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

OLAONIPEKUN OLUWAFEMI ERUNKULU, (Member, IEEE), ADAMU MURTALA ZUNGERU, (Senior Member, IEEE), CASPAR K. LEBEKWE, (Member, IEEE), MODISA MOSALAOSI, (Member, IEEE), AND JOSEPH M. CHUMA, (Member, IEEE)

Department of Electrical, Computer and Telecommunications Engineering, Botswana International University of Science and Technology, Palapye, Botswana

Corresponding author: Adamu Murtala Zungeru (zungerum@biust.ac.bw)

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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 future 5G deployment scenarios 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
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 momentarily 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, IPv4+6), Ethernet, and Unstructured. 5G networks will use softwareization 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.

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.

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].

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 SMF procedures and the session management functionalities are handled 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 mobility management functionalities 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.](image)

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].

![Figure 5. The essential role of SBI in the SBA.](image)

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 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].

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].

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-DU's 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].

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.

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].

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):

$$R_p = W \times SE_p$$ (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):

\[ R = \sum_{i=1}^{H} W_i \times SE_{pi} \]  

(2)

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

\[ R_{user} = W \times SE_{user} \]  

(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].

\[ R = \sum_{i=1}^{Q} W_i \times SE_{useri} \]  

(4)

where \( SE_{useri} \) (\( i = 1, \ldots, Q \)). The UEDR target values are stated in Table 1 for the downlink (DL) and uplink (UL).

4) 5th PERCENTILE USER SPECTRAL EFFICIENCY (PULSE)

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];

\[ r_i = \frac{R_i (T_i)}{T_i \times W} \]  

(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 1 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]:

\[ SE_{avg} = \frac{\sum_{i=1}^{N} R_i (T)}{T \times W \times M} \]  

(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 1 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 \( \left( N_{\text{drops}} \right) \). The value of each drop is \( \sum_{i=1}^{N} R_i (T) \) represented as: \( R_{(1)} (T), \ldots, R_{(N_{\text{drops}})} (T) \). Hence, the estimated ASE (7) is:

\[ \widehat{SE}_{avg} = \frac{\sum_{j=1}^{N_{\text{drops}}} R_{(j)} (T)}{N_{\text{drops}} \times T \times W \times M} = \frac{\sum_{j=1}^{N_{\text{drops}}} R_{(j)} (T)}{N_{\text{drops}} \times T \times W \times M} \]  

(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/m² has been set as the ATC’s target value in the downlink for the InH test environment. Equation (8) denotes
TABLE 1. 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 user spectral efficiency | bit/s/Hz | eMBB | lnH 0.3 | 0.21 |
| Area traffic capacity       | Mbit/s/m²              | eMBB           | lnH 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/km²            | mMTC           | 1,000,000          |
| Energy efficiency           | bit/Joule              | eMBB           | a qualitative and quantitative measure |
| Reliability                 |                        | URLLC          | 1-10⁻³ success probability |
| Mobility                    | bit/s/Hz (NTCLDR)      | eMBB           | lnH 1.5            | 10                  | Stat, Ped |
| Mobility time               | km/h (Mobility)        |                | DU 1.12            | 30                  | Stat, Ped, Veh |
| Mobility interruption       | ms                     | eMBB and URLLC | RU 0.8             | 120                 | Ped, Veh |
|                            |                        |                | 0.45               | 500                 | HS Veh |
| 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.

the ATC as it relates to ASE [14], and it is measured in Mbit/s/m²;

\[ C_{area} = \rho \times W \times SE_{avg} \] (8)

where \( \rho \) and \( W \) denote the TRxP density (TRxP/m²) 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:

a: 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 1 for the two usage scenarios (eMBB, URLLC). Its unit of measurement is ms.
**b: 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 1.

8) **CONNECTION DENSITY**
It describes 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 [14], [54]. 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. One million (1,000,000) connected devices per km$^2$ have been set as the minimum requirement in an urban environment.

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:

\[
EE_{global} = \sum_{scenaria} b_k EE_{scenarioK} \quad (9)
\]
\[
EE_{scenario} = \sum_{loadlevel1} a_1 \frac{V_1}{EC_1} \quad (10)
\]

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 1 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.

**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 operate on various spectrum types and bands, including the licensed, shared, and unlicensed, 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, and 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)

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 telecommunications 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 2. Shows several identified frequency bands for the IMT system globally in ITU Radio Regulations and their corresponding World Radiocommunication Conferences [64], [67].

| 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, URLLC, 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 3 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/km²) 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.

**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].

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 have been identified as a great interest to 5G deployment. It is suitable for the new 5G usage scenarios and implementation of massive MIMO. However, this 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 4, 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.

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.

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. 3GPP focused on the spectrum in the standardization process 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.

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...
designated by 3GPP for the NR bands [75]. 3300 - 4200 MHz is accepted globally, n77 and n78 were terrain characteristics at the point of deployment. The range limited due to the frequency bands in use and the physical or delivery of network coverage propagates further but could be to that of mmWave frequency bands. Likewise, the service line-of-sight (LoS) and non-line-of-sight (NLoS) compared in deploying small cells and pushing significant capacity in bandwidth per operator could be achieved [72]. This spectrum is favorable due to the channel propagation characteristics in line-of-sight (LoS) and non-line-of-sight (NLoS) 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, 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 3GPP designated n257 and n258 for the NR bands [75].

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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. Therefore, 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 the 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 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, NPs 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 NPs 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.

![Figure 15. Service-based network slicing based on the UE type [92].](image)

Each EU 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].

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].

![Figure 16. 5G network slices running on a common underlying multi-vendor and multi-access network [93].](image)

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.

SliceNet developed an NS framework that applies to multiple administrative domains to meet demanding UCs and 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. Although 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].

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 and the expected 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) is 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 5. However, deployment scenarios for three usage scenarios have been described in a recent report TR 38.913 Release 16 [110]. Table 6 summarized the scenarios indicating the key characteristics and application location of the deployment scenarios.

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:

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].

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 telecommunication 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:
TABLE 6. 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/TRAP 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 |

TABLE 6. (Continued.) Summary of IMT-2020 the scenarios indicating key characteristics and application location of the deployment scenarios.

| Satellite Communication services provision of services for data and voice, machine-type communications, broadcast, and other delay tolerant services. |
| Terrestrial extension to terrestrial service and broadcasting service |

- 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 5 and 6, respectively. While a few of the developed UCs that covers different scenarios as well as the identification of the correlated high-level proposed requirements, were stated in this 3GPP technical report [98], Table 7 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
### TABLE 7. 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  
**Latency:** Very low, even for high speed, reliable low-latency connectivity  
**Traffic density:** High such as Tbps/km²  
**Connection density:** High density for UE with up to 2500/km² and 2000/km² with 50 active UEs simultaneously  
**Mobility:** From 0-500km/h, Very high traffic, high bit rate. No Reliability needed, no accuracy need | Mobile broadband for indoor scenario  
Mobile broadband for hotspots scenario  
Broadcasting Support  
Wireless Local Loop  
On-demand networking  
Improvement of network capabilities for vehicular case  
Mobile broadband services with seamless wide-area coverage  
Broadband Direct Air to Ground Communications  
Connectivity Everywhere  
Wireless Local Loop  
SG Connectivity Using Satellites  
Virtual presence  
Higher User Mobility  
Vehicular Internet & Infotainment | Higher Data Rates, Higher Density, Deployment, and Coverage  
Higher Data Rates, Higher Density, Higher User Mobility  
Higher Data Rates  
Deployment and Coverage, Higher User Mobility  
Deployment and Coverage  
Deployment, Coverage, Higher reliability and lower latency  
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])  
**Reliability:** Ultra-high reliability, high availability  
**Packet loss rate:** ≤ 1e-4; 8 ms deliverable  
**Traffic density:** high density distribution such as 10,000 sensor/10km²  
**Position accuracy:** Position accuracy target: 10 cm in densely populated environments.  
Characterized by low latency, ultra-high reliability | Ultra-reliable communication  
Virtual presence (duplicate in eMBB)  
Remote control  
Cloud Robotics  
Industrial Factory Automation  
Industrial Process Automation  
Low-delay speech coding  
Telemedicine Support  
Connectivity for drones  
Industrial control  
Moving ambulance and bio-connectivity  
Tactile Internet  
Localized real-time control  
Extreme real-time communications and the tactile Internet  
Remote control  
Materials and inventory management and location tracking  
High Accuracy Enhanced Positioning (ePositioning)  
*SG 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  
SG Connectivity Using Satellites  
Local UAV Collaboration | Higher reliability and lower latency  
Higher reliability, higher availability and lower latency, Higher accuracy positioning, Mission critical services  
Higher reliability, higher availability, and lower latency  
Very low latency  
Higher accuracy positioning  
Higher availability  
Critical mission services  
Critical mission services, Higher accuracy positioning, Higher reliability, and lower latency |
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
- 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 8 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.

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

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**TABLE 7. (Continued.) Use cases considered by 3GPP.**

| Use cases considered by 3GPP. | Comm. Efficiency: | Lightweight device configuration | Operational Aspects |
|--------------------------------|------------------|---------------------------------|---------------------|
| Low power devices (smart meter) achievement by enhancement of coverage, resource efficiency as well as signalling. | Medium Rate; 10 Mbps/UE | IoT Device Initialization |                          |
| Traffic density: High density due to massive connections like 1,000,000 connections/km², for simultaneous transmission of information for locally dense devices. | Latency: Low latency; E2E latency of 1ms | Subscription security credentials update |                          |
| Position accuracy: High for outdoor and indoor scenarios (set at such as 0.5m) | Reliability: High Reliability of almost 100% | Wearable Device Communication |                          |
| Connection density: MTC cases for Low mobility | Traffic density: Medium | Massive Internet of Things (M2M) and device identification |                          |
| Data Rate: | Medium Connection density: Medium (10k vehicles or more in scenarios with multiple lanes and multiple levels and types of roads) | Diversified Connectivity |                          |
| Mobility: High (up to 500 KM/h). | Position accuracy: High (0.1m) | Wearable Device Charging |                          |
| Enhancement of Vehicle-to-Everything (eV2E) | *Mobile broadband services with seamless wide-area coverage (eMBB replica) | Devices with variable data | *Improvement of network capabilities for vehicular case (eMBB replica) |
| | *Materials and inventory management and location tracking | Domestic Home Monitoring | Connected vehicles |
| | | Bio-connectivity | |
projects. It was initiated to develop the overall NG-RAN design, deliver the needed technical enablers for the effective 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 9 summarizes the METIS-II 5G UCs

| 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                                                                  |
| Broadband everywhere   | high availability for xMBB, Emphasis on suburban, rural, and high-speed trains, and areas with limited infrastructure | 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 |
| 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                                             |
| Tactile internet       | Ultrareliable communication with xMBB                                     | Energy: Grid access                                                                  |
| /automation            |                                                                          | eHealth: Remote health monitoring and data                                            |
|                        |                                                                          | 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                                             |
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 systems 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).

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

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 10, which have been used to evaluate the technology components developed in the project.

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

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 11, including the 5G Services key capability and requirements for

### Table 10. 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 Sensors and Actuators | mMTC | A very large number of devices with low data rate and energy efficiency |
| 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)   |
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-5G 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 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].](image-url)

### TABLE 10. (Continued.) METIS-I use cases.

| UC Group                        | Use Cases                                      | Key capability                                      |
|--------------------------------|------------------------------------------------|-----------------------------------------------------|
| Unmanned aerial vehicles xMBB  | Drones with high data rate, in areas with limited infrastructure | Media content indoor user in dense area with high data rate and low latency |
| Remote tactile interaction uMTC| Remote access (surgery, driving, flying, AR requires very low latency and no mobility) | Cloud services, Outdoor and larger indoor areas using interactive applications, needs high traffic density and mobility, User data rate |
| eHealth                        | uMTC                                           | Dense urban society with distributed crowds           |
| Ultra-low-cost 5G network xMBB | Low cost of Internet access with a high data rate | In urban dense areas with variable user density and demands having high traffic density and low latency |
| Remote car sensing and control mMTC| Automotive applications, control of a large number of devices at low data rate and low power consumption | Smart offices, Indoor communications (homes and office buildings) with high density of devices hence high user data rate and traffic density |
| Forest industry on the remote control xMBB, uMTC| Forest remote control service with a large number of devices, high data rate, and low latency | Immersive early 5G experience in targeted coverage, Dense urban traffic hotspots, outdoor-to-indoor and indoor-to-indoor deployment |

![Concept for mobile RAT](image-url)

### TABLE 11. Summary of mmMAGIC use cases.

| UC Group                        | Use Cases                                      | Key capability                                      |
|--------------------------------|------------------------------------------------|-----------------------------------------------------|
| Broadband access in a dense area Media 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 distributed crowds | In urban dense areas with variable user density and demands having high 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 |
| High Mobility Users Moving Hotspots | High data rate across the coverage area using ultra-dense network |
| Extreme real-time or ultra-reliable communication Tele-control techniques | Access for moving crowds, vehicles, high-speed trains, and aircraft having high mobility |
| Tactile internet, remote surgery Connectivity in ultra-reliable and ultra-low latency for extreme real time communication at near error-free transmission | |

3) FANTASTIC-5G

FANTASTIC-5G (Flexible Air iNterFace for Scalable service delivery wiThin wRcategoria 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].

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-5G 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 12 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.

5G NORMA further grouped and classified the UCs as follows: Service-Application related UCs; Coverage-Capacity related UCs; Performance related UC: Table 13 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.

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

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**TABLE 12. 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 |
| 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 2E latency, reliability, Coverage, and security |
| Automatic traffic control/driving | MCC V2X | + Automotive 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 |
TABLE 13. Summary of 5G NORMA use cases.

| UC family                  | Use cases          | Scenario framework | Descriptions                                                                 |
|---------------------------|--------------------|--------------------|-----------------------------------------------------------------------------|
| Service-Application       | Industry control   | Multi-tenant       | Wireless monitoring and control of Industrial process in a limited physical area and controlled environment. |
| related                   |                    | Multi-service      | Latency Reliability Number of connected devices High uplink data rates         |
| Enhanced Broadband        | Mobile communications | 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      | transport entities, to improve traffic safety, assist drivers with real-time information about road and traffic conditions |
| Sensors Network Monitoring, |                    | Multi-tenant       | control and monitoring a wide area for a particular measured property (temperature, motion, vibration, air quality, moisture, radiation) |
|                           |                    | Multi-service      |                                                                                            |
| 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      | 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      | 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      | + 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      | + 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      | 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) |

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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 IoT communications (mIoT)
- Broadband wireless

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.

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.
- Ultra-Reliable Communications (URC)
- High-Speed mobility

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

Massive IoT communications: 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 14 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.

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 15.
TABLE 15. FlexSGware 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 50+ Mbps everywhere | Connected vehicles                | 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 |
|                                  |                                   | Has two types of traffic: mobile broadband traffic, triggered by humans’ mobile devices and machine initiated traffic, focuses on the vehicle to enable automatic driving that is Vehicle to Everything communication | mobile broadband traffic: mobile data volume, number of users machine initiated traffic: resiliency, latency, and mobile data volume |

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 16. 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
Table 16. 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 |

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].

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 transportsations, furthermore, access nodes deployment in main streets for fast mobile users in cars and public transportsations. The 3 considered use cases in relation to the specified UCs in the D1.1 deliverable are summarized in Table 17.

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.

- **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)

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
TABLE 17. 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                                                                     | Street canyon street-level urban scenario with high capacity mmWave APs microcell layout |
|          | UMi open square            | Dense hotspot in a square                                                                      | A large and open square in an urban scenario with high capacity mmWave APs microcell layout |
|          | UMa                       | Dense hotspot urban areas                                                                      | Urban scenario with intends to increase coverage and capacity using mmWave APs macrocell layout. |
|          | 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                                                                             | Deployment of high-speed wireless connectivity via mmWave APs in a small isolated room to users |
|          | Indoor shopping mall       | Dense hotspot shopping mall                                                                    | Deployment of high-speed wireless connectivity via mmWave APs in large halls and shops with nomadic users |

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 18 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.

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...
| UC family | Use cases | Descriptions | Key capabilities |
|-----------|-----------|--------------|------------------|
| Entertainment | Enhanced real experience | Experience sharing scenario, Simulated Experience 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 Anti-Crime System with Image | Emergency and Anti-Crime System with Image | Criminal monitoring and tracking via videos | Peak data rate, Latency, Mobility, Connection density, Area traffic capacity,
TABLE 18. (Continued.) Summary of the 5GMF UCs and list of required capabilities of individual UCs.

| UC Category                              | Required Capabilities                                                                 |
|------------------------------------------|---------------------------------------------------------------------------------------|
| Disaster relief                          | Recognition of video information to determine any suspicious activity                  |
| Enhanced Emergency Call, Large Scale Disaster Rescue Network | Automatic emergency calls from an incident event. Delivering patient’s vital data and video image by the ambulance, on route to the hospital. Uploading of accident scene information. |
| 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 |

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 19.

Broadband access in dense areas: focused on everyday life availability of service in densely-populated areas (with thousands of people per Km²) for a fully connected society like events and multi-storey 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,
TABLE 19. Summary of the NGMN use cases.

| UC Families | Categories | Use cases | Descriptions | Key Capabilities |
|-------------|------------|-----------|--------------|------------------|
| 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 |
| Indoor ultra-high broadband access | Smart Office | Diversified and customized cloud services to offer mobile “Smart life” experience to users | User Experienced Data Rate |
| | | High traffic demand and user density at urban outdoor | DL: 1Gbps, UL: 500Mbps |
| | | E2E Latency: 10ms |
| | | Mobility: Pedestrian |
| | | Connection Density: 75,000 /km² (75/1000 m² office) |
| | | Traffic Density: DL: 15 Tbps/km² (15 Gbps / 1000 m²) |
| | | UL: 2 Tbps / km² (2 Gbps / 1000 m²) |
| | | User Experienced Data Rate |
| | | DL: 25MbpsUL: 50Mbps |
| | | E2E Latency: 10ms |
| | | Mobility: Pedestrian |
| | | Connection Density: 150,000 / km² (30,000 / stadium) |
| | | Traffic Density: DL: 3.75 Tbps/km² (DL: 0.75 Tbps/stadium) UL: 7.5 Tbps/km² (1.5 Tbps/stadium) |
| 50+ Mbps everywhere | 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 |
| 50 Mbps everywhere | | DL: 50Mbps UL: 25Mbps |
| 50 Mbps minimum user data rate broadband access coverage area everywhere | | E2E Latency: 10ms |
| | | Mobility: 0-120 km/h |
| | | Connection Density: 400/ km² in suburban 100/ km² in rural |
| | | Traffic Density: DL: 20Gbps/km² and UL: 10Gbps/km² in suburban |
| | | DL: 5Gbps/km² and UL: 2.5Gbps/km² in rural |
| Broadband access everywhere | Ultra-low cost broadband access for low ARPU areas | 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 / km² |
| 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 | Traffic Density: 16 Mbps / km² |
|------------------------------|------------------|-------------------------------------------------------------------------------------------------|------------------------------|
| Moving Hot Spots             | Non-stationary, dynamic, and real-time provision of capacity to moving vehicles or crowds with capacity variation | User Experienced Data Rate: DL: 500Mbps UL: 25Mbps |
| Remote computing             | On the go, at high speeds stationary or low-mobility remote computing. Remote processing of automotive & transportation industry | E2E Latency: 10ms |
| High user mobility           | 3D Connectivity: Aircrafts | Commercial connectivity services for aircraft/helicopters and passenger services for a live sporting event such as balloonists, gliders, or skydivers. | Mobility: On-demand, 0-500km/h |
| Airplanes connectivity       | Consisting of multiple types of ultra-light, low power, waterproof sensors integrated into clothing to measure various environmental and health attributes | Connection Density: 2000/km² (500 users/train x 4 trains, or a user/car x 2000 cars) |
| Massive Internet of Things   | Smart wearables(clothes) | User Experienced Data Rate: DL: 100 Gbps/km² (25 Gbps/train, 50 Mbps/car), UL: 50 Gbps /km² (12.5 Gbps/train, 25 Mbps/car) |
| Sensor networks              | Smart services in urban areas suburban and rural areas such as metering, city/building lights management, environment monitoring, and vehicle traffic control. | E2E Latency: 10ms |
| Broadband MTC                | Mobile video surveillance | Mobility: On demand, 0-1000km/h |
| 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. | Connection Density: Up to 200,000/km² |
| Extreme real time communications | Ultra-low latency | User Experienced Data Rate: DL: 100 Gbps UL: 50Mbps |
| 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. | E2E Latency: <1ms |
| Resilience and traffic surge | Natural disaster | Mobility: Pedestrian |
| Provision of robust communications in natural disasters such as earthquakes being able to signal location/presence for response | Connection Density: Not critical |
| Lifeline communications      | | Traffic Density: Potentially high |
|                              | User Experienced Data Rate | DL: 0.1-1Mbps UL: 0.1-1Mbps |
|                              | E2E Latency: not critical | Mobility: 0-120 km/h |
TABLE 19. (Continued.) Summary of the NGMN use cases.

| Use Case                      | Connection Density | Traffic Density | User Experienced Data Rate | DL: | UL: |
|-------------------------------|--------------------|----------------|---------------------------|-----|-----|
| **Ultra-high reliability & Ultra-low latency** |                   |                |                           | 50 kbps - 10 Mbps | up to 10 Mbps |
| Automatic traffic control/driving | Vehicle-to-vehicle, vehicle-to-infrastructure, communication with pedestrians and cyclists, controlled fleet driving |                   |                           | 50 kbps | 10 Mbps |
| Collaborative robots: A Control Network for Robots | Automation of jobs with repetitive tasks such as production, transportation, and also within the services industry. |                   |                           | 1 ms | 10 ms |
| Remote object manipulation – Remote surgery | Mobile remote surgery in such as ambulances, disaster-response, and in remote areas. |                   |                           | On demand, 0-500km/h | On demand, 0-500km/h |
| 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. |                   |                           | On demand, 0-500km/h | On demand, 0-500km/h |
| Public safety | Sending of real-time video and high-quality pictures for emergency services on land, sea, air, in-building, basements, and subway systems. |                   |                           | On demand, 0-500km/h | On demand, 0-500km/h |
| 3D Connectivity: Drones | Ubiquitous coverage for both terrestrial and up-in-the-air locations. Remotely control of drones using 5G communication. |                   |                           | On demand, 0-500km/h | On demand, 0-500km/h |
| **Broadcast like services** | Broadcast services like 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 | Up to 200 Mbps | Modest (500 kbps) |
| 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 | DL: | E2E Latency: | Mobility: | Connection Density and Traffic Density are irrelevant. |

- **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.

- **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/km², E2E latency at ms level, traffic volume density of tens of Gbps/km², 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/Km²), **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 20) which are:

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

**Seamless wide-area coverage**: focuses on the provision of seamless mobile communications service to end-users at anytime 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.

**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.

### 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**

#### TABLE 20. 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 |
| IoT and vertical industries | Low-power massive-connections | Connection density: 100,000,000/km² |
| | Low-latency high-reliability | Air interface latency: 1 ms |

End-to-end latency: ms level
Reliability: nearly 100%
• 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 21.

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.

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]–[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 22. 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 22.

\[ PL_{ABG}(f_c, d) = 10\alpha \log_{10}\left(\frac{d}{d_0}\right) + \beta + 10\gamma \log_{10}\left(\frac{f_c}{f_0}\right) + X_{ABG}^{\sigma} \]

where \( d \geq 1m \) and \( f \geq 1GHz \)

(11)
### TABLE 21. Classification of 5G use cases with respect to the proposed required spectrum for deployment.

| Use Cases                        | Organization Body | SG scenarios                          | Usage | Required spectrum | IMT-2020 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) | MiWave5, NGMN, METIS, Flex5Gware, 5G-NORMA, 5GMF | eMBB | Low-, Mid- and High-band | Dense Urban–eMBB |
| Broadband everywhere (50+Mbps) | 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            | eMBB | High-Band | Indoor Hotspot–eMBB |
| Connected vehicles              | 5G PPP, Flex5Gware, 3GPP, NGMN | eMBB, URLLC | Low-, Mid-band | Urban Macro–URLLC |
| Shopping mall                    | METIS, MiWEBa, MiWave5 | mMTC | High-band | Indoor Hotspot–eMBB |
| Tactile internet/automation     | 5G PPP, METIS, FANTASTIC-5G, NGMN, 3GPP | ULRC | 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 | UURLC | 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, 5G Americas | UURLC | Mid-Band | Urban Macro–URLLC |
| Internet of Things              | 5GPP, SPEED-5G, 3GPP, NGMN, 5G Americas | UURLC | Low-band | Urban Macro–mMTC |
| Connectivity for UAV, Drones     | METIS, 3GPP, NGMN, 5G Americas | UURLC | Low-, mid- and High-band | Urban Macro–URLLC |
| Cloud services                  | MiMAGIC, NGMN, 3GPP | UURLC | Mid- and High-band | Urban Macro–URLLC |
| Real-time remote computing      | METIS-I, 5G NORMA, NGMN, 3GPP | eMBB | Mid- and High-band | Urban Macro–URLLC |
| Hot spots (Dynamic or Moving)    | IMT-2020 (5G) PG, mmMAGIC, Flex5Gware, MIWEBa, MiWave5, 5GMF, NGMN, 3GPP | eMBB | Mid- and High-band | Dense Urban–eMBB |
TABLE 21. (Continued.) Classification of 5G use cases with respect to the proposed required spectrum for deployment.

| High speed train | FANTASTIC-SG, 5GMF, NGMN | eMBB | Low- and Mid- Spectrum | Dense Urban-eMBB | Rural-eMBB |
|------------------|--------------------------|------|------------------------|------------------|-----------|
| Traffic Control, efficiency and safety | METIS-I, FANTASTIC-SG, 3GPP | eMBB, mMTC | Low-, mid-band | Urban Macro–mMTC | Urban Macro–URLLC |
| 5G-NORMA, NGMN | | | | | |
| Broadcasting | FANTASTIC-SG, NGMN | eMBB | Low- and Mid-band | Dense Urban-eMBB | |
| 3GPP | | | | | |
| Industrial Factories Control | 5G-NORMA, 5GMF, 3GPP, 5G PPP | URLLC, eMBB | Mid- and high-band | Urban Macro–mMTC | Urban Macro–URLLC |
| (Manufacturing, Construction) | NGMN, IMT-2020 (5G) PG | mMTC | Low- and Mid-band | | |
| Smart Cities | 5G PPP, FlexSGWare, NGMN | eMBB | Low- and Mid-band | Dense Urban-eMBB | |
| IMT-2020 (5G) PG, 5G Americas | URLLC | | Urban Macro–URLLC | | |
| Smart Agriculture | 5GMF, NGMN, 3GPP | mMTC | Low- and Mid-band | Urban Macro–mMTC | |
| (Monitoring and self-driving vehicles) | | | | | |
| Robot Control | 5GMF, NGMN, 3GPP | URLLC | 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 | URLLC | Low-band | Urban Macro–mMTC | |
| 5G Americas | | | | | |
| Automobile | 5GMF, 5GPP, 5G Americas, METIS | eMBB | Low and High - band | Urban Macro–URLLC | |
| NGMN, IMT-2020 (5G) PG | URLLC | | | | |
| Forest industry | METIS-I | eMBB | Low-, mid-band | Urban Macro–mMTC | |
| | | | | | |
| 5G Connectivity Using Satellites | 3GPP, 5G Americas | eMBB | High- and Mid-band | Rural-eMBB | |
| Wearable Device | NGMN, 3GPP | URLLC | Low- and Mid-band | Urban Macro–mMTC | |
| | | | | | |
| Ultra-low cost networks | METIS-II, | eMBB | Low-, mid-band | Rural-eMBB | |
| NGMN | | | | | |
| Ultra-reliable communications | mmMAGIC, SPEED-5G, 3GPP | URLLC | High- and Mid-band | Urban Macro–URLLC | |
| NGMN | | | | | |
| Cloud Gaming | 5G Americas, 5GPPP, METIS-II | eMBB | High- and Mid-band | Urban Macro–URLLC | |
| 5G NORMA | URLLC | | | | |

where the constant coefficients ($\alpha$ and $\gamma$) indicate the effect of frequency and distance on path loss, $\beta$ is symbolized as an optimized offset value for PL, $f$ is the carrier frequency and $X_{ABG}^\sigma$ is a Gaussian random variable with a standard deviation of $\sigma_{ABG}^\sigma$.

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 22, 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
TABLE 22. Simulation parameters.

| Parameters | Descriptions        | Values                  |
|------------|----------------------|-------------------------|
| Transmitter| BS antenna height    | 30m                     |
|            | Tx Power             | 35 dBm                  |
| Receiver   | UE antenna height    | 1.5m                    |
| Frequency  | Low-band (GHz)       | 0.9, 1.5, and 2 GHz     |
|            | Mid-band (GHz)       | 3.5, 4.5, and 5.8 GHz   |
|            | High-band (GHz)      | 32, 46, and 57 GHz      |
| Path loss  | α = 4.3, β = 55, γ = 1.7, X_{ABG} = 4.3, f_c = 1000 |

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.

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.

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 21. The spectrum for the deployment of each UCs was proposed based on
Developing UC is essential in understanding the application mobile telecommunications has been presented in this survey. Cases from the key SDOs as well as the stakeholders in UCs. A more comprehensive survey of the developed use cases was 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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FIGURE 28. Average channel capacity of the tri-spectrum at higher bands.

FIGURE 29. Path loss of signal at different carrier frequency.

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, and 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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OLAONIPEKUN OLUWAFEMI ERUNKULU (Member, IEEE) received the B.Eng. degree in electrical and computer engineering and the M.Eng. degree in communications engineering from the Federal University of Technology Minna, Nigeria, in 2004 and 2016, respectively. He is currently pursuing the Ph.D. degree with the Electrical, Computer and Telecommunications Department, Botswana International University of Science and Technology, Palapye, Botswana. He is also currently a Lecturer at the Department of Computer Engineering, Federal University of Technology Minna.

ADAMU MURTALA ZUNGERU (Senior Member, IEEE) received the B.Eng. degree from the Federal University of Technology Minna, Nigeria, the M.Sc. degree from the Ahmadu Bello University, Zaria, Nigeria, and the Ph.D. degree from Nottingham University, U.K. He was a Research Fellow at the Massachusetts Institute of Technology (MIT), USA, where he also obtained the Postgraduate Teaching Certificate, in 2014. He is currently serving as a Professor and the Head of the Department of Electrical, Computer, and Telecommunications Engineering, Botswana International University of Science and Technology (BIUST). Before joining BIUST in 2015, he was a Senior Lecturer and the Head of the Electrical and Electronics Engineering Department, Federal University Oye-Ekiti, Nigeria. He is an Engineer registered with the Council for the Regulation of Engineering in Nigeria (COREN), a Professional Engineer registered with the Botswana Engineers Registration Board (ERB), and a Member of the Association for Computing Machinery (ACM), USA. He is the inventor of a Termite-hill routing algorithm for Wireless Sensor Networks and has three of his patent applications registered with the World Intellectual Property Organization (WIPO). He has also authored five Academic books and over 60 international research articles in reputable journals, including the IEEE SYSTEMS JOURNAL, IEEE INTERNET OF THINGS JOURNAL, IEEE ACCESS, JNCA (Elsevier), and others with over 1000 citations and an H-index of 15. He has also served as an International Reviewer for IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, IEEE SENSORS JOURNAL, IEEE ACCESS, IEEE TRANSACTIONS ON MOBILE COMPUTING, IEEE TRANSACTIONS ON SUSTAINABLE COMPUTING, JNCA (ELSEVIER), and numerous others. He has also served as the Chairman of the IEEE Botswana Sub-Section, from 2019 to 2020.

CASPAR K. LEBEKWE (Member, IEEE) received the M.Eng. degree in electronics and communications engineering, in 2008, and the Ph.D. degree in electrical and electronics engineering, sponsored by the General Lighthouse Authorities, from the University of Bath. His Ph.D. Project was focused on eLoran service volume coverage prediction. He is currently a Lecturer at Botswana International University of Science and Technology, where he teaches optical communications, antennas and propagation, discrete mathematics, telemetry, remote control, and electromagnetic field theory.

MODISA MOSALAOISI (Member, IEEE) received the B.Sc. degree in electrical engineering and the M.Sc.Eng. and Ph.D. degrees in electronic engineering from the University of KwaZulu-Natal, Durban, South Africa, in 2009, 2015, and 2017, respectively. He is currently a Lecturer with the Botswana International University of Science and Technology (BIUST). His research interests include power line communication, RF and microwave propagation, free-space optics, and green power technologies. He is a member of the IEEE-HKN Mu Eta Chapter.

JOSEPH M. CHUMA (Member, IEEE) received the Ph.D. degree in electronic systems engineering from the University of Essex, in 2001. He was with the University of Botswana as an Associate Professor and the Dean of the Faculty of Engineering and Technology. He has served as the Acting Deputy Vice-Chancellor of Research, Development, and Innovation. He has over 24 years of experience in teaching and research, consultancy, and human resources development in telecommunication, computer, and electrical and electronics engineering in CISCO computer networking. He is currently a Full Professor and serving as the Substantive Dean of the Faculty of Engineering and Technology, Botswana International University of Science and Technology. He has authored or coauthored three books, three book chapters, and many refereed published scholarly/scientific journal articles in the subject of telecommunications engineering. He holds three patents. He is a member of several professional bodies, among which includes the IET, U.K.; and BIE, Botswana. He is a Professional Engineer registered with the Botswana Engineers Registration Board.

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