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3GPP 5G Core Network: An Overview and Future Directions

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Abstract

The new 5G radio technology (NR) can provide ultra-reliable low latency communications. The supporting 5G network infrastructure will move away from the previous point-to-point network architecture to a service-based architecture. 5G can provide three new things, i.e., wider channels, lower latency and more bandwidth. These will allow 5G to support three main types of connected services, including enhanced mobile broadband, mission-critical communications, and the massive Internet of Things (IoT). In 2015, the 5th generation (5G) mobile communication was officially approved by the International Telecommunication Union (ITU) as IMT-2020. Since then, 3GPP, the international organization responsible for 5G standards, is actively developing specifications for 5G technologies. 3GPP Release 15 provides the first full set of 5G standards, and the evolution and expansion of 5G are now being standardized in Release 16 and 17, respectively. This paper provides an overview of 3GPP 5G technologies and key services.

Index Terms: 5G, Standardizations, Mobile Network, 5G IoT

I. INTRODUCTION

With the advent of the 4th industrial revolution, digital transformation takes place in all industrial fields, and as the amount of wireless data increases accordingly, attention is focused on the performance of mobile communication networks. In this situation, the first 5G mobile communication networks were commercialized in South Korea in April 2019, and each country established national strategies to secure national competitiveness in 5G technologies and services, which is the core infrastructure of the 4th industrial revolution [1-3].

5G technology started with 5G standardization work in 3GPP under ITU's 5G vision. Based on the standardized release 15 in 2018, each country began to prepare for commercialization, and as Release 16 was completed in 2020, efforts to achieve the target performance of 5G continued. It is now planned to freeze Release 17 in March 2022 [4].

This paper introduces the 3GPP 5G standards development which started in mid 2017. The fifth generation radio and network technology is a major enhancement from its predecessors 3G and 4G systems. The 3GPP specifications for 5G took an extra effort due to its complexity. The new 5G radio technology (NR) will provide ultra-reliable low latency communications, and the supporting 5G network infrastructure will move away from the previous point-to-point network architecture to a service-based architecture. The new 5G network infrastructure will allow operators to tailor it to their specific needs through easily manageable cloud-based network entities.

The rest of this paper is organized as follows. The next section (Section II) gives an overview of 3GPP 5G stan-

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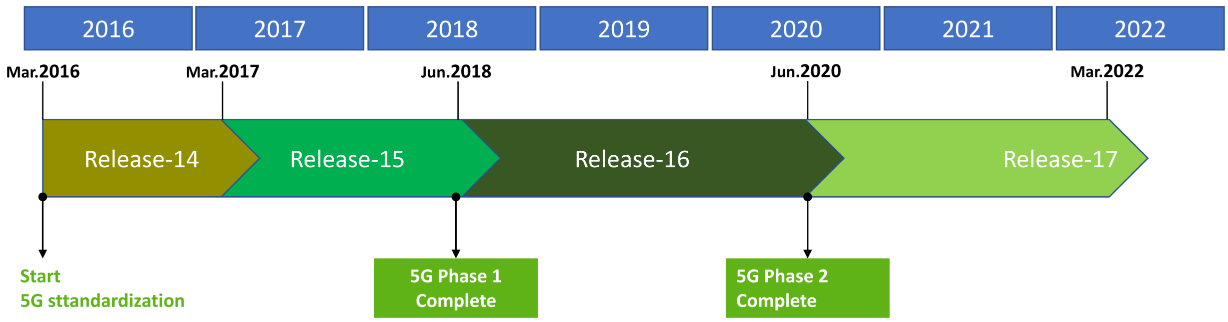

Fig. 1. 3GPP 5G standards milestone. 3GPP 5G, known as Release17, anticipates completion in 2022, with a freeze in Mar. 2022.

dards. Section III describes key features of 5G standards that are mainly developed as parts of 3GPP Release-17. The paper finishes with future directions and conclusions in Section IV.

II. 5G STANDARDS OVERVIEW

This section provides a brief historical overview of 3GPP standards and key differences of 4G and 5G technologies.

A. 3GPP 5G

3GPP started a preliminary study for the development of 5G specification in Release 14 and proceeded with the complete set of 5G specifications in earnest in Release 15 and Release 16. In Release 15, 5G basic features including New Radio (NR), massive machine type communications (mMTC), vehicle to everything phase 2, service-based architecture, etc., were defined as the 3GPP 5G Phase 1 specification. In Release 16, additional features, for example enhancing 5G system, industrial IoT, URLLC enhancements, were standardized as the 3GPP 5G Phase 2 specification [5]. As shown in Fig. 1, the 5G specifications for Phase 1 were officially released in June 2018 and the Phase 2 specification is frozen in June 2020 and complete in September 2020. Release 17 is scheduled to be delivered in March 2022 [6, 7].

The scope of Release 15 covers both non-standalone (NSA) 5G radio systems integrated LTE networks and standalone (SA) 5G with a new radio system complemented by a next-generation core network. Therefore, the 3GPP Releases 15 was not only comprising NR with 5G Core Network (CN), but also 4G to connect 5G base stations (gNB) for non-standalone deployment. Release 15 also focuses on supporting eMBB among three 5G usage scenarios (eMBB, mMTC, URLLC) defined by ITU with some supports on URLLC [8].

- >10 Gb/s peak data rates for the enhanced mobile broadband (eMBB)
- >1 M/km^2 connections for massive machine-type communications (MMTC)
- <1 ms latency for ultra-reliable low-latency communications (URLLC)

As a major release for 5G specification, Release 16 provides an initial full 5G system as the results from around 25 studies on various topics such as vehicle-to-everything (V2X) phase 3, 5G satellite access, network slicing, security enhancements [9], novel radio techniques and the IoT.

3GPP Release 17, which is nearing completion, targets further 5G system enhancements to expand the mobile ecosystem to new areas supporting new services/protocols/devices, new spectrum bands and business models with covering new topics or further enhancing features from previous releases such as Multimedia Priority Service, Mobile Edge computing (MEC), Unmanned Aerial Systems (UAS), 5G Proximity-based Services (5G_ProSe), 5G multicast-broadcast services (5MBS), Non-Public Networks (NPN), Network Automation (eNA), Network Slicing, Wireless and Wireline Convergence (WWC), enhanced Vehicle-to-everything (V2X) application layer services, Industrial IoT, system enablers for multi-USIM devices, Location Services, and Local Area Network support in 5G [9].

B. Benefit of 5G over 4G

What is 5G and how does it differ from 4G? This is a question that is paramount on the minds of the general public. When we speak of 5G we really mean 5G radio technology and not so much about the core network that is also an integral part of the entire 5G system. Currently, 4G radio

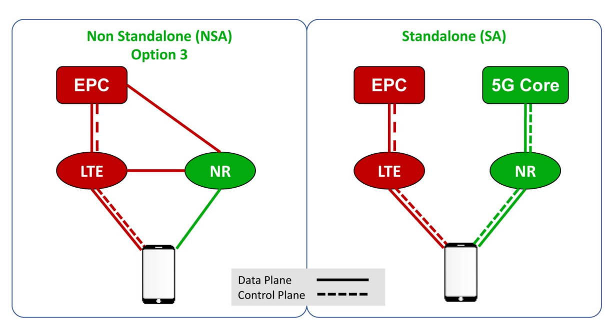

Fig. 2. Conceptual view of NSA/SA structures.

technology is robust and matured, i.e., enhanced over last 10 years and widely deployed. The real benefits of 5G radio technology will take time to realize until it matures and is widely deployed in the next 10 years. It should be noted that 5G isn't replacing 4G any time soon. In fact, both will coexist for many years and work together. 5G capable phones will support both 4G and 5G technology. Here is a list of key differences of 4G vs. 5G from a technical standpoint:

- Radio frequency spectrum – 3GHz vs. 30-300 GHz
- Spectrum efficiency – 3 times better (more bits per Hz)
- Wavelength
- Data transmission/speed – up to 1 Gbps vs. 50 Gbps
- Lower latency – 50ms vs. 1ms
- Connection density – 10 times higher in 5G
- Reliability

The 5G radio's key benefits in the spectrum it operates in are higher speeds, less latency, and capacity for a larger number of connected devices along with less interference and better efficiency. One disadvantage in higher frequency band for 5G would be its broadcast range as signal does not travel long distance in higher frequency bands, and does not penetrate buildings very well. This will require large number of cell sites to be deployed for 5G. In the day-to-day experience, users will not experience a big difference using 5G technology, other than downloading videos faster. The biggest benefits of 5G will not be apparent right away but developments are underway to offer fancy features which we can't even foresee right now as 5G technology matures and is widely deployed.

Unlike previous generations of mobile networks, 5G technology is expected to fundamentally transform the role that telecommunications technology plays in the society. The next section explains key features of 3GPP 5G standards.

III. 5G Features and Services

Some 5G key features to look into are new radio capabilities, network slicing, ultra-reliable low-latency communications, enhance security, high-capacity for large-scale internet of things devices, and enhanced core network to support service-based architecture. These features allow to operate more flexible and dynamic networks to uniformly enables user services with different needs, access networks. These 5G features enables to support various value-added real-time services such as self-driving car, smart city, augmented reality and virtual reality (AR/VR), online interactive learning and 3D video.

A. 5G Deployment Options

The integration of the new radio technology NR in 5G with the ones of the previous generation 4G LTE (Long Term Evolution) was studied in different options in 3GPP TR 33.801 [10] with two general possibilities as shown in Fig. 2: Standalone (SA) options consist of only one generation of radio access technology, 4G LTE or 5G NR. Non-Standalone (NSA) options have both generations of radio access technologies (4G LTE and 5G) by means of (Dual Connectivity). The most important options are for NSA the so-called Option 3 with the LTE eNB as primary node and the 5G gNB, which is a 3GPP 5G Next Generation base station that supports the 5G NR, as secondary node, and both connected to the 4G core network (Evolved Packet Core, EPC). This allows a fast deployment in the operator networks that already deployed 4G LTE and from User Equipment (UE, the phone in 3GPP language) only a 5G radio needs to be added. The evolution in the core network to the 5G core (5GC) is more difficult. For SA, the most important option is the so-called Option 2, where the 5G gNB is directly connected to the 5GC. While all 5G benefits can be used directly with this option, it is more beneficial with green field operators who start deploying 5G without any legacy network, since interworking with 4G requires much more effort.

B. Network Radio (NR) capabilities

NR is an OFDM based radio interface which provides more resistance to frequency selective fading, and is efficient in use of spectrum. NR operates from low to very high bands: 0.4 to 100 GHz. This allows NR to utilize a diverse radio spectrum for different applications. In lower bands (<1 GHZ) it can be used for providing applications which require longer range (massive IoT). In mid-bands (1 GHZ – 6 GHZ) it can be used for applications requiring wider bandwidths (eMBB and mission critical). In higher bands (>24 GHz) it can be used for applications requiring a large number of devices to be supported (V2X). To meet URLLC requirements, the NR supports latencies down to 0.5 msec uplink (UL) / downlink (DL), and delivers error-free packets through the 3GPP system within a bounded latency.

C. Ultra-Reliable Low Latency Communication (URLCC)

One of the key requirements in 5G systems is the support of URLCC communications essential for time sensitive machine-machine communications (e.g., factory automation, autonomous driving) requiring 5-nines reliability. The URLCC has to be supported end-to-end in the 5G system, i.e. both RAN and CN required improvements to assist in delivering highly reliable data transmission not achievable in 3G and 4G. The main areas of improvements are latency, reliability, and availability to enable, as mentioned earlier. These improvements were met with an improved radio interface,

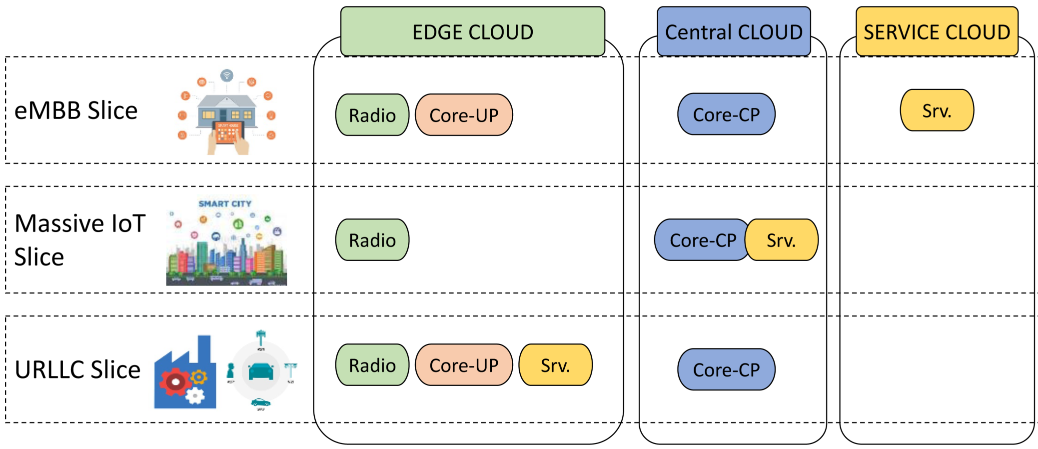

Fig. 3. Conceptual view of network slicing.

optimized architecture, and dedicated core and radio resources. From RAN perspective, the simplification of protocol processing as well as the improvements in physical layer design is essential to meet ultra-low requirements in terms of latency (1 msec) and 5-ninves reliability. In the 5GC, support of dual redundant paths for data transfer is provided to ensure there is zero loss in end-to-end data transmission. With dual paths data delivery end-to-end is able to better meet URLLC requirements. These URLLC capabilities can be selected by the UE depending on the type of service being provided.

D. Network Slicing using Network Function Virtualization (NFV)

One of the new features of the 5G System (5GS), is called network slicing (NS) which enables operators to manage their network resources in unique ways based on customer traffic needs. The NS feature is an end-to-end feature which is supported both on the RAN and 5GC. It allows partitioning the network resources via creation of Network Slices (NSs) consisting of dedicated network resources that are needed to do the job, rather than using the entire network and wasting resources, as done previously when there was only a single monolithic network whose resources could not be partitioned resulting in under or over utilization of resources. For example, NSs can be created to address different requirements on functionality (i.e., priority, charging, policy control, security, and mobility), or different requirements on performance (i.e., latency, mobility, availability, reliability and data rates), or a NS can be created to serve only specific users (i.e., MPS users, Public Safety users, corporate customers, roamers, or hosting an MVNO). The network slice behavior in terms of features and services can be described with the Slice/Service type (SST) as part of the slice identifier. So far there are four SSTs specified [11] for eMBB, URLLC, MIoT and V2X [12].

The 5G network nodes can be virtualized and sliced through the use of cloud computing working in the same fashion as virtual machines (VMs) (see Fig. 3). This concept is called network function virtualization (NFV) which has gained importance to allow operators to reduce CAPEX (no dedicated hardware for the network nodes) and ability to tailor the network nodes easily through just software updates. The NFV standards are conducted by the European Telecommunication Standards Initiative (ETSI) NFV Industry Specification Group (ISG), founded in November 2012.

E. Enhanced Mobile Broadband (eMBB)

The requirements for the eMBB services were increased compared to 4G. Many different coverage and deployment scenarios were considered i.e. Urban & Rural macro, Indoor hotspot, Broadband access in a crowd, Dense urban, Broadcast-like services, High-speed train & vehicle and Airplanes connectivity [13]. The data rate requirements start from 25 Mbit/s for broadband access in a crowd of pedestrians in a confined area scenario to 1 Gbit/s for Indoor hotspot in a residential/office scenario. While in airplanes a user can have only 15 Mbit/s, but up to 400 users with an aggregated data rate of 1,2 Gbit/s/plane should be supported.

F. Enhanced Security

The security functions of 5G are specified in TS 33.501 [14]. 5G offers some enhancements in security compared to 4G, i.e. functionality that was not available before, and the most important ones are listed below:

- Enhanced Subscriber Privacy: the secret SUbscriber Permanent Identity (SUPI, successor of IMSI) is always transmitted concealed and only provided to the serving network (which might be a roaming partner) after successful authentication.

- Home Control: authentication is not performed in the serving network but in the home network, the serving network is informed about the result.
- Primary Authentication: an additional authentication method EAP-AKA' is added to the 3GPP defined 5G-AKA method.
- Multiple NAS Connections: The UE can now have two Non-Access Stratum (NAS) connections at the same time for 3GPP and non-3GPP (e.g. Wifi) access. Both accesses may or may not belong to the same operator.
- User Plane Security Enhancements: User Plane Integrity Protection (UP IP) support can be per UE either with 64 kbps or the UE's full rate, based on its capability. Current discussions propose to have full rate only, due to recently discovered vulnerabilities in 4G (which has no UP IP).
- Secondary Authentication: the UE now can be triggered based on its subscription to perform an additional secondary EAP based authentication when requesting a PDU Session to a specific data network.
- PLMN Interconnect Security: in order to allow intermediate service providers (IPX) to perform their analytics and services, no TLS or IPsec is used, but JSON Patch objects on a hop-by-hop basis.
- SBA Security: TLS (Transport Layer Security) is used for transport layer protection and authentication of the NFs but NDS (Network Domain Security) can be used instead or in addition to TLS.

G. New QoS mechanism

The 5G system will support massive IoT (i.e., support huge number of devices) with URLLC. It is expected that mobile networks built on the basis of 5G technologies will provide data transfer speed of more than 10 Gb/s. Hence the 5G system had to be designed to be able to efficiently support massive growth in data traffic generated by different types of devices requiring management of data traffic with ultra-reliable end-to-end QoS. The QoS management mechanisms in 5G will be controlled at the network level similar to 4G, but the QoS concept is flow-based rather than radio bearer-based, where packets are classified and marked with QoS Flow Identifier (QFI). Both types of QoS flows are supported in 5G, the ones that require guaranteed flow bit rate (GBR QoS flows) and QoS flows that do not require guaranteed flow bit rate (Non-GBR QoS flows). A QoS flow is managing traffic at a much finer granularity enabling more flexible QoS control.

H. Massive Machine Type Communications and Cellular IoT

In the 5G standard, the core network for the evolution from 4G to 5G considers using both SA and NSA deployment options, which are two major 5G deployment alternatives. NSA is an option that is expected to be implemented in the initial stage

I. Standalone (SA) vs Non-Standalone (NSA)

In the 5G standard, the core network for the evolution from 4G to 5G considers using both SA and NSA deployment options, which are two major 5G deployment alternatives. NSA is an option that is expected to be implemented in the initial stage of a 5G commercial network. In NSA, the operation of the control plane responsible for mobility management of the terminal utilizes the 4G LTE network while the data traffic corresponding to the user plane is the 5G network. On the other hand, SA comprises New Radio (NR) and 5G Core Network (5GC). This means that both control and data signaling do not depend on the 4G network at all. In both scenarios, the terminal evolves to support both 4G and 5G connections simultaneously.

J. SBA – Cloud Native Architecture

The SBA functionality is described in TS 23.501 [11] and the procedures are documented in TS 23.502 [15]. 5G SBA is based on technologies known from the internet i.e. the

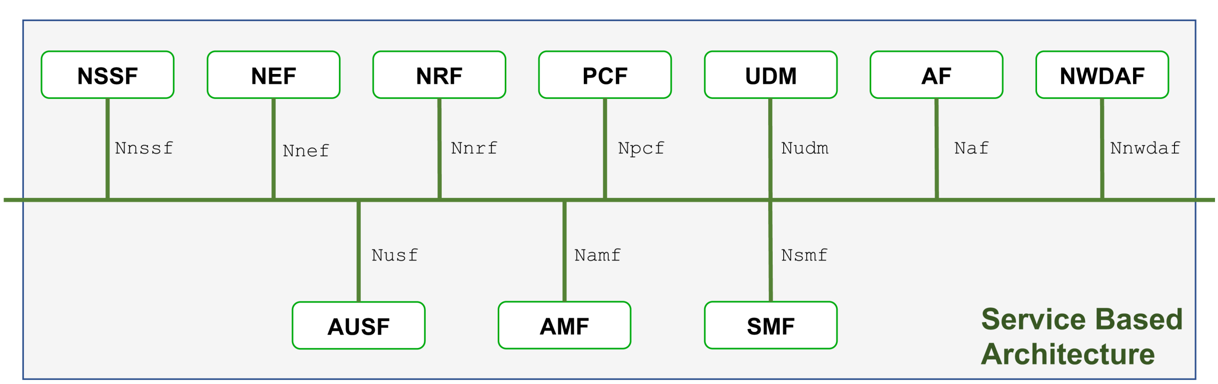

Fig. 4. 3GPP Service Based Architecture.

Service-Oriented Architecture (SOA) and Representational State Transfer (REST). SOA consists of the three components Service Repository, Service Consumer and Service Provider. A Service Producer publishes its service(s) to the Service repository and a Service Consumer queries the Service Repository for a Service Provider for a specific Server. Then the Service Consumer queries or subscribes to events of the requested service. Network Functions (NF) of SBA can act according to one or more roles of the three, depending on the NF, i.e. they can consume a service from one NF but notify other NFs as a producer at the same time. Without going into details, SBA in 5G defines a variety of NFs as shown in Fig. 4, here are the most important ones: Access and Mobility management Function (AMF), Session Management Function (SMF), User Plane Function (UPF), Policy Control Function (PCF), Network Exposure Function (NEF), Network Repository Function (NRF), Unified Data Management (UDM), Unified Data Repository (UDR), Authentication Server Function (AUSF), Application Function (AF), Network Slice Selection Function (NSSF).

K. 5G Deployment Options

The integration of the new radio technology NR in 5G with the ones of the previous generation 4G LTE (Long Term Evolution) was studied in different options in 3GPP TR 33.801 [16] with two general possibilities: Standalone (SA) options consist of only one generation of radio access technology, 4G LTE or 5G NR. Non-Standalone (NSA) options have both generations of radio access technologies (4G LTE and 5G) by means of (Dual Connectivity). The most important options are for NSA the so-called Option 3 with the LTE eNB as primary node and the 5G gNB as secondary node, and both connected to the 4G core network (Evolved Packet Core, EPC). This allows a fast deployment in the operator networks that already deployed 4G LTE and from User Equipment (UE, the phone in 3GPP language) only a 5G radio needs to be added. The evolution in the core network to the 5G core (5GC) is here more difficult. For SA, the most important option is the so-called Option 2, where the 5G gNB is directly connected to the 5GC. While all 5G benefits can be used directly, this option is more beneficial with green field operators who start deploying 5G without any legacy network, since interworking with 4G requires much more effort.

L. Enhanced Vehicle to Everything (eV2X)

The Vehicle to Everything (V2X) services in Release14 and 15 were only limited to LTE, but in Release 16 V2X was introduced also to the 5G system. It was then further enhanced in Release 17, to support a new functionality in 5G called, groupcast communication, in addition to the broadcast communications known from LTE. Also, in Release 17 5G unicast was introduced as a major enhancement based on ETSI Intelligent Transport System (ITS) and IEEE 1609 standards. Unicast was never supported in 3GPP LTE V2X.

The New Radio sidelink protocol between two vehicles (V2V) supports advanced V2X use cases, which can be grouped into four use case groups [12]:

- Vehicles platooning: vehicles travelling together form a platoon and retrieve management information from the leading vehicle, e.g. on speed, distances etc.
- Extended Sensors: local sensors in vehicles can share their raw or processed data or live video with other vehicles, pedestrians or roadside units and application servers.
- Advanced Driving: by sharing perception data between vehicles and roadside units, it allows synchronization and coordination of the vehicle movements to enable semi-automated or full-automated driving.
- Remote Driving: a vehicle can be operated by a remote driver or a V2X application in a different location.

IV. FUTURE WORK AND CONCLUSIONS

New studies have been proposed in 3GPP for Release 17 and work has nearly finished on them. Some of them are mentioned here which are proposed for enhancement of the 5G core network.

- Proximity-based services: To study applicability of direct mode device-to-device (D2D) capability of the ProSe feature that is used in mission critical services, for commercial applications like virtual reality (VR) interactive services.
- 5G multicast-broadcast services: To study the applicability of The MBMS (Multicast/Broadcast Multimedia Subsystem) feature of 3G/4G for supporting multicast requirements/use cases for CIoT, Public Safety, V2X etc.
- Network automation for 5G: To study applicability of the Release 15 functionality called network data analytics function (NWDAF) responsible for analyzing data of any part of the network, for enabling Artificial Intelligence (AI) related services.
- Edge Computing in 5G: To study the applicability of the mobile edge computing (MEC) technology for improving response times for real-time applications based on URLLC, V2X, AR/VR/XR, UAS, 5GSAT (satellite access in 5GS), and CDN (content delivery network), etc., use cases.
- Support of non-public private networks: To study the applicability of the Release 16 feature called “Vertical LAN”, which offered specific industry (verticals) solutions for companies/factories like redundant transmissions and URLLC, to be available to private networks.
- Enhancement of network slicing: To study further enhancements of the Release 16 network slicing feature.
- Support of satellite access: To study the architecture

enhancements in the 5GC for using satellite access.

Currently the upcoming Release 18 is under discussion, it is envisioned that it will span from Jan. 2022 to Mar. 2023 for the stage 2 work. At the time of writing this paper, in the 3GPP SA2 architecture group 49 new study and work items for Release 18 are proposed. Some proposals as in [18] have the following architectural priorities for the upcoming Release 18:

- System enhancements to improve existing features
- Enhancements to multi-access communication (ATSSS)
- Edge computing improvements
- Enhancements to network analytics
- Improve integration with verticals
- Enhancements to network slicing
- UPF enhancements for control and SBA
- UE policy enhancements
- Enhancements to support XR and media services

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All authors have the same contribution to the paper.

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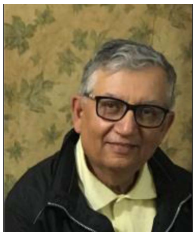

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K. Andreas

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