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5G Mobile Communication Applications: A Survey and Comparison of Use Cases

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ABSTRACT The mobile demands and future business context are anticipated to be resolved by the fifth-generation (5G) of mobile communication systems. It is expected to provide an utterly mobile device, connected society, and support the demanding services of various use cases (UCs). This is intended to meet the demand requirement by providing services at tens of Gbps in terms of data rates, higher mobility range, lower latencies, and massive connectivity density devices per square kilometer. A comprehensive and up-to-date survey of the different developed and proposed use cases is presented in this paper. The first part of the paper presents the overview of the new 5G Architecture by introducing new features such as the new radio interface (New Radio), an overview of the 5G Core Network, minimum requirements, and the Radio Access Network, 5G spectrum requirements and other fundamentals of the network. Secondly, a detailed review of the developed and proposed use cases for 5G communications by the standards development organizations (SDO) and other key players in mobile communication is provided. Thirdly, we went ahead to propose spectrum bands for the deployment of the various use cases based on the low-, mid-, and high- band spectrum and further classified the use cases with respect to their relevance and family, identifying the IMT-2020 test environments and the usage scenarios derived by the 3GPP, fourthly, the channel capacity and the bandwidth of the spectrum was studied, simulated and compared to ascertain the spectrum proposed in this paper for each UC family. Hence, this paper serves as a guideline for understanding the usage scenarios for the future 5G deployment in various environments. This would allow system developers to design and implement 5G channel characterization models specific to the usage scenarios to meet the system requirements.

INDEX TERMS Use Cases, Network slicing, NG-RAN, 5G core network, Spectrum, Key Performance Indicators, Usage Scenarios, Standard Development Organization

NOMENCLATURE

LIST OF ACRONYMS

5G	Fifth Generation
5GC	5G Core Network
AMF	Access and Mobility Management Function
AN	Access Network
AR	Augmented Reality
ASE	Average Spectral Efficiency
ATC	Area Traffic Capacity
CDF	Cumulative Distribution Function
CN	Core Network
CP	Control Plane
DU	Dense Urban
eMBB	enhanced Mobile Broadband
eNB	enhanced NodeB
en-gNB	Next Generation NodeB
EPC	Evolved Packet Core
gNB	Next generation NodeB
IMT	International Mobile Telecommunications
InH	Indoor Hotspot
IoT	Internet of Things
ITU	International Telecommunications Union
KPIs	Key Performance Indicators
M2M	Machine-to-Machine
MIMO	Massive Multiple-Input and Multiple-Output
mMTC	Massive Machine-Type Communications

mWave	Millimeter-Wave
NFs	Network Functions
NFV	Network Function Virtualization
ng-eNB	Next generation eNodeB
NG-RAN	Next Generation Radio Access Network
NR	New Radio
NRFs	Network Repository Functions
NSA	Non-Stand Alone
PDR	Peak Data Rate
QoE	Quality of User Experience
QoS	Quality of Service
RU	Rural
SA	Stand Alone
SBA	Service-Based Architecture
SDN	Software-Defined Networking
SDO	Standard Development Organizations
SMF	Session Management Function
STS	Sociotechnical Systems
UCs	Use Cases
UE	User Equipment
UEDR	User Experienced Data Rate
UP	User Plane
URLLC	Ultra-Reliable and Low Latency Communications
VR	Virtual Reality (VR)
WRC	World Radiocommunication Conference

I. INTRODUCTION

Mobile communication networks have experienced tremendous development over the decades, starting with the first generation (1G) mobile communications rendering voice services alone to the fourth generation (4G), providing more services with higher efficiency and capacity. This evolution of mobile communications has driven the sociotechnical systems (STS), which enabled social and economic development. The use of mobile communications has become a daily part of humanity. It provided access to various modern applications and services and made the world a global village by bridging the distance gap. The mobile communications systems and STS trends are expected to form society's fundamental aspect in 2020 and beyond [1]. Since the invention of mobile communications, the subscriber base has progressively increased, leading to the enormous demand for more traffic volume, more device connectivity, speed, and better quality of user experience (QoE). Ericsson’s reports [2] estimated the global mobile data traffic to reach 160 exabytes per month by 2025. It illustrated the expected mobile data consumption by six billion people using smartphones and various connected devices. While Cisco’s Visual Networking Index (VNI) anticipated that the number of internet users, networked devices and machine-to-machine (M2M) applications would grow to 5.3 billion, 29.3 billion, and 14.7 billion, respectively, by 2023 [3].

With this massive and exponential increase of data usage and the connectivity of a large number of mobile-connected devices, significant pressure has been placed on mobile service providers and the research community to find ways to provide high data rates and rendering good quality of service (QoS) at affordable rates [4]. This demand can only be met by advancing to new technologies, that is, the fifth-generation (5G) mobile communications [5], [6], to provide such wireless systems and services to various subscribers. 5G is the future of mobile communications standards that advanced the present 4G networks, which will conform with the requirements of the International Mobile Telecommunications-2020 (IMT-2020) standards established by the ITU-R (radio section of the International Telecommunications Union) [7]. ITU-R played an essential part in developing mobile communication networks right from the third-generation (3G) development. On the other hand, 5G would have various advanced features that would provide solutions to everyday life problems. It would offer huge capacity at the full deployment of 5G, higher throughput at very low latency than the present 4G mobile communication systems. Thus, enabling the adaptation and incorporation of vastly advanced services and applications in the wireless environment.

5G is expected to take the stage and beyond, and it is planned to momentously increase the wireless network's responsiveness as well as speed. 5G is designed for mobile devices alone. It is a system that connects different types of devices, improves and enhances the end-user experience, enhances network reliability, provision for new applications, services, business, supports ultra-high traffic volume density, and enhanced network performance [8]–[10]. 5G will provide a system of “anything and anyone” connected at any time and anywhere. Furthermore, 5G communication networks and services will permeate the world of various industries. In addition to the Internet of Things (IoT). It would be integrated to satisfy the different service requirements of industries such as medicine, automotive, education, media, manufacturing, transportation, agriculture, among others, to achieve a real “Internet of Everything”. These are expected to be designed and developed in alliance with the various vertical industries, which implies novel requirements, novel ways of developing and managing the cellular communication networks [11]. Several protocol data unit (PDU) session types are supported, which include Internet protocols (IPv4, IPv6, IPv4v6), Ethernet, and Unstructured. 5G networks will use softwarization and virtualization to accomplish new features such as flexibility, configurability, and scalability [12]. The network is expected to offer what is termed as “networks as a service” by creating logical network slices (NS) that are flexible and efficient in a multi-operator environment [13].

As far back as 2012, the ITU-R initiated the implementation of the IMT-2020 and beyond [14], with the establishment of research forums and groups from various countries for the development of the 5G concept. The investigations were centered around the use cases (UCs) and the capability requirement, which became the ITU-R global foundation for 5G vision developments [15]. UCs are used to identify, produce, and document end-user requirements for a communication network. Due to the massive demands of applications of 5G, the 5G will have to induce entirely new UCs. Enabling the 5G UCs will require additional allocation, and flexible management proficiencies of spectrum for mobile broadband [16]. However, a vast range of unparalleled and evolving UCs and business or vertical models will emerge along with the 5G networks' ecosystem. Hence, the need for future IMT systems to support the envisaged and emerging new UC. ITU-R [1] has made some recommendation based on trends observation, which includes the following;

- Internet of Things
- User and application trends
- Maintaining high mobility at high quality
- Ultra-accurate positioning applications
- Supporting extremely high reliability with low latency machine-centric communications and human-centric communication
- Supporting high user density
- Enhanced multimedia services

Therefore, it is essential to establish and customize the 5G communication networks for various individual scenarios and UCs. Appropriately, the deployment of mobile communications needs to be dimensioned. Hence, selecting the right UCs scenarios will cover the envisioned environments and services for a successful deployment. UCs are essential aspects of the process of 5G technology development as well as the standards. Different UCs are expected to meet various network requirements, which determine the various spectrum for effective deployment of the network.

This paper aims to present a detailed survey and review on the progress of various developed UCs for 5G networks. The focal contributions of this paper are as follows:

1) Review, analyze, and provide a comprehensive and up-to-date survey of the existing various use cases proposed to deploy 5G mobile communications.
2) Summarizes the new 5G Architecture system and introducing new features such as the new radio interface, the 5G Core Network, and the Radio Access Network
3) Technical Performance minimum requirements, 5G spectrum requirements, Key capabilities, Relevant KPIs, and other fundamentals of the network
4) Spectrum bands in terms of low, mid, and high spectrum bands for effective deployment were proposed for each of the UCs surveyed.
5) The average capacity of the spectrum, as well as bandwidth proposed for the UCs, were studied, simulated, and compared to ascertain the spectrum proposed in this paper for each UC family
6) Classification of the UCs for their relevant and family, IMT-2020 test environments, and the usage scenarios derived by the 3GPP were also reviewed.
7) The survey gives a guideline for understanding usage scenarios for the future 5G deployment as well as the spectrum band for the effective deployment of the network to meet the expected network requirement.

To the best of our knowledge, the survey emphasis and proposed frequency bands presented in this survey stand as an extension and up to date when compared to related survey papers such as [17] that concentrated on 5G eMBB UCs for satellite communications and others such as [18], [19]. These survey papers did a comprehensive survey on the subject. However, other developed UCs, recommending frequency bands for the UCs as well as exploring the spectrum channel capacity were not captured, hence, the need for this survey.

The paper focuses on the UCs developed or proposed for 5G mobile communication deployment scenarios. The rest of this paper is organized as follows: Section II discusses the next generation Architecture. In Section III, the Spectrum Requirements and Considerations were discussed. In Section IV, the Network Slicing concept was discussed, while in Section V, the 5G Usage Scenarios (Use Case) was discussed, the developed 5G use cases by Standards Development Organizations and Main Stakeholders were discussed in Section VI. Section VII handled the classification and mapping of the use cases as well as the channel capacity simulation, while conclusions are drawn in Section VIII.

II. 5G ARCHITECTURE

The 5G communication networks' target is to render services that would meet the different requirements of vastly mobile systems (high throughput, low latency, and massive connections) as well as an entirely connected society. Part of the 5G communication networks' diverse function and performance requirements is ensuring the definition of human-centric coexistence with machine-type applications. The framework of 5G is dynamic, logical, consistent, and flexible of numerous advanced technologies that would be supporting a diversity of applications. In corresponding to the 3GPP NR, the entire architectural system of both the RAN and the Core Network were reassessed, and the functional split amongst the two networks (CN and RAN). Unlike the previous mobile communication networks, the 5G employs a more intelligent architecture that would no longer be constrained by the proximity of base stations (BS). In addition to complex infrastructure constraints. Instead, it has a flexible deployment employing novel concepts like network slicing (NS), software-defined networking (SDN) as well as network function virtualization (NFV) [20][21].

In [21], the 3rd Generation Partnership Project (3GPP) defined the 3GPP 5G system architecture, indicating the needed features and functionality for the deployment of a commercially operational 5G system. Usually, the technical specifications for mobile communication are constantly evolving due to new features and service demands, making it an ongoing development process. Conventionally, mobile system architecture consists of two core components: the Access Network (AN) and the Core Network (CN). The 3GPP has defined the 5G system architecture to be an interaction between the user equipment (UE) and an endpoint, this endpoint could be a server like the Application Server (AS), or it could be an alternative UE [22]. Hence, the 3GPP system consists of the AS, 5G Core Network (5GC), the Next Generation Radio Access Network (NG-RAN), and UE [23], which establishes communication between the DN and UE via AN and CN [21]. Figure 1 illustrates a simple end-to-end architecture of 5GC.

FIGURE 1. 5G system end-to-end architecture

The introduction of the new radio interface: New Radio (NR) is the key characteristic of the new 5G mobile network, which created the possibility and the needed flexibility to accommodate various new features, applications, and services [24]. It was developed by the 3GPP [25] mainly for the 5G communications. It was created to serve as the new standard (globally) for the 5G networks air interface. It is expected to be a more capable and unified 5G air interface and access method that would provide meaningfully faster and more receptive mobile broadband experiences, which in turn encompass various mobile technologies of the multitude of industries [26]. The NR will facilitate communications between the transmitter and the receivers at frequency bands of up to 52.6 GHz. 3GPP envision adopting a closely related modulation, just like LTE's OFDM-based signal modulations [27]. The NR is intended to be a scalable and flexible air interface that would fulfill the three requirements (usage scenarios) for 5G mobile communications: Ultra-Reliable and Low Latency Communications (URLLC), massive Machine-Type Communications (mMTC), and enhanced Mobile Broadband (eMBB), discussed in detail in section V. The NR air interface was developed to aid the deployments of the networks in frequency spectrum lesser than 6 GHz, in the Millimetre Wave (mmWave) as well as in the centimeter wave (cmWave) frequency bands [26]. The framework of the NR was designed to accommodate massive multiple-input and multiple-output (MIMO at a large scale [28], [29]. The massive MIMO purposes are to enhance the network coverage as well as capacity performance; these are essential in meeting the huge demand for data services [26].

Another significant characteristic of the 5G system architecture is the Non-Stand Alone (NSA) architecture as well as the Stand Alone (SA) architecture [30]. The NSA can connect the NG-RAN to both the 5GC, 4G (LTE) CN, as shown in Figure 2, while the SA connects the 5GC and NG-RAN alone, as shown in Figure 3.

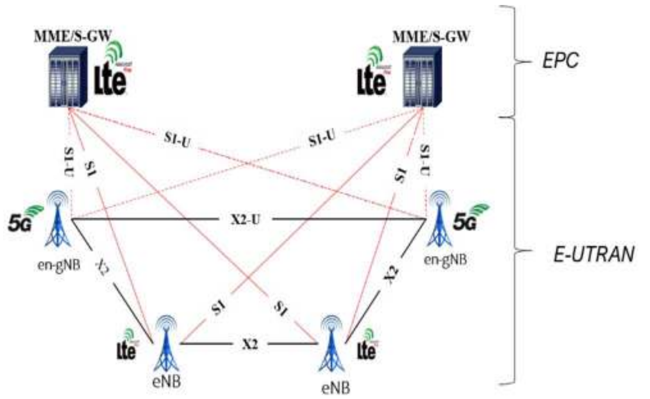

FIGURE 2. NSA architecture for 5G system

In the NSA architecture, the NG-RAN and NR interface is used in combination with the existing 4G AN and its CN. This would ensure the availability of 5G NR technology without undergoing network replacement. However, only services provided by 4G would be available at the capacities of the 5G NR with respect to lower latency, higher capacity, and so on [31]. The BS of the 5G NR (logical node), which is referred to as the Next Generation NodeB (en-gNB), links to the 4G/LTE BS, which is referred to as the enhanced NodeB (eNB) through the X2 interface. The en-gNB is responsible for connecting the UE and the 5GC interface [32]. The S1 interface connects the eNB to the Evolved Packet Core (EPC) made up of the Mobility Management Entity/Serving Gateway components (MME/S-GW), while the S1-U interface connects the en-gNB to the EPC, en-gNB is connected to the other en-gNB through the X2-U interface [33].

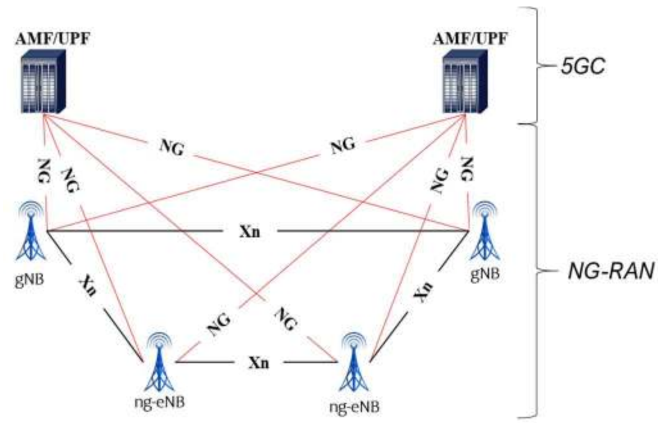

FIGURE 3. Stand Alone (SA) architecture for 5G system (Overall 5G architecture)

The Evolved-UMTS Terrestrial Radio Access Network (E-UTRAN) receives information from MME and configuration data via the local E-UTRAN about the UE to determine whether to use dual connectivity or not for the UE. For the NSA, the 4G components will handle the control plane of the early 5G networks [32]. Therefore, before the full deployment of the 5G SA operation, the QoS implementation is dependent on the heavy deployment of the 4G infrastructure [34]. The SA architecture is the full and overall 5G architecture. In this architecture, both the LTE and NR radio access are provided by the NG-RAN; the NG-RAN node (the BS) consists of the next generation NodeB (gNB) and the next generation eNodeB (ng-eNB). Furthermore, the ng-eNB provides the control plane (CP) as well as the user plane (UP) functions of the LTE/EUTRA towards the UE while the gNB (which is the 5G base station) delivers the UP and CP functions of the 5G NR [35]. The Xn interface interconnects both the gNBs and ng-eNBs, while the NG interfaces connect both the ng-eNBs and gNBs to the 5GC, which is directly connected to the Access and Mobility Management Function (AMF) through the NG-C (NG control plane) interface as well as to the UP Function through the NG-U (NG user plane) interface [21], [36].

The overview of the 5G core network, next generation radio access network, and the functional splits of the 5G architecture is discussed in the following sub-section A, B, and, C respectively.

A. OVERVIEW OF THE 5G CORE NETWORK

The 5G core network manages all data, voice, and internet connections usually referred to as the mobile exchange and data network. The basis of the 5G network architecture was defined based on the service requirements, which started as a preliminary study in [37] and was fully specified in [21], [38], [39]. Unlike in the EPC, where MME handles the session management and mobility management function, these functionalities and procedures are governed by Session Management Function (SMF) and AMF in 5GS. The control plane connection of AN and UE are terminated at the AMF. The connection link between the UE and AMF via the AN is called the Non-Access Stratum (NAS). The procedures and the session management functionalities are handled by the SMF, as actual user data are transmitted through the UPF. Likewise, the UPF selection/re-selection are handled by the SMF [40]. The AMF can accommodate various ANs (3GPP/non-3GPP), due to the separation of the functionalities of mobility management and that of the session management. Likewise, specific accesses can be achieved by the SMF. In short, the AMF/UPF/SMF delivers the CP functions primarily from the 5GC. More on the functions of AMF/SMF/UPF can be found in the 3GPP technical reports [41], [21].

3GPP defines the Service-Based Architecture (SBA) as a process of delivering the standard data repositories as well as the CP functionality of the 5G system through a set of interconnected Network Functions (NFs), having the authorization of accessing each other's services. Unlike the EPC of the 4G CN, the 5GC architecture has the SBA in its framework. SBA offers a flexible framework for the deployment of common applications despite using different sources or suppliers' components. Figure 4 shows a basic SA (non-roaming) 5G System architecture with a set of interconnected NFs in the 5GC. The NFs offer specific services to other NFs utilizing interfaces of a common framework. The service could be extended to any other service-permitted consumers. Hence, the SBA provides reusability and modularity and enables a virtualized deployment. Furthermore, the uniform interface connections among the NFs are known as Service-Based Interfaces (SBI) [42], [43].

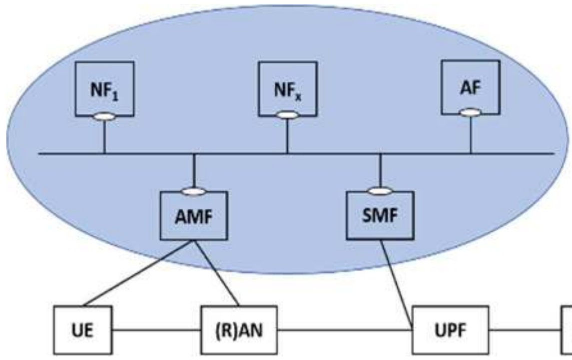

FIGURE 4. Illustrating 5G System architecture with a set of interconnected NFs

The individual NF comprises smaller unit functions; these functions are referred to as NF services. The service framework defines the interaction between the SBI and NFs by making use of a producer-consumer model. Thus, the NF service in a specific NF can access the NF service of another authorized NF without necessarily passing through other nodes. Figure 5 exemplifies the essential role of SBI in the SBA. Other authorized NFs are enabled by a Control Plane NF service to grant their services via the SBI. Either of these two models, subscribe-notify or request-response, are supported by the SBI as its primitive operation [43]. The Network Repository Functions (NRFs) play a unique part in this architecture by aiding each of the NF in discovering other NFs services [44].

An NF instance would be deployed in several ways, such as fully redundant, fully scalable, distributed mode, and stateless. Quite a lot of NF instances can be available within the same NF set, thus, providing services for several locations. Invoking the NF services enables the virtualization to route messages from UE to any proficient entity that is within a pre-specified set of corresponding NFs. The NFs are installable in dedicated servers as well as general-purpose servers or devices. NFs will be easily upgradable due to the SBA, which is according to the Cloud Native, thus increasing the utilization rate of the network resource and accommodating authorization from a third party [44].

The 5GC will be a combination of various networks such as terrestrial and/or non-terrestrial, it would be either fixed or mobile or both, combination or single communication of unicast, multicast and, broadcast, and lastly, local area access networks or wide area access networks. Hence, accommodating services across various mechanisms will offer service ubiquity, continuousness coverage, and scalability for numerous UCs [45].

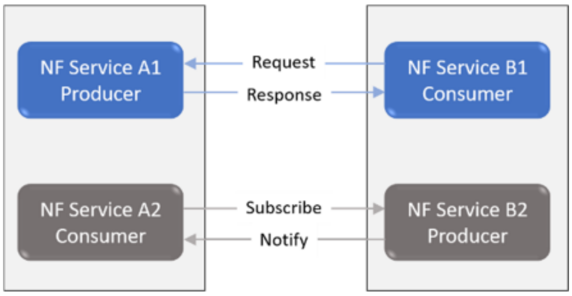

FIGURE 5. The essential role of SBI in the SBA

B. NEXT GENERATION RADIO ACCESS NETWORK (NG-RAN) OVERVIEW

The functionality of all radio-related operations of the network, which includes functions such as coding, retransmission protocols administration, handling of radio-resource, scheduling, and different multiple antenna structures, are handled by RAN. 3GPP [46] defined the universal principles that steered the architecture and interfaces of the NG-RAN as follows;

(a) the logical separation between the signaling and the data transport networks.

(b) the 5G core network functions and the NG-RAN are completely distinguished from that of the transport functions. Hence, the applied addressing scheme of 5GC/NG-RAN and that of transport functions are not tied to each other.

(c) the mobility of the Radio Resource Control (RRC) protocols is entirely controlled by the NG-RAN.

(d) in terms of the NG-RAN interfaces, it has fewer options for the functional division, controls by logical model via an interface and, multiple logical nodes could be implemented by a physical network element.

The NG-RAN interfaces and air interface protocols consist of the UP Protocols and the CP protocols [47]. The actual PDU session services are implemented by the User-plane Protocols and make use of access stratum (AS) to transmit user data. Figure 6 illustrates the NG and Uu user plane. The functionality of CP protocols includes controlling the protocol data unit sessions and the link between the UE and different network aspects, including service requesting, controlling various transmission resources, and handover. Figure 7 illustrates the NG and Uu control plane. For further study, [48] described the NG protocols in detail while [49] and [50] defines the radio interface protocols. The Session Management (SM) and Connection Management (CM) is a set of Non- access stratum (NAS) control protocols that exist amid the 5GC and UE.

Two node types can be linked to 5GC in the RAN, they are gNB and ng-eNB. The gNB uses the NR protocols of CP and UP to serve the NR devices, while the ng-eNB makes use of the LTE UP/CP protocols to serve the LTE devices. Hence, a RAN type has both the ng-eNB and the gNB and is referred to as NG-RAN [51].

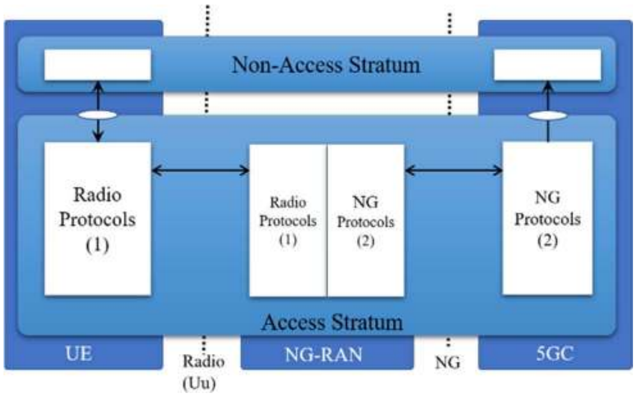

FIGURE 6. Illustration of the NG and Uu user plane

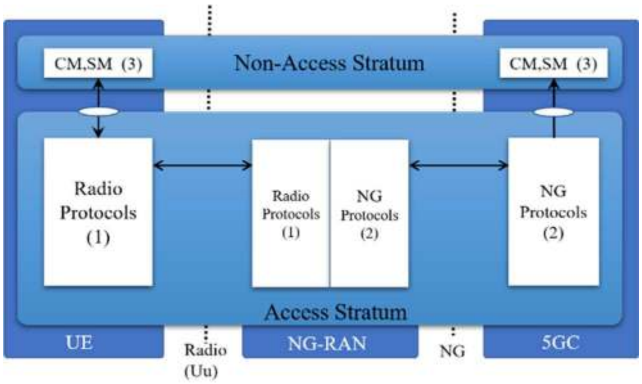

FIGURE 7. Illustration of the NG and Uu control plane

The NG-RAN comprises gNBs linked through the NG interface to the network core, while the Xn interface connects a gNB (5G Node B) to another gNB. An in-depth view of the interfaces and NG-RAN is shown in Figure 8, where the gNB is linked to the 5GC through the NG interface, but more explicitly to the AMF through the NG CP part (NG-c) and UPF via the NG UP part (NG-u). The multiple connections of the gNB to multiple UPFs/AMFs aids in sharing the load as well as redundancy. The connection between two gNBs utilizing the Xn interface helps support the dual connectivity and active-mode mobility [52].

Likewise, the Xn interface is resourceful as it performs multicell Radio Resource Management (RRM) functions and caters for lossless mobility amongst neighboring cells by using packet forwarding. Within the gNB, there are two functional entities known as gNB Central unit (gNB-CU) and gNB Distributed unit(s) (gNB-DU) and are linked through the F1 interface.

The gNB-CU being a logical node, hosts protocols such as PDCP (Packet Data Convergence Protocol), RRC, and Service Data Adaptation Protocol (SDAP) of en-gNB or that of gNB, which controls one or multiple gNB-DUs operations. On the other hand, the gNB-DU is also a logical node that hosts the Media Access Control (MAC), Radio link control (RLC), and physical (PHY) layers of both the gNB and en-gNB, gNB-CU partly controls its operation [47]. The interface that connects the UE to either the gNB or gNB-DU is called the Uu interface. Various performance tasks of the gNB are listed in [25].

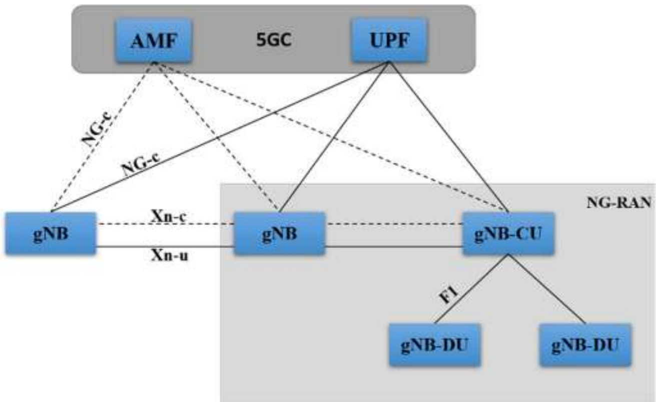

FIGURE 8. NG-RAN and the RAN interfaces

C. THE RAN AND 5GC FUNCTIONAL SPLIT

The functional splits of the 5G architecture [41] as illustrated in Figure 9, indicates a few of the different 5G NFs that are executed in the 5GC and NG-RAN. It illustrates the SBA of the 5G networks, indicating the interfaces of the SBI connection of the NFs (for example, NRF, NEF, AF) with the SMF, AUSF, and AMF. The NFs exchanging information on the CN and AN interface are on the CN side, while the AMF, UPF, and SMF are found on the AN side of the gNB. Figure 10 summarizes the functional split where the main task performed by the NFs are shown in the grey boxes While green boxes depict the logical nodes.

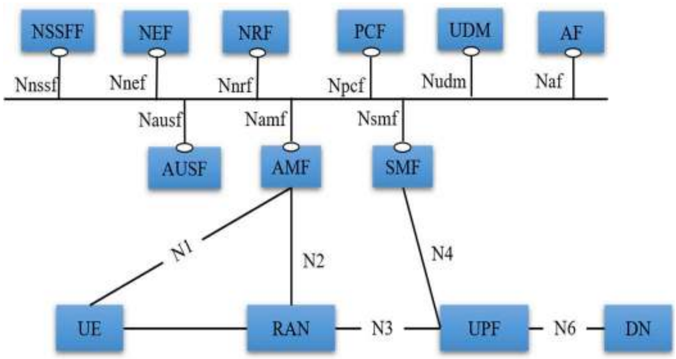

FIGURE 9. 3GPP 5GS service-based architecture

D. TECHNICAL PERFORMANCE MINIMUM REQUIREMENTS FOR THE IMT-2020 RADIO INTERFACE(S)

A resolution by ITU-R [53] defined the IMT-2020 as mobile communication systems which consist of the NR interface(s) that supports the proposed system's capabilities which is beyond the previous IMT systems (IMT-Advanced and IMT-2000). The intention of the IMT-2020 capabilities is identified in [1] to attain flexibility, reliability, and a more secure IMT-2020 system as compared to the earlier IMT, in the process of offering various services based on the three usage scenarios (eMBB, URLC, and mMTC). Furthermore, the key requirements of the IMT-2020 minimum technical performance with respect to the radio interface technologies are defined in [7].

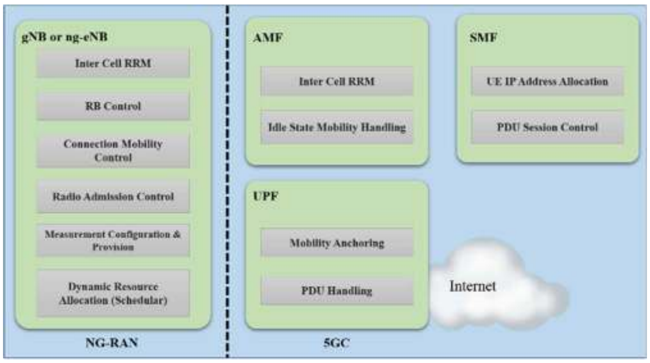

FIGURE 10. NG-RAN and the RAN interfaces

Likewise, the individual requirement information and the justification of the chosen items and values were presented. The report illustrated the requirements to ensure the fulfillment of the IMT-2020 objectives by the radio interface technologies (RITs) and Set of radio interface technologies (SRIT) of the IMT-2020 and setting of specific performance level.

The thirteen technical performance requirements for the IMT-2020 as well as their relevant equations as stated in [7] and [14] are defined briefly. However, detailed guidelines procedure, criteria, and the methodology used in candidate IMT-2020 RITs/SRITs evaluation, as well as the test environments and conditions, are reported in [14];

1) PEAK DATA RATE (PDR)

This refers to the maximum attainable data rate under assumed error-free conditions: the data bits received in error-free conditions (assumption), conveyable to one UE, upon full utilization of the conveyable radio resources with respect to the conforming link direction. This occurs under the full use of all the radio resources assigned (but with the exclusion of resources used for synchronization in the physical layer, pilots or signals referencing, guard bands, and guard times) to the corresponding link direction. In the single band scenario, the peak data rate is correlated to the peak spectral efficiency (PSE) in the same band. The user PDR is given in bit/s unit, and the equation [14] is given by (1):

$$R_p = W * SE_p \quad (1)$$

Where W is the channel bandwidth and SE_p is the PSE in that band.

Most likely, PSE and available bandwidth values may vary in diverse frequency ranges. In such an aggregated channel bandwidth across several bands, the PDR tends to be the summation across the bands. Hence, the total PDR [14] of aggregated bandwidth across H bands is given in (2):

$$R = \sum_{i=1}^{H} W_i * SE_{pi} \quad (2)$$

Where the bandwidths and spectral efficiencies component are W_i and SE_{pi} (i = 1,…H) respectively. The minimum requirements for PDR are stated in Table I for the downlink (DL) and uplink (UP) PDR.

2) PEAK SPECTRAL EFFICIENCY

The peak spectral efficiency (PSE) is the maximum theoretical data rate in ideal and standardized conditions divided by channel bandwidth. Hence, it is the highest data rate of data bits received in assumed error-free conditions, conveyable to one UE. This occurs under the full utilization of all radio resources assigned (but with the exclusion of resources used synchronization in the physical layer, pilots, or signals referencing guard times, and bands) to the corresponding link direction. The PSE measurement unit is bit/s/Hz. The minimum requirements for PSE are stated in Table I for the downlink (DL) and uplink (UL).

3) USER EXPERIENCED DATA RATE

The user experienced data rate (UEDR) gives the five percentage points of the cumulative distribution function (CDF) of the throughput of any user. User throughput refers to the number of correctly received bits throughout an active time. In other words, it is the number of bits that are contained in Service Data Units (SDUs) through a specific period that is delivered to Layer 3. For a band of frequency and a Transmission Reception Points (TRxP) layer, the fifth percentile user spectral efficiency was used to derive the UEDR [14] as given in (3)

$$R_{user} = W * SE_{user} \quad (3)$$

Where W is as defined before and SE_{user} is the 5th percentile user spectral efficiency.

For aggregated bandwidth across various bands (that is, one or more TRxP layers), the summation of the UEDR over the bands as given in (4) is used [7].

$$R = \sum_{i=1}^{Q} W_i * SE_{useri} \quad (4)$$

Where $SE_{user}(i = 1, \dots Q)$. The UEDR target values are stated in Table I for the downlink (DL) and uplink (UP).

4) 5th PERCENTILE USER SPECTRAL EFFICIENCY (PUSE)

It is also the fifth percent point of the CDF of the normalized throughput of any user (user throughput). However, this normalized user throughput refers to the number of bits that are accurately received. In other words, it is the number of bits contained in the SDUs over a specific period delivered to Layer 3 divided by the channel bandwidth. Channel bandwidth is effective bandwidth multiply by the frequency reuse factor, and the effective bandwidth is appropriately normalized in consideration of the UL and DL ratio. The user r_i (normalized) user throughput is defined by (5) and measured in bit/s/Hz [14];

$$r_i = \frac{R_i(T_i)}{T_i . W} \quad (5)$$

Where $R_i(T_i)$ and T_i denotes the user i number of bits that are correctly received and the session time (i.e. active), respectively, and W denotes the same as mentioned. Table I summarized the minimum requirements for 5th PUSE for various test environments, which include Dense Urban (DU)-eMBB, Indoor Hotspot (InH)-eMBB, as well as Rural (RU)-eMBB. However, the Rural-eMBB requirement evaluation configurations cannot be applied to that of the RU-eMBB Low Mobility Large Cell (LMLC) [14].

5) AVERAGE SPECTRAL EFFICIENCY

The ASE is the all user's aggregate throughput (refers to the number of bits that are correctly or accurately received, in other words, it is the number of bits that are contained in the SDUs over a specific period that is delivered to Layer 3) and divided by the specific band channel bandwidth and the number of TRxPs. The bandwidth of the channel is the same as described for 5th PUSE. Equation (6) defined the ASE, and it is unit is bit/s/Hz/TRxP [14]:

$$SE_{avg} = \frac{\sum_{i=1}^{N} R_i(T)}{T.W.M} \quad (6)$$

Where $R_i(T)$ denotes the user i (downlink or uplink) number of bits that are correctly received in a system including M TRxPs and a N users of the user population. Also, W and T denotes the channel bandwidth and the received data bits time. Table I summarized the minimum requirements for ASP for various test environments. However, with respect to the RU-eMBB test environment, the RU-eMBB requirement evaluation configurations cannot be applied to that of the RU-eMBB LMLC [14].

Likewise, the ASE may be projected in terms of the number of drops (N_{drops}). The value of each drop is $\sum_{i=1}^{N} R_i(T)$ represented as: $R^{(1)}(T), \dots . R^{(N_{drops})}$. Hence, the estimated ASE (7) [7]is:

$$\widehat{SE}_{avg} = \frac{\sum_{j=1}^{N_{drops}} R^{(j)}(T)}{N_{drops} T.W.M} = \frac{\sum_{j=1}^{N_{drops}} R_i^{(j)}(T)}{N_{drops} T.W.M} \quad (7)$$

6) AREA TRAFFIC CAPACITY

The area traffic capacity (ATC) is the overall traffic throughput based on the terrestrial area. The throughput refers to the number of bits that are correctly or accurately received. In other words, it is the number of bits contained in the SDUs over a specific period that is delivered to Layer 3. It is derivable for a specific deployment scenario or UC of a single frequency band and TRxP Layer. This derivation is channel bandwidth, network deployment, and ASE-based.

10 Mbit/s/m^2 has been set as the ATC's target value in the downlink for the InH test environment. Equation (8) denotes the ATC as it relates to ASE [14], and it is measured in Mbit/s/m^2;

$$C_{area} = \rho * W * SE_{avg} \quad (8)$$

Where ρ and W denote the TRxP density (TRxP/m^2) and channel bandwidth, respectively. ATC is summed over the various bands in cases of aggregated bandwidth across multiple bands.

7) LATENCY

Latency, which is the end-to-end (E2E) one-way delay in communication, can be described as the time interval for a response to be received by the sender with respect to the information or data sent. There are two latency types considered:

User plane latency

The user plane (UP) latency has to do with the radio network's contribution factor affecting the period of sending the packets from the source to receiving at the destination. It can be described as a one-way time for the successful delivery of a packet (at the application layer), usually from the ingress point to the egress point of the radio protocol layers 2 and layer 3 of the SDU. This occurs in an unloaded condition of the network either for uplink or downlink service, assuming an active state UE. It is also referred to as the transport delay. The requirements with the assumption of a single user unloaded conditions (for both downlink and uplink) for UP latency are stated in Table I for the two usage scenarios (eMBB, URLLC). Its unit of measurement is ms.

Control plane latency

The control plane (CP) latency defines the time difference between the most battery efficient (Idle) state and the initiation of continuous data transfer (referred to as the Active state). The CP latency minimum requirement is set as 20 ms but with the encouragement of considering lower CP latency such as 10 ms, as stated in Table I.

8) CONNECTION DENSITY

It defines the overall number of devices satisfying a targeted QoS in a given area. The QoS target has been set as less than 1% packet drop rate for packet size S with 1 as the packet arrival rate [54], [14]. Where the packet drop rate is defined as the quantity of packet outage divided by the number of packets that are generated. Connection density is expected to be achievable for the number of TRxPs as well as limited bandwidth. In an urban environment, one million (1,000,000) connected devices per km^2 have been set as the minimum requirement.

9) ENERGY EFFICIENCY

The energy efficiency discussed is for both the energy efficiencies which are related to the device and network. Therefore, the network energy efficiency is the RIT/SRIT capability of minimizing the RAN's energy consumption with respect to the offered area traffic capacity. At the same time, that of the device is the RIT/SRIT capability of minimizing the device power consumption with respect to the traffic characteristics. Both energy efficiency consent to these aspects:

- In a loaded case, data transmission efficiency is essential
- In the case of no data, energy consumption should be low

The energy efficiency in case of the global and scenario are described in (9) and (10) respectively:

$$EE_{global} = \sum_{scenaria} b_k EE_{scenario\ K} \quad (9)$$

$$EE_{scenario} = \sum_{load\ level\ 1} a_1 \frac{V_1}{EC_1} \quad (10)$$

Where b_k represents the network energy efficiency evaluation of every deployment scenario weights, traffic per second produced by BS (in bits/s) is V_1, the weight of each traffic load level is a_1, while the EC_1 is the BS consumed power (in Watt = Joule/s) to serve V_1.

10) RELIABILITY

This is defined as the success probability of a given amount of traffic transmission within a determined duration of time, that is, the success probability of transmission of the packets (layer 2 and layer 3) within a mandatory limit time. It describes the period of successful delivery of a packet, usually small data from the ingress point to the egress point of the radio protocol layers 2/3 SDU at a specified channel quality. The minimum requirement for a 32 bytes layer 2 PDU transmission has been set as 1-10^5 success probability.

11) MOBILITY INTERRUPTION TIME

This describes the mobile network system supported time duration (shortest) in which transmission or exchange of UP packet between a UE and BS cannot occur during transitions. This is in the inclusion of the required execution time of the procedure of any RAN, protocol (radio resource signaling), and any other interactions between the RAN and UE as related to the candidate RIT/SRIT. 0 ms has been set as the minimum mobility interruption time requirement.

12) MOBILITY

It describes the maximum speed of UE at which a predetermined QoS set is achievable. Mobility set classes are as follows: Stationary is set as 0 km/h, Pedestrian starts from 0 km/h to 10 km/h, Vehicular has a set range of 10 km/h to 120 km/h while the high-speed vehicular set range is from 120 km/h to 500 km/h. However, the high vehicular speed (500 km/h) was intended for high-speed trains.

Table I defined the test environments for the mobility classes and the supported UL data rate of the traffic channel when normalized by the bandwidth. It was assumed that the user's movement was at maximum speed.

13) BANDWIDTH

This refers to a system bandwidth that is maximally aggregated. A single or multiple radio carrier frequency may support the bandwidth. For IMT-2020 evaluation, the RIT/SRIT bandwidth capability was defined, and the requirement was set to a minimum of 100 MHz. However, for operation in a frequency higher than 6 GHz, bandwidths up to 1 GHz should be supported by the RIT/SRIT. Furthermore, scalable bandwidth (operation at various bandwidth) should be supported too.

TABLE I
ILLUSTRATING THE TECHNICAL REQUIREMENT WITH RESPECT TO THE APPLICABLE USAGE SCENARIOS AND MINIMUM REQUIREMENT VALUES

Technical requirement	Units	Applicable Usage Scenario	Minimum Requirement			
			Downlink (DL)		Uplink (UL)	
Peak data rate	Gbit/s	eMBB	20		10	
Peak spectral efficiency	bit/s/Hz	eMBB	30		15	
User experienced data	bits/s	eMBB	100		50	
5th percentile		eMBB	InH	0.3	0.21	
user spectral	bit/s/Hz		DU	0.225	0.15	
efficiency			RU	0.12	0.045	
Average spectral efficiency	bit/s/Hz/TRxP	eMBB	InH	9	6.75	
			DU	7.8	5.4	
			RU	3.3	1.6	
Area traffic capacity	Mbit/s/m^2	eMBB	InH	10		
User plane latency	ms	eMBB and URLLC	eMBB: 4 URLLC: 1			
Control plane latency	ms	eMBB and URLLC	20, consideration encouraged for 10			
Connection density	Devices/km^2	mMTC	1,000,000			
Energy efficiency	bit/Joule	eMBB	a qualitative and quantitative measure			
Reliability		URLLC	1-10^{-5} success probability			
			Classes	NTCLDR	Mobility	TE
Mobility	bit/s/Hz (NTCLDR)	eMBB	InH	1.5	10	Stat, Ped
	km/h (Mobility)		DU	1.12	30	Stat, Ped, Veh
			RU	0.8	120	Ped, Veh
				0.45	500	HS Veh
Mobility interruption time	ms	eMBB and URLLC	0			
Bandwidth	Hz		100 M and 1 G for frequency higher than 6 GHz			

Where TE - Test environments, Stat - Stationary, Ped - Pedestrian, Veh - Vehicular, HS Veh - High speed vehicular. NTCLDR - Normalized traffic channel link data rate.

III. SPECTRUM REQUIREMENTS AND CONSIDERATIONS

The demand for mobile communications usage by consumers has been increasing, with the need for higher data rate, lower latency, improved performance, availability, among others. Unfortunately, the present spectrums allocated for the present mobile communications networks cannot support these exponential increases [5]. The importance of spectrums choice, requirements as well as the considerations were discussed in this section. The 5G mobile service is expected to have newer technology, services, devices, and applications in the future that would require more capacity and spectrum to accommodate the evolution of the data traffic [55]. Radio spectrum is a major factor for steering the evolution and demand for mobile communications services. Therefore, the accomplishment of the 5G mobile communications would be based on the unlimited accessibility and availability of the spectrum [56]. To guarantee the availability of spectrum, 5G must have the capability of operating on various spectrum types and bands, which includes the licensed, shared, and unlicensed, and ranging from sub-6GHz to the mmWave [57].

A report by ITU-R [58] illustrated the growth of data traffic to be more than anticipated. Hence, causing a substantial challenge to mobile and wireless communications network development. Historically, lower spectrums such as 800 - 900 MHz were assigned to 1G and 2G mobile networks. While 2 GHz was the focus of the rollout of 3G (IMT-2000) mobile networks, as the IMT services expanded for both the 3G and 4G continued, newer bands at lower and higher spectrum were added ranging from 0.45 GHz to 6 GHz. It is important to note that the previously used frequency bands for older mobile generations are included and used in the new generation.

This will also be used in the 5G mobile communication networks. Amazingly, different frequency bands display other characteristics because of the propagation properties. Lower frequency bands tend to propagate further and are preferable for deployments in a wide area. Such coverage includes environments like suburban, urban, and rural. On the other hand, the higher frequency propagation properties, such as the mmWave frequencies, are lesser. However, the higher frequencies tend to have a tremendous amount of spectrum and very broad transmission bandwidths for dense capacity deployment but with higher attenuation and various implementation challenges [59]. Planning a wireless deployment requires stringent planning and using the appropriate path loss model [5].

Spectrums are usually defined by the governing body and specify for every mobile generation. These are discussed in this sub-section, and also the importance of spectrum harmonization and flexibility of the 5G network was also discussed.

A. ITU-R SPECTRUM DEFINITION FOR IMT SYSTEMS

The ITU [60] is an agency of the United Nations (UN) specialized in information and communication technologies (ICTs). It is an intergovernmental organization initiated in the year 1865 based on an international agreement between governments as well as various private sectors which includes Sector Members, Associates, Academia to enable connection of communications network, allocating radio frequency band, satellite orbits, and development of technical standards which ensures unified interconnection of networks and technologies and improvement of access to ICTs globally.

The overall aspects of the radio system in terms of the IMT systems, which include the 3G, 4G, 5G as well as future generations, are covered by ITU. ITU has been involved in the standardization process of frequency bands identification as well as frequency bands harmonization for the operation of IMT, thus facilitating interoperability, roaming, and economies globally. ITU is also responsible for guiding, reviewing, and supervising 5G technology by defining the standards definition [61]. ITU has three main sector areas (as illustrated in Figure 11), which are [62]:

- Radiocommunication Sector (ITU-R),
- Telecommunication Standardization Sector (ITU-T)
- Telecommunication Development Sector (ITU-D)

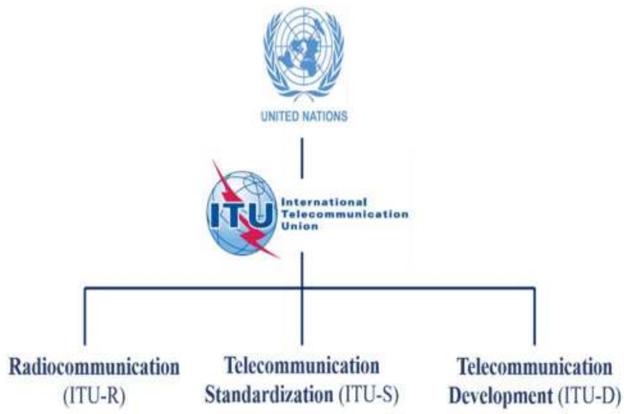

FIGURE 11. International Telecommunications Union Organisation (Relationship chart of UN, ITU, and three ITU sectors)

Over the years, ITU-R had been involved in assigning spectrum for various services and applications, and such are described in the ITU Radio Regulations (ITU-RR) [63] documents while the IMT bands usage is defined in ITU-R Recommendations [64]. The radio regulations complete texts (edition 2016) were first adopted in 1995 at the World Radiocommunication Conference (WRC-95), Geneva. Afterward, it was reviewed and accepted at the WRC-97, WRC-2000, WRC-03, WRC-07, WRC-12, and WRC-15, the next edition is expected to come out in Sept/Oct 2020 [63]. ITU-R has contributed to the development and setting of standards for mobile and wireless communications.

The Working Party 5D (WP 5D) has been handling for the overall aspects of the radio system in term of the IMT systems, that has added to the harmonize usage and standardization at a global level, of the IMT technology such IMT-2000 [65] as well as the IMT-Advanced [66] for the 3G and 4G respectively. IMT-2000, which started in 2000, offers access through radio links to a wide-ranging of communications services to specific mobile users as well as supported various fixed telecommunications systems [67]. It has since been continually enhanced and updated accordingly. Furthermore, the enhancement of the IMT-2000 capabilities by the introduction of new features and technologies. However, the IMT-Advanced for the 4G includes the IMT-2000 and new capabilities that go far beyond. These systems can accommodate conditions for low to high mobility as well as broadband data rates with respect to end-user and service demands in different scenarios.

The technology trends by ITU-R in preparation for the IMT-Advanced development were documented in this report [68]; however, advances had been continually made to the IMT systems. Both the Recommendations for the detailed radio interface specifications of IMT (-2000 and -Advanced) are available in [65] and [66], respectively; likewise, the modes of operation for the two include frequency division duplex (FDD) as well as time division duplex (TDD).

With the identification of frequencies for IMT, the telecommunication industries globally are confident in deploying the IMT services and networks, which provides a reliable foundation for manufacturers. Various bands of frequency were specified for IMT, as stated in the ITU-RR. Table II. Shows several identified frequency bands for the IMT system globally in ITU Radio Regulations and their corresponding World Radiocommunication Conferences [64], [67].

TABLE II
SPECTRUM IDENTIFIED FOR IMT SYSTEM

IMT frequency bands (MHz)	World Radiocommunication Conference
450–470	WRC-07
470–608	WRC-15
614–698	WRC-15
694–960	WRC-2000, WRC-07, WRC-12
1427–1518	WRC-15
1710–2025	WARC-92, WRC-2000
2110–2200	WARC-92
2300–2400	WRC-07
2500–2690	WRC-2000
3300–3400	WRC-15
3400–3600	WRC-07
3600–3700	WRC-15
4800–4990	WRC-15

ITU had adopted the term IMT-2020 and beyond [1] for 5G, in which the capabilities of the system of IMT are still being enhanced continuously. IMT-2020 and beyond had successfully described the potential user, application and technological trends, traffic growth, spectrum implications, framework provision, and the capabilities guidelines.

This constant increase in data traffic requires an increase in the spectrum resources to accommodate future mobile communication networks. Another report released by ITU-R [69] had estimated that the spectrum requirement of terrestrial IMT to be 1.34 GHz and 1.96 GHz by the year 2020 for both low and high user density. However, the national spectrum requirement of countries would differ from each other. To some, the spectrum requirement may be lesser than the low user density estimation, while in some cases, it may be higher than the high user density estimation. Furthermore, the IMT traffic is expected to increase between 10–100 times in the year 2030.

In general, 5G is expected to be built on previous generations, in addition to a new physical layer of millimeter-wave (mWave) to enable high capacity and data rates and very low latency in needed areas [70]. The 5G requirements and vision in terms of applications and services were defined in this ITU-R recommendation [1], convened in three usage scenarios, which are the eMBB, URLC, and mMTC. However, the eMBB is an extension/upgrade of the present 4G/LTE network while the others are newly introduced in the 5G communication networks. With the UC, coupled with the forthcoming trends, a huge variety of requirements is expected; hence, the flexibility and diversity in the design principle of the UCs and scenarios capabilities of IMT-2020. Figure 12 described the considered eight parameters as the IMT-2020 key capabilities, while Table III illustrated the expected values. However, the capabilities had been described in the previous section.

The relevance of some specific key capabilities is dependent on the UC or scenario even though all the key capabilities are of significant importance to most UCs. Hence, Figure 13 illustrates each of the capability importance of the usage scenarios; mMTC, eMBB, and URLLC. This was achieved by using three steps scaling: “high”, “medium,” and “low”. *For eMBB scenarios*, the following are of very essential: energy efficiency, UEDR, ATC, mobility, PDR, and spectrum efficiency, while the importance of UEDR and that of mobility is not simultaneous in all UC. Connection density is of high importance to connect a great number of devices (1,000,000 devices/km^2) in the case of *mMTC*. On the other hand, for the *URLLC*, latency (UP and CP latency) the highest importance as well as mobility, having very low interruption time. However, high data rates could be of low importance.

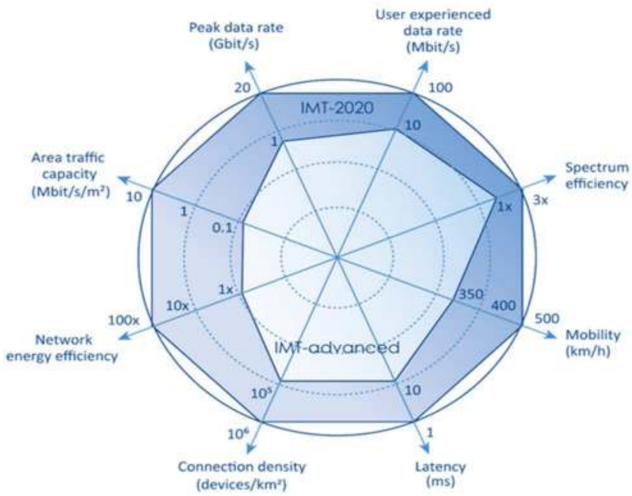

FIGURE 12. Enhancement of key capabilities from IMT-Advanced to IMT-2020 [71]

B. SPECTRUM DEFINED FOR IMT-2020

Various 5G comprehensive studies and research has been carried out in the past few years, which had led to the achievement of the significant and ambitious system or technologies. Furthermore, other important factors such as the service requirements, network standard development, new spectrum usage, New waveforms, multiple access schemes, Massive MIMO usage, new network architecture, software-defined networking, multi-connectivity [51] are ongoing for the deployment of the 5G services. Currently, the previous mobile generation has reached the capacity limits of its various cell density, despite the aggregation of the carrier frequency for small cells. Hence, the new spectrum needs to accommodate the exponential growth of wireless usage, as enhancements in capacity and spectral efficiency alone are not adequate [72].

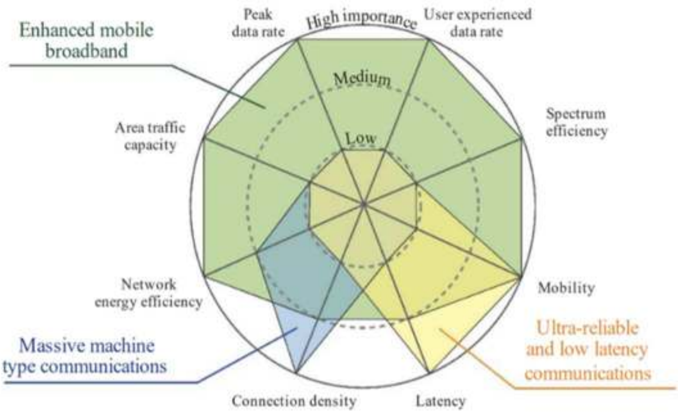

FIGURE 13. **Illustration of the key capability importance to the usage scenarios (eMBB, mMTC, and URLLC) [1],** [71]

At the WRC-15 [73], an important milestone stage was set for the 5G as new band sets were identified for IMT at frequencies lower than 6 GHz and that of higher frequencies. The frequency ranges of 3300–4200 MHz, 4400-5000 MHz, and 700 MHz has been identified as a great interest to 5G deployment, as it is suitable for the new 5G usage scenarios and implementation of massive MIMO. However, these spectrum has no widespread usage for mobile communications; hence, the need for assigning new larger spectrum blocks to support higher data rates [73].

In other to make the identification of IMT bands decisions at WRC-19, 11 candidate frequency bands (ranging from 24.25 GHz to 86 GHz) were suggested to be studied by ITU-R at the WRC-15. The frequency ranges are illustrated in Table IV, indicating the bands assigned as the primary basis for mobile communication services and the not-assigned bands. At the WRC-19 [74], the ITU-R studies on the suggested spectrum with respect to sharing and compatibility with services for IMT were identified, and the following frequency bands were presented 24.25-27.5, 37-43.5, and 66-71 GHz.

TABLE III
TECHNICAL PERFORMANCE MINIMUM REQUIREMENTS FOR THE IMT-2020 RADIO INTERFACE(S)

Technical Requirement	Values	Extended Values
Peak data rate	to reach 10 Gbit/s	certain conditions and scenarios 20 Gbit/s
User experienced data rate	wide area coverage: 100 Mbit/s for urban and suburban areas	hotspot cases: 1 Gbit/s in (Indoor)
Connection density	10^6 /km^2	
Area traffic capacity	10 Mbit/s/m^2 (in hot spots)	
Energy consumption (RAN)		
Over-the-air latency	1ms	
Mobility	500 km/h with acceptable QoS	
Spectrum efficiency	thrice of IMT-Advanced	five times in some scenarios (subject to further research)

However, some individual country has also identified and adopted these frequency bands: 45.5-47 and 47.2-48.2 GHz. ITU-R was also tasked to conduct the sharing and compatibility studies on 3600-3800, 3300-3400, 7025-7125, 6425-7025 MHz, and 10 -10.5 GHz frequency bands.

TABLE IV
PROPOSED FREQUENCY BANDS RANGING FROM 24.25 GHZ TO 86 GHZ FOR WRC-19 DISCUSSION

The primary basis for mobile service			Extension
24.25–27.50	45.50–47.00	66.00–76.00	31.80–33.40
37.00–40.50	47.20–50.20	81.00–86.00	40.50–42.50
42.50–43.50	50.40–52.60		47.00–47.20

There are quite significant differences between bands for the NR due to the broad range of frequency bands, massive MIMO, innovative antenna systems, and beamforming that would be widely used for the higher frequency. Hence, the creation of the difference in the definition of the RF requirements, performance measurement, and the set requirement limit [51]. According to 3GPP (full details of the operating bands and channel arrangement are listed in [75]), the NR spectrum consists of two frequency bands of operation, which are [76]:

- Frequency range 1 (FR1) consists of the existing and new bands between 410 MHz to 7.125 GHz. (this includes the frequency bands for LTE)

- Frequency range 2 (FR2) consists of the new frequency bands (mmWave) range of 24.25 – 52.6 GHz.

In the standardization process, 3GPP focused on the spectrum with high interest in providing the expected high speed with low latency and higher device density. Among others, the spectrums are divided into low, medium, and high spectrums. Therefore, the 5G network would operate on a multi-layer (triple-layer) approach based on the scenarios and different service requirements, as illustrated by Figure 14.

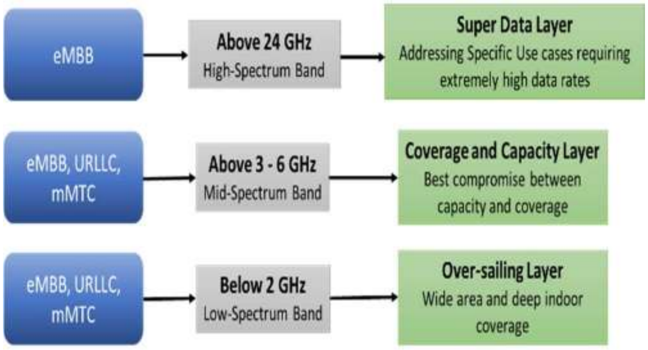

FIGURE 14. A multi-layer approach (triple-layer) based on the scenarios and different service requirements for 5G networks

A vigorous combination of each of the spectrum provides unique benefits and challenges [72], [77]:

Low-band spectrums are frequency bands below 2 GHz, which deliver an extensive coverage layer, ensuring a wide and deep coverage area connectivity, deep indoors, and remote rural area coverage. The 600 and 700 MHz bands correspond with the NR bands n28 and n71[75] with a maximum channel bandwidth of 20 MHz [51].

The Mid-band spectrum lies between 3 – 6 GHz bands. These are vital bands for 5G deployment in terms of coverage, breadth, high data rates, and spectrum depth to meet up with the traffic growth. It has wider channel bandwidth as compared to the low-band spectrum, which can offer about 100 MHz channel bandwidth averagely. However, about 200 MHz channel bandwidth per operator could be achieved [72]. This spectrum is favorable due to the channel propagation characteristics in terms of deploying small cells and pushing significant capacity in line-of-sight (LoS) and non-line-of-sight (NLoS) when compared to that of mmWave frequency bands. Likewise, the service delivery of network coverage propagates further but could be limited due to the frequency bands in use and the physical or terrain characteristics at the point of deployment. The range 3300 - 4200 MHz is accepted globally, n77 and n78 were designated by 3GPP for the NR bands [75].

The High-band spectrum uses the mmWave spectrum (above 24 GHz). This is a newly introduced spectrum for commercial use in mobile communications (IMT deployment). It can accommodate high capacity and deliver high data rates (in gigabits) in cases of high traffic demand, hence very suitable for hotspot coverage. The spectrum can easily support the 5G key requirements of the IMT-2020. It has a much wider channel bandwidth as compared to the mid-band spectrum, which can offer up to 400 MHz channel bandwidth averagely [51]. However, with frequency carrier aggregation, much higher channel bandwidth per operator could be achieved [72]. Despite its capability to support high traffic demands, the high-band spectrum has low propagation, hence the need for reusing the frequency bands in closely spaced small cells. The range 24.25 - 29.5 GHz is accepted globally, and n257 and n258 were designated by 3GPP for the NR bands [75].

C. SPECTRUM HARMONIZATION AND FLEXIBILITY

Spectrum harmonization is the procedure of globally defining measures that ensure the frequency band's application will have the necessary cohesion [78]. The global usage of radio systems has increased drastically, hence, the need for allocation of new spectrums for the required mobile services, this requires the harmonization of the newly allocated, identified, and existing spectrum. Spectrum harmonization globally determines the success of mobile communication system development and deployment [15]. ITU-R [1] coordinates the spectrum harmonization internationally. This includes the additional spectrum specified for the 5G mobile systems [61]. Development economies of scale facilitation, global roaming enablement, reduction in equipment design complexity, battery life preservation, spectrum efficiency improvement, and potential reduction of cross-border interference are benefits of spectrum harmonization and even development of radio equipment [72]. UEs are designed with multiple antennas along with associated RF to aid the operation of multiple frequency bands by using variances in frequency arrangements and common chipsets. However, it requires a complex equipment design to accommodate these differences. Hence, spectrum harmonization for IMT provides commonality in equipment production.

Spectrum flexibility is a system that operates and exploits the diverse prospects in accessing spectrum allocations [79]. That is, the flexibility of a designed system to operate at various ranges of frequency (higher frequencies and broader bandwidths channel), handle different scenarios, duplex arrangements (FDD and TDD), and diverse sizes of the available spectrum [1]. Spectrum flexibility has become a vital feature in radio access technology (RAT). The introduction of more spectrum and multi-band systems for mobile broadband usage as well as the need for varying channel bandwidth to meet various services and applications, created the necessity for the flexibility of spectrum usage [80]. The previous mobile generation radio technologies (LTE) were built to operate in a different spectrum and were deployed with various bandwidths to accommodate efficient migration of the prior radio technology. Likewise, spectrum flexibility is essential for the NR development and deployment since the deployment of the 5G network would be done at low-, mid-, and high-spectrum. Due to the envision new UCs, all frequency band

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utilization is essential, from spectrum lower than 6 GHz to that of the higher frequencies, based on the frequency characteristics. Hence, the need for deploying the Heterogeneous Network (HetNet) across the lower and higher spectrum. This novel concept of deploying spectrum will enable flexibility in the networks [81].

The joint operation of TDD-FDD, dynamic TDD, as well as dual connectivity, are an enhancer of the spectrum flexibility. The use of Orthogonal Frequency Division Multiplexing (OFDM) in NR provides the needed flexibility for the needed spectrum allocation size, usage of instantaneous transmission bandwidth, hence the enablement of frequency-domain scheduling [82]. Spectrum flexibility and flexible uplink/downlink resource allocation and joint management of multiple RATs have the potential solutions in tackling the future increase in traffic demand and the efficient usage of radio resources [1]. In conclusion, the use of a variety of bands for the deployment of the new technologies has provided the flexibility need by operators.

IV. 5G NETWORK SLICING

5G network slicing (NS) is considered an important innovation in mobile communications because of its ability to maximize sharing of network resources, flexibility optimization to accommodate various requirements from different vertical businesses [83]. NS also upgrades the capabilities of operation in terms of QoS and QoE [84]. NS intends to change the usual mobile network from an inert "one size fits all" concept to a dynamic concept with logical partitions and logical networks, having suitable isolation, resources as well as topology optimized for a specific function or service such as UCs, traffic category or individual [85].

Accommodating the various UC efficiently in the same mobile communications infrastructure while ensuring a reduction in bandwidth requirements of fronthaul necessitated the restructuring and optimization of the architectural network [86]. NS concept allows the creation of logical networks that are service-customized by operators to ensure optimized and improved solutions such as functionality, performance, and isolation for various services with different requirements [87], [88]. In other words, NS is a network architecture that allows the logical networks (independent) and virtualized multiplexation on the same physical communication network infrastructure. 3GPP has concluded the NS as an E2E logical Communication network with defined features as well as functionalities contained by the Public Land Mobile Network (PLMN), including 5GC, CP, 5G AN, UP, NFs to offer services to set of UE [44], [21]. The construction of various networks on the physical (unified) infrastructure is achieved through SDN, NFV, and cloud computing [89], [90].

A network slice comprises a set of customized logical NFs that support specific UCs or business models' requirements. Each slice has a devoted remedy such as functionality (resiliency, security) and performance (latency, throughput). The 5G UEs are addressed separately and differently in terms of the UE characteristics (UE Use cases) [91], [92]. Figure 15 demonstrates a service-based network that is based on the UE type.

Each EUs is linked to a particular and specially designed slice for that UE device. However, the architectures are flexible for future slice types. 5G technology is based on Network softwarization, hence, NFV and SDN, network softwarization will offer the programmability, flexibility, and modularity needed to establish the many logical (virtual) networks, where each will be tailored for an assigned UC, on the same network [93].

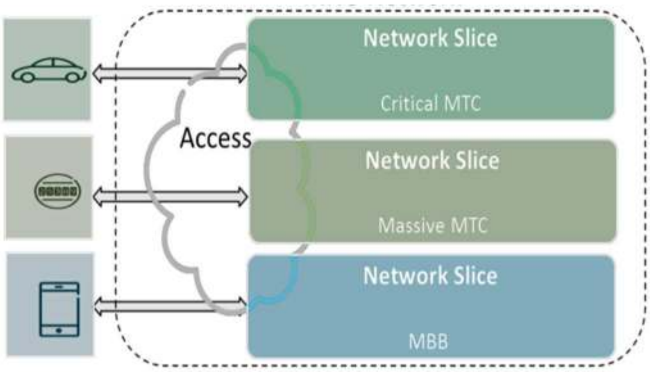

FIGURE 15. **Service-based network slicing based on the UE type** [92]

These networks have to be flexible in order to concurrently accommodate various business-driven UCs on the same network infrastructure as illustrated in Figure 16. NS designs are based on the specific requirements and optimization of each UCs. For further studies on the 5G network slicing using the SDN and NFV, a comprehensive review along with the solution can be found in [94].

The EU 5G Infrastructure Public-Private Partnership (5G PPP) sponsored the project called SliceNet [13], and NS was its focus in terms of managing, controlling the associated challenges, setting up new user services (vertical sectors). It intends to maximize the 5G services and infrastructures using advanced software networking and cognitive network management.

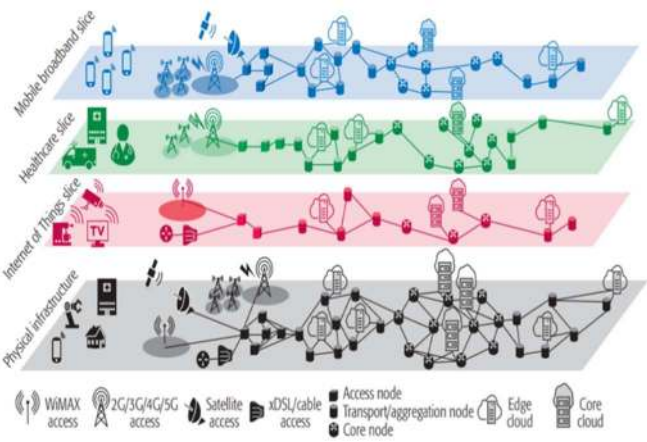

FIGURE 16. **5G network slices running on a common underlying multi-vendor and multi-access network** [93]

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SliceNet went ahead to develop an NS framework that applies to multiple administrative domains to meet demanding UCs as well as the management of services QoE. An approach known as the layered architectural approach was used to develop the framework, which provided a modular, extensible, and scalable framework. Figure 17 illustrates the SliceNet overall system architecture. The framework applies to many vertical sectors [23], SliceNet UCs in eHealth, Smart Grid [95], and Street Lighting were demonstrated. The deliverable in terms of dissemination, exploitation, and standardization was another achievement of the project [96].

In conclusion, the mobile generation is required to accommodate multiple QoS for different services compared to the current mobile generations. Therefore, network operators will make use of NS to offer different services with different treatment, it will also accommodate the releasing and allocating of network resources in accordance with the operators' context and contention policy, hence, the allowance of a substantial decrease in expenditures of the operations and the provision of satisfying multiple QoS [57].

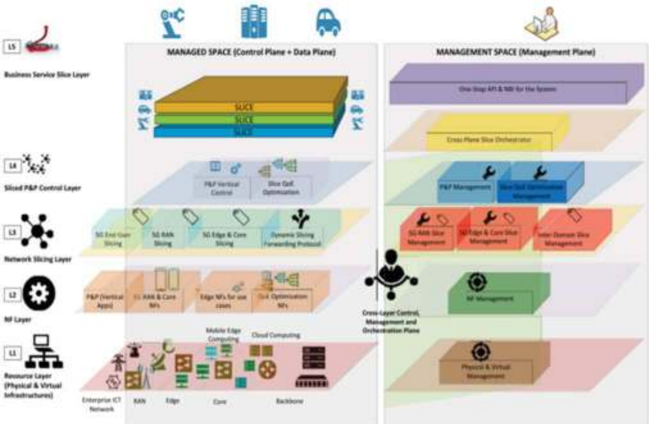

FIGURE 17. SliceNet Overall System Architecture [13]

V. 5G USAGE SCENARIOS

The mobile communications network was initially designed for human-to-human (H2H) communications to provide voice and data transmission. However, these have changed with time, and an extensive range of new evolving and unique UCs and vertical/business models have emerged along with the 5G ecosystem. Hence, establishing the appropriate UCs that accommodate the envisioned environments and services for the various sectors along with the expected requirement performance. IMT-2020 and beyond have envisioned these provisions, usage scenarios, applications, and services that would extend further than the current IMT [1]. As earlier defined, UCs are used to identify, produce, and document end-user requirements for a communication network. The activated UCs by 5G would enable significant economic and social values [97]. 5G is anticipated to meet the E2E QoS requirement in a broader range of UCs in flexibility, efficiency, and a secured manner. Hence, the need for a jointly working of the NG-RAN and 5GC to ensure extreme flexibility [81]. Each of the UCs requires diverse requirements, such as reliability, capacity, low latency, etc [57].

ITU, in a report [1] has defined the complete objectives and framework of the IMT-2020 and beyond future development in terms of providing better services to meet the needs of the future. Furthermore, a comprehensive diversity of capabilities (which has already been discussed in section III) are coupled with the various usage scenarios, services, and applications for IMT-2020 and beyond. In 2015, 3GPP initiated a project known as the "SMARTER project" [98], to develop high-level UCs and identification of the needed functionality and structures of 5G networks. As a result, five categories comprising of over 70 UCs were initially developed but have been reduced to three. The characterization was done based on the performance attributes of each UCs requirement. The three primary UCs or families of usage scenarios include eMBB, URLLC and mMTC. With respect to usage, a high reliable communication is needed for URLLC and mMTC because both are latency sensitive whereas, the eMBB relates to higher data rates and capacities.

A. ENHANCED MOBILE BROADBAND

eMBB is an improved/extension of the typical LTE broadband connectivity scenario. eMBB is the first phase of the implementation of the 5G NR access technology. Unlike the 4G mobile broadband, the 5G eMBB is enabled via the service-based architecture [44] which will offer improved performance as well as increased seamless user experience [40]. It will address the data-driven and human-centric UCs that require high data rates, access to multimedia content, and services, especially for a wide coverage area. The eMBB goals are to meet the ever-increasing digital lifestyle demand of users, offering the required high bandwidth for the needed services such as virtual reality (VR), access to cloud-based applications and services, high definition (HD) videos, home fixed wireless internet access, outdoor broadcasting, and augmented reality (AR) [99], [100].

The eMBB covers various cases, including hotspot and wide-area coverage, with different requirements such as high user density, low mobility, and a high user data rate (very high capacity) for hotspot coverage. On the other hand, a seamless and unified coverage with a higher data rate per user under moderate mobility to high mobility is required for the wide-area coverage. Furthermore, the data rate is usually lesser than that of the hotspot [40], [101]. Enhancing the spectral efficiency, signaling efficiency, bandwidth, enabling massive MIMO, beamforming and coverage are sure ways to accommodate the eMBB requirements [102]. It would provide an extreme and uniform experience over coverage areas with low latency.

B. ULTRA-RELIABLE AND LOW LATENCY COMMUNICATIONS

URLLC conveys a significant innovation to the 5G network. Along with mMTC, both are new features introduced to this generation of mobile communication networks. Its focuses are on the ultra-responsive connection with ultra-low latency for mission-critical applications, very high communications service availability, and real-time control of devices [103]. It requires an E2E data delivery with minimum latency, reliability as well as security. Unlike the eMBB with a high data rate, URLLC needs a moderate data rate but with high mobility. The requirement of these UCs is stringent for capabilities like latency, throughput, and availability [1].

URLLC would meet the digital industry's demanding expectations, which are latency-sensitive services [100], [104]. Assisted and automated driving, industrial robotics, remote management, vehicle to vehicle communications, wirelessly controlled manufacturing industrial, remote medical, and smart grids are a few examples of URLLC cases. 3GPP has set the latency of the air interface as 1 ms while that of the reliability of the system is set as 99.999% for the desired QoS requirements for URLLC [105].

C. MASSIVE MACHINE TYPE COMMUNICATIONS

mMTC is also a novel archetype that enables a wide diversity of applications and services from deploying enormous sensors and actuators for mission-critical services [106]. mMTC is categorized by fully automated data generation, exchanging, processing, as well as actuation amongst intelligent devices or machines, with little or no human intervention [107].

mMTC focuses is in achieving and developing a digital society where various users' demands are met, it also emphasizes the high requirements services for density connectivity [100]. Its provision of connectivity at low reliability is focused on a huge connected device, that is, the IoTs, basically transmitting a moderately low non-delay-sensitive amount of data [103], [108]. The devices would be remote areas deployable due to the very long lifetime of the battery. The devices will be diverse in character or content (heterogeneous), such as in capabilities, power transmission, consumption of energy, and cost [109]. Examples of these UCs are smart services, including smart city, healthcare, manufacturing, smart agriculture, consumer goods, business communications, and transportation.

Further UCs were expected to arise in the short future, hence the flexibility of 5G systems to support and accommodate support these new UCs and requirements. Some of the examples of the usage scenarios by ITU [1] for IMT-2020 and beyond are illustrated in Figure 18. The future IMT systems are expected to comprise of other variety of features in large numbers based on the different needs and circumstances of various countries.

According to the report ITU-RM.2412-0 [14], the IMT-2020 test environments were identified and defined as a combination of geographic environment and usage scenario. A total of five test environments for IMT-2020 was identified as summarized in Table V. However, deployment scenarios for three usage scenarios have been described in a recent report TR 38.913 Release 16 [110]. Table VI summarized the scenarios indicating the key characteristics and application location of the deployment scenarios.

FIGURE 18. Usage scenarios of IMT for 2020 and beyond [1]

VI. DEVELOPED 5G USE CASES BY STANDARDS DEVELOPMENT ORGANIZATIONS AND MAIN STAKEHOLDERS

Different standard development organizations (SDO) and industry fora have carried out various research on the different generations of mobile communications UCs. In this survey, the focus is on 5G UCs. Based on the organizations, UCs are sometimes referred to as usage scenarios or technical scenarios. A summary of various UCs from the following organizations/initiatives are presented as follows:

TABLE V
SUMMARY OF IMT-2020 TEST ENVIRONMENTS

Name	Capacity	Application Location	Users
Indoor Hotspot-eMBB	very high user density	indoor environment (offices, shopping malls)	Stationery and pedestrian
Dense Urban-eMBB	high user density with traffic loads	Urban environment	vehicular and pedestrian
Rural-eMBB	A wide area with continuous coverage	rural environment	pedestrian, vehicular and high speed vehicular
Urban Macro–mMTC	continuous coverage	urban macro environment	huge machine-type devices
Urban Macro–URLLC	continuous coverage	urban macro environment	ultra-reliable and low latency communications

A. 3GPP

3GPP is a partnership project that brought together various SDOs globally to develop and produce technical reports and specifications for the 3G mobile communications: the Universal Mobile Telecommunications System (UMTS) [111].

TABLE VI
SUMMARY OF IMT-2020 THE SCENARIOS INDICATING KEY CHARACTERISTICS AND APPLICATION LOCATION OF THE DEPLOYMENT SCENARIOS

Name	key characteristics	Application Location
Indoor Hotspot	high capacity, user density, and consistent user experience	Building with small coverage per site/TRxP and high user throughput or user density
Dense urban	high traffic loads, outdoor and outdoor-to-indoor coverage	City centers or areas that are dense with huge traffic loads and user density
Rural	continuous and ubiquitous coverage for high-speed vehicles	larger and continuous with low-density coverage
Urban macro	continuous and ubiquitous coverage in urban areas	large cells and continuous coverage
High speed	Reliability: train communication, mobility: very high consistent passenger user experience	continuous and ubiquitous coverage deployment for the track of high-speed train
Extreme long-distance coverage in low-density areas	large coverage macrocells support for voice and data services, user throughput: low to moderate, user density: low	very large areas with a low density of humans and/or machines users
urban coverage for massive connection	continuous and ubiquitous coverage connection density: very high designed for mMTC devices	Continuous coverage with large cells offering mMTC
Highway	Reliability, availability, high mobility	vehicles on the high-speed highways
Urban Grid for Connected Car	Reliability, availability, latency in high network load and high UE density scenarios	An urban environment with vehicles extremely deployed
commercial Air to Ground	Macrocells pointing towards the sky covers a large area to support voice service and moderate user throughput data service for onboard users.	Communication services for machines and human on commercial aircraft
light aircraft	Macrocells pointing towards the sky covers a large area to support voice service and moderate user throughput data service for low user density onboard users.	Communication services for machines and human on aviation aircraft
Satellite extension to Terrestrial	Communication services through Satellite system for data and voice, machine-type communications, broadcast, and other delay tolerant services.	provision of services for areas without terrestrial service and broadcasting service

3GPP was involved in the maintenance of the GSM specifications and further initiated 4G with LTE and lately, the 5G. The 3GPP comprises of seven telecommunications organizational partners (SDOs) from different countries which include the Alliance for Telecommunications Industry Solutions (ATIS) USA, the Association of Radio Industries and Businesses (ARIB), and Telecommunication Technology Committee (TTC) both in Japan, the European Telecommunications Standards Institute (ETSI) France, China Communications Standards Association (CCSA) China, Telecommunications Standards Development Society (TSDSI) India, Telecommunications Technology Association (TTA) Korea, it provides a stable environment to the members for the production of the reports and Specifications which define the 3GPP technologies [21], [112].

3GPP had been involved in system description for cellular communications technologies which include the radio access, capabilities of service, and core network, likewise, 3GPP specifications also accommodate non-radio access to the core network, which interwork with non-3GPP networks. It has three Technical Specification Groups (TSGs) namely:

- Radio Access Networks (RAN),
- Service & System Aspects (SA),
- Core Network & Terminals (CT)

The 3GPP initiated a project known as the "SMARTER project" [98], it came up with seventy UCs which were later categorized into three usage scenarios namely eMBB, URLLC, and mMTC (discussed in detail in section IV) and illustrated in figure 18. However, there are high-level UCs needed for the new services and markets. The test environments [14] and the deployment scenarios [110] along with the key characteristics for the IMT-2020 and beyond, as discussed in section IV, are summarized in Table V and VI, respectively. While a few of the developed UCs that covers different scenarios as well as the identification of the

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correlated high-level proposed requirements, were stated in this 3GPP technical report [98], Table VII lists the majority of the UCs indicating the vertical group, common characteristics of the UCs as well as the potential service requirements (Data Rate, Latency, Reliability, Communication Efficiency, Traffic density, Connection density, Mobility, and Position accuracy). However, new UCs are bound to be proposed that will have different requirements.

B. 5G PPP

The 5G PPP [113] was initiated by a combination of the EU Commission and the EU ICT industry, comprising of the ICT manufacturers, telecommunications operators, service providers, Small and medium-sized enterprises (SMEs), and research institutions. The 5G PPP association is made up of members (industry, research, SME), associate members, and partners [114]. The 5G PPP scopes include delivering solutions, architectures, technologies, and standards for 5G and future communication infrastructures in Europe. Hence, the research activities in particular areas such as smart cities, e-health, intelligent transport, education, entertainment & media. The 5G PPP initiative will reinforce the European industry to compete in global markets and open innovation opportunities successfully. The 5G PPP projects agreed with the three 3GPP 5G usage scenarios in defining their UCs. The 5G PPP identified the three 5G main services [115] as:

- Xtreme mobile broadband (xMBB) services which allow Gbps peak data rates,
- massive Machine-type communications (mMTC) for efficient energy data transmission devices deployed in immense volumes, and
- ultra-reliable machine-type communications (uMTC) for robust service and low latencies.

TABLE VII
USE CASES CONSIDERED BY 3GPP

Vertical Group	Requirements	Use Cases	Common characteristics
enhanced Mobile Broadband	Data Rate: Very High, peak rate of up to 10 Gbps for a slow-moving user	Mobile broadband for indoor scenario	Higher Data Rates, Higher Density, Deployment, and Coverage
		Mobile broadband for hotspots scenario	Higher Data Rates, Higher Density, Higher User Mobility
	Latency: Very low, even for high speed, reliable low-latency connectivity	Broadcasting Support Wireless Local Loop On-demand networking	Higher Data Rates
	Traffic density: High such as Tbps/km²	Improvement of network capabilities for vehicular case	Higher Density
	Connection density: High density for UE with up to 2500/km² and 2000/km² with 50 active UEs simultaneously	Mobile broadband services with seamless wide-area coverage Broadband Direct Air to Ground Communications Connectivity Everywhere	Deployment and Coverage, Higher User Mobility
	Mobility: From 0-500km/h, Very high traffic, high bit rate. No Reliability needed, no accuracy need	Wireless Local Loop 5G Connectivity Using Satellites	Deployment and Coverage
		Virtual presence	Deployment, Coverage, Higher reliability and lower latency
		Higher User Mobility Vehicular Internet & Infotainment	Higher User Mobility
Critical communications	Latency: Realtime low latency E2E as low as 1 ms; Smart grid system: less than 8 ms Round trip: < 150 ms, low latency (~1 ms), UE-UE latency: low latency [1-10 ms], 0.5ms one-way delay, Round trip latency less than [150 ms])	Ultra-reliable communication Virtual presence (duplicate in eMBB) Remote control Cloud Robotics Industrial Factory Automation Industrial Process Automation Low-delay speech coding Telemedicine Support	Higher reliability and lower latency
	Reliability: Ultra-high reliability, high availability Packet loss rate: $\leq 1e^{-4}$; 8 ms deliverable	Connectivity for drones	Higher reliability, higher availability and lower latency, Higher accuracy positioning, Mission critical services
		Industrial control Moving ambulance and bio-connectivity	Higher reliability, higher availability, and lower latency
	Traffic density: high density distribution such as 10,000 sensor/10km²	Tactile internet	Very low latency
		Localized real-time control Extreme real-time communications and the tactile Internet	
	Position accuracy: Position accuracy target: 10 cm in densely populated environments.	Remote control	Higher accuracy positioning

	Characterized by low latency, ultra-high reliability	Materials and inventory management and location tracking High Accuracy Enhanced Positioning (ePositioning) *5G Connectivity Using Satellites (eMBB replica) *Ultra reliable communication Lifeline communications / natural disaster Temporary Service for Users of Other Operators in Emergency Case *Moving ambulance and bio-connectivity *Telemedicine Support 5G Connectivity Using Satellites Local UAV Collaboration	Higher availability Critical mission services Critical mission services, Higher accuracy positioning, Higher reliability, and lower latency
Massive Internet of Things (MIoT)	Comm. Efficiency: Low power devices (smart meter) achievement by enhancement of coverage, resource efficiency as well as signalling. Traffic density: High density due to massive connections like 1,000,000 connections/km^2, for simultaneous transmission of information for locally dense devices. Connection density: MTC cases for Low mobility Position accuracy: High for outdoor and indoor scenarios (set at such as 0.5m)	Lightweight device configuration IoT Device Initialization Subscription security credentials update Wearable Device Communication Massive Internet of Things M2M and device identification Diversified Connectivity Wearable Device Charging Devices with variable data Domestic Home Monitoring Bio-connectivity Wearable Device Communication Wide area monitoring and event driven alarms Low mobility devices *Materials and inventory management and location tracking Light weight device communication	Operational Aspects Operational Aspects, Resource Efficiency Aspects Connectivity Aspects, Operational Aspects, Resource Efficiency Aspects Connectivity Aspects, Resource Efficiency Aspects Resource Efficiency Aspects
Enhancement of Vehicle-to-Everything (eV2E)	Data Rate: Medium Rate; 10 Mbps/UE Latency: Low latency; E2E latency of 1ms Reliability: High Reliability of almost 100% Traffic density: Medium Connection density: Medium (10k vehicles or more in scenarios with multiple lanes and multiple levels and types of roads) Mobility: High (up to 500 KM/h). Position accuracy: High (0.1 m)	*Mobile broadband services with seamless wide-area coverage (eMBB replica) *Improvement of network capabilities for vehicular case (eMBB replica) Connected vehicles	

In 2016, the 5G Initiative released a white paper [116] through an inter 5G-PPP project collaboration. The paper gave a comprehensive assessment of UCs and models. It elaborated on the definition of 5G scenarios based on the service perspective, key performance indicators (KPIs) definitions, requirements, and models. 5G-PPP projects defined its UC and classified them into 6 families, namely:

- Dense urban
- Broadband (50+Mbps) everywhere
- Connected vehicles
- Future smart offices

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- Low bandwidth IoT
- Tactile internet /automation

Furthermore, 5G PPP considered the following KPIs (Device Density, Mobility, traffic type, Infrastructure, User Data Rate, latency, reliability, 5G Service Type, and availability) for clustering the UCs. Likewise, the UC families were mapped to five vertical industries: automotive, e-Health, Energy, Media & entertainment, and Factories of the future. The family classification of the UCs illustrates the relationship of each UCs and their requirements. Table VIII summarizes this relationship of the use scenarios and the listed vertical industries.

Under the Horizon 2020 programme [117], these organizations (METIS-II, FANTASTIC-5G, mmMAGIC, SPEED-5G, 5G-NORMA, Flex5GWare) were part of the Research and Innovation action (RIA) call that developed various UCs for the NG-RAN. It is worth noting that all 5G-PPP projects agreed on the three 5G services (xMBB, uMTC, and mMTC) and started their UC definition from the METIS project results NGMN, ITU, and other fora.

TABLE VIII
SUMMARY OF THE 5G PPP UC FAMILIES, USE SCENARIOS, AND THE LISTED VERTICAL

Group	Scenarios	Vertical Industries
Dense urban	Both indoor and outdoor in a dense urban environment	*eHealth:* Remote monitoring of health or wellness data, Smarter medication *Energy*: Grid access *Media & Entertainment*: On-site live event experience, Collaborative gaming *Factories of the future*: Non-time-critical optimizations inside a factory, Remote maintenance, and control optimization to increase operation uptime, Seamless Intra-/inter-enterprise communication, Connected goods
Broadband (50+Mbps) everywhere	high availability for xMBB, Emphasis on suburban, rural, and high-speed trains, and areas with limited infrastructure	*eHealth:* Remote health monitoring and data, Smarter medication *Factories of the future*: Non-time-critical optimizations to increase flexibility and eco-sustainability, and operational efficiency, Seamless Intra-/inter-enterprise communication *Media & Entertainment*: User and machine-generated content, ultrahigh fidelity media, Immersive and integrated media
Connected vehicles	eMBB for on-board entertainment, URLLC, mMTC and/or xMBB for vehicles communications (V2V)	*Automotive:* Automated driving, Information society on the road, road safety and traffic efficiency services, transport digitalization, logistics, Automotive, Intelligent navigation
Future smart offices	eMBB service, Very high data rates indoors and low latency,	*Media & Entertainment:* Cooperative media production
Low bandwidth IoT	A very large number of connected objects	*Factories of the future*: Connected goods *Energy:* Grid access *eHealth:* Remote health monitoring and data
Tactile internet /automation	Ultrareliable communication with xMBB	*Factories of the future*: Time-critical process optimization for zero-defect Manufacturing, Remote maintenance, and control optimization to increase operation uptime. *eHealth:* Robotics (remote surgery, cloud service robotics), Remote health monitoring, and data. *Energy*: Grid backhaul and Grid backbone

1) METIS-II

The Mobile and wireless communications Enablers for the Twenty-twenty (2020) Information Society-II (METIS-II) [118] is an EU project built on the success of the METIS projects. It was initiated to develop the overall NG-RAN design, deliver the needed technical enablers for the effective

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integration and usage of different developed technologies and components. METIS-II is in collaboration within 5G PPP to prepare concerted action and evaluate the NG-RAN concepts towards regulatory and standardization bodies.

The focus of the project was to initiate the basis for a future mobile and wireless communications system for 2020 and beyond, paving the way for future standardization. One of the METIS-II objectives is to aid the discussion on scenarios, UCs, KPIs, and the 5G requirements based on the comprehensive work carried out in the METIS project [119], various EU projects, and bodies like ITU-R, NGMN, and 3GPP. In line with the three primary services (xMBB, mMTC, and uMTC), METIS-II presented five 5G consolidated UCs, namely [120]:

- Dense Urban Information Society
- Virtual Reality Office
- Broadband Access Everywhere
- Massive Distribution of Sensors and Actuators
- Connected Cars

These are set of 5G UCs that were typically combined from multiple service types. The project carried out an analysis of UCs based on various entities and classified the UCs into families by considering some special characteristics like covered services, mobility, several users, infrastructure, and so on, hence the choice of five UCs to represent the different families [120]. Table IX summarizes the METIS-II 5G UCs and to which use case family or families these use cases belong. The main KPIs and requirements of the METIS-II UCs are illustrated in Figure 19. However, METIS had researched scenarios, requirements, and KPIs for 5G mobile and wireless system which was concluded in 2013, the deliverable [119] introduced generic scenarios with respect to fundamental challenges, as well as the description of test cases (later referred to use cases) that are relevant for the future radio access. The deliverable introduced five scenarios based on five relevant challenges which are; *"Amazingly fast"* (high data-rates), *"Great service in a crowd"* (mobile broadband experience), *"Ubiquitous things communicating"* (efficient handling of huge devices), *"Best experience follows you"* (moving end-users experience), and *"Super real-time and reliable connections"* (new applications with very strict requirements on latency and reliability).

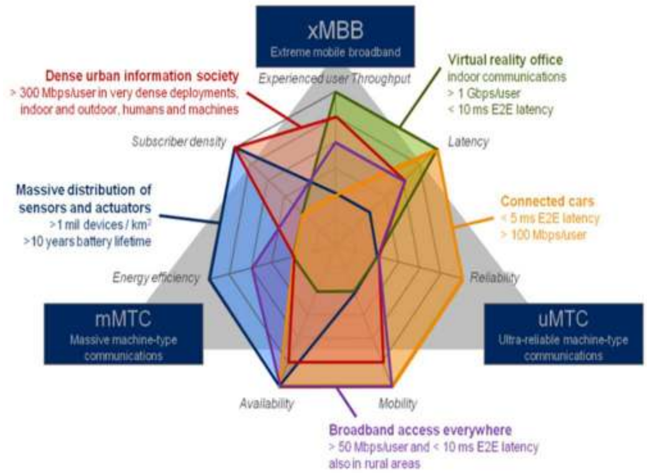

FIGURE 19. METIS-II 5G UCs and the respective mapping to the 5G services [120]

Based on these scenarios, twelve concrete test cases (TC) were developed with corresponding challenges from one or more scenarios. The overview of the METIS scenarios and test cases is illustrated in Figure 20. The TCs as reported in [119] includes

- Virtual Reality Office
- Dense Urban Information Society
- Shopping mall
- Stadium
- Teleprotection in smart grid network
- Traffic jam
- Blind spots
- Real-time remote computing for mobile terminals
- Open-air festival
- Emergency communications
- Massive Distribution of Sensors and Actuators
- Traffic efficiency and safety

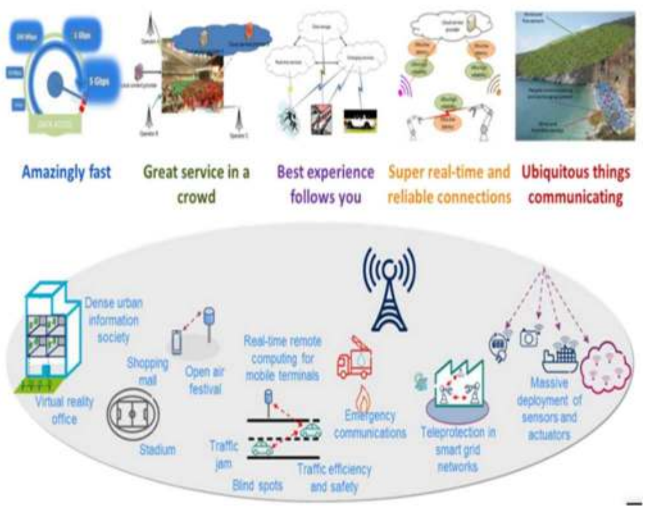

FIGURE 20. Overview of METIS scenarios and test cases [121]

The project on the scenarios, requirements and KPIs for 5G mobile and wireless systems [119] was later reviewed, and an updated deliverable D1.5 [122] was released in 2015. The deliverables confirmed the listed TCs, KPI, and requirements defined in [119] as essential, valid, and highly relevant for the future 5G research. Additionally, five vertical industries (Industrial automation, Automotive industry, Energy industry, Broadcasting, and Music industry), a new KPI on security, and nine new UCs were added. The report concluded using the contents of [119] and [122] for future evaluations of 5G technologies. The nine UCs are presented:

- Gaming
- Marathon
- Media on demand
- Unmanned aerial vehicles
- Remote tactile interaction
- eHealth
- Ultra-low cost 5G network
- Remote car sensing and control
- Forest industry on remote control

The 21 UCs proposed by METIS-I are presented in Table X, which have been used to evaluate the technology components developed in the project.

METIS considered four deployments as the RAN architecture scenarios which are a combination of various outdoor and indoor network deployments. The scenario strategies are macrocells with no or a limited number of outdoor small cells, macrocells with massive deployment of indoor small cells, massive deployment of outdoor small cells, and massive deployment of indoor and outdoor small cells.

TABLE IX
AN ILLUSTRATION OF THE METIS-II 5G UCS AND USE CASE FAMILY OR FAMILIES

Use cases	Description	5G Services	
Dense Urban Information Society	Indoor/outdoor Urban with a broad range of any place and at any time humans connectivity communication	xMBB, mMTC	Updated version based on NGMN requirements of METIS-I (Dense urban information society)
Virtual reality Office	A broad range of communication services in the indoor like office context, telepresence services into high-resolution 3D versions	xMBB	based on test case one of METIS-I (Virtual reality office)
Broadband Access Everywhere	Full coverage of very high data rate Internet access at any time and at any place for outdoor/indoor in rural and suburban areas, at a target value of 50 Mbps everywhere	xMBB	A new developed METIS UCs based on elements of NGMN UC [NGM15] and combined with some aspects from the METIS-I (Blind spots)
Massive Distribution of Sensors and Actuators	a massive deployment of low cost/energy consumption devices that communicates with other devices as well as with the network	mMTC	Same like that of METIS-I
Connected Cars	information exchange among vehicles and the infrastructure	xMBB and uMTC	Based on a Traffic jam, Real-time remote computing for mobile terminals and Traffic efficiency and safety

TABLE X
METIS-I USE CASES

Use Cases	5G Services	Key capabilities
Virtual Reality Office	xMBB	Indoor office space with low user density and no mobility but very high data rate
Dense Urban Information Society	xMBB	Urban setting with high user density and high data traffic rate as well as high mobility
Shopping mall	xMBB	An environment with a high density of customers and staff using a high data rate but low mobility
Stadium	xMBB	Event with bursty traffic and high user density using high data rate but low mobility
Teleprotection in a smart grid network	uMTC	Smart grid network with a low data rate, latency, no mobility but high reliability
Traffic jam	xMBB	The in-vehicle user using high data rate in areas with limited infrastructure
Blind spots	xMBB	Low user density areas (rural or shadowed urban) with limited infrastructure but high data rate
Real-time remote computing for mobile terminals	xMBB	Remote computing and cloud facilities with high data rate, high mobility but low latency
Open air festival	xMBB	Rural area with limited infrastructure having high user density and data rate
Emergency communications	uMTC	dense urban with low data rate, no infrastructure, high, energy efficiency
Massive Distribution of	mMTC	A very large number of devices with low data rate and energy efficiency

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Sensors and Actuators		
Traffic efficiency and safety	uMTC	Automotive safety transmitting at a low data rate, very low latency but high reliability
Gaming	xMBB	integration of cloud real-time gaming with low user density, mobility but high data rate
Marathon	xMBB, mMTC	long-distance running event with wearable devices needs high data rate in limited infrastructure and high user density with diverse traffic
Media on demand	xMBB	Several media individual users with high data rate and low latency (indoor user)
Unmanned aerial vehicles	xMBB	Drones with high data rate, in areas with limited infrastructure
Remote tactile interaction	uMTC	Remote access (surgery, driving, flying, AR requires very low latency and no mobility
eHealth	uMTC	healthcare by electronic processes and communication with low latency, high mobility
Ultra-low-cost 5G network	xMBB	Low cost of internet access with a high data rate
Remote car sensing and control	mMTC	Automotive applications, control of a large number of devices at low data rate and low power consumption
Forest industry on the remote control	xMBB, uMTC	Forest remote control service with a large number of devices, high data rate, and low latency

2) mmMAGIC

mmMAGIC (The Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications) is an EU co-funded 5G-PPP programme comprising major infrastructure vendors, European operators, and leading research institutes and universities, measurement equipment vendors, and one SME [123]. Its research focus was on designing and developing a new mobile RAT at the mmWave spectrum range of 6 – 100 GHz, it also covered other mmWave technologies such as UCs identification, scenarios, spectrum suitability, 5G requirement, capabilities, network deployments among others. Attention was given to the xMBB as a tool in meeting the demand for 5G requirements, that is, a massive increase in capacity and data rates [124].

mmMAGIC identified its relevant UCs based on a survey of various consortia and projects which includes the NGMN, METIS, Millimetre-Wave Evolution for Backhaul, and Access (MiWEBA), Beyond 2020 heterogeneous wireless network with Millimetre-Wave Small cell access and backhauling (MiWaveS), IEEE 802.11ad and ay standardization Task Groups. In this project, the UCs of interest were characterized into four UC families with eight UCs that are suitable for the 5G systems operating in the range 6-100GHz. The identified different families of UCs and their corresponding UCs in the deliverable [125] are summarized in Table XI, including the 5G Services key capability and requirements for each use case. Figure 21 shows the summary of all use cases, and how each use case heavily depends on one of the KPIs.

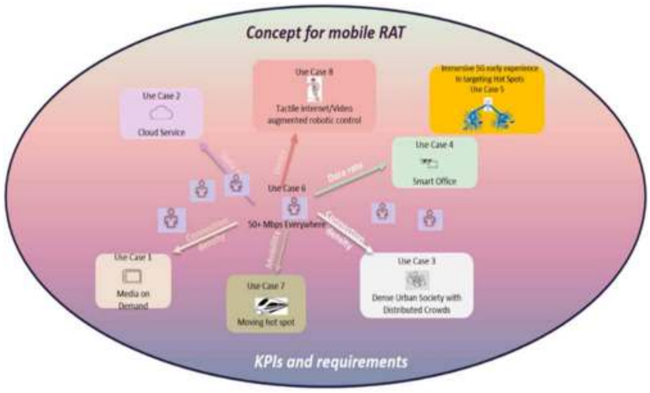

FIGURE 21. shows the summary of all use cases, and how each use case heavily depends on one of the KPIs [125]

3) FANTASTIC-5G

FANTASTIC-5G (Flexible Air iNTerfAce for Scalable service delivery wiThin wIreless Communication networks of the 5th Generation) is an EU project within the 5G-PPP project which was initiated to develop a novel multi-service Air Interface (AI) to support various 5G UCs at sub-6 GHz frequency via a modular design [126]. FANTASTIC-5G took the time to research and analyze the various challenges concerning the mobile and wireless infrastructure envisioned for beyond 2020, hence, the specification of the following service to tackle the development and evaluation of the air interface: mobile broadband (MBB), massive machine communication (MMC), mission-critical communication (MCC) [127].

TABLE XI
SUMMARY OF MMMAGIC USE CASES

UC Group	Use Cases	Key capability
Broadband access in a dense area	Media on demand	Media content indoor user in dense area with high data rate and low latency
	Cloud services	Outdoor and larger indoor areas using interactive applications, needs high traffic density and mobility, User data rate
	Dense urban society with	In urban dense areas with variable user density and demands having high

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	distributed crowds	traffic density and low latency
	Smart offices	Indoor communications (homes and office buildings) with high density of devices hence high user data rate and traffic density
	Immersive early 5G experience in targeted coverage	Dense urban traffic hotspots, outdoor-to-indoor and indoor-to-indoor deployment
Broadband access everywhere	50+Mbps everywhere	High data rate across the coverage area using ultra-dense network
High Mobility Users	Moving Hotspots	Access for moving crowds, vehicles, high-speed trains, and aircraft having high mobility
Extreme real-time or ultra-reliable communication	Tactile internet, remote surgery	Tele-control techniques connectivity in ultra-reliable and ultra-low latency for extreme real time communication at near error-free transmission

However, in the deliverable [128], the 5G UCs, KPIs, and corresponding requirements were fully defined, and five core services were defined, which included the three from [127]. Several UCs are a combination of these core services with respect to their corresponding KPIs and requirements.

The five core services of the FANTASTIC-5G project are:

- Mobile Broadband (MBB)
- Massive Machine Communications (MMC)
- Mission Critical Communications (MCC)
- Broadcast/Multicast Services (BMS)
- Vehicle-to-vehicle and vehicle-to-infrastructure communications (V2X)

FANTASTIC-5 G proposed seven UCs to represent the challenges in future 5G networks. Previous work done by NGMN [16], SMARTER [98], and METIS-I/II [119], [120], [122] frameworks were taken into account in identifying and selecting the reasonably comprehensive list of the UCs. FANTASTIC-5G made used of seven sets of criteria to select the UCs which are;

1) not covered by LTE and LTE-Advanced or even earlier RATs;
2) not covered by frequencies higher than above 6 GHz RATs;
3) more demanding encompass than other UCs with respect to corresponding KPIs and requirements;
4) representation of the NGMN use case category;
5) of high preferences among operators (addressing new services/markets);
6) possibility of simulations with the simulators made available in the framework of the project;
7) aligned with the 3GPP activity

The set of criteria selection process led to the consideration of seven use cases by FANTASTIC-5G [129], which are listed and summarized in Table XII including the corresponding 5G core services:

- 50 Mbps everywhere
- High speed train
- Sensor networks
- Tactile Internet
- Automatic traffic control/driving
- Broadcast like services: Local, Regional, National
- Dense urban society below 6GHz

Most of these scenarios employ macrocell deployments except tactile Internet and dense urban society, which also use small cells. It is worthwhile noting that the UCs represent all the 5G core services (MBB, MMC, MCC, BMS) either as a single or a combination of core services.

4) 5G-NORMA

5G-NORMA (5G Novel Radio Multiservice adaptive network Architecture) project [130] is within the 5G-PPP projects under the Horizon 2020 framework, intending to develop a new 5G mobile network architecture that offers resource efficiency in adaptability to accommodate variations in traffic demand as a result of heterogeneous and dynamically changing service portfolios and to changing local context. For this purpose, the SDN, NFV, and NS concepts were applied [131].

The 5G-NORMA deliverable [121] identified and defined UCs with respect to their requirements, it also defined the 5G-NORMA architecture, and proposed scenarios by a combination of several UCs. 5G NORMA has proposed twelve UCs based on those UCs developed by METIS, 3GPP, and NGMN. This influenced the proposed architecture definition. Hence, the selection of the UCs based on criteria which include the *potential business case or societal needs*, *use cases not supported by 4G technology, relevant for the design of the 5G network architecture, and needed by various market segments and verticals* to meet the requirements.

TABLE XII
SUMMARY OF FANTASTIC-5G USE CASES

Use Cases	5G Service	Descriptions
50 Mbps everywhere	MBB	wide-area coverage for urban to suburban and rural areas, guaranteed minimal data rate of 50Mbps everywhere, cost-effective and minimal energy consumption

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High speed train	MBB + V2X	higher speeds on-the-go, target for onboard train users. traffic density, mobility with great coverage, and User experienced data rate are key KPIs
Sensor networks	MMC	stationary or movable sensors/actuators for a wide range of applications transmit data occasionally, low cost, low throughput requirements. Energy efficiency, coverage, Connection density are key KPIs
Tactile Internet	MCC	wireless control of a real and virtual object, requires 1 ms E2E latency, reliability, Coverage, and security
Automatic traffic control/driving	MCC + V2X	Automobile control to improve traffic efficiency, mobility of emergency vehicles-to-vehicles communication, vehicles and vulnerable road users, real-time, reliability availability, and high mobility, low latency and high coverage requirements
Broadcast like services: Local, Regional, National	BMS	Broadcast-like services (TV, radio) for efficient distribution of information, both real-time and non-real-time delivery of video content over cellular networks, local emergency services. User experienced data rate, Traffic density, Coverage, Connection density are key KPIs
Dense urban society below 6GHz	MBB	High traffic demand and user density at urban outdoor (streets, urban roads) and indoor (shopping malls, train stations) environments, primary KPIs are user experienced data rate; traffic density; latency; coverage, and mobility.

5G NORMA further grouped and classified the UCs as follows: *Service-Application related UCs*; *Coverage-Capacity related UCs*; *Performance related UC*: Table XIII summarises the grouping and other relevant information about 5G NORMA UCs. 5G NORMA also identified a set of functional and performance requirements that are associated with each UCs to facilitate the consideration and definition of the network architecture.

TABLE XIII
SUMMARY OF 5G NORMA USE CASES

UC family	Use cases	Scenario framework	Descriptions
Service-Application related	Industry control	Multi-tenant + Multi-service (medium or low related)	Wireless monitoring and control of Industrial process in a limited physical area and controlled environment. Latency Reliability Number of connected devices High uplink data rates
	Enhanced Mobile Broadband	Multi-service	ubiquitously connections with extremely high data rates, urban, suburban, and rural areas with different physical properties in terms of buildings, mobility, streets, or indoor coverage
	Emergency communications	Multi-service	Due to natural disaster, the network adapts to the emergency service requirements, prioritizing emergency services, minimizing energy consumption, applicable in the Urban environment
	Vehicle communications	Multi-service + Multi-tenant	transport entities, to improve traffic safety, assist drivers with real-time information about road and traffic conditions
	Sensors Network Monitoring,	Multi-tenant + Multi-service (medium or low related)	control and monitoring a wide area for a particular measured property (temperature, motion, vibration, air quality, moisture, radiation)
	Real-time remote computing	Multi-service	Cloud computing for UEs, remote gaming, remote device control, tactile internet, latencies below 10 ms, enables remote servers
	Massive nomadic-mobile MTC	Multi-service (medium or low related)	Physically mounted sensors or actuators on nomadic and mobile objects to enable smart services, useful in eHealth, automotive industry, etc
	Fixed-Mobile Convergence	Multi-service (medium or low related)	Seamless communication within the fixed and mobile technologies to offer optimal network capabilities to the end-user
Coverage-Capacity	Blind Spots,	Multi-service	accessible high data rate services with high Quality of Experience (QoE) in blind spots
	Traffic Jam,	Multi-service + Multi-tenant	public cloud services for high user density inside vehicles during traffic. Adaptation of network to meet each end-user QoE

	Open Air-festival	Multi-service Multi-tenant	+	Remote and small rural area with an extremely high user and device density and data traffic demands for a few days. Need adaptation of network to meet each end-user QoS
Performance	Quality-aware communication	Multi-service		Provision of optimal service quality (QoS and QoE) based on service-specific and subjective end-user perceptions in any environment (Urban, rural, corporate, indoor/outdoor)

The functional requirements are eleven groups of requirements which are: Fast network reconfiguration within a network slice, Fast network reconfiguration between network slices, Device duality, Separation and prioritization of resources on a common infrastructure, Multi-connectivity in access and non-access part of the 5G system, Massive scalability of protocol network functions, Highly efficient transmission & processing, QoE/QoS awareness, Adaptability to transport network capabilities, Low latency support, and Security. While the performance requirements were grouped around three axes namely: very low latency and reliability for critical machine-type communications; high throughput for massive broadband communication, and the ability to support high volumes of devices for massive machine-type communication. Figure 22 illustrates the topology of the 5G NORMA UCs with respect to their corresponding requirements and 5G network evolution axes.

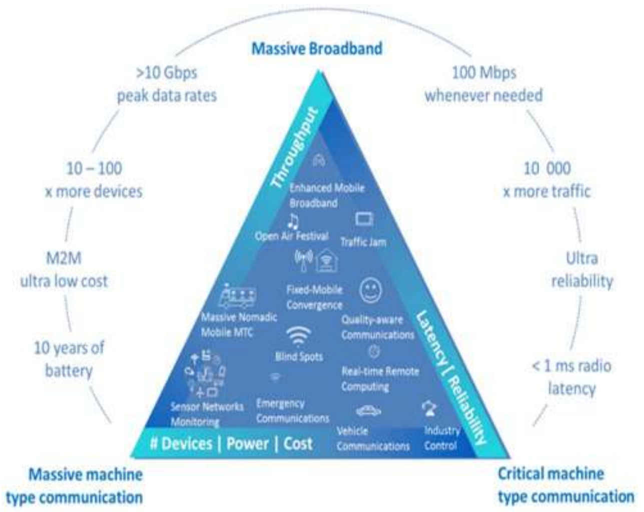

FIGURE 22. **5G NORMA Use cases in the 5G ecosystem** [132]

5G NORMA also defined two scenario frameworks as its architectural solutions (flexibility) validation. These scenarios are a combination of UCs that consents to the need for 5G NORMA enhanced functionalities. The two scenario frameworks: *Multi-service scenario framework*: focused on multiservice and context-aware adaptation and *Multi-tenant scenario framework*: sharing the same network infrastructure among various tenants such as participant, operators, vertical market players.

5) SPEED-5G

The SPEED-5G (quality of Service Provision and capacity Expansion through Extended-DSA for 5G) [133] focused on achieving eloquently improved exploitation of heterogeneous wireless technologies and higher capacity in conjunction with the cellular technology ultra-densification, and efficiently supporting the new requirements of the 5G QoE. Hence, the initiation of enhanced dynamic spectrum access (eDSA) by densification, heterogeneous wireless technologies with a rationalized traffic allocation, and resourceful or improved balancing of load across spectrum availability.

The SPEED-5G [134], investigated indoor and indoor-outdoor scenarios where capacity demands are at their highest. The scenarios covered urban communications, IoT, mission-critical, and vehicular services which are the SPEED-5G concepts, hence, the proposed four main UCs are:

- Massive IoTcommunications (mIoT)
- Broadband wireless
- Ultra-Reliable Communications (URC)
- High-Speed mobility

A few of the UCs by NGMN and METIS project were used as reference.

Massive IoTcommunications: are low-end IoT that is, devices with irregular and delay-tolerant traffic, and primarily composed of small data packets, examples are wearable devices, smart meters, home automation, smart domestic appliances, healthcare devices, smart cities sensors, and actuators that are non-critical, wireless sensor networks (WSN) for environmental monitoring.

Broadband wireless: centers on a combination of domestic, enterprise, and public access in an urban area that is densely populated like apartment blocks, recreation parks. It covers applications like streaming high-resolution multimedia, gaming, video calling, cloud services, etc.

Ultra-Reliable Communication enables high degrees of network, reliability, availability, and latency for applications such as M2M, real-time, mission-critical control for industrial and military applications.

High-Speed mobility considers high-speed for an urban environment with cars on highways and not for high-speed trains, access to superfast networks for communication, safety, entertainment to road users anywhere and at any time. It also includes a reduction in traffic congestion and higher comfort standards for the users. Table XIV indicates the SPEED-5G UCs along with each key capability.

6) Flex5GWare

Flexible and efficient hardware/software platforms for 5G network elements and devices (Flex5GWare) [135] focused on delivering a platform with extremely reconfigurable hardware (HW) and HW-agnostic software (SW) platforms for network elements and devices, as well as accounting for increased capacity, scalability, modularity to aid the swift transition from 4G to 5G. The approach necessitated the meeting requirement of the diversity of applications and data traffic exponential growth.

The deliverable [136] proposed UC families and specific UCs based on previous research related to the overall objectives and targets of the project. The deliverable also named scenarios for the 5G systems, requirements as well as the associated KPIs.

TABLE XIV
SUMMARY OF SPEED-5G USE CASES

Use Case	Deployment	Key Capacity
Massive IoTcommunications	indoor/outdoor femtocells and/or macrocells	High connection density, bursty transmissions, low data rate and traffic density, low mobility
Broadband wireless	indoor/outdoor massive deployment of small cells, femtocells	High user Data Rate, low Latency, high Mobility, Connection Density, Traffic Density
Ultra-Reliable Communications	indoor/outdoor	User Experienced Data Rate, very low Latency, Mostly static, high Traffic Density
High-Speed mobility	vehicles on highways; high--speed trains urban environment	Moderate user Experienced Data Rate and Latency but high Mobility and Traffic Density

The project's UC families were taken from the NGMN white paper. The UC families are *Broadband access in dense areas, Broadband access everywhere*, and *Massive internet of things* while the proposed UCs are:

- Crowded venues
- Dynamic hotspots
- Smart cities
- Performance equipment
- 50+ Mbps everywhere
- Connected vehicles (including Mobile broadband in vehicles and V2X communication for enhanced driving)

Broadband access in dense areas: focus on urban and crowded places with many users demanding services at very high data rates, a reliable, simultaneous, and consistent services from business needs to human leisure.

Broadband access everywhere: focuses on consistent coverage of broadband mobile access at high data rates available everywhere.

Massive Internet of Things: focuses on handling multiple connected devices with various characteristics to meet the expected service levels.

Flex5Gware deliverables [137], [138] presented the summary and evaluation with respect to target KPIs. The Flex5Gware UC families along with the UCs and KPIs are summarized in Table XV.

C MiWaveS

Beyond 2020 Heterogeneous Wireless Networks with Millimeter-Wave Small Cell Access and Backhauling (MiWaveS) [139] is an EU-funded project aimed at developing the mmWave key radio technologies to deliver better data transmissions to the 5G networks users by making use of the spectrum flexibility of the mmWave and peak capacities above 10 Gbps aggregated throughput. The project is a consortium of fifteen telecommunications operators, vendors, research centers, and academic institutions. MiWaveS illustrated the possibility of high-throughput and low-latency heterogeneous mobile networks, which was based on spectrum flexibility usage of the mmWave frequency bands at 57–66 GHz and 71–86 GHz. It proposed a system architecture embracing mmWave small cells that are HetNet consists of macrocells and ultra-densely deployed small cells) with high data rate access points [140].

In order to offer a solid execution of the MiWaveS vision, the project proposed the five UCs to derive the suitable KPIs and requirements of the 5G system [19]. The 5 UCs devised and refined which are relevant for the mmWave HetNet system are:

- Urban street-level outdoor mobile access and backhaul system
- Massive public events and gatherings
- Indoor wireless networking and coverage from outdoor
- Rural detached small-cell zones and villages
- hotspots in shopping malls

MiWaveS initiated the project by defining the UCs, Key Performance Indicators, and calculating the link budgets with respect to coverage and throughput [141]. The descriptions and related KPIs for each of the MiWaveS UCs are summarized in Table XVI. While Figure 23 illustrates the MiWaveS UCs combination on a single topology.

D MiWEBA

Millimetre-Wave Evolution for Backhaul and Access (MiWEBA) is another EU-funded project that aims to enhance the LTE-Advanced (LTE-A) systems towards 5G systems, it focused on fulfilling the 1000-time network capacity increment in the next decade with constant power consumption and reasonable cost of infrastructure deployment. Hence, designing innovative Multi-Technology Cellular Networks (MTCN) included access, backhauling, and fronthauling of mmWave systems. It also exploited unused frequency in the mmWave bands such as the 60 GHz [142].

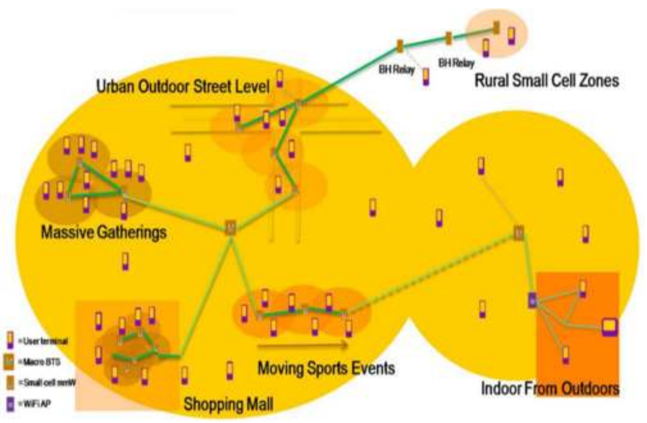

FIGURE 23. MiWaveS UCs combined on a single topology [143]

The MiWEBA deliverable D1.1 [144] proposed 5 main UCs under three focuses, as listed and described below:

- Indoor Hotspot:
  - Dense Hotspot in Shopping Mall
  - Dense Hotspot in an Enterprise
  - Dense Hotspot in Home Environment
- Indoor/Outdoor Hotspot:
  - Dense Hotspot in a Square
  - Dense Hot Spot in Urban areas
- Outdoor Non-Hotspot:
  - Mobility in the city
  - Bakhauling and Fronthauling in both dense Urban and Metropolitan areas

Dense Hotspot in Shopping Mall: focuses on the efficient ad-hoc deployment of small/nano cells for indoors to accommodate the demanding high data rate traffic. This is applicable for urban, rural, and suburban areas. *Dense Hotspot in an Enterprise*: focuses on the provision of ubiquitous coverage and high capacity mobile services to users in workplaces (enterprise space). *Dense Hotspot in Home and indoor environments*: focused on using unlicensed bands (like 60 GHz) technologies to deploy high data rate capacity in indoor environments, reducing interference. *Dense Hotspot in a Square*: focuses on a high user-populated square, located in the city center with frequent crowding of people. Applicable for indoor/outdoor environments such as bus stops, restaurants, enterprises, and recreation parks. *Mobility in the city*: focused on the provision of access with high capacity of data inside public transportations, furthermore, access nodes deployment in main streets for fast mobile users in cars and public transportations. The 3 considered use cases in relation to the specified UCs in the D1.1 deliverable are summarized in Table XVII.

However, Deliverable D4.5 [145] used some of the UCs parameterized scenarios to assess the performance of the MiWEBA architecture, hence the division of the use case into two groups, namely: *outdoor environment* (full or partial coverage for a very small area with a mmWave hotspot to a larger area with many mmWave small cells) and *indoor environment* (coverage for indoor areas such as shopping malls, enterprise areas, and homes) as listed.

TABLE XV
FLEX5GWARE UC FAMILIES AND THE USE CASES

UC family	Use Cases	Descriptions	Relevant KPI
Broadband access in dense areas	Crowded venues	Dense urban areas, wireless high capacity seamless connections variable user's density and demands, diversified traffic. locations like sports events, concerts, and streets	ultra-high number of users, high user data rate and mobile data volume, latency below 10 ms, Bandwidth
	Dynamic hotspots	uniformly distributed users in dense urban area with momentary large crowds, network dynamically handle user connections eg train/bus station, sports events, concerts, random gatherings, etc	Flexibility, high user data rate, energy efficiency, radio bandwidth, moderate mobile data volume
Massive internet of things	Smart cities	Depends on scenarios, urban massive deployment of small, cheap, and energy-efficient IoT devices for traffic assistance, environmental monitoring, Vehicle, and human detection, etc	Energy efficiency, Number of users, IoT devices integration size, Cost, Resilience flexibility, versatility, and latency
	Performance equipment	designed and benchmarked according to performance metrics that go beyond IoT baseline, e.g. power consumption and cost, and target both consumer markets and industry applications	User data rate, Operational bandwidth, Latency, Energy efficiency, Cost, and Number of users
Broadband access everywhere	50+ Mbps everywhere	very high data rates always and everywhere with a minimum throughput experience of 50Mbps for urban, suburban, and rural area	Mobile data volume, Bandwidth, Flexibility, versatility, Energy efficiency
	Connected vehicles	Has two types of traffic: *mobile broadband traffic*, triggered by humans' mobile devices and *machine*	*mobile broadband traffic:* mobile data volume, number of users

	initiated traffic, focuses on the vehicle to enable automatic driving that is Vehicle to Everything communication	*machine initiated traffic:* resiliency, latency, and mobile data volume

TABLE XVI
MIWAVES USE CASES AND RELEVANT KPIS

Use cases	Descriptions	Relevant KPIs
Urban street-level outdoor mobile access and backhaul system	1000x higher data volume per area, high capacity seamless connections almost anywhere and for area-specific network uses	End-user capacity, Area throughput/system capacity, QoS and QoE, Energy efficiency/power consumption
Massive public events and gatherings	Coverage for a massive user in a small area in some period eg. Events, sport, vacation resorts	End-user capacity, Area throughput/system capacity, Reliability, System coverage, Energy efficiency/power consumption
Indoor wireless networking and coverage from outdoor	Provision of backhaul and access mmWave with high capacity. Seamless handover and intelligent offloading from outdoor to indoor or vice versa. Useful in urban industrial and semi-rural zones.	End-user capacity, Reliability, Energy efficiency/power consumption, Network adaptation versatility, Cost efficiency
Rural detached small-cell zones and villages	deploying mmWave wireless backhaul technologies for rural connections	Reliability, Backhaul range, QoS and QoE, Energy efficiency/power consumption.
hotspots in shopping malls	ad-hoc deployment of small cells and mmWave backhaul as a cost-efficient solution to enable high data rate services inside the malls	Area throughput/system capacity, QoS and QoE, Energy efficiency/power consumption

- Outdoor environment:
  - Urban Microcell in street canyon (like Street Canyon scenario),
  - Urban Microcell in open square (like Open Area scenario),
  - Urban Macrocell.
- Indoor environment:
  - indoor open office,
  - indoor closed office
  - indoor shopping malls (like Hotel Lobby scenario)

TABLE XVII
SUMMARY OF THE THREE CONSIDERED USE CASES SPECIFIED BY D1.1

Grouping	UCs	D1.1 use cases and scenarios	Descriptions
Outdoor	UMi street canyon	Dense hotspot urban areas High rate areas	Street canyon street level urban scenario with high capacity mmWave APs microcell layout
	UMi open square	Dense hotspot in a square High rate areas Ultra-high rate hotspots	A large and open square in an urban scenario with high capacity mmWave APs microcell layout
	UMa	Dense hotspot urban areas Mobility in the city Backhaul and fronthaul dense urban and metropolitan areas Larger areas	Urban scenario with intends to increase coverage and capacity using mmWave APs macrocell layout. Two-tier HetNet network
Indoor	Indoor open office	Dense hotspot enterprise	Deployment of high-speed connectivity in large and crowded open spaces with static and nomadic users and furniture.
	Indoor closed office	Dense hotspot home Isolated rooms	Deployment of high-speed wireless connectivity via mmWave APs in a small isolated room to users
	Indoor shopping mall	Dense hotspot shopping mall Large public area	Deployment of high-speed wireless connectivity via mmWave APs in large halls and shops with nomadic users

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E 5GMF

Fifth Generation Mobile Communication Promotion Forum (5GMF) [146] was founded in Japan (2014), to conduct research and develop the 5G communications systems with respect to standardization, it acted as a liaison and coordinator with other organizations for information collection, and educational and awareness promoting of the 5G communications systems.

5GMF [81] addressed the typical 5G usage scenarios, based on the IMT Vision recommendation [1]. The research proposed new usage scenarios (UC) for 5G networks after the consideration of future user and market trends. These were categorized into four facets as described. Table XVIII summarizes the 5GMF UCs and clarified the list of required capabilities of individual UCs:

Entertainment: provides unique and/or advanced real to fully virtualized experiences for leisure time such as games watching in the stadium, playing online games, and going for travels. Seamless communication even in a highly congested area.

Transportation: provides comfortable experiences via advanced transportation methods for automobiles and high-speed trains. It includes Self-driving vehicles, driver assisting services against traffic jams, and computer-aided management of crowds.

Industries/Verticals: provides novel methods of enhancing manufacturing and agriculture using sensor networks, big data analysis to improve productivity (uses for robots, drones, instruments, and machinery), creating new business models and new customer values.

Emergency and disaster relief: provides anti-measures against disasters and emergencies (earthquakes, traffic accidents, floods, fires, sudden illnesses, and typhoons) by providing support.

F. NGMN

Next Generation Mobile Network Alliance (NGMN Alliance) [147] an open forum, focused on expanding the experience of communications by offering an integrated and cohesively platform that provides reasonably priced mobile broadband services to 5G users while the LTE-Advanced development and its ecosystem are advancing.

It is expected for the industry to witness emerging new UCs and business models that are driven by the operators' as well as users' needs, These will be achieved by advancing the present and emergence of new key technologies enabled both by the development of existing and new technologies. Hence, NGMN envisages 5G as an "end-to-end system", intended to provide value and empowerment to different businesses which in turn, enhances productivity, sustainability as well as a fully mobile and connected society of 2020 and beyond [148]. It also envisioned 5G to empower the creation of value for customers and partners, via existing and evolving or emerging UCs, that will be delivered with a reliable experience, and aided by sustainable business models.

NGMN anticipated the need for new radio interface(s) for 5G networks, one that is driven by using a higher spectrum, specific UCs, and capabilities, that supersede LTE and LTE-Advanced technology. Furthermore, 5G operations will be in a highly heterogeneous environment described by multiple kinds of access technologies, devices, user interactions, and multi-layer networks, multiple kinds. NGMN and other stakeholders/partners worked together to define and describe the key elements of NGMN's 5G Vision which includes *use cases, business models, and value Creation*, these are expected to be employed to provide a global and commercial 5G network.

TABLE XVIII
SUMMARY OF THE 5GMF UCS AND LIST OF REQUIRED CAPABILITIES OF INDIVIDUAL UCS

UC family	Use cases	Descriptions	Key capabilities
Entertainment	Enhanced real experience entertainment	Experience sharing scenario, Simulated Experiences Scenario, Virtual Reality Scenario	Peak data rate, User experienced data rate, Mobility, Connection density, Spectrum efficiency, Area traffic capacity
	Dynamic HotSpot services	Variable data and voice traffic due to variable population density in a location at a time. Eg Stadium, Concert attendance, fireworks viewing, festival-goers	User experienced data rate, Connection density, Area traffic capacity, Dynamic Flexibility
	A large marathon	Marathon race in the city, using many sensors to collect atmospheric information. Videos capture from runners and upload, monitoring the health status of runners. big data useful for industries for health care and sports equipment.	Peak data rate, Latency, Connection density, Area traffic capacity
	A trip on the shinkansen high-speed train	Multiple passengers enjoying real-time or live-stream entertainment services on a high-speed train. Similar cases include: Cars on the highway, Ships, and Airplanes	User experienced data rate, Mobility, Connection density, Energy efficiency, Area traffic capacity

	Content downloads by commuters	Instantaneously download of large-volume files with a mobile device at a High-Rate Close Proximity (HRCP) access point, eg an automatic ticket gate	Peak data rate, User experienced data rate, Energy efficiency
	Communications during the rush hour commuters	railway commuters in the Tokyo metropolitan area, going through a terminal station creating huge communication traffic	Connection density, Area traffic capacity
Transportation	Smart automobiles	Automobile collision avoidance system for intersections monitoring of cars, bicycles, and people in real-time, captured information sent via low-latency 5G networks.	User experienced data rate, Latency, Mobility
	Behaviour support in city	Obtaining environmental data from installed sensors in a city and user devices, processed and used for real-time human behavior support such as space congestion control, as well as individual characteristics such as disability, age, and so on.	Peak data rate, Latency, Mobility, Connection density, Area traffic capacity
Industries/Verticals	Robot Control	An urban environment filled with intelligent robots, use for various services such as delivery, assisting people, unmanned emergency transportation of medical equipment.	Peak data rate, Latency, Mobility, Connection density, Area traffic capacity, and Group Mobility
	Smart agriculture	Automated, autonomous driving and operations of agricultural machines, Big data collection of atmospheric condition and soil using sensors.	Latency, Mobility, Spectrum efficiency
Emergency and disaster relief	Anti-Crime System with Image Recognition	criminal monitoring and tracking via videos /images captured by surveillance. Collection of video information to determine any suspicious activity	Peak data rate, Latency, Mobility, Connection density, Area traffic capacity
	Enhanced Emergency Call, Large Scale Disaster Rescue Network	automatic emergency calls from an incident event. Delivering of patient's vital data and video image by the ambulance, en route to the hospital. Uploading of accident scene information.	Peak data rate, Latency, Mobility, Connection density, Spectrum efficiency, Area traffic capacity, Reliability
	Emergency Calls for Earthquake/Tsunami	Mobile networks handle calls to confirm people's safety after an earthquake, sending a specific warning or evacuation course information, Automatic control of abandoned cars, mobile communication systems connecting medical helicopters and medical institutions	Peak data rate, Latency, Mobility, Connection density, Spectrum efficiency, Area traffic capacity, Reliability

NGMN [16] developed twenty-five UCs for 5G, which are grouped into eight UC families, contributing to the stipulated requirements and the definition of the 5G architecture building blocks. In reflecting on the UCs dependency, the UCs were further categorized as "Use Case Categories" based on their requirement.

A set of the requirement was given to each UC category to represent the category's extreme UCs. As a result, satisfying the requirements of a category leads to satisfying the requirements of all the use cases in this category. The UCs were divided into fourteen categories as described below: The UC families, UCs, and categories are further summarized in Table XIX.

Broadband access in dense areas: focused on everyday life availability of service in densely-populated areas (with thousands of people per Km^2) for a fully connected society like events *and* multistorey structures.

Broadband access everywhere: provision of broadband service to everywhere in urban, suburban, and rural areas that guarantee consistent user experience with regards to throughput having a minimum data rate.

High user mobility: focuses on mobile broadband communication services in vehicles, trains, and aircrafts such as in-vehicle entertainment, internet access, an enhanced navigation system, autonomous driving, safety, and vehicle diagnostics.

Massive Internet of Things focuses on massive devices such as sensors and actuators with a broad range of demands and characteristics. It includes both MTC: broadband and low-cost/long-range/low-power.

Extreme real time communication: This family focuses on UCs with huge demand for real-time interaction, which requires extremely high throughput, latency, ultra-reliable communication, mobility, high availability, critical reliability, such as autonomous driving and remote computing.

Lifeline communication: focuses on public safety and emergency services, alerting and supporting through authority-to-citizen and citizen-to-authority communication, prediction of emergency, disaster relief, and mobile network acting as a lifeline.

Ultra-reliable Communications: focuses on a new world of remote operation and control of industries such as manufacturing, agriculture relying on reliable MTC as well as enterprise services or critical infrastructure services like Smart Grid.

Broadcast: Broadcast-like services (TV, radio) for efficient distribution of information, both real-time and non-real-time delivery of video content over cellular networks, local emergency services. While personalization of communication will reduce demand for legacy broadcasts as deployed today, e.g. linear TV, the fully mobile and connected society will need an efficient distribution of information from one source to many destinations.

Furthermore, the second NGMN 5G white paper [45] introduced other UCs, to validate the diverse industries and requirements supportable by the 5G network. The second white paper was built based on the previous white paper, hereby, extending the vision, UCs, and enablers, but with great focus on the vertical industries that will be supported by the 5G network. The UCs includes:

Manufacturing Industry: flexible and convenient wireless connections in the manufacturing industry for real-time control, monitoring, optimization of materials, products, and processes.

Construction Industry: remote management/safe operation of the vehicles and machines, autonomous operation, and synchronization between the construction industry vehicles.

Transport: provision of efficient, comfortable, and safe transportation using artificial intelligence (AI) under the platform of 5G network, ensuring wireless connection and automatic driving via perception, the decision as well as control. The feature would enable video/images capturing conditions of the road and roadside facilities, V2V, road infrastructures, and real-time communication.

Health: provision of flexible and convenient wireless connections to accommodate the health industry such as continuous provision of wide-area coverage for ambulances, sensors, home patients, or in-hospital patients wearable devices (collection and monitoring of vital signs), creating a dedicated and reliable communication channel among hospitals, guidance, hospital equipment, assets as well as personnel management and monitoring.

Smart Cities and Communities: using 5G wireless communications for creating an intelligent urban infrastructure, which will enhance the collection and processing of information, improve government efficiency, security capabilities, and quality of life in general.

Education: enabling virtualized and augmented teaching and experiments, using VR/AR services, remote interactive teaching amongst the teachers and students from the same schools or from different schools, managing and monitoring the school personnel, assets as well as the environment.

Tourism: delivering immersive (generation of a three-dimensional image), interactive and exciting experiences to provide in-depth knowledge of the sites, attractions, and facilities. Entails provision of 3D virtual reconstruction using AR.

TABLE XIX
SUMMARY OF THE NGMN USE CASES

UC Families	Categories	Use cases	Descriptions	Key Capabilities
Broadband access in dense area	Broadband access in dense area	Pervasive Video	Available person-to-person or person-to-group video communication with extremely high resolution for everyone	User Experienced Data Rate DL: 300Mbps UL: 50Mbps E2E Latency: 10ms Mobility: On demand,0-100km/h Connection Density: 200-2500 /km² Traffic Density: DL: 750 Gbps / km² UL: 125Gbps/km²
		Operator Cloud Services	Diversified and customized cloud services to offer mobile "Smart life" experience to users	
		Dense urban society	High traffic demand and user density at urban outdoor	
	Indoor ultra-high broadband access	Smart Office	multiple wireless connected devices in the office using ultra-high bandwidth to	User Experienced Data Rate DL: 1Gbps, UL: 500Mbps

			process services/applications, videos in the cloud.	E2E Latency: 10ms Mobility: Pedestrian Connection Density: 75,000 /km^2 (75/1000 m^2 office) Traffic Density: DL: 15 Tbps/km^2 (15 Gbps / 1000 m^2) UL: 2 Tbps / km^2 (2 Gbps / 1000 m^2)
	Broadband access in a crowd	HD Video/Photo Sharing in Stadium/Open-Air Gathering	A temporary high connection density scenarios such as stadium, concert, that offer integrated physical and virtual information, HD videos sharing	User Experienced Data Rate DL: 25MbpsUL: 50Mbps E2E Latency: 10ms Mobility: Pedestrian Connection Density: 150,000 / km^2 (30.000 / stadium) Traffic Density: DL: 3.75 Tbps/km^2 (DL: 0.75 Tbps/stadium) UL: 7.5 Tbps/km^2 (1.5 Tbps/stadium)
Broadband access everywhere	50+ Mbps everywhere	50 Mbps everywhere	50 Mbps minimum user data rate broadband access coverage area everywhere	User Experienced Data Rate DL: 50Mbps UL: 25Mbps E2E Latency: 10ms Mobility: 0-120 km/h Connection Density: 400/ km^2 in suburban 100/ km^2 in rural Traffic Density: DL: 20Gbps/km^2 and UL: 10Gbps/km^2 in suburban DL: 5Gbps/km^2 and UL: 2.5Gbps/km^2 in rural
	Ultra-low cost broadband access for low ARPU areas	Ultra-low cost networks	flexible Internet access deployed under ultra-low cost requirements providing new business and opportunities in underserved areas of the world.	User Experienced Data Rate DL: 10Mbps UL: 10Mbps E2E Latency: 50ms Mobility: On demand,0-50km/h Connection Density: 16 / km^2 Traffic Density: 16 Mbps / km^2
High user mobility	Mobile broadband in vehicles	High-Speed Train	Provision of satisfactory internet service to the passengers (up to 1000) at a speed of 500 km/h	User Experienced Data Rate DL: 50Mbps UL: 25Mbps E2E Latency: 10ms Mobility: On-demand, 0-500km/h Connection Density: 2000/km^2 (500 users/train x 4 trains, or a user/car x 2000 cars) Traffic Density: DL: 100 Gbps/km^2 (25 Gbps/train, 50 Mbps/car), UL: 50 Gbps /km^2 (12.5 Gbps/train, 25 Mbps/car)
		Moving Hot Spots	Non-stationary, dynamic, and real-time provision of capacity to moving vehicles or crowds with capacity variation	
		Remote computing	On the go, at high speeds stationary or low-mobility remote computing. Remote processing of automotive & transportation industry	

	Airplanes connectivity	3D Connectivity: Aircrafts	Commercial connectivity services for aircraft/helicopters and passenger services for a live sporting event such as balloonists, gliders, or skydivers.	User Experienced Data Rate DL: 15Mbps per user UL: 7.5Mbps per user E2E Latency: 10ms Mobility: On demand, 0-1000km/h Connection Density: 80/plane 60 airplanes/18,000km^2 Traffic Density: DL: 1.2 Gbps/plane UL: 600 Mbps/plane
Massive Internet of Things	Massive low-cost/long-range/low-power MTC	Smart wearables(clothes)	consisting of multiple types of ultra-light, low power, waterproof sensors integrated into clothing to measure various environmental and health attributes	User Experienced Data Rate Low (1-100 kbps) E2E Latency: Seconds to hours Mobility: On demand,0-500km/h Connection Density: Up to 200,000/km^2
		Sensor networks	Smart services in urban areas suburban and rural areas such as metering, city/building lights management, environment monitoring, and vehicle traffic control.	
	Broadband MTC	Mobile video surveillance	mobile video surveillance with medium/high-end devices available on aircraft, drones, cars, and safety and security personnel for monitoring houses/buildings, targeted areas, special events, etc.	The same as the Broadband access in dense areas and 50+Mbps everywhere
Extreme real time communications	Ultra-low latency	Tactile internet	Wireless control of real and virtual objects. such as using cloud-based software to interact with the environment. Robotic control and interaction in manufacturing, remote medical care, and autonomous cars.	User Experienced Data Rate DL: 50Mbps UL: 25Mbps E2E Latency: <1ms Mobility: Pedestrian Connection Density: Not critical Traffic Density: Potentially high
Lifeline communications	Resilience and traffic surge	Natural disaster	Provision of robust communications in natural disasters such as earthquakes being able to signal location/presence for response	User Experienced Data Rate DL: 0.1-1MbpsUL: 0.1-1Mbps E2E Latency: not critical Mobility: 0-120 km/h Connection Density: 10,000/km^2 Traffic Density: Potentially high
Ultra-reliable communications	Ultra-high reliability & Ultra low latency	Automatic traffic control/driving	Vehicle-to-vehicle, vehicle-to-infrastructure, communication with pedestrians and cyclists, controlled fleet driving	User Experienced Data Rate DL: 50 kbps - 10 Mbps; UL: up to 10 Mbps E2E Latency: 1 ms Mobility: On demand, 0-500km/h Connection Density: Not critical Traffic Density: Potentially high
		Collaborative robots: A Control Network for Robots	Automation of jobs with repetitive tasks such as production, transportation, and also within the services industry.	
		Remote object manipulation – Remote surgery	Mobile remote surgery in such as ambulances, disaster-response, and in remote areas.	

	Ultra-high availability and reliability	eHealth: Extreme Life Critical	mobile applications for remote health monitoring, surveillance, treatment, using several devices/sensors eg electrocardiography, pulse, etc. The monitoring applications, including the surveillance of patients remotely,	User Experienced Data Rate DL: 10 Mbps UL: 10 Mbps E2E Latency: 10 ms Mobility: On demand, 0-500km/h Connection Density: Not critical Traffic Density: Potentially high
		Public safety	Sending of real-time video and high-quality pictures for emergency services on land, sea, air, in-building, basements, and subway systems.	
		3D Connectivity: Drones	Ubiquitous coverage for both terrestrial and up-in-the-air locations. Remotely control of drones using 5G communication.	
Broadcast like services	Broadcast like services	News and information	simultaneous receiving of text/pictures, audio, and video, news, and information everywhere irrespective of devices or network connection	User Experienced Data Rate DL: Up to 200 Mbps UL: Modest (500 kbps) E2E Latency: <100 ms Mobility: On demand, 0-500km/h Connection Density and Traffic Density are irrelevant.
		Broadcast like services: Local, Regional, National	Local services at a cell and covers 1 to 20 km, eg stadium, advertisements, emergency services, etc Regional service covers 1 to 100 km eg, communication of traffic jam information, Regional emergency warnings National/continental/world-reach broadcast services for radio or television, useful for vertical and automotive industries	

Agriculture: using 5G for smart farming to improve productivity. This includes Agricultural robots (self-driving tractors, precision seeders, automated harvesters and weed, pest controllers), UAVs/drones spraying crops, taking images. Real-time monitoring sensors for crop health, location of livestock, environmental, and climate conditions. Real-time processing and communication amongst the machines and sensors.

Finance: using 5G to provide an ultra-reliable and low latency communication, robust connectivity, platform for the digital transformation of banks, which in turn boosts the ubiquitous banking operations, enhances security, and offers better customer services.

G. IMT-2020 (5G) Promotion Group

The group was initiated in the year 2013 in China by three ministries, which includes the Ministry of Industry and Information Technology (MIIT), the Ministry of Science and Technology (MOST), and the National Development and Reform Commission (NDRC), it was based on the initial IMT-Advanced Promotion Group. The group was set up to promote 5G research in China and it is made up of various key players of the mobile operators, vendors, universities, and research institutes [149].

The group has envisioned 5G to meet the element of future society, providing an all-dimensional, as well as a user-centered information ecosystem. It expects 5G systems to outperform the previous generation of mobile systems and identified the key capabilities such as, up to 1 Gbps user experienced data rate, connection density of 1,000,000 connections/km^2, E2E latency at ms level, traffic volume density of tens of Gbps/km^2, and more than 500Km/hr mobility. These also include the energy, cost, and spectrum efficiency [150].

Five typical scenarios and services were identified by the group which includes *High traffic* (Office, Residential Area), *High density* (Stadium and Subways with 1 million connections/Km^2), *High mobility* (Highway, High-speed Train), *Mobile Internet services* (UHD Video Streaming, AR, Cloud Storage, VR), *IoT services* (Intelligent Transport System (ITS), Smart Home, Surveillance, Smart Grid)

In order to achieve the service requirements of mobile internet and IoT towards 2020 and beyond according to the white paper [151], IMT-2020 (5G) Group focused on four main technical scenarios (summarized in Table XX) which are:

- Seamless wide-area coverage,
- High-capacity hot-spot,
- Low-power massive-connections, and
- Low-latency high-reliability.

Seamless wide-area coverage: focuses on the provision of seamless mobile communications service to end-users at any time and anywhere.

High-capacity hot-spot scenario targets the provision of local hot-spot areas with ultra-high data rates to handle ultra-high volume traffic and users.

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Low-power massive-connections scenario main focus is on sensors for sensing and data collection UCs such as smart city, environmental monitoring, intelligent agriculture.

Low-latency high-reliability scenario's main focus is on vertical industries just like the Internet of Vehicles (IOV) and industrial control.

TABLE XX
SUMMARY OF IMT-2020 (5G) PG TECHNICAL SCENARIOS

Main Scenarios	Technical Scenarios	Key Capabilities
mobile internet	Seamless wide-area coverage	100 Mbps user experienced data rate
	High-capacity hot-spot	User experienced data rate: 1Gbps
		Peak data rate: Tens of Gbps
		Traffic volume density: Tens of Tbps/km²
IoT and vertical industries	Low-power massive-connections	Connection density: 1000000/km²
		Low power consumption & low cost
	Low-latency high-reliability	Air interface latency: 1 ms End-to-end latency: ms level Reliability: nearly 100%

H. 5G AMERICA (5G SERVICES INNOVATION)

5G Americas is a wireless industry trade organization comprising various telecommunications service providers as well as manufacturers. The mission focus is on advocating and encouraging the development, the advancement of LTE technologies, as well as the evolution to 5G and beyond, by promoting unified interoperability and convergence throughout the wireless network ecosystem, services, applications, and connected devices in the Americas [152].

5G Americas (known then as 4G Americas') published a white paper [153] on its recommendations for 5G requirements and solutions in 2014, as a foundation layout for the proposed future network of 5G. Regulatory considerations, UCs, market drivers, as well as the elements of the network potential technologies were examined. The key UCs defined for the North American perspective are as follows:

- Internet of Things (IoT)
  - Smart Grid and Critical Infrastructure Monitoring
  - Smart Cities
  - m-Health and Telemedicine
  - Automotive
  - Sports and Fitness
- Extreme Video, Virtual Reality, and Gaming Applications
- Explosive Increase in Density of Data Usage
- Public Safety
- PSTN Sunset
- Context-Aware Services

In 2019, 5G Americas released another white paper titled "5G Services Innovation" which classifies evolving services across a broad range of UCs, it highlighted in detail the various UCs that possibly will provide prospective new revenue flows for organizations and network service providers, the requirements and KPIs were highlighted, and the UCs are:

- Health Care
- Fixed Wireless Access
- Unmanned Aerial vehicles
- Non-Terrestrial networks in 5G
- XR – Augmented Reality (AR) & Virtual Reality (VR)
- Cloud gaming
- Smart grid

Health Care: Monitoring, diagnosis, and treatment through personal wearables. high-speed mobility communication between an ambulance and hospital(s). remote diagnosis and treatment.

Fixed Wireless Access: It is a cost-effective and efficient way of offering broadband connectivity to a broader population in suburban, rural, and urban areas.

Unmanned Aerial vehicles: Unmanned Aerial System (UAS) consists of the UAV as well as the UAV controller. 5G UAV offers Beyond-Visual-Line-of-Sight (BVLOS), useful for remote medicine, factory robotics, drones, and Unmanned Ground Vehicles (UGV).

Non-Terrestrial networks in 5G: Using the Low Earth Orbit (LEO) satellites and High-Altitude Platform Station (HAPS) systems to establish 5G Non-Terrestrial Network for rural or remote connectivity, agriculture, transportation, and public safety and disaster recovery.

XR-Augmented Reality & Virtual Reality: XR applications include all real-and-virtual combined environments and human-machine interactions generated by computer technology and wearables.

Cloud gaming: online playing of games that are computationally and graphical intensive, played based on network servers. Its key KPIs are low latency and high throughput.

Smart grid: focuses on the electricity grid wireless network for communication, substations monitoring, usage, remote status detection, transmission lines monitoring, among others. It consists of sensors, smart meters as well as the data management systems

VII. CLASSIFICATION AND MAPPING OF USE CASES

A summary study of the understudied UCs from various organization bodies developed for the IMT-2020 and beyond are presented in this section. Likewise, simulations of the average capacity of different spectrums proposed for the UCs were also presented and compared. Each UCs are developed to meet the certain objective(s) of the user or vertical demands for the future mobile communication generations, hence we classified the 5G UCs based on the different and similar organizations, recommended spectrum for the deployment of the UCs, identifying the IMT-2020 test environments and the usage scenarios derived by the 3GPP as shown in Table XXI.

Some factors determine the development of UCs, which include the proposed technology, the environment or scenarios for the deployment, type of UE or devices for connections, applications, and services. These require different system requirements for performance measurement. Likewise, Mobile networks function on various spectrums ranging from 450 MHz to 60 GHz, with different spectrums used for the different mobile generations [5].

For the NR of the 5G systems, frequency ranging from sub-6 GHz to that of the higher spectrum, that is (3300 MHz to 86 GHz) were identified for the IMT bands at the WRC-19 [74], The spectrums are divided into three groups of spectrums (already explained in detail in section III) namely: *Low-band spectrum* for frequency bands below 2 GHz, *Mid-band spectrum* lies between 3 – 6 GHz bands, and High-band spectrum uses above 24 GHz. Some UCs may rely on latency (ultra-low) while the others may rely on the speed of the download, likewise, others require connectivity that is either localized or nationalized, hence, the need for various spectrum as well as network resources. For instance, the services provided by broadband and Ultra-low latency operate on a different spectrum due to the incompatibility of the requirements of each radio resource.

TABLE XXI
CLASSIFICATION OF 5G USE CASES WITH RESPECT TO THE PROPOSED REQUIRED SPECTRUM FOR DEPLOYMENT

Use Cases	Organization Body	5G Usage scenarios	Required spectrum	IMT-2020 test environments
Dense urban	5GPPP, METIS-II, METIS-I, mmMAGIC, FANTASTIC-5G, MiWEBA, NGMN, 3GPP, Flex5Gware	eMBB URLLC	Low-, Mid- and High band	Urban Macro–mMTC
Massive public events and gatherings (marathon, stadium, open-air festival)	MiWaveS, NGMN, METIS, Flex5GWare, 5G-NORMA, 5GMF MmMAGIC, MiWEBA	eMBB mMTC	Low-, Mid- and High band	Dense Urban-eMBB Urban Macro–mMTC
Broadband (50+Mbps) everywhere	5G PPP, METIS-II, mmMAGIC 5G-NORMA, SPEED-5G, 3GPP Flex5GWare, NGMN	eMBB	Low- and High Band	Dense Urban-eMBB
Future smart offices	5G PPP, mmMAGIC, NGMN	eMBB	High-Band	Indoor Hotspot-eMBB
Virtual Reality Office	METIS-II METIS-I	eMBB	High-Band	Indoor Hotspot-eMBB
Connected vehicles	5G PPP, Flex5GWare, 3GPP, NGMN METIS-II	eMBB, URLLC mMTC	Low-, Mid-band	Urban Macro–URLLC
Shopping mall	METIS, MiWEBA, MiWaveS	eMBB	High-band	Indoor Hotspot-eMBB
Tactile internet /automation	5G PPP, METIS, FANTASTIC-5G NGMN, 3GPP	URLLC	Mid-band	Urban Macro–URLLC
Sensors and Actuators Network	3GPP, METIS-I, METIS-II, NGMN FANTASTIC-5G, 5G-NORMA 5G Americas	mMTC	Low-, Mid-band	Urban Macro–mMTC
Emergency communications	METIS-I, 5G-NORMA, 5GMF 3GPP, NGMN, 5G Americas	URLLC	Low-, Mid-band	Urban Macro–URLLC
Media on demand/ Media & Entertainment	METIS-I, mmMAGIC, 3GPP, 5G PPP METIS-II	eMBB	Mid-and High-band	Dense Urban-eMBB
eHealth	5G PPP, METIS-I, NGMN, 3GPP	URLLC	Mid-Band	Urban Macro–URLLC

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	5G Americas			
Internet of Things	5GPP, SPEED-5G, 3GPP, NGMN 5G Americas	URLLC mMTC	Low-band	Urban Macro–mMTC
Connectivity for UAV, Drones	METIS, 3GPP, NGMN, 5G Americas	URLLC eMBB	Low-, mid- and High-band	
Cloud services	MmMAGIC, NGMN, 3GPP	URLLC	Mid- and High-band	Urban Macro–URLLC
Real-time remote computing	METIS-I, 5G-NORMA, NGMN 3GPP	eMBB URLLC	Mid- and High-band	Urban Macro–URLLC
Hot spots (Dynamic or Moving)	IMT-2020 (5G) PG, mmMAGIC Flex5GWare, MiWEBA, MiWaveS 5GMF, NGMN, 3GPP	eMBB	Mid- and High-band	Dense Urban-eMBB
High speed train	FANTASTIC-5G, 5GMF, NGMN	eMBB	Low- and Mid-Spectrum	Dense Urban-eMBB Rural-eMBB
Traffic Control, efficiency and safety	METIS-I, FANTASTIC-5G, 3GPP 5G-NORMA, NGMN	eMBB, mMTC URLLC	Low-, mid-band	Urban Macro–URLLC
Broadcasting	FANTASTIC-5G, NGMN 3GPP	eMBB	Low- and Mid-band	Dense Urban-eMBB
Industrial Factories Control (Manufacturing, Construction)	5G-NORMA, 5GMF, 3GPP, 5G PPP NGMN, IMT-2020 (5G) PG	URLLC, eMBB mMTC	Mid- and high-band	Urban Macro–mMTC Urban Macro–URLLC
Smart Cities	5G PPP, Flex5GWare, NGMN IMT-2020 (5G) PG, 5G Americas	eMBB URLLC	Low- and Mid-band	Dense Urban-eMBB Urban Macro–URLLC
Smart Agriculture (Monitoring and self-driving vehicles)	5GMF, NGMN, 3GPP	mMTC eMBB	Low- and Mid-band	Urban Macro–mMTC
Robot Control	5GMF, NGMN, 3GPP	URLLC mMTC	Low-, mid-band	Urban Macro–mMTC Urban Macro–URLLC
Airplanes connectivity	NGMN, 3GPP	eMBB	Low-, mid-band	Urban Macro–URLLC
Blind Spots	METIS-I, 5G-NORMA	eMBB	Low-, mid-band	Rural-eMBB
Energy Sector (Smart Grids, Smart Meters)	5G PPP, METIS-II, METIS-I, NGMN 5G Americas	URLLC mMTC	Low-band	Urban Macro–mMTC
Automobile	5GMF, 5GPP, 5G Americas, METIS NGMN, IMT-2020 (5G) PG	eMBB URLLC	Low and High - band	Urban Macro–URLLC
Forest industry	METIS-I	eMBB mMTC	Low-, mid-band	Urban Macro–mMTC
5G Connectivity Using Satellites	3GPP, 5G Americas	eMBB URLLC	High- and Mid-band	Rural-eMBB
Wearable Device	NGMN, 3GPP	URLLC mMTC	Low- and Mid-band	Urban Macro–mMTC

Ultra-low cost networks	METIS-II, NGMN	eMBB	Low-, mid-band	Rural-eMBB
Ultra-reliable communications	mmMAGIC, SPEED-5G, 3GPP NGMN	URLLC	High- and Mid-band	Urban Macro–URLLC
Cloud Gaming	5G Americas, 5G PPP, METIS-II 5G NORMA	eMBB URLLC	High- and Mid-band	Urban Macro–URLLC

A. CHANNEL CAPACITY SIMULATIONS

Irrespective of the transmission medium (channel), every channel has its maximum transmission rate known as channel capacity, this is defined based on the channel's inherent properties and it is data content independent, measured in bits/second. [154]. In a wireless communication system, the channel capacity is an imperative QoS parameter especially for the various applications envisioned for 5G networks and future networks that require maximum data transmission capability. Channel capacity determines the maximum rate of data supportable with low error probability, hence, it is the measure of the spectral efficiency of that system [155], [156], [157]. The frequency bands at which the signal is been transmitted affect the channel capacity.

The 3GPP [158] has specified the channel models as well as the link-level for the NR, in which the frequency range 0.5 to 100 GHz was addressed. The capacity of a channel for transmitting signals is simulated and compared based on the *tri-spectrum* specified for the NR. The Clustered Delay Line (CDL) models of the MathWorks [159] were used to model the MIMO channels. The CDL model was implemented by the nrCDLChannel System object using the CDL-D models for the LoS links, MIMO multiplexing was implemented for the mmWave hence, evaluating the average channel capacity of the frequencies.

A LoS urban macro-cell outdoor scenario with single data stream transmission was assumed for the simulation to evaluate the feasible average channel capacity of the proposed *tri-spectrum* with respect to distances. The parameters used are stated in Table XXII. The Alpha-Beta-Gamma (ABG) [5] path loss model (equation (11)) was selected for modeling the mmWave channel, the parameter values were assumed and extracted from the manuscripts [160]–[164] that had carried out research and measurement on ABG path loss model are stated in Table XXII.

$$PL^{ABG}(f_c, d) = 10\alpha log_{10}\left(\frac{d}{d_0}\right) + \beta + 10\gamma log_{10}\left(\frac{f_c}{f_0}\right) + X_\sigma^{ABG} \quad (11)$$

$$where\ d \geq 1\ m\ and\ f \geq 1\ GHz$$

where the constant coefficients (α and γ) indicate the effect of frequency and distance on path loss, β is symbolized as an optimized offset value for PL, f is the carrier frequency and X_σ^{ABG} is a Gaussian random variable with a standard deviation of σ^{ABG}.

TABLE XXII
SIMULATION PARAMETERS

Parameters	Descriptions	Values
Transmitter	BS antenna height	30m
	Tx Power	35 dBm
Receiver	UE antenna height	1.5m
Frequency (GHz)	Low-band	0.9, 1.5, and 2 GHz
	Mid-band	3.5, 4.5, and 5.8 GHz
	High-band	32, 46, and 57 GHz
Path loss Model	ABG	$\alpha = 4.3, \beta = 55, \gamma = 1.7, X_\sigma^{ABG} = 4.3, f_c = 1000$

The average channel capacity for each of the spectrum in terms of "low-band, mid-band, and high-band" are simulated and compared. The parameters used for evaluating the MIMO channel capacity are stated in Table XXII, which included the transmitter power, antenna heights for both UE and BS, path loss model, and the different frequency used.

The channel capacity depends on the carrier frequencies. The average channel capacity of each band is plotted against distance. Figure 24 compared the possible average channel capacity of the listed frequencies (0.9, 1.5, and 2 GHz) of the low-band spectrum, Figure 25 compared the possible average channel capacity of the frequencies (3.5, 4.5, and 5.8 GHz) of the mid-band spectrum, while Figure 26 compared the possible average channel capacity of the frequencies (32, 46 and 57 GHz) of the high-band spectrum. Figure 27 compared the average channel capacity of the *tri-spectrum* at the lower bands of each spectrum while that of Figure 28 compared the upper frequency of the *tri-spectrum.*

The plotted Figures 24 -28 indicated how the average capacity of the wireless channel varies with respect to frequency and distance between the BS and UE. From Figures 27 and 28, it is seen that the channel capacity value is high with respect to the high carrier frequency likewise, the bandwidth also increased. This gives the possibility of providing the NR network with the required high throughput for various UCs. However, the capacity reduces as the distance between the BS and UE increases due to path loss as indicated in Figure 29.

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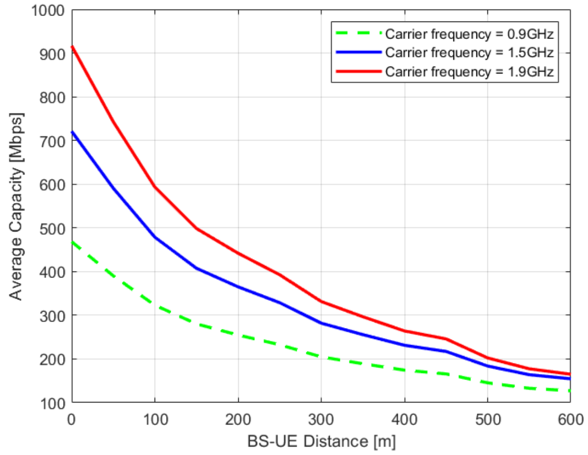

FIGURE 24. Average channel Capacity for the Low-band Spectrum

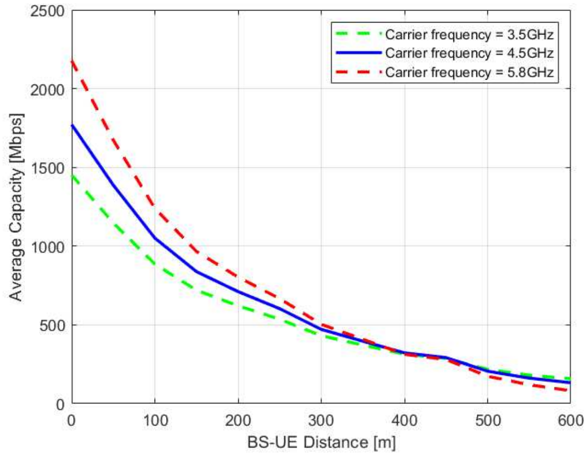

FIGURE 25. Average channel Capacity for the Mid-band Spectrum

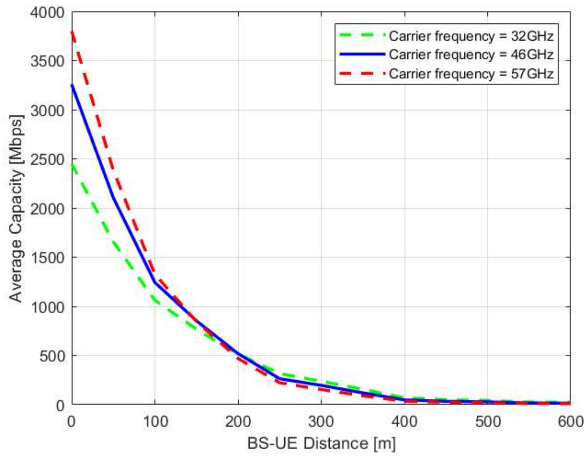

FIGURE 26. Average channel Capacity for the High-band Spectrum

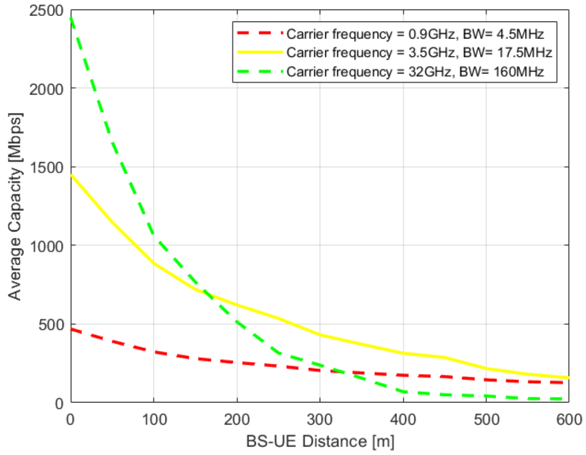

FIGURE 27. Average Channel Capacity of the Tri-Spectrum at Lower Bands

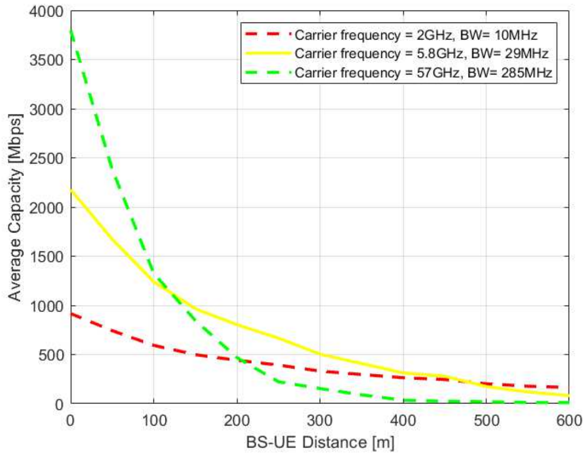

FIGURE 28. Average Channel Capacity of the Tri-Spectrum at Higher Bands

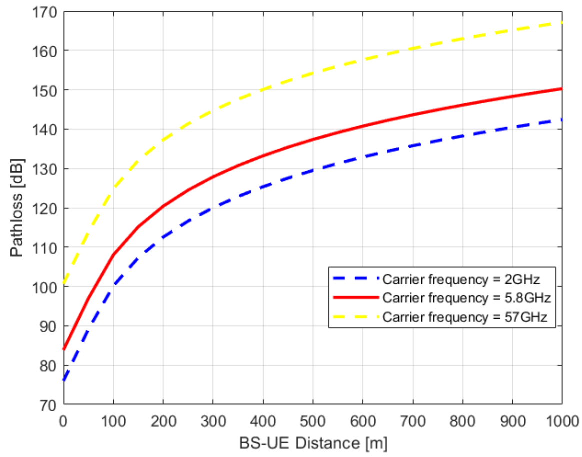

FIGURE 29. Path Loss of Signal at different Carrier Frequency

3GPP focus is on high speed with low latency and higher device density as the solution to the present mobile network. These are expected to be addressed by the 5G NR network.

In section six of this paper, the various UCs developed by SDO and other key players in mobile communication and were classified as shown in Table XXI. The spectrum for the deployment of each UCs was proposed based on the *tri-spectrum* and the 5G services which are the eMBB, mMTC, and URLLC. To meet these requirements, the 5G network would operate on a multi-layer (triple-layer) approach based on the scenarios and different service requirements. For instance, for a higher speed, the networks require higher carrier frequencies as shown in Figure 26, for UC that falls under the classified eMBB while coverage would be compromised, hence the need for a lower spectrum that is capable of delivering reasonable high speed (Figure 24 and 25) as well as wider coverage for UCs like the mMTC and URLLC.

VIII. CONCLUSION

5G is the beginning of a new era for mobile communication, intending to provide the necessary platform to meet the huge demanding services and applications that will pave the way for automated vehicles, smart cities, automated factories, and a new wave of business communications. The network can accommodate easily, a broader range of old as well as new UCs. A more comprehensive survey of the developed use cases from the key SDOs as well as the stakeholders in mobile telecommunications has been presented in this survey. Developing UC is essential in understanding the application and services supported by the network and evaluating the performance proposed by the new network, as new requirements are designed based on the use cases. The paper further presented an overview of the new 5G Architecture, which included the NR interface, 5GC, the NGRAN, minimum requirements as well the network fundamentals. A new spectrum had been proposed by the governing body to accommodate the future demand; hence, we proposed the required spectrum at which the services of the different use cases would be deployed based on the low-, mid-, and high-band spectrum as recommended by the governing body, the use cases were further classified with respect to their relevance and family, as well as mapping each use case to the IMT-2020 test environments and the usage scenarios derived by the 3GPP. Finally, the channel capacity of the proposed spectrum was studied, simulated, and compared to ascertain the spectrum proposed in this paper for each UC family. This survey serves as a guideline for researchers as well as operators in understanding the various developed use case for the future 5G network deployment.

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