**	**H**	L	L	M	**L**
RG#4: Separation & prioritization of resources on a common infra-structure	M	**H**	L	**M**	L	**M**	**H**	**L**	H	H	M	**H**
RG#5: Multi-connectivity in access & non-access part	H	**H**	L	**H**	L	**M**	**L**	**M**	M	H	H	**M**
RG#6: Massive scalabil-ity of protocol NW functions	H	**L**	H	**H**	M	**H**	**L**	**H**	L	M	M	**L**
RG#7: Highly efficient transmission & processing	L	**L**	M	**M**	H	**M**	**H**	**H**	L	L	M	**M**
RG#8:	H	**M**	M	**H**	M	**M**	**M**	**M**	H	M	M	**M**

QoE/QoS awareness												
RG#9: Adaptability to transport NW capabilities	L	**H**	L	**L**	L	**M**	**M**	**L**	L	M	H	**H**
RG#10: Low latency support	H	**L**	L	**H**	L	**L**	**H**	**L**	L	L	L	**L**
RG#11: Security	H	**M**	H	**H**	M	**L**	**M**	**H**	L	M	L	**L**

Except for the Open Air Festival all selected use cases can be simulated in the proposed Manhattan grid deployment of scenario C1. In order to simplify coordination of simulation activities the Open Air Festival should be excluded from simulation point of view.

The scope of the planned demonstrations can be deduced from Section 6.3.1. The demonstrated features fit well with the selected use cases and scenarios. As for the mapping of the PoC campaigns to the use cases' requirements, Table 6-2 presents from a high level point of view the relationship between the RGs extracted in WP2 and the different demos introduced in Section 6.3.1. As the table shows, most of the RGs are covered by the PoC campaigns, except the ones related to multi-slice, scalability, high communication/computing efficiency and security. This is due to the limitations of the PoC available hardware devices, which restrict the amount (scalability) and performance characteristics (efficiency) of the hardware components used in the different demos. These PoC shortcomings shall be addressed by the simulator campaigns.

Table 6-2: Requirement groups – demos mapping

Requirement group	Software demo	Hardware demo	SDMC demo
RG#1: Fast network reconfiguration within a network slice	Yes	Tentative	Yes (the network slice will reconfigure itself using SDN techniques)
RG#2: Fast network reconfiguration between network slices	Tentative	No	No
RG#3: Device duality	Yes. (only network- controlled V2X)	No	No
RG#4: Separation and prioritization of resources on a common infrastructure	Yes	No	Yes (SDN flows re-routing)
RG#5: Multi-connectivity in access and non-access part of the 5G system	Yes	No	No
RG #6: Massive scalability of protocol NFs	No	No	No (depends on the size of the testbed)
RG #7: Highly efficient transmission & processing	No	No	No

RG #8: QoE/QoS awareness	Tentative	Yes	Yes (QoE / QoS requirement extraction)
RG #9: Adaptability to transport network capabilities	Yes	No	No
RG #10: Low latency support	Yes	Yes	Yes (by moving NFs close to the user and a better redirection of data flows)
RG #11: Security	No	No	No

Table 6-3 describes the overview of the scenarios considered for the PoC evaluations. The table follows the template used in WP2 dividing each scenario in different parts, namely the applications, deployment & channel model, traffic model, KPIs and relevance of 5G NORMA's key innovations.

Table 6-3: Demo scenarios overview

	Software demo	Hardware demo	SDMC demo
Application/s	Traffic safety with V2X communications. Multimedia file-download. Video streaming. Gaming.	Low latency remote driving ("Real-time remote computing" in [18]).	Multimedia, Non-critical V2X communications.
Deployment & channel model	Urban outdoor environment. Multi-cell heterogeneous network. Dense small-cell deployment. Real-world city layout and mobility mode. Channel model with support for frequencies up to 28 GHz and bandwidths up to 500 MHz.	Urban small cell. Indoor user being vehicular up to 5/10 Km/h.	Several BSs, could be applied to different scenarios.
Traffic model	V2X communications: time-critical with low-latency requirement. Video Streaming: delay-tolerant with high data rate requirements. Constant bit-rate. Broadcast for alarms. Multicast for live streaming of events.	Low data rate.	Video Streaming, high data rate.
KPIs/ Performance metrics	User throughput. E2E latency. System throughput. Cell throughput.	E2E Latency.	Reduced latency. Better infrastructure utilization.

Relevance of 5G NORMA's key innovations	Adaptive functional composition/decomposition. Service-aware and context-aware adaptation of network functionality.	Context-aware adaptation of NFs. Adaptive (de) composition and allocation of mobile NFs. Joint optimization of mobile access/core.	Multi-service and context-aware adaptation of NFs.

The economic evaluation will also be based on the three example scenarios. In each scenario, we will assume that massive broadband (MBB) is the baseline service to be deployed and we will assess the cost and revenue impacts of adding the additional use cases, as defined in the scenarios.

The objective will be to analyse whether there is a positive net benefit to one or more operators deploying the infrastructure necessary for each scenario. In other words, whether the incremental revenues from 5G services in each scenario are likely to be greater than the incremental costs of the 5G NORMA network over and above the existing costs of legacy networks. We will project forward costs and revenues over a suitable timeframe, perhaps 10 years that correspond broadly to the lifetime of the assets in the 5G network we model. We will calculate the net present value of the revenues minus the costs over this time period which is a standard approach to calculating the financial or economic value of an investment such as this.

In modelling revenues, we are cognizant that there will be a number of ways in which operators receive revenue services: end-users may pay directly for new services; end-users may pay indirectly by choosing to buy a more expensive subscription for a higher quality service (e.g. lower latency, guaranteed levels of service) which might be a pre-requisite for applications such as virtual reality gaming; third parties such as public transport providers may pay directly and end-users pay indirectly through ticket prices. We also recognise that some proportion of revenues may go to other service providers than the network operators, such as OTT service providers and we will seek to take this into account.

In modelling costs we will link demand to the capacity of traffic and demand sensitive network elements thus ensuring that the revenue calculations are consistent with the cost calculations. This will ensure that the 5G architecture whose cost we evaluate is fully able to meet the needs of the scenario i.e. the underlying demand from all the services that need to be delivered within each scenario and given the technical KPIs which have been set out in the use case descriptions in [18].

We will also introduce geographic specificity into our modelling so that we can take into account the different network deployment needs of urban, suburban, and rural areas. We intend to model sample geographic areas which contain the necessary mix of geographic areas that are relevant to each scenario. If appropriate for the economic evaluation, we may scale up results from sub-national sample areas to a national level.

7 Summary and Conclusions

This report provided a comprehensive and concise overview of the 5G NORMA architecture. It detailed the underlying requirements which result in qualitative as well as quantitative metrics. Qualitative metrics include flexibility and scalability which are difficult to measure but highly important in a 5G system where a multitude of functionalities needs to cope with diverging requirements. We further defined quantitative metrics which are relevant for the 5G NORMA architecture and which must be evaluated rather for scenarios composed of multiple use cases than for single use cases alone. Finally, the two main functional requirements were detailed, i.e.

mobile network multi-tenancy and multi-service and context-aware adaptation and allocation of NFs.

Furthermore, the key innovative enablers are introduced, namely software-defined mobile network control and orchestration, adaptive composition and allocation of NFs, and joint optimization of mobile access and core. These key enablers may not be fully supported with existing architectures but are important in order to accommodate the diverse service landscape in a 5G mobile network. Furthermore, these key enablers are necessary to fulfill the operational requirements derived in this report.

Due to the complexity of the architecture, the report introduced four distinct architecture views along the two major functional requirements and two major key technologies. These different views are required in order to analyse and evaluate the architecture which is not possible with a single view on the architecture. Most important, these different architecture views are used to further develop novel technologies for the 5G NORMA mobile network architecture.

Finally, we introduced the 5G NORMA validation concept which must evaluate both qualitative and quantitative metrics. This is done through a well defined validation process which incorporates the architecture definition in this document as well as PoC demonstrators, simulation campaigns, and analytical tools. While PoC demonstrator allow for concluding whether a specific technology is feasible, simulation campaigns allow for concluding whether these technologies provide the promised benefits also in a system. In addition, analytical tools allow for evaluating scalability as well as consistency of protocols.

In the next report, the 5G NORMA architecture will be further detailed, also including specific technologies developed in WPs 4 and 5.

8 References

[1] A. Banchs, M. Breitbach, X. Costa, U. Doetsch, S. Redana, C. Sartori, and H. Schotten: "A Novel Radio Multiservice Adaptive Network Architecture for 5G Networks," IEEE VTC Spring 2015, Glasgow, Scotland, May 2015

[2] NGMN Alliance: "5G White Paper". Version 1.0, 17 Feb. 2015, https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

[3] D. Wübben, P. Rost, J. Bartelt, M. Lalam, V. Savin, M. Gorgoglione and A. Dekorsy, "Benefits and Impact of Cloud Computing on 5G Signal Processing", IEEE Signal Processing Magazine, vol.31, no.6, pp.35-44, Nov. 2014

[4] EU FP7 iJOIN, "D5.2: Final definition of iJOIN requirements and scenarios," Available: http://www.ict-ijoin.eu/deliverables

[5] EU FP7 iJOIN, "D5.3: Final definition of iJOIN architecture," online, Available: http://www.ict-ijoin.eu/deliverables

[6] P. Rost, C. J. Bernardos, A. De Domenico, M. Di Girolamo, M. Lalam, A. Maeder, D. Sabella, D. Wübben, "Cloud Technologies for Flexible 5G Radio Access Networks", IEEE Communications Magazine, vol.52, no.5, pp.68-76, May 2014

[7] C. Bernardos, A. De Domenico, J. Ortin, P. Rost, and D. Wübben, "Challenges of designing jointly the backhaul and radio access network in a cloud-based mobile network," Future Network and Mobile Summit (FutureNetworkSummit), Lisbon, Portugal, July 2013

[8] F. Giust, L. Cominardi, C. Bernardos, "Distributed mobility management for future 5G networks: overview and analysis of existing approaches", IEEE Communications Magazine, vol.53, no.1, pp.142,149, January 2015

[9] C.J. Bernardos, A. de la Oliva, P. Serrano, A. Banchs, L.M. Contreras, H. Jin and J.C. Zúñiga, "An Architecture for Software Defined Wireless Networking", IEEE Wireless Communications, vol.21, no.3, pp.52,61, June 2014

[10] ICT-317669 METIS, Deliverable D6.3 "Intermediate system evaluation results," August 2014, Available: https://www.metis2020.com/documents/deliverables/.

[11] J. Eichinger, et al., "Building a New Multi-Facial Architecture of 5G", IEEE MMTC E-Letter, September 2014.

[12] P. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, "Design Considerations for a 5G Network Architecture," IEEE Communications Magazine, vol. 52, no. 11, November 2014.

[13] ETSI Industry Network Functions Virtualisation Industry Specification Group (NFV ISG), White Papers, Specifications, etc., http://www.etsi.org/technologies-clusters/technologies/nfv.

[14] 4G Americas, "Bringing Network Function Virtualization to LTE", White Paper, November 2014.

[15] 3GPP TR 22.852, Study on Radio Access Network (RAN) Sharing enhancements, Rel.13, Sep. 2014.

[16] 3GPP TS 32.130, Telecommunication management; Network Sharing; Concepts and requirements, Rel.12, Dec. 2014.

[17] 3GPP TS 23.251, Network Sharing; Architecture and Functional Description, Rel.12, Jun 2014.

[18] EU H2020 5G NORMA, "D2.1: Use cases, scenarios, and requirements," September 2015

[19] 3GPP TS 33.401, 3GPP System Architecture Evolution (SAE); Security architecture, Release 13, September 2015

[20] 3GPP TR 33.821, Rationale and track of security decisions in Long Term Evolution (LTE) RAN / 3GPP System Architecture Evolution (SAE), Release 9, June 2009

[21] L. Cominardi, C.J. Bernardos, P. Serrano, A. Banchs, and A. de la Oliva, "An SDN-based architecture for 5G networks: design and proof of concept," submitted to IEEE Network Magazine, November 2015

[22] ETSI GS NFV-MAN 001, "Network Functions Virtualisation (NFV); Management and Orchestration", V1.1.1 (2014-12), December 2014

[23] 3GPP 36.300, Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2, Release 13, September 2015

[24] Peter Ashwood Smith: "CPRI 'FrontHaul' requirements discussion with TSN". July 2014, San Diego, CA; http://www.ieee802.org/1/files/public/docs2014/new-ashwood-tsn-cpri-fronthaul-0714-v03.pdf

[25] Harrison J. Son, S. M. Shin: "Fronthaul Size: Calculation of maximum distance between RRH (at cell site) and BBU (at CO)". Netmanias Tech-Blog, April 1st, 2014, http://de.slideshare.net/Netmanias/netmanias20140401calculation-of-fronthaul-fiber-distance-en

[26] Kevin Murphy: "Centralized RAN and Fronthaul". Whitepaper, Ericsson Inc. OSP Magazine, May 2015, http://www.ospmag.com/files/pdf/whitepaper/C-RAN_and_Fronthaul_White_Paper.pdf

[27] ITU-T, SERIES Z: LANGUAGES AND GENERAL SOFTWARE ASPECTS FOR TELECOMMUNICATION SYSTEMS, Formal description techniques (FDT) – Message Sequence Chart (MSC), Recommendation ITU-T Z.120 (02/2011), February 2011

[28] D. Bertsekas, R. Gallagher: Data Networks. Prentice Hall, Englewood Cliffs, 1992

[29] ICT-317669 METIS, Deliverable D6.4, "Final report on architecture," January 2015, Available: https://www.metis2020.com/documents/deliverables/.

[30] Open Networking Foundation, "Software-Defined Networking: The New Norm for Networks", [online document], White Paper, April 2012.

[31] Open Networking Foundation, "OpenFlow-Enabled Mobile and Wireless Networks," Technical report, September 2013

[32] US National Institute of Standards and Technology (NIST), "The NIST Definition of Cloud Computing", 2011, available at http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf

[33] ETSI GS NFV 002, V1.1.1, "Network Functions Virtualisation (NFV); Architectural Framework", 2011

[34] ETSI GS NFV 003, V1.2.1, "Network Functions Virtualisation (NFV); Terminology for Main Concepts in NFV", 2014

[35] 3GPP TR 36.874, Coordinated multi-point operation for LTE with non-ideal backhaul, Release 12, December 2013

[36] 3GPP TR 36.819, Coordinated multi-point operation for LTE physical layer aspects, Release 11, September 2013