5G NORMA: System Architecture for Programmable & Multi-Tenant 5G Mobile Networks

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***Abstract*—This paper describes the status of the 5G NORMA architecture after the second design iteration. It integrates the control and data layer functions developed in the project into a harmonized mobile network architecture, applying the paradigms of adaptive (de-) composition and allocation of network functions (NFs), programmable network control, and end-to-end network slicing. The paper depicts the design of a multi-service management & orchestration layer with dedicated interfaces for mobile network tenants. The security threats arising in virtualized multi-tenant networks are discussed and novel security solutions are presented. The architecture verification applies a methodology with three evaluation cases and the generic 5G services (eMBB, mMTC, and URLLC) to analyze to what extent the current architecture design meets the different requirements as defined in 5G NORMA and the overall ecosystem, including the 5G-PPP initiative and 3GPP.**

***Index Terms*—5G networks; mobile network architecture & design principles; network slicing; control and data layer split; software-defined mobile network control, management, and orchestration; security; architecture verification; QoS/QoE control**

I. Introduction

The coexistence of human-centric and machine type applications will impose very diverse functional and performance requirements that the 5G network will have to support, such as broadband everywhere and enhanced mobility management. The 5G architecture should be future-proof in terms of performance by realizing heterogeneous KPIs and their varying target ranges as well as in terms of flexibility by concurrently supporting multiple network services (voice, eMBB[1], URLLC, V2X, gaming, etc.). Multi-tenancy will realize cost savings to be expected when hosting multiple logical mobile network instances on a largely shared infrastructure [1].

A. Motivation of 5G NORMA Architecture Design Objectives

In the light of the outlined architectural requirements and ongoing 3GPP standardization activities (e.g., [2], [3]), 5G NORMA architecture design [6] has motivated three major design objectives:

Service-aware resource sharing: Legacy systems are characterized by monolithic network elements that have tightly coupled hardware, software, and functionality. In contrast, the 5G NORMA Software-Defined mobile Network Orchestration (SDMO) decouples software-based NFs from the underlying infrastructure resources by means of utilizing different resource abstraction technologies. In combination with Network Function Virtualization (NFV) and Software-Defined Networking (SDN), these technologies allow to build fully decoupled end-to-end networks on top of a common, shared infrastructure that can finally be exploited to host heterogeneous services (in terms of target KPIs) on the same infrastructure.

Network customization by adaptive allocation of network functions: By adaptively (de-) composing and allocating NFs, the architecture not only allows for (re)programming the behavior of individual NFs, but also for adapting the network topology, i.e., the geographical distribution of NFs.

Network programmability for flexible network control: The Software-Defined Mobile network Control (SDMC) concept splits between the *logic* and *agent* for any NF in the network. The approach implies to have a unique control point for the network: a logically centralized controller that abstracts and thus homogenizes different network technologies and implementations. The more easily exchangeable controller application (i.e., the logic) will make network slices programmable by controlling the topology and functionality of the service chains (i.e., the agents) that comprise the network slices. The realization of SDMC and SDMO in management, orchestration, and control layers (cf. Sec. III) enable the 'Virtualized Network Platform as a Service (VNPaaS)' scenario in a multi-tenant environment as described in [9].

B. Beyond State of the Art – Combining Technologies for e2e Network Slicing

On the functional level, so-called multi-operator core networks (MOCNs) are standardized in 3GPP since Release 8 [4]. In MOCN, the RAN is common to several mobile network operators. The shared eNodeB is connected to multiple CNs via S1-flex interface. Each mobile network operator has its own EPC (i.e., an own core network slice). The so-called DCN (Dedicated Core Network) feature [5] allows to operate CNs dedicated to serve specific types of subscribers, e.g., terminals can be routed to the desired core network based on UE identification parameters. Considerable shortcomings

[1]a list of acronyms can be found in Table II

of both approaches include focus on CN as well as lacking possibility for UEs to connect to multiple CNs.

On the resource level, 5G NORMA complements well-known sharing technologies such as multiplexing and multitasking, e.g., wavelength division multiplexing or radio scheduling, with softwarization techniques such as NFV and SDN. Virtualization (1) abstracts the functionality from the underlying execution environment, i.e., decouples the application from the physical server hardware, and (2) partitions resources into multiple, isolated execution environments that can be assigned to different tenants or services. Multiplexing combines multiple signals into one combined signal that can be carried over a shared medium, thus partitioning an expensive resource among multiple services. 5G NORMA combines hypervisors, multiplexers, and multitasking mechanisms in a common abstraction layer. While hypervisors manage the resources of x86-based servers in the central cloud and the network edge cloud, multiplexers and multitasking mechanism perform the same task for components like Digital Signal Processors and accelerators in the base stations and other physical nodes that cannot be virtualized. This yields several options for the design of network slices, ranging from standalone slices with own hardware and spectrum, to slices that are completely unaware of the resources they are using and hence have no (direct) control on the resource scheduling. The differences between these slice variants is reflected in the formal description of the respective slice (e.g., network slice template [6], Chapter 4). Utilizing such templates, the orchestration functions (cf. Sec. III-A) can set up slices and merge them properly at the described multiplexing point.

II. The 5G NORMA Mobile Network Architecture

This section elaborates on the overall architecture, giving an end-to-end view across multiple layers. The section depicts an overview on the control and data layers and how they support the 5G NORMA network programmability paradigm.

A. Overall Architecture

The 5G architecture shall incorporate the performance and flexibility to support multiple telco services, with heterogeneous KPIs and sharing the same infrastructure. Further, 5G will give operators unique opportunities to address and offer new business models to consumers, enterprises, verticals, and third party tenants. The functional perspective of the 5G NORMA architecture, depicted in Fig. 1, defines the architectural elements that deliver the systems functionality. It includes the key functional elements, their responsibilities, the interfaces exposed, and the interactions between them.

The **service layer** comprises Business Support Systems and business-level Policy and Decision functions as well as applications and services operated by the tenant. The **management & orchestration layer** extends the ETSI NFV management & orchestration (MANO) architecture for multi-tenant and multi-service networks. It comprises the Virtual Infrastructure Manager (VIM), the VNF Manager and the Software-Defined Mobile Network Orchestrator (SDM-O), which is further split as follows: an Inter-slice Resource Broker for cross-slice resource allocation and slice-specific NFV Orchestrator(s) (NFVO). Further, the layer accommodates application management functions from various domains, e.g., 3GPP or enterprise networks. In the case of 3GPP, this comprises Element Managers (EM) and Network Management (NM) functions which would also implement ETSI NFV MANO interfaces to the VNF Manager and the NFVO. The Service Management is an intermediary function between the service layer and the SDM-O. It transforms consumer-facing service descriptions into resource-facing service descriptions and vice versa. The **control layer** accommodates the two main controllers, Software-Defined Mobile Network Coordinator (SDM-X) for the control of common (shared) NFs and Software-Defined Mobile Network Controller (SDM-C) for dedicated NFs. Following the SDN principles, SDM-X and SDM-C translate decisions of the control applications into commands to Virtualized NFs (VNFs) and Physical NFs (PNFs). Finally, the **data layer** comprises the VNFs and PNFs needed to carry and process the user data traffic.

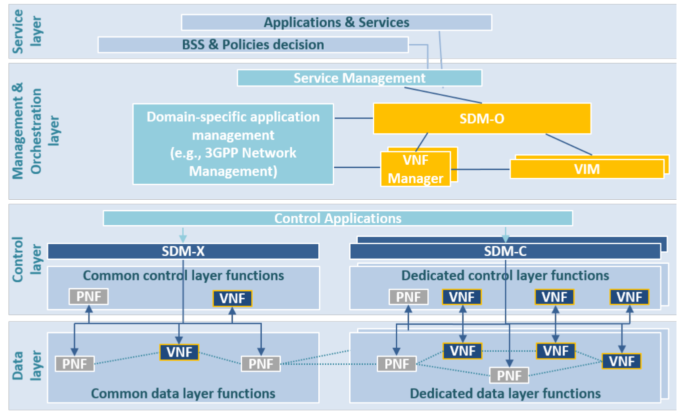

Fig. 1: High-level 5G NORMA functional architecture

B. Control & Data Layer Architecture

5G NORMA introduces a novel concept of network control by extending the software-defined routing (switching) approach to all kinds of mobile NFs from both data and control layer, with a focus on wireless control functions, such as scheduling or interference control. For this purpose, 5G NORMA has defined two controllers types (SDM-C and SDM-X) that split between the *logic* of the NF and the part that has to be controlled (*agent*). Generally, the logic comprises the traditional control plane part of a NF and is realized as an SDM-C application, while the agent consists of the user plane (data layer) part.

The major objective of the SDM-C is to abstract from technology-specific or implementation-specific aspects of the NFs. It has northbound interfaces (NBIs) towards different Control Applications implementing, e.g., QoE/QoS control or mobility management (MM) [7]. NBIs are used to enforce the conditions defined by the SDM-C applications that have to be realized on NFs for a given traffic flow identifier in order to fulfill the targeted SLA. E.g. via this interface, the

MM application passes to the SDM-C the exact configuration information for data layer NFs enforcing the selected mobility management scheme. If such (re)configuration requests include a re-selection of VNFs or a re-composition of a chain of NFs, the SDM-C passes an according request for re-orchestration to the SDM-O. Further, the SDM-C is in charge of building the path for data layer service chains and adjusting the VNF parameters in order to accommodate QoS, policy enforcement, or legal interception requirements.

When the control logic is too time critical and/or is deemed to be not efficiently implementable in a more centralized way as SDM-C application, this functionality is offloaded to Distributed control NFs. For example, the radio scheduler is carried out as distributed control NF because it would incur too much signaling over the southbound interface (SBI) between antenna location and location of the controller. Another example of a distributed NF is RRC, to enable fast reconfigurations triggered by the radio scheduler to adapt to the time variant radio channel and interference [8].

III. Software-defined Mobile Network Orchestration and Control

The 5G NORMA SDMO framework enables multi-tenant and cross-domain resource management by extending the MANO architecture as defined by ETSI NFV. Further, the SDMC concept splits control and data layer and introduces network programmability in mobile networks. This is illustrated using the example of QoS/QoE control.

A. Management and Orchestration

Among other novel features, the 5G NORMA management & orchestration layer provides ‘Virtualised Network Platform as a Service (VNPaaS)’ [9]. It allows infrastructure providers, mobile service providers and tenants to independently perform management and orchestration tasks.

Fig. 2 shows a scenario comprised of three NFV MANO stacks: one of them is operated by the Infrastructure Provider (InP, depicted in green) which at the same time could be a Mobile Network Operator (MNO). The remaining two stacks (orange & red) are assigned to different tenants (each tenant could manage one or more slices). In other words, the scenario depicts a single infrastructure domain environment that can consist of one or multiple physical sites (points-of-presence, PoP). MANO stack-0 (shown in green) has a special role, since it is specifically associated to the InP (or MNO). The stack provides orchestration and management capabilities on the whole NFV infrastructure (NFVI) resources.

Utilizing their dedicated NFV MANO stacks, tenants can deploy their slices using either customized (and certified) or InP-provided network slice templates. In that case, the NFV MANO stack instances (e.g., stacks 1 to n in Fig. 2) are operated by the tenant and each stack manages its own subset of NFVI-0 resources, as allocated by the InP (or MNO). Such allocations are decided by the Inter-slice Resource Broker (IS-RB). For the regular NFV MANO stacks (orange & red), the view would be limited to its own VNFs and the according NFVI resources (e.g., NFVI-1 to NFVI-n). For this purpose, 5G NORMA assumes sufficient isolation between the resource partitions. Moreover, NFVI-1 and NFVI-n resources can be extended with resources not belonging to NFVI-0, e.g., 3rd party resources or resources directly owned by tenants 1 to n. The tenant-specific VIMs (i.e., VIM-1 to VIM-n) would manage all these resources together (note: this is not depicted in Fig. 2).

The IS-RB derives the resource quotas (or quota ranges) for each NFV MANO stack from the SLA with the different tenants and the prioritization policies, i.e., tenants have an SLA specifying the amount of resources they can use. Initially, fixed quotas are assigned to the different stack instance when they are commissioned. Nevertheless, such fixed quotas can be reshaped at runtime if tenants request for that. This also implies that if a tenant does not utilize all allocated resources, the idle resources will not automatically be re-allocated to the other tenants.

Except for the InP (or MNO), tenants are neither aware of the existence nor the resource utilization level of further tenants. They only have an SLA specifying their right to use certain resources in a certain manner. For instance, special terms in SLAs would allow a tenant to exceed its assigned quota for a certain time and at certain cost. In case a stack is permanently decommissioned, respective resources are released so that the IS-RB could assign them to other tenants or to keep them for future use. Such re-allocation decisions are communicated to the affected NFV MANO stacks (particularly the VIMs) for further enforcement.

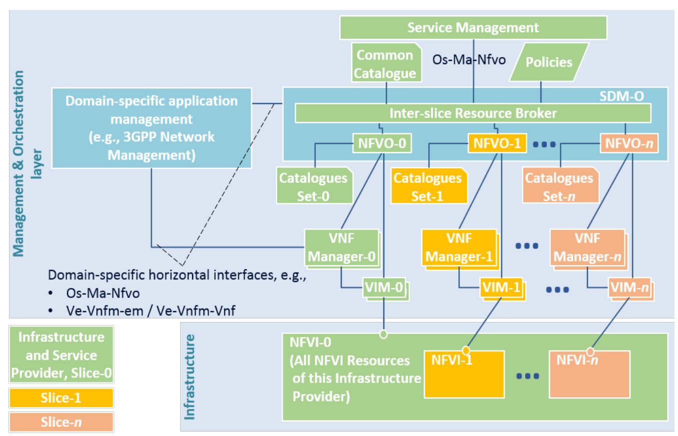

Fig. 2: 5G NORMA management & orchestration layer

B. QoS / QoE Control

5G NORMA defines a flexible QoS/QoE control framework to accommodate the possible diversity of QoS/QoE requirements coming from different tenants and their requested ’vertical’ services. The framework is used to eventually trigger (through the SDM-C and SDM-X components) a re-orchestration request if different arrangement of resources are needed.

The objective for 5G NORMA is to provide a common QoS/QoE control framework a) to compute QoS based on objective network metrics (packet loss, jitter, throughput, etc.), and b) to integrate subjective QoE influence factors in order to estimate the subjective user experience. The main challenge for this is to provide a general solution for 5G heterogeneous multi-tenant and multi-service scenarios. The 5G network is assumed to support a multiplicity of services (voice, MBB, IoT, V2X, gaming, etc.), devices (smart phones, tablets, remote sensors, vehicles, etc.), and network elements (e.g., macro and small cells) in a future-proof manner.

Providing services in a multi-tenant environment means that each tenant could require a very different approach for its specific QoS/QoE control, i.e., on the same network, some tenants could request just simple QoS measurements based on a small set of parameters while others could request more complex approaches requiring for example real-time QoE measurements for a large set of UEs inside certain areas. The latter might require a complex infrastructure with multiple nodes and execution of real-time DPI and 'Big Data' analytics.

This calls for a different QoS approach than in legacy networks, which can be implemented flexibly and efficiently by a components-based software engineering approach. This basically consists of a common and well-defined execution environment (software container) able to host and execute well-specified software components which can be freely defined and deployed on it. Fig. 3 illustrates this general idea.

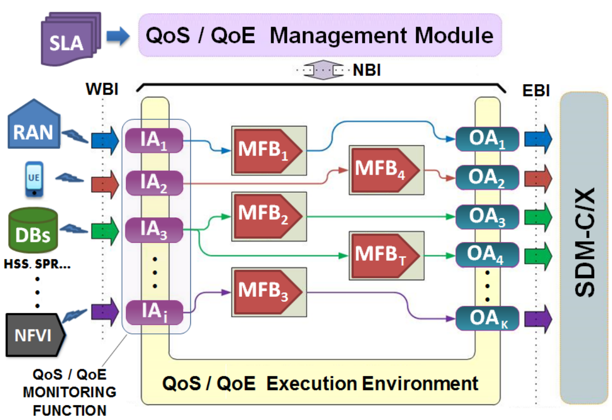

Fig. 3: QoS/QoE Execution Environment & Building Blocks

The yellow U-shaped block represents the 'Software Container' that works as the execution environment. Three main interfaces are defined:

- NBI (Northbound Interface), to communicate with the QoS/QoE Management Module in the 5G NORMA Management & Orchestration Layer.
- WBI (Westbound Interface), to receive incoming parameters.
- EBI (Eastbound Interface), to send QoS/QoE-relevant events towards the SDM-C/X modules.

The execution environment can host three types of deployable components: Input Adapters (IA), Mapping Function Blocks (MFB), and Output Adapters (OA). The development of these components uses general purpose programming languages in order to capture the different specificities for each service. However, the development is conditioned to implement well-defined interfaces and procedures to allow the integration of these freely defined modules in the system. The deployment of these elements on the execution environment is performed using well-defined deployment descriptors. This is performed from the QoS/QoE Management Module. Moreover, the execution environment also performs the life-cycle management primitives for the deployed components.

IAs are used to collect and transform the variety of data that come from diverse sources (RAN, UE, subscribers databases, billing systems, etc.) into a common internal data model. Since information from each source could be represented in different formats, the main functions of these components are protocol adaptation, data normalization, and possibly, integration of data during certain time windows. As shown in Fig. 3, the set of all IAs deployed on the system comprise the QoE/QoS monitoring system. This enables selecting the most adequate monitoring system (e.g., reactive, proactive, or hybrid) for each tenant or service by developing the IAs according to their specific needs.

QoS/QoE MFBs basically implement the mapping function relating the input parameters from the IAs with the corresponding QoS and QoE values. If they receive objective QoS parameters (jitter, delay, throughput, etc.), they generate QoS values, but if they receive subjective influence factors they can also generate QoE measurements. Each MFB can be developed in a different way: for instance, some of them could be designed using a rather objective approach (an experts team select the relevant input parameters and design the mapping function according to their expertise) while others could be developed following more subjective approaches by integrating also certain information coming from the end users (e.g., based on the 'Mean Opinion Score' method).

Finally, QoS/QoE OAs work as the MFB's output interface. Their primary function is to receive the information from the MFB in order to generate events towards the SDM-C/X blocks. They could perform additional functions, such as integrating measurements during certain time windows to raise events only if the degradation has persisted for a certain time. In order to support the SDM-C/X re-orchestration requests, OAs attach relevant information such as the event type (e.g., threshold reached), priority level, subscriber information, or tenant identifier.

IV. Security

5G NORMA has substantiated the need for security by analyzing important 5G use cases and setting up dedicated security requirements [10]. A security architecture fulfilling such requirements does not need to be designed from the scratch, but should build on well established, sound and scrutinized principles. One natural starting point and benchmark in this respect is undoubtedly the LTE security architecture. 5G NORMA has investigated the applicability of LTE security, with the result that substantial enhancements are needed for 5G NORMA networks, in particular:

- The adoption of the new networking paradigms NFV and SDN requires respective security concepts (but also facilitates efficient implementation of security functions).

TABLE I: 5G NORMA features and related security concepts

5G NORMA feature	Related security concept
NFV environments for core and radio functions	NFV security concepts (for central and distributed NFV environments)
Network programmability	SDN security, extended for SDMC
Mobile network multi-tenancy	Tenant isolation, slicing security
Multi-service awareness	Flexible security approach, e.g., choice of crypto algorithms
Adaptive allocation of NFs, joint optimization of RAN and CN	Flexible security approach, e.g., flexible allocation of security functions

- The need to support a variety of use cases calls for more flexibility, affecting security procedures like authentication between UEs and the network and the selection of crypto-algorithms to protect the radio interface.

Table I gives an overview of the basic features of the 5G NORMA architecture that call for new security concepts. Focusing on the general architecture, 5G NORMA does not aim at covering exhaustively fields like NFV security or SDN security. Still, selected topics in these areas have been tackled, such as role-based virtual machine introspection in the field of NFV security [6]. SDN security concepts like protecting the controllers southbound and northbound interfaces, and doing access control and authorization for control applications on top of the controller, fully apply to the 5G NORMA components SDM-C and SDM-X.

Multi-tenancy is facilitated in the 5G NORMA architecture by network slicing. It is assumed that verticals (like industry enterprises) will rent and operate dedicated network slices. Isolation of such slices is a fundamental security requirement, and 5G NORMA has elaborated that it can be achieved in NFV environments as well as on bare metal equipment. Slicing also facilitates the usage of slice specific security policies. For example, a slice supporting massive IoT applications may use different user credentials, authentication methods and radio interface security algorithms than a slice supporting the mobile broadband use case. Supporting the interaction of slice-specific functions and common functions requires specific care in securing the interfaces of common functions, to protect this functions against intentional or unintentional corruption by tenant slices. More details are provided in [6] (refer to Chapter 5).

Concerning the flexible network adaption to support multiple services, 5G NORMA has specifically investigated the implications on the radio interface security architecture. [6] describes a new access stratum security architecture that allows for multiple different security endpoints that can be flexibly allocated and re-located within the 5G NORMA RAN. Moreover, [6] comprises a survey of crypto algorithms tailored to specific use cases, with a focus on so called 'lightweight crypto algorithms', which are designed to provide high security for massive IoT deployments where the mobiles are sensors with very limited energy budget.

5G NORMA has investigated the security implications of the new architecture and developed a number of innovative security concepts. Besides the new flexible access stratum security architecture and the role-based virtual machine introspection mentioned above, these include a virtualized AAA concept, shielded network behavior, and the Trust Zone approach that facilitates the secure, isolated operation of edge clouds [6]. Concluding, the security concepts mitigate the specific risks arising due to the use of enablers such as NFV and SDN as well as the support of multi-tenancy and network slicing in the 5G NORMA architecture. Carefully implemented 5G NORMA networks can be highly secure.

V. Verification of Architecture Design

It is important that project outcomes are sufficiently mature and can be handed over to subsequent realization activities. Therefore, architecture design verification analyzes to what extent the current architecture design meets requirements defined in 5G NORMA and the overall ecosystem, including the 5G-PPP initiative and 3GPP. In order to cover all eigenvectors of future 5G systems, the verification methodology includes requirements and KPI defined for generic 5G services eMBB, mMTC and URLLC [10]. Applied evaluation criteria are depicted in Fig. 4.

Fig. 4: Evaluation criteria for architecture design verification

The inspection of requirement and KPI fulfillment is accompanied by roll out case studies that provide a link between evaluations on technical and economic feasibility. Additionally, these studies may reveal potential show stoppers and challenges that become visible when putting the developed system into practice. For a typical urban sample area in London, three so called evaluation cases have been defined. The 'baseline' evaluation case studies the development of eMBB RANs in the sample area for the time span between 2020 and 2030 and tries to identify benefits of 5G NORMA key innovations for MBB. The 'multi-tenant' evaluation case expands the view from one up to four mobile operators and elaborates on feasibility and advantages of 5G NORMA multi-tenancy. Finally, a 'multi-service' evaluation case adds network slices for mMTC and V2X to an already existing eMBB slice.

Intermediate verification results for eMBB performance, functional, operational, and security requirements as well as soft-KPI fulfillment are compiled in [6] (refer to Chapter 6).

Performance requirements for eMBB include peak data rates, different kind of transmission latencies, network capacity, and network behavior at increasing device mobility. The baseline case study detected that most of the MBB traffic in future as in the past will be carried by WiFi [11]. Nevertheless, future spectrum extensions at macro sites will lead to bottlenecks with antenna panel deployment that could be mitigated by bare-metal sharing among multiple tenants. Network capacity is measured as data volume that the network is capable to carry during the busy hour. The analysis shows that under realistic assumptions and an assumed annual increase of traffic densities by 20%, macro cells with their limited spectrum efficiency would not be able to provide sufficient capacity to cope with this traffic growth. Hence, small cell layer at lower and high frequency bands will be needed. Due to limited line-of-sight cell ranges the contribution by small cell layers at high frequency bands will be limited by their capability to offload the macro layer. Concluding, from capacity perspective, because of these off-load limitations there is no need for spectrum efficiency improvements for millimeter wave (mmW) radio nodes.

Many of the functional requirements identified for the generic 5G services are already fulfilled by the current design iteration. Further, operational requirements considered up to now are mainly related to deployment of multi-tenant and multi-service networks. Enablers for multi-tenant dynamic resource allocation, service specific and context aware adaptation and placement of NFs as well as dynamic network monitoring are currently being finalized.

As far as security verification is possible on the pure architectural level (as opposed to an assessment of a concrete implementation of the architecture), the analysis shows that implementations of the 5G NORMA architecture can comply with the security requirements. Innovative security solutions inside the framework of the 5G NORMA architecture have been proposed. Indeed, the flexible architecture design based on NFV and SDN is an excellent basis for integrating also future security solutions addressing those issues that are not in the immediate focus of the 5G NORMA security work.

Evaluation of 'Soft-KPIs' shall cover additional non-quantifiable requirements. For instance, verification shows that interfaces between service management and SDM-O are able to carry all information needed for automated processing of service deployment requests from tenants. Verification of scalability of centrally arranged control functions builds on methods used to evaluate scalability of SDN controllers. Further, the introduction of several network instances (slices) increases complexity, e.g., by multiplying many of the existing network operability processes. While this aspect can be tackled by increased levels of automation, the number of feasible network slices is rather going to be limited by the scarce bottleneck resources (e.g. spectrum, backhaul capacity).

VI. Conclusion

This paper has summarized the intermediate results in 5G NORMA regarding the development of a system architecture for programmable and multi-tenant 5G mobile networks. Service-aware resource sharing, network customization by adaptive allocation of NFs, and network programmability for flexible network control have been motivated as major design criteria. The 5G NORMA functional architecture design realizes these objectives, among others by introducing software-defined controllers and orchestration entities as well as a stringent control and data layer split. The example of QoS/QoE control illustrates the advantages of the proposed architecture. A more formal, systematic architecture design verification has confirmed most of the expected benefits, including customizable security levels. Identified gaps and shortcomings are tackled in the final design iteration, yielding the final system architecture of the project until the end of 2017.

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TABLE II: List of acronyms

AAA	Authentication, Authorization, Accounting	N(S)BI	North (South)-Bound Interface
CN	Core Network	NFVI	Network Function Virtualization Infrastructure
DCN	Dedicated Core Network	PoP	Point of Presence
DPI	Deep Packet Inspection	RAN	Radio Access Network
InP	Infrastructure Provider	RRC	Radio Resource Control
IS-RB	Inter-slice Resource Broker	SDM-C	Software-Defined Mobile network Controller
KPI	Key Performance Indicator	SDM-O	Software-Defined Mobile network Orchestrator
MANO	Management & Orchestration	SDM-X	Software-Defined Mobile network Coordinator
(e)MBB	(enhanced) Mobile Broadband	SLA	Service Level Agreement
MFB	Mapping Function Block	URLLC	Ultra-Reliable Low Latency Communications
MNO	Mobile Network Operator	V2X	Vehicular-to-Anything Communications
MOCN	Multi-Operator Core Network	VIM	Virtualized Infrastructure Manager
mMTC	massive Machine-Type Communications	VNPaaS	Virtualized Network Platform as a Service

References

[1] 5G PPP Architecture Working Group, "View on 5G Architecture", White Paper, v1.0, July 2016, https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-5G-Architecture-WP-July-2016.pdf [accessed 31-01-2017]

[2] 3GPP, "TR 23.799, Technical Specification Group Services and System Aspects; Study on Architecture for Next Generation System (Release 14)", December 2016.

[3] 3GPP, "TS 23.501, System Architecture for the 5G System, v0.2.0", January 2017, http://www.3gpp.org/ftp//Specs/archive/23_series/23.501/23501-020.zip, [accessed 07-02-2017]

[4] 3GPP, "TS 23.251, Network sharing; Architecture and functional description, v8.2.0", March 2010.

[5] 3GPP, TS 23.401 General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access, v13.3.0, June 2015.

[6] EU H2020 5G NORMA, Deliverable D3.2, 5G NORMA network architecture - Intermediate report, 2017, https://5gnorma.5g-ppp.eu/wp-content/uploads/2016/11/5g_norma_d3-2.pdf, [accessed 31-01-2017].

[7] EU H2020 5G NORMA, Deliverable D5.1, Definition of connectivity and QoE/QoS management mechanisms - intermediate report, 2017, https://5gnorma.5g-ppp.eu/wp-content/uploads/2016/11/5g_norma_d5-1.pdf, [accessed 31-01-2017]

[8] EU H2020 5G NORMA, Deliverable D4.1, RAN architecture components - intermediate report, 2017, https://5gnorma.5g-ppp.eu/wp-content/uploads/2016/11/5g_norma_d4-1.pdf, [accessed 08-02-2017]

[9] ETSI, "GS NFV 001, v1.1.1, Network Functions Virtualisation (NFV); Use Cases, Oct. 2013, http://www.etsi.org/deliver/etsi_gs/nfv/001_099/001/01.01.01_60/gs_nfv001v010101p.pdf [accessed 07-02-2017].

[10] EU H2020 5G NORMA, Deliverable D2.1, Use cases, scenarios and requirements, 2017, https://5gnorma.5g-ppp.eu/wp-content/uploads/2016/11/5g_norma_d2-1.pdf, [accessed 31-01-2017]

[11] Whitepaper: Smartphone & tablet usage trends & insights, 4G LTE and Wi-Fi powering data consumption, 2015