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Overview of 5G cellular networks

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Abstract: *The 5G technology corresponds to the 5th generation of mobile cellular networks, which, by the time this paper was written, was not yet commercially available in some countries, like Portugal. Therefore, the reason for this paper subject is to make known a general description of this new 5G technology, namely, its main improvements in respect to the previous 4th generation: the support of higher data transmission rates, enabling a network capacity/connectivity increase and the lower radio transmission latency, with their benefits for users and operators.*

Keywords: *5G, eMBB, mMTC, URLLC, CUPS, SBA, virtualization, cloud, slicing*

I. Introduction

The 5th generation of mobile cellular networks was defined for the following main goals and features, as referred to in Figure 1 [1][2]:

Enhanced Mobile Broadband (eMBB):

In 5G networks are expected to be achieved data rates of 2 Gbit/s in DL and UL with 100MHz bandwidth channel, 256QAM modulation and 8x8 MIMO parallel transmission paths. These rates should improve existing mobile broadband services and the usage of new services based on augmented and virtual reality equipments, like virtual reality glasses for teaching, personal communications and entertainment.

Massive Machine Type Communications (mMTC):

The supported higher transmission rates will also enable a network capacity/connectivity increase, which will boost new equipments usage, like IoT devices. These IoT devices should be used as sensors in vehicles, clothing and buildings.

Ultra-Reliable Low Latency Communications (URLLC):

This feature will support the usage of time-critical or low latency applications, like autonomous vehicles, remote surgeries and industrial controls.

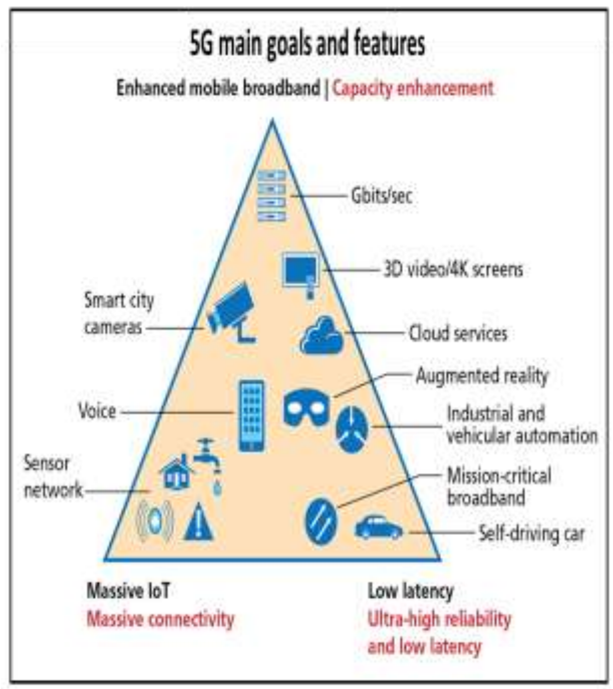

Figure 1: 5G main goals and features [1]

II. 5G network architecture

The 5G architecture is defined by new nodes and interfaces different from those used in the 4G architecture [3]. Therefore, as described in Figure 2, the 5G architecture nodes have the following main functions and interfaces [2][7][17]:

UE: User Equipment

The user terminal, like a smartphone or IoT device, equipped with a USIM card that identifies the user to the network.

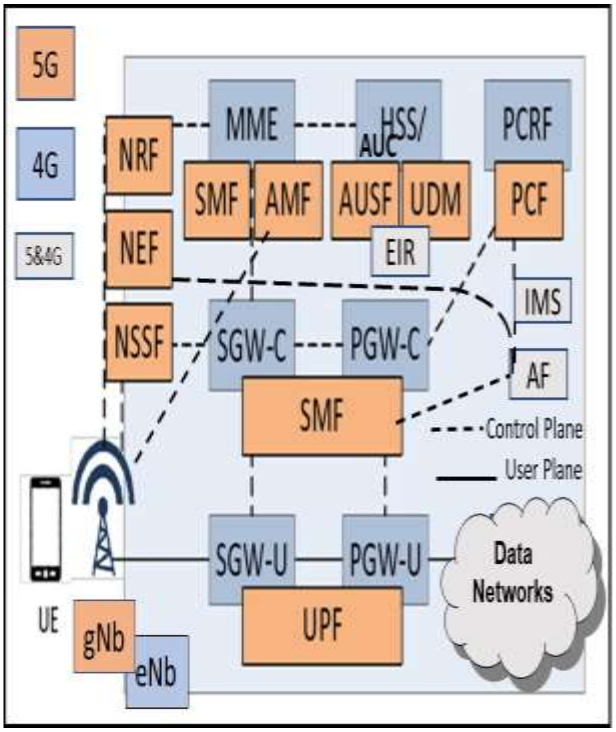

Figure 2: 5G/4G network functions mapping

gNb: next generation NodeB

The radio base stations that support network communication via radio access interface (antennas) with the UEs. This node has the same function as the 4G eNb.

AMF: Access and Management Mobility Function

The node performs functions like connection and mobility management between the network and the UE. These functions in 4G are performed by MME.

SMF: Session Management Function

The node performs functions like UE session management, IP address allocation and QoS&policy enforcement for Control Plane. These functions in 4G are performed by MME, SGW-C and PGW-C.

UPF: User Plane Function

The node performs functions like user data (User Plane) routing, QoS handling and policy enforcement for User Plane, and interface with other data networks. These functions in 4G are performed by PGW-U and SGW-U.

UDM: Unified Data Function

This node is a database with the operator's native users' service profile and location information. This node has the same function as the 4G HSS.

PCF: Policy Control Function

This node is responsible for the network QoS policy and charging control functions. This node has the same function as the 4G PCRF.

AUSF: Authentication Server Function

This node is responsible for the operator native users authentication and key agreement (5G-AKA) to secure data and signal radio interface transmission of authorized users. This node has the same function as the 4G AuC.

EIR: Equipment Identity Register

This node is a database responsible for UE IMEI checks to protect networks and revenues against stolen and unauthorized devices. The EIR also exists in 4G.

IMS: IP Multimedia Subsystem

This subsystem controls the users' access to several IP multimedia services, like voice service. The IMS also exists in 4G.

AF: Application Function

This node acts as a quality controller for network applications and interacts with PCF and with NEF for retrieving resources for external applications. The AF also exists in 4G.

NEF: Network Exposure Function

This node is new in 5G and is used to control secure access to external applications, like OTT or 3rd-parties (e.g., enterprises).

NSSF: Network Slice Selection Function

This node is new in 5G and is used to maintain a list of the Operator defined network slices instances (see Section IV). The network slice is selected based on information provided during UE attach that enables this node to redirect the UE traffic to the corresponding network slice, that controls its network activities.

NRF: Network Repository Function

This node is new in 5G and is used to maintain a list of available core network nodes instances, named Network Functions (see Section V), and their profiles. Additionally, NRF also performs service registration and discovery so that different Network Functions can find each other via APIs. For instance, an SMF registered in NRF, gets discoverable by AMF when a UE tries to access a network service served by the SMF.

III 5G New Radio network

The 5G radio access network is named New Radio (NR) and is composed of the radio base stations (gNbs) on the operator network. The 5G NR is based on the 4G radio access network architecture (E-UTRAN) [4].

Therefore, to allow a smooth transition from the existing 4G to a new 5G core, as described in Figure 3, operators with 4G legacy network for launching new 5G NR have two architecture options: Non-Standalone (NSA), where 5G NR can be connected and supported by 4G EPC core, or Standalone (SA), where 5G NR is supported by a new 5G core [5].

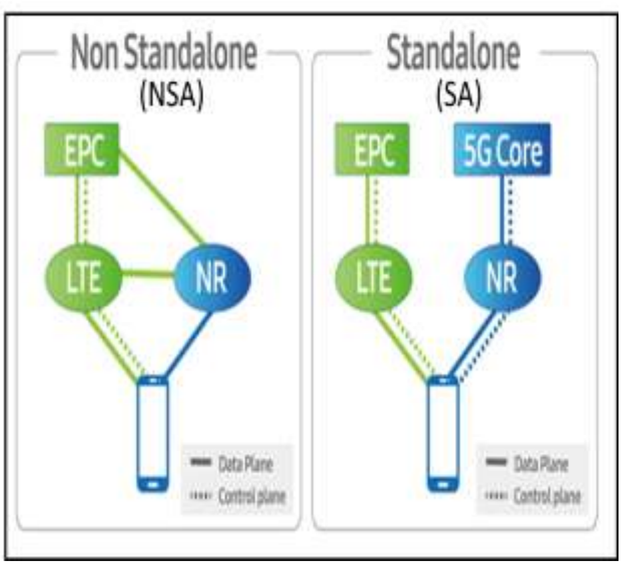

Figure 3: NSA/SA NR architecture [12]

Most of the 4G operators chose NSA to monetize their 4G core network investments and avoid deploying a new 5G core to support 5G NR and therefore reduce CAPEX and OPEX, namely, to compensate the purchase cost of the 5G spectrum. Finally, the NSA option should also accelerate the 5G commercial launching, however, limited to offer faster data speeds (eMBB) due to higher bandwidth channels usage.

However, only with the SA (later) deployment the following 5G NR new features and improvements should become completely available [1]:

Higher bandwidth channels:

The 5G will support different frequency bands and channels, as described in Figure 4. In addition, the usage of higher bandwidth channels above 20 MHz will contribute to supporting the 5G transmission data rates increase in respect to 4G (20 MHz).

In most EU countries, the 5G will be launched only with the frequency ranges of 700 MHz and 3600 MHz and not including the 5G more disruptive frequency: the mmWave. This mmWave will use higher frequencies, like 28GHz in Figure 4, and therefore should enable very high transmission rates, namely in indoor environments.

However, despite not being planned to be massively available shortly, as referred to in Figure 5 with 3GPP 5G Timeline, mmWave has already started to be used in some countries for private enterprises solutions.

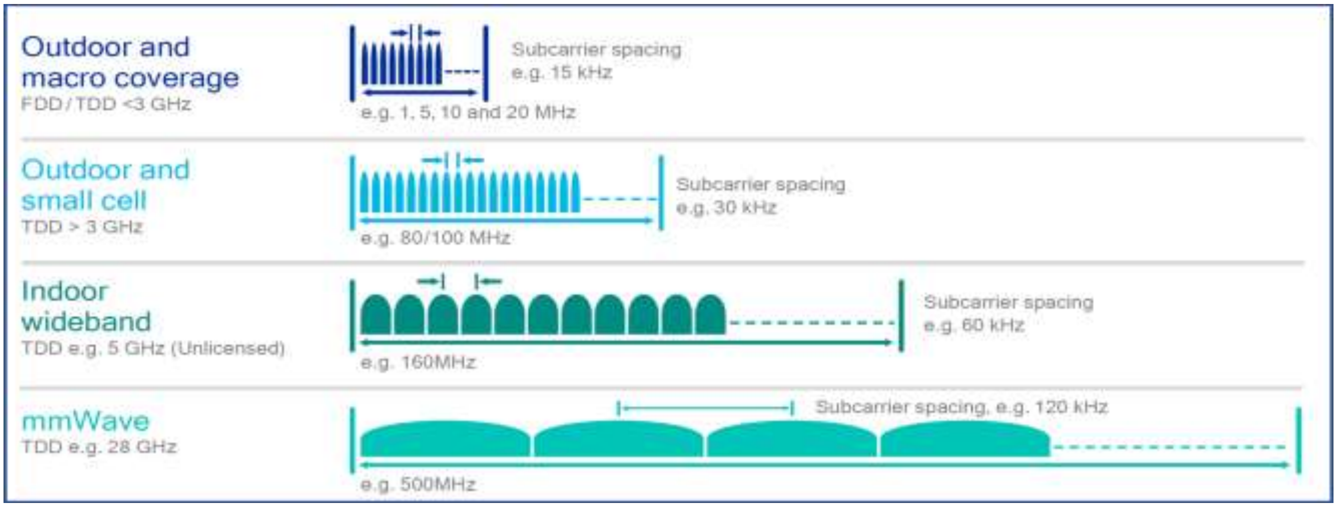

Figure 4: 5G frequency bands and channels [1]

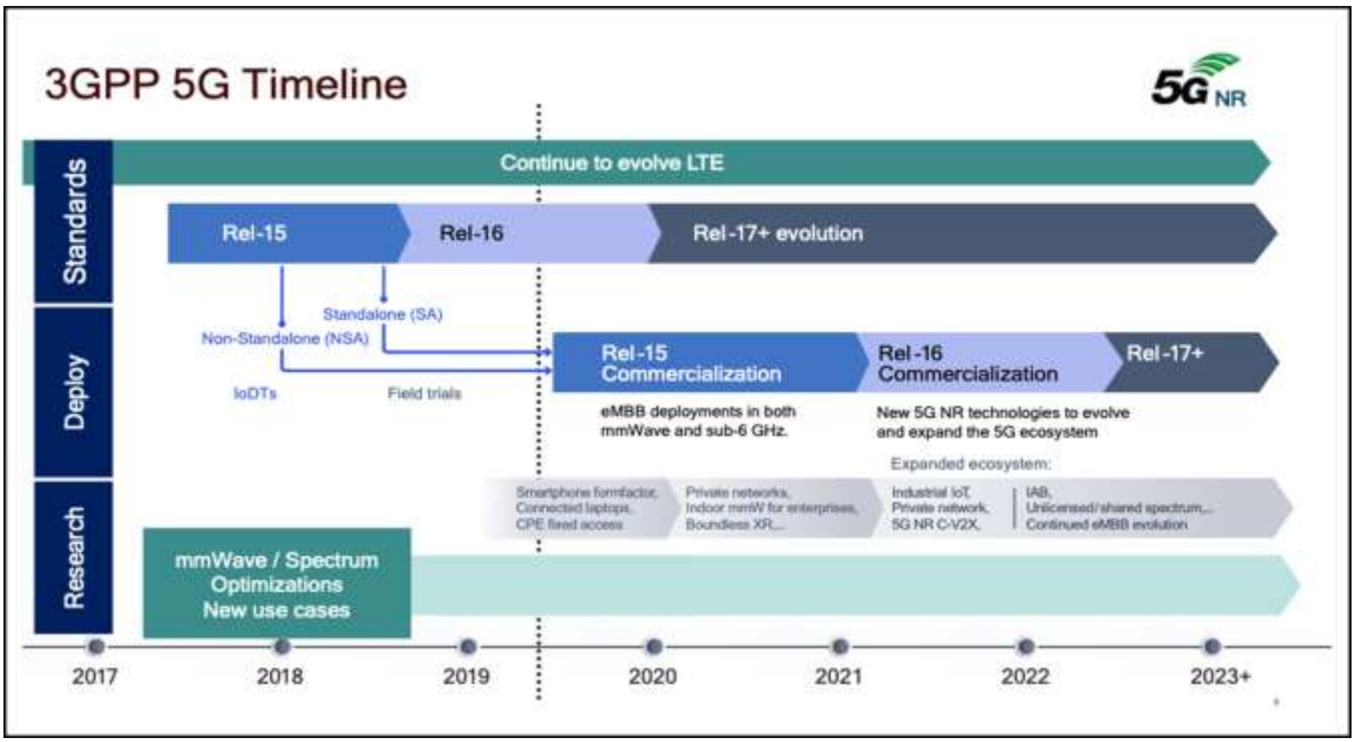

Figure 5: 3GPP 5G timeline [13]

<u>Active antennas, with beamforming and beam steering:</u>

This feature, described in Figure 6, will enable an array of antennas (sub-carriers) to direct individual beams to a given terminal, improving the transmission path and signal quality [4].

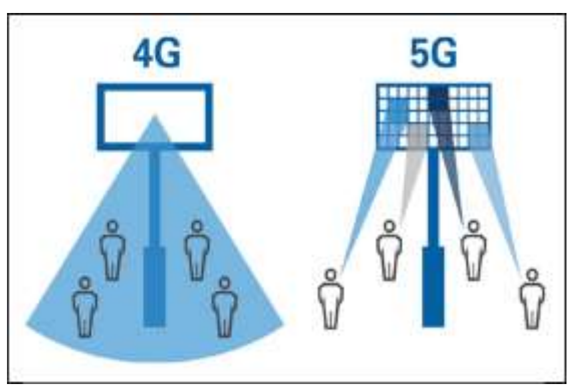

Figure 6: Active antennas [14]

Multi-User MIMO:

This feature is an evolution of 4G SU-MIMO. It will enable the setting-up of several parallel transmission paths (layers) between the gNB and several UEs, as described in Figure 7. Therefore, up to 16 layers per cell: with 4 users x 4 layers or 2 users x 8 layers might be paired simultaneously [4].

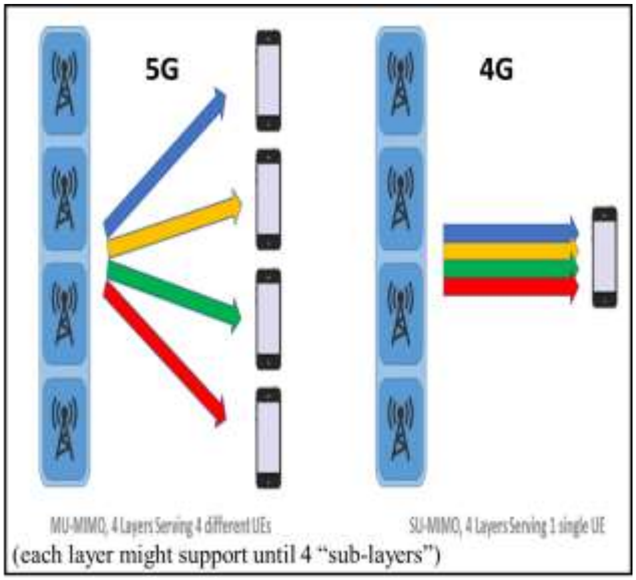

Figure 7: MU-MIMO / SU-MIMO [15]

It should be remarked that this feature complements beamforming antennas contributing to the 5G data rate increase and higher spectral efficiency.

Subcarriers with variable bandwidth:

This feature will enable a more flexible radio resources allocation depending on user services requirements [1].

More efficient data modulation:

The 5G will support data modulation in radio interface up to 256QAM in contrast to 4G with up to 64QAM, contributing to a 5G higher spectral efficiency [1].

IV. 5G Network evolution

To simplify the operator's network deployment, optimize resources usage and reduce operational costs, the 5G networks introduced from the beginning a set of new features in the telecommunications networks, from which the following should be highlighted [2][6][7]:

CUPS (Control and User Plane Separation):

This feature enables 5G networks to adopt a complete splitting between physical functionalities (user plane) and signal/control processing (control plane). Therefore, CUPS enables the usage of a cloud computing architecture to support most of the features referred in this section and gives the ability to manage the user plane and control plane independently of each other, promoting a more cost-effective and future-proofing network architecture for 5G.

Complete network virtualization of control resources:

For enabling the usage of cloud computing and the deployment of network slicing, the network control elements should be virtualized at both the radio and core components, as described in Figure 8 [8].

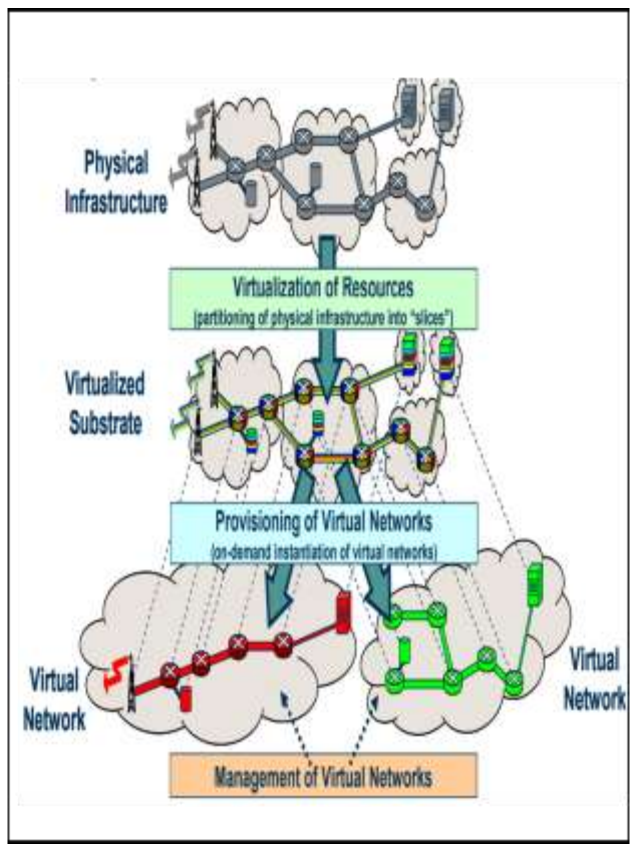

Figure 8: Network virtualization [1]

Network functionalities slicing:

The usage of a new sliced architecture, as described in Figure 9, will allow different groups of users (e.g., mMTC for IoT), with different network requirements to access different instances of the same Network Functions, customized to their needs, in an isolated way.

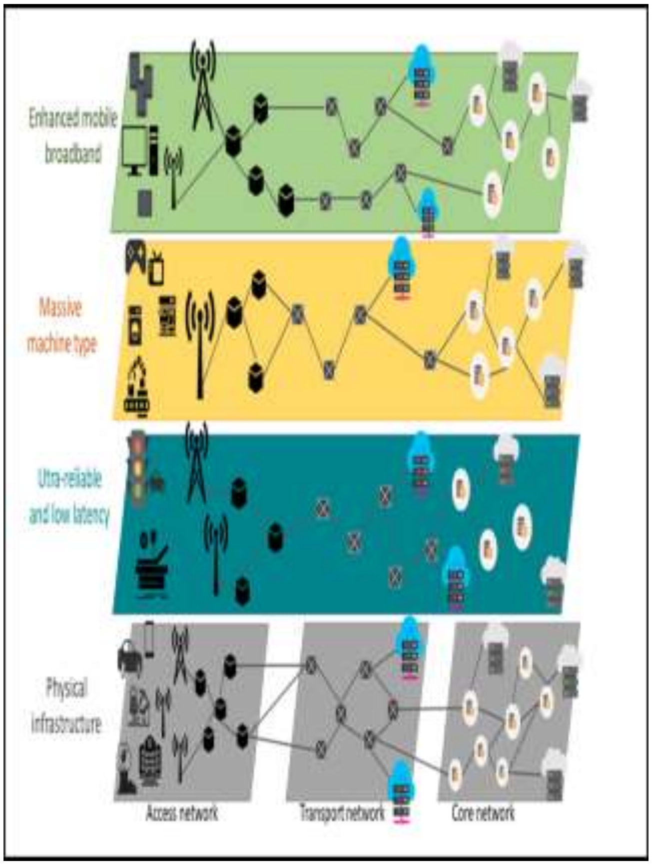

Figure 9: Network slicing [1]

Multi-access Edge Computing (MEC):

This feature enables Network Functions and services/contents, required by the users, to be placed on edge nodes (e.g., 5G NR), closer to them, as described in Figure 10.

The MEC's primary purposes are network congestion reduction and better services performance by running applications and performing related control tasks closer to the users.

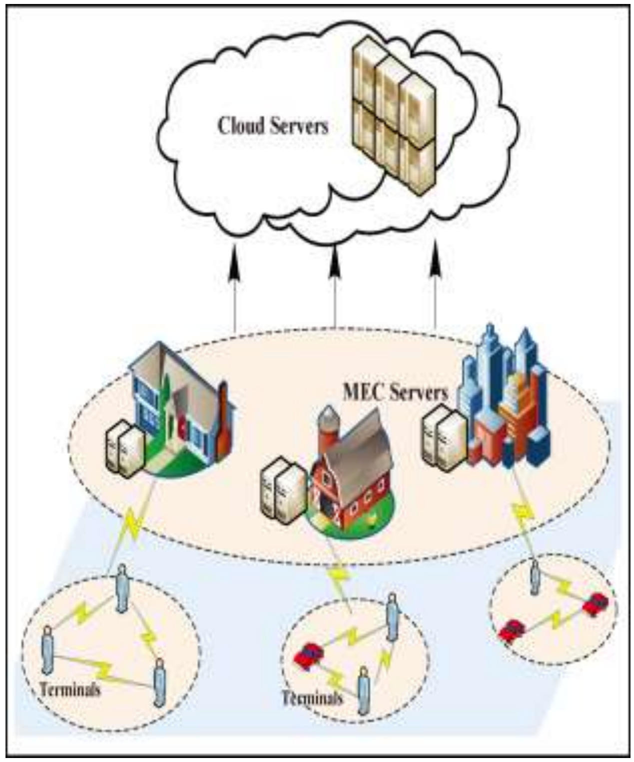

Figure 10: Multi-access Edge Computing [1]

Common Core for multi-RAT access:

In 5G Core, not only 5G NR but also 3GPP legacy LTE (4G) access and non-3GPP Wi-Fi access can be integrated via standard interfaces, as described in Figure 11. This feature defines the 5G core network support for multi-RAT or access agnostic, which will allow operators to reduce OPEX costs to have different radio access technologies controlled by a common 5G core.

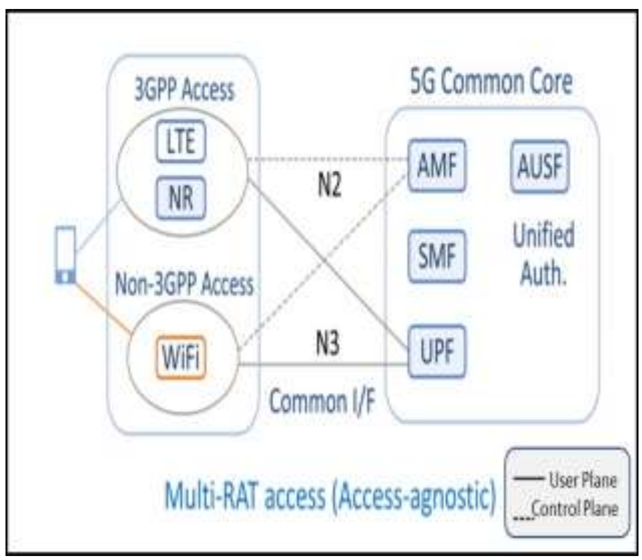

Figure 11: 5G Common core for multi-RAT [6]

V Service Based Architecture

The cellular core networks until 4G used specific telecom protocols running on specific telecom hardware. However, in 4G networks, the first steps have been taken towards virtualization, and the Service-Based Architecture (SBA) that the 5G networks have adopted is an evolution of this approach [9][10][11].

The SBA is defined by Network Functions (NFs) that provide services to other NFs. These NFs are software implementations running on commercial off-the-shelf hardware, most likely in the cloud. An NF can offer one or more services and is interfaced via well-defined APIs, where, as described in Figure 12, each NF plays the role of either service consumer or service producer. Therefore, traditional telecom signaling messages are replaced with API calls, using a web common control protocol: HTTP/2, on a logically shared service bus.

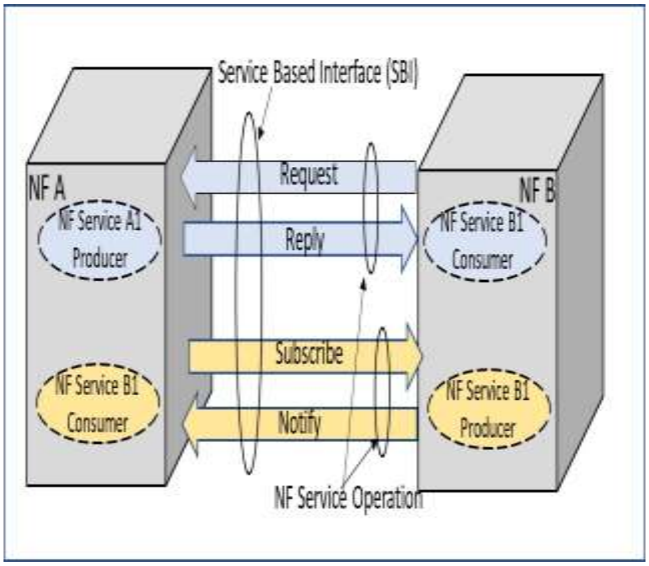

Figure 12: Service-Based Interfaces (SBI) [16]

The SBA intends to use the maturity of web and cloud technologies with the following main benefits [11]:

Easier maintenance:

Since services will operate with finer granularity and less dependence on each other than in legacy networks, it should be possible to upgrade individual services with minimal impact on the others.

This feature provides many operational benefits, such as shrinking testing and integration timescales, which reduces the time to market for installing error corrections and rolling out new network features and operator applications.

Scalability & Resilience:

Rather than add new physical nodes like in legacy networks that may take weeks, new instances of (virtualized) NFs can be created/destroyed dynamically in minutes. Furthermore, if an instance or a physical node fails, monitoring systems can detect this and quickly set up new instances.

Modularity & Reusability:

The SBA comprises modularized services reflecting the network capabilities and provides support to 5G key features such as network slicing. Furthermore, a service can be easily invoked by other services (with appropriate authorization), enabling each service to be reused as much as possible.

Openness:

With some management and control functions (i.e., authentication, authorization, accounting), the information about a 5G network can be easily exposed via NEF to external users such as 3rd-parties (e.g., enterprises). This feature enables services customization and faster innovation.

The 5G network is described by a reference point architecture that names the points by which each NF connects to other NFs, as described at the top of Figure 13. However, in practice, the reference points are implemented by corresponding NF Service-Based Interfaces (SBIs), as described at the bottom of Figure 13. Therefore, instead of physical point-to-point connections, like in legacy networks, NFs interconnect through a logically shared infrastructure or service bus. For instance, AMF and SMF are connected via the N11 reference point, for which the corresponding SBIs are Namf and Nsmf.

The SBIs are defined only for the 5G core control plane NFs. Therefore, reference points N1, N2 and N3 that involve the UE or 5G NR do not have SBIs. Likewise, the reference point between SMF and UPF is N4, and it has no equivalent SBI.

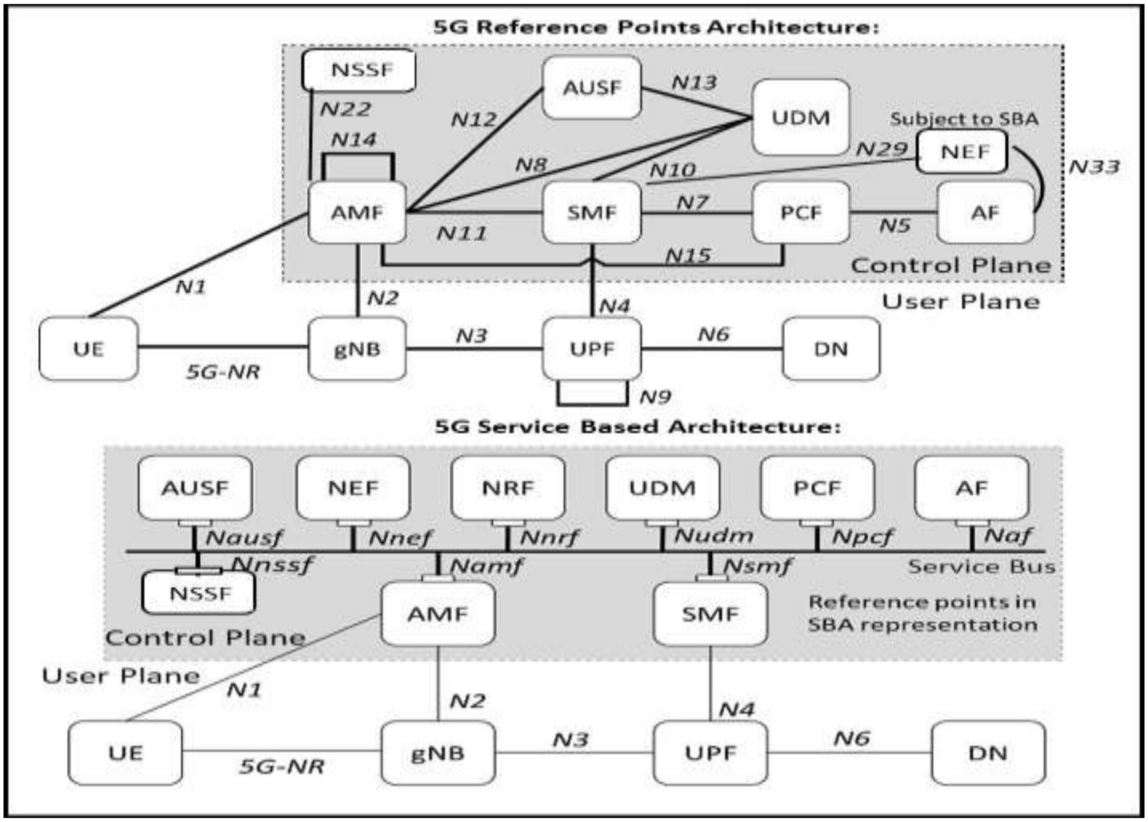

Figure 13: 5G Reference Points / SBA architecture [10]

VI. Conclusion

The 5G networks are an evolution of 4G, not only supported by a new radio interface with higher data rates, higher network capacity and lower transmission latency, but also with a more flexible, agile and scalable network architecture. Therefore, 5G networks aim to improve user's experience, provide new services, simplify operator's network deployment, optimize resources usage and reduce operational costs.

The following 5G networks main requirements should be highlighted [2][11]:

- Support various communication scenarios (such as eMBB, mMTC and URLLC), which ask for different network requirements, such as network capacity, data rate, transmission delay and information security.
- Support emerging new services, which require better network performance and expose network capabilities to operator's services and 3rd party applications.
- Support of easier and faster network deployment and network resources usage optimization. For instance, each functionality shall be upgraded according to new requirements and scale-up according to system capability without affecting other functionalities.
- Interworking with other systems, like non-service-based core network (e.g., the voice service in IMS). Likewise, the 5G core should also control and aggregate other radio access networks, namely 3GPP 4G and non-3GPP Wi-Fi.

Based on these requirements, virtualization and service-based mechanisms are a significant industry trend especially relevant for the 5G networks.

Finally, 5G should be deployed in phases; in a first phase should only be a faster 4G, with operators mainly using 5G NR with NSA architecture. Therefore, only afterward, namely, by the commercial launching of the new mmWave frequencies, the major technological innovations should appear and be massively available.

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VII Abbreviations

3GPP 3th Generation Partnership Project
4G 4th Generation of mobile cellular networks
5G 5th Generation of mobile cellular networks
AF Application Function
AMF Access and Management Mobility Function

API Application Programming Interface
AKA Authentication and Key Agreement
AUC Authentication Centre
AUSF Authentication Server Function
CAPEX Capital expenditures
CUPS Control and User Plane Separation
DL Down Link
EIR Equipment Identity Register
EPC Evolved Packet Core
eMBB Enhanced Mobile Broadband
eNB evolved NodeB
E-UTRAN Evolved Universal Terrestrial Radio Access Network
IMEI International Mobile Equipment Identity
IMS IP Multimedia Subsystem
gNB next Generation NodeB
HSS Home Subscriber Server
IoT Internet of Things
MEC Multi-access Edge Computing
MIMO Multiple Input Multiple Output
MME Mobile Management Entity
mMTC massive Machine Type Communications
MU-MIMO Multi User MIMO
NF Network Function
NEF Network Exposure Function
NR New Radio access network
NRF Network Repository Function
NSSF Network Slice Selection Function
NSA Non-Stand Alone 5G NR architecture
OPEX Operating Expense
OTT Over The Top
PCF Policy Control Function
PCRF Policy Control and Charging Rules Function
QAM Quadrature Amplitude Modulation
QoS Quality of Service
RAN Radio Access Network
RAT Radio Access Technology
REST Representational State Transfer
SA Stand Alone 5G NR architecture
SBA Service-Based architecture
SMF Session Management Function
SGW Serving Gateway
SU-MIMO Single User MIMO
UDM Unified Data Function
UL Up Link
UPF User Plane Function
UE User Equipment
URLLC Ultra-Reliable Low Latency Communications
USIM User Services Identity Module