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PAPER

Technology and Standards Accelerating 5G Commercialization

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SUMMARY Communications industry will see dramatic changes with the arrival of 5G. 5G is not only about high capacity and ultra-low latency, but also about accommodating Verticals, providing newer flexibility in business development and agility. Network slicing has become an enabler for on-demand accommodation of such Verticals in a mobile network. To support such new features, 3GPP is continuing standardization of a 5G system with all necessary requirements in mind. This paper provides a detailed view of the standards and the technologies that'll make 5G a reality. Specifically, this paper focuses on the new 5G Radio Access Network (RAN), network slicing enabled new 5G Core (5GC) Network, and new management system capable of handling network slicing related management aspect of a mobile network.
key words: 5G, 3GPP, NR, 5GC, Network Slicing

1. Introduction

The whole communications industry is looking forward to the commercial arrival of 5G. It is not only about the mobile telecom industry anymore, rather for anything connected including fixed communications, vehicular communications, Internet-of-Things (IoT), factory automation and other Verticals. Nevertheless, it is the responsibility of the 3rd Generation Partnership Project (3GPP) to define and specify 5G which is the next generation of a mobile cellular network i.e. a 3GPP system.

3GPP addresses a complete 3GPP system through three Technical Specification Groups (TSGs)- Radio Access Network (RAN), Service & Systems Aspects (SA) and Core Network & Terminals (CT) [1]. TSG RAN, in its six Working Groups (WGs), creates specifications ranging from the physical layer to mobile terminal (aka User Equipment (UE)) conformance testing. TSG SA consists of six WGs. SA WG1 (SA1) and SA WG2 (SA2) handle the mobile core network specification works. SA WG5 (SA5) is responsible for delivering specifications for managing a 3GPP system. Other SA WGs work on security, codec and mission critical applications. TSG CT, in its four WGs, addresses several topics including UE interfaces and protocols.

3GPP produces sets of specifications in releases, each delivered in about every 1.5 years. At present, Release 15 (Rel. 15) is being concluded. 5G specifications are planned to be delivered in two phases. Rel. 15 delivers Phase 1. Rel. 16, spanning from Jun 2018 to Dec 2019 is expected to deliver Phase 2. Where Phase 1 provides initial standards for the first roll out of a 5G system, Phase 2 is expected to provide more robust and extensive standards for a complete 5G system. As many mobile network operators around the world including NTT DOCOMO declared 2018~2020 as the potential time frame for their first 5G roll out, Rel. 15 will become extremely vital. The first 5G system roll outs in the next few years is expected to be based on Rel. 15.

The rest of the papers are organized as follows. Section 2 provides the detailed schedule of 5G standardization works in 3GPP. Section 3 sheds light on 5G use cases and requirements and Section 4 explains the features available in a 5G System (5GS). Section 5 provides details on management features of a 5GS and Section 6 concludes this paper with summary and future works.

2. 5G Standardization Schedule

3GPP has been progressing with its 5G standardization works over multiple releases. In Rel. 14, studies on new 5G-specific radio communications system (called New Radio (NR) [2]) with no backward compatibility with Long Term Evolution (LTE) or LTE-Advanced [3] systems, and on the next generation core network were conducted in 2016~2017 [4]. Study on candidate component technologies and their comparison were also performed. Rel. 15 that started at the beginning of 2017 carried out specification work on 5G, and concluded in June 2018. Rel. 15 is considered as Phase 1 of 5G specification. In Rel. 15, Non-Standalone (NSA) operation has been specified that enables NR as the Secondary RAT to provide service along with LTE by using Evolved Packet Core (EPC) [5]. Rel. 15 also contains specifications for Standalone (SA) 5G deployment where a UE connects via NR to the 5G Core network (5GC) [6]. Although Rel. 15 was scheduled to be completed in June 2018, some works, called the late drop, require time until December 2018. The objective of

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Table 1: 5G use case and requirements

Rel.	Category	Related specifications	Main use cases	Requirements
Rel. 15	enhandced Mobile BroadBand (eMBB)	TR22.863 TS22.261	Indoor, hotspots, wide area	High data rate, high traffic density, diverse coverage, high user mobility
Rel. 15	Critical Communications (CriC)	TR22.862 TS22.261	Virtual presence, tactile Internet, remote control, telemedicine, remote first-aid, drone control	High reliability, (very) low latency, high availability, high accuracy positioning
Rel. 15	Massive IoT (MIoT)	TR22.861 TS22.261	Improved IoT device initialization, large capacity support, wearable device communications, bio-connectivity, wide are monitoring	Improved operation, diversified connectivity, improved resource usage efficiency than IoT
Rel. 15	NEtwork Operation (NEO)	TR22.864 TS22.261	Service-independent common system requirements	System flexibility, scalability, mobility, efficient content delivery, improved security, diverse backhaul/access considerations, migration/interworking considerations
Rel. 15	enhanced V2X (eV2X)	TR22.886 TS22.186	Autonomous driving, convoy driving, remote driving	High data rate, high reliability, high availability, low latency, wide area coverage
Rel. 16	Communication for Automation in Vertical Domains (cyber CAV)	TR22.804 tbd for TS	Rail-bound mass transit, building automation, factories of the future, smart living, smart city, electric-power distribution, centralized power generation, program making and special events, smart farming	Dependable communication, high reliability, low latency, clock synchronization, high accuracy positioning, private network, ethernet support, QoS monitoring, service exposure, security

Rel. 15 is to provide specifications for initial 5G commercial roll out. Rel. 16, considered as Phase 2 of 5G, would span from mid-2018 till the end of 2019 and is expected to produce more comprehensive 5G specifications.

3. 5G Requirements

Along with well-known high throughput, high capacity and low latency requirements, 5G aims at creating new business opportunities across the industry including the Verticals. Below, main 5G use cases and requirements are explained.

3.1 5G use cases and functional requirements

From the perspective of radio technology, 5G use cases are considered to be enhanced Mobile BroadBand (eMBB), massive Machine Type Communications (mMTC) and Ultra-Reliable and Low Latency Communications (URLLC). There are also use cases and requirements from the perspective of services. For example, telemedicine, autonomous driving, and factory automation have been pointed out as use cases requiring a certain level of low latency. 3GPP TR 22.891 [7] summarizes 74 use cases in 5G along with the requirements in each use case. Table 1 focuses on the service perspective and shows use cases and corresponding requirements grouped into six different categories.

3.2 5G performance requirements

Main performance requirements for NR are shown in Table 2 [7], [8]. To highlight a few, the peak data rate is set to 20 Gbps in the downlink (DL), and 10 Gbps in the uplink (UL). A three-fold spectrum efficiency gain is expected. As low as 0.5 ms of one way radio transmission latency and 10^{-5} of maximum packet error rate have been set as target values for the 5G radio link.

Performance requirements on data rate, latency, reliability, traffic density and connection density for the whole 5GS [6] have been specified for different use cases too. The 5GS comprises of NR as well as 5GC. Along with the information in Table 2, 10 ms of end-to-end latency for intelligent transport system, 5 ms for remote control, 0.5 ms for tactile Internet are some other examples of such requirements on 5GS.

Table 2: Summary of 5G requirements

Use cases	Key Performance Indicator (KPI)	NR	
		DL	UL
eMBB	Peak data rate	20 Gbps	10 Gbps
	Control-plane (C-plane) latency	10 ms	
	User-plane (U-plane) latency	4 ms	
	Cell/TRxP spectral efficiency (bps/Hz/TRxP[1])	3 times higher than LTE-A	
	Area traffic capacity (bps/sq. m)	3 times higher than LTE-A	
	User experienced data rate (bps)	3 times higher than LTE-A	
	Target mobility speed (relates also to URLLC, mMTC)	500 km/h	
	Mobility interruption time (relates also to URLLC, mMTC)	0 ms	
mMTC	Coverage	Max coupling loss 164 dB	
	UE battery life	Beyond 10 years	
	Connection density	1000000 devices/sq. km	
URLLC	U-plane latency	0.5 ms	
	Reliability	10^{-5} for 32 Bytes with U-plane latency of 1 ms	

4. Feature of NR and 5G Core Network

In this section, NR and 5GC features for satisfying the 5G requirements in the previous section are presented.

[1] TRxP (Transmission Reception Point): Antenna array with one or more antenna elements available to the network located at a specific geographical location for a specific area.

4.1 NR Features

A key feature of NR is its support for NSA operation. In this case, service can be provided in combination with LTE/LTE-Advanced (LTE/LTE-A) without the necessity of setting up an NR standalone area.

The NSA mode provides three benefits to a mobile network operator (mentioned as operator in the rest of the paper). The first one is the usage of existing frequency bands. Existing LTE/LTE-A networks are already providing services in the 800 MHz and 2 GHz bands. 5G, in its initial deployment, is expected to use higher frequency bands such as millimeter wave band providing higher data rate. Therefore, NR can be used to augment LTE/LTE-A where higher demands exist within LTE/LTE-A areas. Along with satisfying demands for high data rate, this also ensures sound coverage, leading to improved customer satisfaction.

The second benefit is the migration from LTE/LTE-A to 5G. The above-mentioned local NR deployment in the LTE/LTE-A areas can be gradually expanded as demand rises. This allows for a smooth and demand-based expansion of 5G.

The third benefit is that the NSA mode allows for keeping using EPC and the S1 interface [5] between EPC and eNB. This minimizes the necessary investment and testing burden before introducing NR to the market. Due to such benefits, many of the early adopting operators of 5G are considering the NSA mode as the initial 5G commercialization scenario. Details of radio specifications of 5G can be found in [8~12].

4.2 Features of 5G Core (5GC) Network

While EPC, together with the NR NSA mode, seems sufficient for eMBB use cases, 5GC is much expected to satisfy URLLC use cases and for Vertical support.

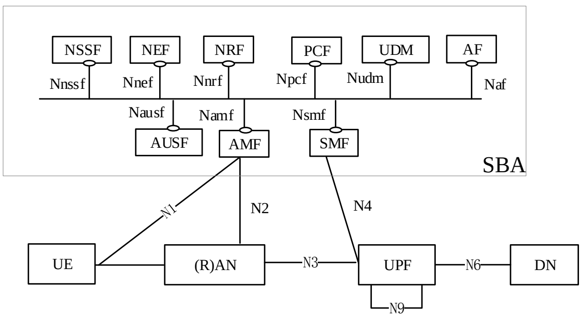

Fig. 1: 5GC with SBA C-plane [6].

3GPP has specified 5GC in June 2018 in Rel. 15, and now is working on for Rel. 16, targeting to complete it in December 2019. 5GC is shown in Fig. 1 and has the following five main characteristics,

a. Service-Based Architecture
b. Network slicing
c. Private network
d. Low latency
e. Various access accommodation

These are explained briefly below,

a. Service-Based Architecture

Interfaces among C-plane in 5GC have changed drastically, while interfaces have not been changed so much between 5GC and NG-RAN [13], between 5GC and UE, between C-plane and U-plane in 5GC, and among U-plane functions in 5GC [6]. Service-Based Architecture (SBA) has been introduced to adopt up-to-date virtualization and cloud technologies in the telecom industry, and sophisticate its development/operation process. Mono-functional Network Function (NF [2]) services are combined to define NF. NF offers services to each other via a unified protocol. Along with RESTful APIs, HTTP/2 and JSON are used. Specified NFs include Access and Mobility Management Function (AMF) which takes care for mobility management, Session Management Function (SMF) for session management, Policy Control Function (PCF) for policy control, Unified Data Management (UDM) for handling subscription information as a front end, and Unified Data Repository (UDR) for retaining policy and subscription information. User Plane Function (UPF), though not included as part of SBA, forwards U-plane data. AMF is specified as stateless. AMF stores context data in Unstructured Data Storage Function (UDSF). A set of AMFs access this UDSF. AMFs can change even during call processing. Details of the Rel. 15 5GC can be found in [6], [13].

Rel. 16 will be enhanced (i) by adopting Quick UDP Internet Connections (QUIC) [14] for the transport layer, (ii) by extracting communication services that are implicitly contained in each NF service (merging them with Rel. 15 Network Repository Function (NRF)) and setting it up as an framework of Service Mesh, and (iii) by making other NFs also stateless. Regarding (ii), utilizing commonly used cloud technologies instead of specifying everything in 3GPP is being considered as a way forward.

b. Network slicing

EPC has a procedure to select Mobility Management Entity (MME), Serving Gateway (SGW), and Packet Data Network Gateway (PGW) suitable to each service i.e. usual services or IoT services (DECOR) [5]. 5GC has enhanced it such that an AMF, SMF(s), and UPF(s) can be properly selected depending on each service. By that,

[2] NF and Network Element (NE) are used inter-changeably in this paper.

UE can simultaneously access multiple services with diverse traffic requirements.

In SA2, a network slice [15] can be roughly understood as a combination of an AMF, an SMF, and a User Plane Function (UPF). For example, in case where two SMFs and two UPFs are involved, a UE belonging to both of them can be considered as receiving services from two network slices, and the AMF is shared between two network slices.

Rel. 16 enhances network slicing by adding scenarios that (i) a network slice can be used only for a particular third party service and that (ii) a network slice can be privately used for a particular group of subscribers. In addition, SA1 has a requirement that says (iii) a third party shall be able to setup a private network slice easily via API of 5GC. This aspect is also expected to be studied soon.

c. Private network

A target of 5GC is to support Vertical's communication, e.g. for factory automation. Rel. 15 has not progressed well and only defined a concept of private network which is independent of a Public Land Mobile Network (PLMN), and specified that Protocol Data Unit (PDU) sessions can carry Ethernet frames as well.

Rel. 16 has started (i) categorization and re-definition of private network and (ii) study of Time-Sensitive Networking (TSN). SA1 has a requirement that says (iii) a private network and a private slice shall be able to be operated/managed in a combined manner. This aspect is also expected to be studied soon.

d. Low latency

EPC has a mechanism to realize low latency by putting PGW at the network edge by using Selected IP Traffic Offload (SIPTO) [5]. However, this is not capable of handling UE's mobility. 5GC has introduced a mechanism to support UE's mobility and change UPFs that work as a gateway.

Rel. 16 will be enhanced (i) by specifying interaction between 5GC and an application server in the external network and (ii) to guarantee low latency even during handover. It is expected that low latency study is going to focus on private network, in particular, on TSN rather than on PLMN.

e. Various access accommodation

Rel. 15 5GC accommodates Evolved Universal Terrestrial Radio Access (E-UTRA) [3], NR, and WLAN, considering also a fixed wireless access scenario. Rel. 16 will study fixed broadband access and satellite access too.

4.3 Deployment options of 5G

Unlike the previous generations of 3GPP systems e.g. 3G or 4G, 5G considers different deployment options for step-by-step deployment and smoother migration from 4G. Specifications are also being created to support such options [16], [17], as shown in Fig. 2.

As could be understood from Fig. 2, Option 3 (including 3a and 3x) and Option 7 (Note: 7a and 7x are also possible, but omitted from this figure) are NR NSA options. In Option 3, the EPC, which is the core network of 4G, provides the core network functionalities to both the LTE and 5G. The U-plane, which carries traffic generated from user applications, is processed and routed by the EPC.

In all other options, it is the 5GC that is responsible for handling traffic from LTE (eNB) and 5G (gNB). Terminology in the parenthesis represents the name of the base stations in each system.

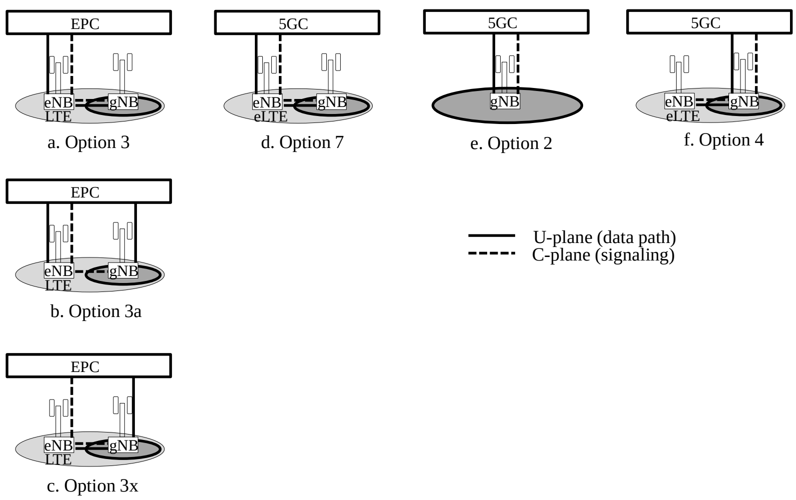

Fig. 2: Deployment options in 5G.

Fig. 2.e, which is the Option 2, represents a completely standalone (SA) scenario of 5G where the complete cellular system is constructed from NR/gNB and 5GC only. Different operators, based on their business as well as present network status, can chose from any of these options. From a smoother migration point of view, Option 3 seems better and is preferred by many cellular operators around the world. The authors of this paper contributed in defining the specifications of this option, as well as its promotion.

Along with high capacity low latency 5G NR, a very distinguishing feature of 5G lies in its native support to network slicing. As explained above, a network slice is a logical network [15] with dedicated compute, storage and network resources. The resource dedication could be of various degrees and not part of standardization. Research needs to be conducted for efficient resource management schemes for slicing.

Existing mobile networks e.g. LTE/EPC are monolithic where all services and traffic types are supported by a single instance of network. However, slices can be optimized for specific services, traffic types or Verticals. A slice can be created around the edge of the 5G mobile network to support URLLC applications for vehicular communication services, whereas conventional voice application can be accommodated in another slice ranging a whole country.

Fig. 3 highlights the native slice support in 5GC. As an example, sets of SMF-UPF-DN can be implemented as different 5GC slices. Note that AMF is shared between the slices. Each may have different topologies, resource allocations, and even lifetime. As slice selection identifiers have been defined for UE and support for slicing has been made mandatory in SA2 [6], a UE or an application in it can explicitly ask for connection to a particular slice during session establishment procedure. When the RAN/NR would support slicing, such slices can be realized on an end-to-end basis.

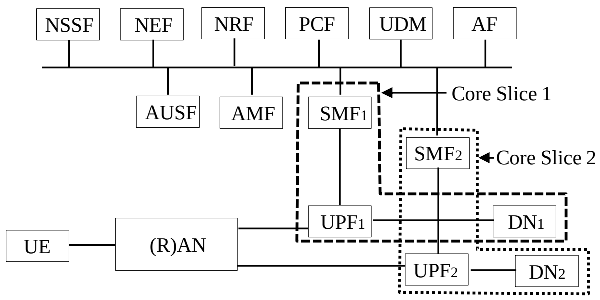

Fig. 3: Native slice support in 5GC.

Slices, which are inherently based on virtualization technologies e.g. Virtual Machine (VM)/Virtual Container (VC), Software-Defined networking (SDN), then would require newer management systems capable of handling network virtualization technologies and solutions. 3GPP SA5, which is responsible for delivering standards for 3GPP network management, therefore, is defining new slice management specifications. The next section presents the works in SA5.

5. Operation and Management of 5G network

Due to the arrival of network slicing in 5G, new management challenges arise. 3GPP SA5, responsible for drafting management specifications for 3GPP system is continuing its work to meet the challenges. This section provides the progress of SA5 focusing on network slicing.

5.1. 3GPP TSG SA5

3GPP SA5 is responsible for defining standards for the management of a 3GPP network including RAN, Core Network (CN) and IP Multimedia Subsystem (IMS). SA5 defined standards encompass management architecture, management interface specification for the FCAPS (Fault, Configuration, Accounting, Performance, Security) of 3GPP Network Elements (NEs), charging, energy management etc. Legacy SA5 management architecture is presented in Fig. 4 [18]. Main functional blocks of the legacy SA5 architecture is presented below,

<u>Network Manager (NM):</u> Responsible for the End-to-End (E2E) management of a 3GPP network through the Domain Managers.

<u>Domain Manager (DM):</u> Responsible for the overall management of the elements inside a domain. Examples of domains are RAN, CN etc. Network Elements (NEs) in a domain can be managed via their Element Managers (EMs).

<u>Element Manager (EM):</u> Responsible for the FCAPS management of individual NEs. In the legacy SA5 management architecture, the interface in between the EM and its NE is closed and therefore, the implementation is vendor-dependent.

As 3GPP SA2 has defined network slicing a basic feature of 5GS, SA5 took the responsibility of defining new management mechanisms to handle network slicing specific management tasks. In Rel. 15, SA5 has defined basic procedures and architecture principles for network slice management [19], [20]. Such work includes but not limited to a network slice management architecture framework, management models, slice provisioning management, fault management and performance management. Until this stage, the slice management architecture framework has been investigated independently from the legacy SA5 management architecture (Fig. 4). Integration of the two is a future work.

5.2 Management concept of Network Slicing in SA5

From the SA5 management perspective, a Network Slice Instance (NSI) is a logical network instance created for a business purpose e.g. a slice for voice communication within an operator, or to offer Network-Slice-as-a-service (NSaaS) to a 3rd party [19]. As such, an NSI will include all necessary Network Functions (NFs) necessary (Fig. 5) for any particular communication service being offered by using that NSI.

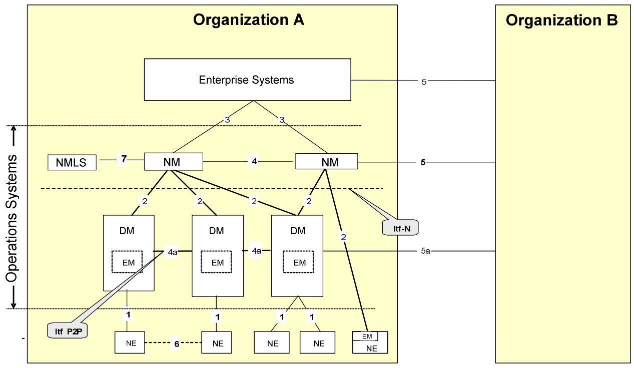

Fig. 4: Management reference model [18].

For slice management, SA5 has employed the concept of Network Slice Subnet Instance (NSSI). Network Slice Subnet is a concept available in NGMN [21], which refers to a partial slice. From an E2E 3GPP NSI perspective, an NSSI could be the CN, RAN etc. which are not E2E by nature (a Core Slice in Fig. 3 would be an NSSI in this case). Unlike the conventional network slices, which are isolated from each other, in 3GPP, one NSSI can be shared by multiple NSIs. An example could be multiple CN NSSIs connected to a common RAN defined as an NSSI (see Fig. 3). Similarly, NFs can also belong to multiple NSSIs. Obviously, Transport Network (TN) is also a part of an NSI. However, TN remains out-of-scope in 3GPP SA5. SA5 will define network slice-specific requirements on TN, but will request TN related Standardization Organizations (SDOs) to perform specification works on the TN.

5.3 Servicing concept of Network Slices

There are two types of offering of network slices in SA5 [19]. These are,

a. Network-Slice-as-a-Service (NSaaS) and

b. Network Slices as Network Operator (NOP) internals

In NSaaS, NSI(s) are offered to 3rd parties and their management interfaces, although in a limited manner, are exposed to the respective 3rd parties. The NSI(s) might be visible to the 3rd parties as independent networks (Fig. 6.a).

For NOP internal slices, the existence of a slice is not visible to any 3rd party. In this case, a 3rd party e.g. a Communication Service Provider (CSP) external to the NOP only provides services to Communication Service Customer (CSC) by using a NOP network (Fig. 6.b). Whether such communication service is provisioned by a network slice or not remains a NOP internal issue. The authors of this paper have major contributions in clarifying such business offerings in SA5.

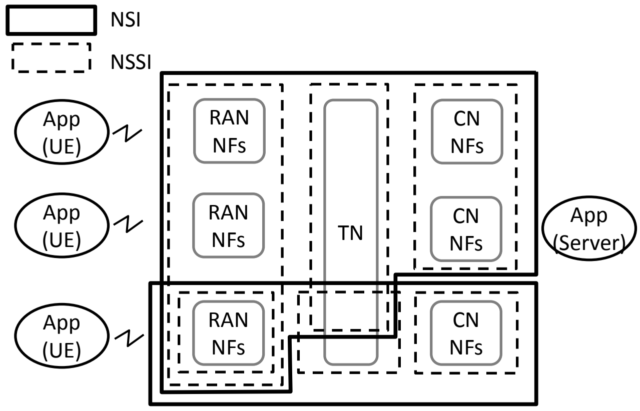

Fig. 5: NSI/NSSI concepts.

5.4 Management Architecture

From Rel. 15, SA5 decided to follow the SBA approach for architecture work [19]. As opposed to conventional architectures where functional blocks and point-to-point interfaces are defined, SBA does not define any point-to-point interface, rather APIs for the consumption of a particular function or service (see Section 4.2.a). The consumer of a particular function or service may vary from implementation to implementation. A function may provide multiple services and in such cases, APIs to consume the services are defined (Fig. 7) [20]. It is also possible to define only the services. A group of accumulated services then becomes a function, a Management Function (MF) in this context, which can be implementation-specific.

3GPP SA5 defines the following management services,

Provisioning Management service: This service creates/updates/deletes managed object instances for NSI/NSSI/NF necessary for their Life Cycle Management (LCM).

Fault Management service: This service enables alarm acquisition/notification/removal etc. on NSI/ NSSI/NF.

Performance Management service: This service enables registration of performance data, retrieval as well as notification of performance data, etc.

Further services can be defined in future.

TS 28.533 [20] provides implementation example of MFs consisting of different management services in a

slice management framework (Fig. 8). MFs necessary for slice management in 3GPP SA5 are,
Network Function MF (NFMF): provides management services for one or more NF(s). It can consume management services provided by other MFs.

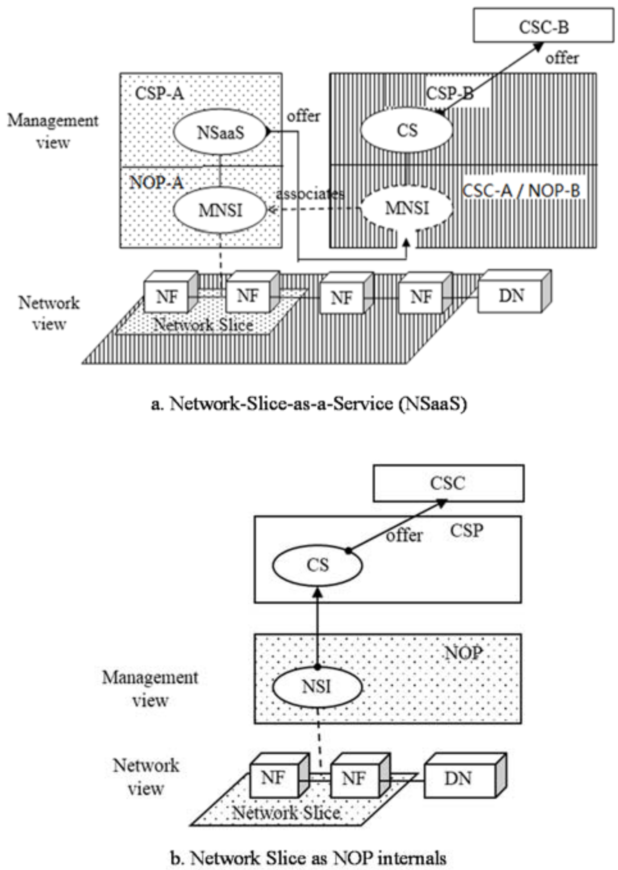

Fig. 6: Service offerings by Network Slice [19].

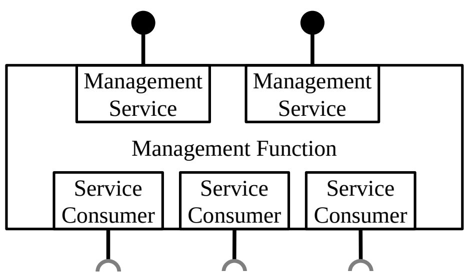

Fig. 7: Example of Management Function consisting of Management Services [20].

Network Slice Subnet MF (NSSMF): provides management services necessary to manage NSSIs. It can also consume management services provided by other MFs.
Network Slice MF (NSMF): provides management services necessary to manage NSIs. It also consumes management services offered by other MFs.
Communication Service MF (CSMF): performs the management of communication services. This only consumes from other MFs, but does not provide management service to other MFs.
Network Function (NF): realizing a particular communication function (e.g. AMF, UPF, gNB). It can provide management services described in NFMF. However, it does not consume management services from other MFs. The authors of this paper were heavily involved in defining the slice management framework (Fig. 8), and decoupling the NF from its MF.

It is worth noting that the capability of an NF to offer management services required to manage itself (by other MFs) exposes the management interfaces/APIs necessary for this purpose. As mentioned above, these interfaces so far were closed in SA5, and implementations are vendor-dependent. This is a mentionable progress made by 3GPP SA5. This will allow operators use generic NFMF instead of procuring NF dedicated NFMF (bundling of NE-EM in legacy SA5 architecture, see Fig. 4), as was the case so far.

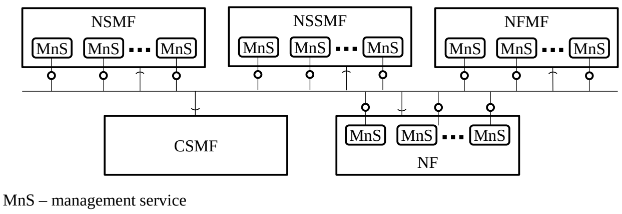

Fig. 8: Network Slice management framework in SA5 [20].

Standardizing management services instead of management functions enables operators to decide the grouping of management services in MFs and thus influencing the productization of future MFs. Exposing management APIs instead of point-to-point interfaces also gives more flexibility in network and management system design and product selection. Usage of higher layer protocols (e.g. http) in SBA also reduces costs in interoperability tests and integration. However, operator-determined service grouping into MFs may lead to operator-specific product development and create confusion in the market.

In Rel. 15, 3GPP SA5 addressed many new topics like network slicing and SBA. Significant progresses have been made in use case description, requirement drafting and determining the architecture principles. Detailed specification required for product and system development is expected in Rel. 16 and onward.

6. Conclusions

In this paper, we provided the features and progresses of 5G standardization works in 3GPP. As many operators have publicly declared that they would commercially roll out 5G by 2020, the robustness of the necessary standards is of utmost importance. Availability of different deployment options e.g. NSA, SA also provides engineering and business flexibility to the operators in selecting the right options for them. Support for network slicing also facilitates the on-demand accommodation of different Verticals in a mobile cellular network. Although most early 5G implementations will be based on Rel. 15, most may see upgrade when Rel. 16 is ready.

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