IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received September 13, 2020, accepted October 8, 2020, date of publication October 15, 2020, date of current version May 12, 2021.

Digital Object Identifier 10.1109/ACCESS.2020.3031234

A Survey on Beyond 5G Network With the Advent of 6G: Architecture and Emerging Technologies

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This work was supported by the 5G and IoT Lab, SoECE, TBIC, TEQIP-III at Shri Mata Vaishno Devi University, Katra, Jammu.

ABSTRACT Nowadays, 5G is in its initial phase of commercialization. The 5G network will revolutionize the existing wireless network with its enhanced capabilities and novel features. 5G New Radio (5G NR), referred to as the global standardization of 5G, is presently under the 3rd Generation Partnership Project (3GPP) and can be operable over the wide range of frequency bands from less than 6GHz to mmWave (100GHz). 3GPP mainly focuses on the three major use cases of 5G NR that are comprised of Ultra-Reliable and Low Latency Communication (uRLLC), Massive Machine Type Communication (mMTC), Enhanced Mobile Broadband (eMBB). For meeting the targets of 5G NR, multiple features like scalable numerology, flexible spectrum, forward compatibility, and ultra-lean design are added as compared to the LTE systems. This paper presents a brief overview of the added features and key performance indicators of 5G NR. The issues related to the adaptation of higher modulation schemes and inter-RAT handover synchronization are well addressed in this paper. With the consideration of these challenges, a next-generation wireless communication architecture is proposed. The architecture acts as the platform for migration towards beyond 5G/6G networks. Along with this, various technologies and applications of 6G networks are also overviewed in this paper. 6G network will incorporate Artificial intelligence (AI) based services, edge computing, quantum computing, optical wireless communication, hybrid access, and tactile services. For enabling these diverse services, a virtualized network slicing based architecture of 6G is proposed. Various ongoing projects on 6G and its technologies are also listed in this paper.

INDEX TERMS 5G, 5G NR, eMBB, mMTC, uRLLC, EVM, inter-RAT, 6G, network slicing, Tactile Internet.

I. INTRODUCTION

The 5G networks are emerging as the foundation for industrial transformation in terms of digitalization and advance communication. It has promised to provide reliable services at ultra-high speed with very low latency. 5G will deliver both fixed as well as mobile broadband services anywhere to anyone at any time. Previous generation wireless network has various challenges related to the data rates, connectivity, and latency. For example, the 4G LTE-A system ensures the DL data rate of up to 3Gb/s and UL data rate up to 1.5Gb/s with the connectivity of 600 users per cell approximately and latency of around 30-50 milliseconds [1]. Due to these challenges, 4G networks were not capable of supporting various applications like VR, AR, HD screening, video conferencing, and 360° video streaming. Whereas in the 5G network, these challenges are mitigated by introducing various new features, services, and technologies. The technologies of 5G network are Massive MIMO, mmWave, Full-duplex Radio, D2D communication, UDN, Multi-RAT, and Cognitive Radio. In [1], the author has surveyed several eminent technologies of 5G network and on the basis of these technologies, a 5G architecture is proposed. These technologies have opened up many possibilities to fulfill the requirements of 5G given in Table 1. These requirements are defined as the 2020 minimum requirements laid by the ITU [2].

In order to achieve the requirements of the 5G network, an entirely new radio air interface has been developed, that is named as the 5G New Radio or 5G NR air interface. For defining the 5G standard properly, the 3GPP in its two

The associate editor coordinating the review of this manuscript and approving it for publication was Wei Yu.

TABLE 1. Various technical requirements that are laid by ITU as 2020 minimum requirements [2].

Metric	Requirement
Peak data rate	20 Gb/s for DL 10 Gb/s for UL.
Peak spectral efficiency	30 bps/Hz for DL 15 bps/Hz for UL
Area Traffic Capacity	10 Mb/s/m^2 for indoor hotspot DL
User plane latency	4ms for eMBB 1ms for uRLLC
Control plane latency	20ms (10ms as lower control plane latency)
Connection density	1M devices/km^2
User experienced data rate	100 Mbps for DL 50 Mbps for UL
Bandwidth	greater than 100 MHz up to 1GHz for above 6 GHz
Reliability	1-10^{-5} success probability.
5th Percentile User Spectral Efficiency	For Indoor Hotspot (0.3 bps/Hz for DL, 0.21 bps/Hz for UL)
	For Dense Urban (0.225 bps/Hz for DL, 0.15 bps/Hz for UL)
	For Rural (0.12 bps/Hz for DL, 0.045 bps/Hz for UL)
Average Spectral Efficiency	For Indoor Hotspot (9 bps/Hz/TRxP for DL, 6.75 bps/Hz/TRxP for UL)
	For Dense Urban (7.8 bps/Hz for DL, 5.4 bps/Hz/TRxP for UL)
	For Rural (3.3 bps/Hz for DL, 1.6 bps/Hz for UL)
Mobility	For Indoor Hotspot- 10 Km/h (with the normalized data rate of 1.5 bps/Hz)
	For Dense Urban- 30 Km/h (with the normalized data rate of 1.12 bits/s/Hz)
	For Rural- 500 Km/h (with normalized data rate of 0.45 bits/s/Hz) And 120 Km/h (with normalized data rate of 0.8 bps/Hz)
Mobility interruption time	Less than 1 ms

releases splits 5G NR into two-phase: Release 15, which corresponds to NR phase 1 and Release 16, which corresponds to the NR phase 2. In Release 15, 3GPP has specified the frequency band allocated for the 5G network. It has also highlighted the three leading Key Performance Indicators (KPIs) that define various use cases of 5G NR. The three KPIs are eMBB, mMTC, and uRLLC [3]. These use cases enable various services provided by the 5G network. The eMBB provide the service of mobile broadband which will help in ensuring consistent user experience. The mMTC will furnish the 5G network with massive connectivity. The uRLLC services will open up various new capabilities of the network by extending its limits for reliability and latency.

The diverse deployment of the 5G network is due to the addition of various new features. These features are scalable numerology, flexible spectrum, forward compatibility, and ultra-lean design. The present technologies of 5G systems form the basis for many new technologies in beyond 5G/ 6G network.

II. BACKGROUND

The massive demand for higher data rates and bandwidth with the increased number of users led to the deployment of the 5G network in the coming future. 5G networks are expected to support higher connectivity, improved capacity, high-speed data rates, and low latency. Various emerging technologies that will be employed in the 5th generation network include UDN, massive MIMO, D2D communication, SCA, Full-Duplex Radio, and Cognitive Radio. These technologies have enabled various features of the 5G network. In [4], several new channel estimation models like hybrid channel models are discussed for carrying out channel measurements. These models will be adaptable to the different scenarios of 5G networks. In [5], various trails that are being carried out for enabling 5G scenarios are overviewed. The author has concluded that researchers have mainly focused on eMBB. Whereas, other KPIs like mMTC and uRLLC has left untouched because the connection density for validating mMTC is very high, which is very difficult to attain for trial purposes.

Next-generation systems will enable various applications that may require high QoS. Thus Power optimization will be the primary requirement [6]. The use of relays and small cells increases the efficiency of the system and supports green communication. There are various key features of 5G NR systems, which include Forward Compatibility, Ultra-Lean Design, and flexible spectrum [7]. Forward compatibility allows the network to support future applications that are not yet discovered. The ultra-lean design incorporates the reduction of 'always on' signals so that the performance of the system can be enhanced, and the power utilization can be reduced. The flexibility of the spectrum helps in enabling numerous applications of 5G network in different scenarios.

In [8], the author has discussed the deployment scenarios of 5G system with NR waveforms, access techniques and frame structure. New Radio will operate both as Standalone (SA) NR and Non-Standalone (NSA) NR. The SA NR network will make use of a Next-Generation Core (NGC) network, and it will require new infrastructure for its deployment. Whereas the NSA NR network will use the LTE- EPC as the core network and will utilize the already installed infrastructure for carrying out its operations. NR networks will employ NOMA as multiple access technique, and OFDM based new waveforms that have additional functionalities.

OFDM is associated with a high Peak to Average Power Ratio (PAPR) and Out of Band Emission (OOBE), which deteriorates the expected spectral efficiency of the system. Several techniques like Filtering, windowing, and precoding are used in 5G NR for reducing these issues. 5G NR will enable various new applications with the deployment of several new technologies. The existence of 5G network with the existing network and next-generation wireless network in real-time scenarios is one of the critical challenges that needed to be considered.

NR will operate in the mmWave band, and for the enhancement of gains, beamforming will be an eminent technology. Beamforming is essential for increasing the link budget in the environment of mmWave communication [9].

It manages the transmission of data in highly mobile scenarios. In [10], a multi-beam operation based on the process of initial access is used for getting system information, performing synchronization, and providing random access in the NR system. The author has also highlighted the handover procedures for Inter-cell mobility. It is suggested that the handover will be based on the measurements of the downlink channel which also compensates the requirement of always-on signals in NR.

In [11], conventional Beam management and Interference coordination algorithms are modified into a deep neural network based method. It is concluded that a deep neural network requires fewer calculations and thus reduces computational complexity with comparable sum-rate concerning the conventional method. In [12], the author has discussed that with the evolution in modulation scheme, a modified receiver must be used that can be reliable for handling denser constellations. Computational complexity is reduced by employing the receivers that can directly work on digitalized observations and can consider error variance. 5G systems will rely on mmWaves, but the beyond 5G/6G network will operate on Terahertz (THz) frequencies. For the deployment of mmWaves, new Channel estimation models are required for carrying out communication. In [13], the channel gain coefficients are calculated by using least square estimations in mmWave MIMO systems. The author focuses on achieving better performance as compared to the conventional Bayesian compressive sensing. As compared to the present literature, the contribution of this paper is summarized as:

- The paper provides a detailed overview of 5G NR, its features, and use cases. Along with this, various issues related to the implementation of 5G NR are also summarized deeply.
- We have proposed an architecture that connects 5G Systems with beyond 5G/6G network. The architecture compares the earlier foundations of 5G with the 5G NR standardization and lays out several ways to migrate towards the 6G network.
- The paper demonstrates the issues related to the adaptation of higher modulation schemes and inter-RAT handover synchronization.
- We provide the AI-based slicing architecture for 6G network that can enable numerous applications.

The paper is organized as: Section III provides an overview of the 5G NR as the first standard of the 5G network. Various features of 5G NR and its use cases are discussed as the subsection. Section IV discusses the network architecture that connects the 5G network with the next-generation wireless networks. During the migration of the network from 5G to 6G, various challenges and issues are required to be solved. In section V, these challenges are illustrated in detail. Section VI comprises of recent work on 6G network. In Section VII, virtualized network slicing based 6G architecture is proposed with its enabling services and applications. Section VIII covers several backhaul challenges and future scope of 6G network. In section IX, the paper is concluded. Figure 1, shows the structure of the paper. A list of used abbreviations and various ongoing projects on 6G technologies is shown in the Appendix.

III. 5G NEW RADIO

Based on the Release 15 by 3GPP, the first version of 5G networks is comprised of the 5G Core (5GC) and 5G NR as the air interface, which will be deployed throughout the world over the wide range of frequency bands from less than 6GHz (0.45GHz-6 GHz) to mmWave (24.2-52.6 GHz) [3], [7]. For implementing the full version of 5G NR, the deployment of entirely new hardware is essential with the reusability of present infrastructure. NR architecture will have both NSA and SA modes of deployment. NSA will be dependent on the already existing networks and utilize the functionalities of present infrastructure. These types of deployment ensures the smooth rollout of new technologies. On the other hand, SA architectures will be solely dependent on the Next Generation Core (NGC) or 5th Generation Core (5GC), which will operate fully on 5G specifications.

5G NR is expected to attain all the targets that are required to be fulfilled, as demonstrated in Table 1. For these fulfilments, various features are integrated into NR systems, which include flexibility of spectrum, flexible numerology, ultra-lean designing and forward compatibility [8]. These features will not only enable enhanced data rates but also ensures the massive connectivity of UE and machines with reliable communication and low latency. 5G NR uses OFDM waveform for data transmission as in LTE with flexible spectrum and numerology that were not the features of LTE systems. The flexibility of the physical layer ensures the implementation of NR over the broad applications. Initial access procedures in NR are much similar to that of LTE with the difference that the transmission of the reference signal is specific to the user only, not to the whole cell. It will be transmitted only when the user has some data for transmissions. This kind of user-specific transmissions leads to efficient network architectures and designs.

5G NR will implement both FDD for low-frequency bands and TDD for high-frequency bands. It also supports dynamic TDD for allocating dynamic slots according to

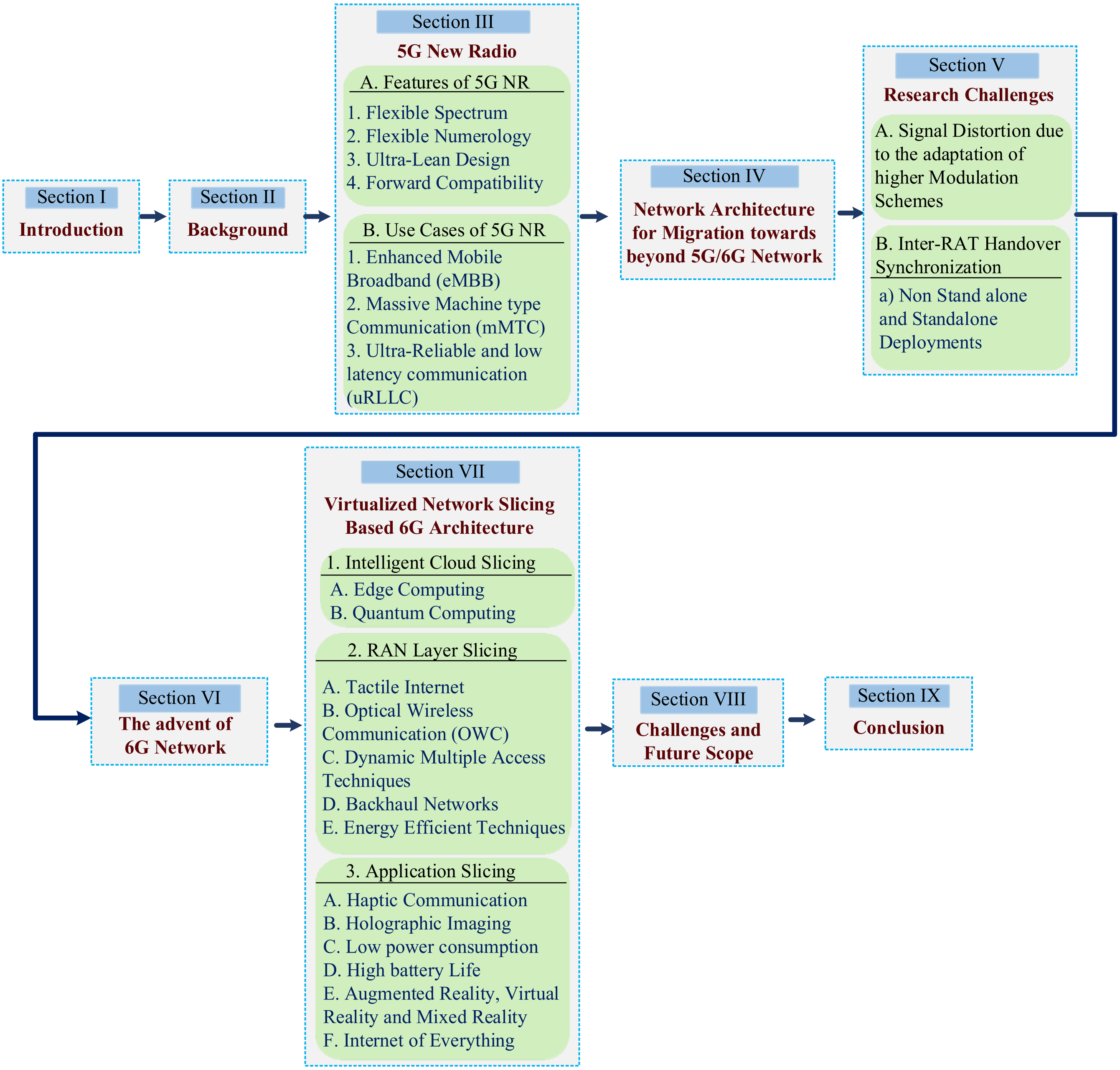

FIGURE 1. Structure of the paper.

the data traffic. For providing high data rate transmissions, coding of data in 5G NR is based on LDPC in place of turbo coding and polar coding in place of TBCC, used in traditional networks. Interworking is another feature of NR systems that supports the existence of different RATs together so that mobility and the flexibility of NR architecture can be maintained. The technique of Enhanced Carrier Aggregation (CA) has been introduced for enabling Dual Connectivity (DC) by combining the carriers of LTE and 5G NR systems that will result in the enhancement of data rates and throughput [7], [8].

3GPP, in its various releases, defines 5G as the new evolution to the next generation networks. In the early drop of release 15 in 2017, it provides some initial specifications for the implementation of 5G NR and focuses on NSA deployment, where the core network is LTE-EPC. The main drop of release 15 in 2018, introduces about SA deployments that are not dependent on LTE and solely operate on NGC or 5GC as its core network. The late release 15 comprises the modified architecture of 5G NR with various functionalities that include backward compatibility and Dual Connectivity (DC).

TABLE 2. Frequency bands with supporting subcarrier spacing and bandwidth [7], [18].

Designation	Frequency range	Maximum Bandwidth	Subcarrier spacing	Usage
FR1	Below 2 GHz	50/100 MHz	15 kHz	Wide area and in-depth indoor coverage.
	2 GHz to 6GHz	50/100/200 MHz	15/30/60 kHz	Optimal balance between capacity and coverage
FR2	Above 6 GHz (24.2 MHz -52.6 MHz)	200/400 MHz	60/120/240/480 kHz	for usage cases requiring high data rates

Release 15 of 3GPP is generally referred to as phase 1 of the 5G NR system, which involves various standard functionalities of LTE and 5G. It discusses various scenarios for the deployment of 5G systems (including both NSA and SA scenarios). Several technical specifications of 5G NR including numerology, waveform, synchronization procedures, and modulation, are also defined. Further, in new Releases, these features are modified to support various applications and use cases [3]. 3GPP in Release 16 includes the extensions of 5G, which comprises Vehicle to Everything (V2X) connectivity, Industrial IoT (IIoT), improved uRLLC for Time Specific Communication (TSC) and various unlicensed spectrum for operating 5G NR.

Release 16 basically focuses on the evolution of the vertical industry. Various commercial applications based on Mission critical services are addressed, that can revolutionize the area for security and safety. Release 16 is referred to as phase 2 of 5G NR and expected to be finalized in June 2020. In short, release 16 concludes the extended usage of 5G NR and improvement in the performance and capacity of the network [14]. Work on Release 17 is still under study and it is expected to be delivered in 2021. In release 17, as per the 3GPP reports, various features like Non-Terrestrial Networking (NTN), Extended Reality (XR), edge computing in 5G core, network slicing, network automation, enhanced V2X services, RAN slicing etc. will be covered [15], [16]. Various 3GPP releases are described briefly in Table 3.

TABLE 3. Various 3GPP releases of 5G NR.

Releases	Description
Release 15 (Phase 1)	Early drop provides general specifications, including flexible numerology, frame structure, supported waveform, synchronization procedures, and NSA deployment of 5G NR. The main drop provides insights over SA deployment and NGC, and late drop covers the enhanced architectures for supporting DC and backward compatibility [3].
Release 16 (Phase 2)	It provides an extension to the previous release and extends various use cases of 5G NR. It includes the enhanced connectivity of V2X communication, uRLLC, IIoT, and various time-specific applications [14].
Release 17 (not delivered yet)	It will cover various advanced features of 5G NR, which include, RAN slicing, network automation, IoT for NTN Extended Reality, network slicing, Multi-SIM, 5GC location services, advanced interactive services, and many more [15][16].

A. FEATURES OF 5G NR

5G NR will be quite superior to the existing network in terms of the services and applications that are being enabled. These networks will provide support to the excessive user demand for high-speed data rates, higher mobility, lower latency, and higher reliability. For ensuring these demands, the 5G NR architecture is made to be flexible so that numerous applications can be enabled. In 5G, various new features are added as compared to the previous generations. These features are overviewed as:

1) FLEXIBLE SPECTRUM

The flexibility of 5G NR is due to its design for flexible spectrum and flexible numerology. The flexibility of the spectrum includes the usage of different frequency bands for different types of communication so that several functionalities and features of the system can be enabled. 5G NR generally focuses on using higher frequency bands (i.e., the mmWave bands). It will operate on very wide transmission bandwidth for enabling the high data rate services and providing high traffic capacity. 5G NR system design is made to be flexible so that the three different use cases (eMBB, MMTC and uRLLC) can be supported in different deployment scenarios. This flexible design of NR is based on its flexible physical layer design. 5G NR will use OFDM as the core modulation scheme. In LTE/LTE-A systems, OFDM is used with a subcarrier spacing of 15 kHz, but NR will operate on different subcarrier spacing ranging from 15 kHz to 240 kHz. 5G NR will operate in two frequency bands named FR1 and FR2.

TABLE 4. Subcarrier spacing with corresponding sub frame and symbol duration.

Subcarrier spacing (kHz) Δf_s	OFDM symbol duration (µs)	CP duration (µs)	Total symbol duration (µs)	Slot duration (µs)
15	66.67	4.69	71.35	1000
30	33.33	2.34	35.68	500
60	16.67	1.17	17.84	250
120	8.34	0.585	8.92	125
240	4.17	0.293	4.46	62.5
480	2.08	0.146	2.23	31.25
2^n *15kHz (n=0,1,2,…5)	66.67/2^n	4.69/2^n	71.35/2^n	1000/2^n

FR1 includes frequency band from 0.45 GHz to 6 GHz and FR2 includes frequency band from 24 GHz to 52.6 GHz [17].

For addressing the requirements and usage scenarios, the spectrum is divided into three different frequency layers, as in Table 2. The first layer is below 2 GHz that basically provide broad and deep indoor coverage. The second layer is for coverage and capacity and it ranges from 2 to 6 GHz. The first two layers are included in the FR1 frequency band (3GPP, Release 15). Furthermore, the third layer is for frequencies above 6 GHz and generally used for sustaining applications and cases that require extremely high data rates. This layer is included in the FR2 frequency band (3GPP, Release 15). The frequencies of the second layer are capable of enabling most of the use cases of 5G NR. Frequencies within the range of 3.3GHz to 4.2GHz and 4.4GHz to 5GHz are best for providing extensive coverage and maximum capacity for efficient fulfillment of all the KPIs [18]. It is recommended to allocate almost 100 MHz bandwidth from this frequency range to each network of 5G NR. Below 2GHz bands are beneficial for mMTC and uRLLC applications. Above 6GHz bands ensure high data rates and capacity and thus enables eMBB use case of 5G NR. Flexible Spectrum will help the NR systems in the following ways:

✓ It provides much lower power and lower bandwidth options.
✓ It enhances the channel capacity.
✓ It ensures effective bandwidth utilization.

2) FLEXIBLE NUMEROLOGY

5G NR supports scalable numerology by extending the spacing between the subcarriers of the OFDM waveform. The spacing ranges from 15 kHz to 240 kHz depending upon the service requirement, deployment scenario, and carrier frequency. Table 2 stated various frequency ranges and supported subcarrier spacing (SCS). The Below 2 GHz frequency band supports the SCS of 15 kHz. For above 2 GHz and below 6GHz, the SCS will be 15/30/60 kHz depending upon the service. The Above 6 GHz frequency band will use the SCS of 60/120/240/480 kHz. Corresponding to each SCS, OFDM symbol duration, Cyclic Prefix (CP) duration, and slot duration will vary as shown in Table 4.

The SCS in 5G NR is scaled by multiplying the factor 2^n to 15 kHz. The 15 kHz is the SCS used in the LTE system, and n will be any integer whether positive, negative or zero. In 5G systems, n €[0, 1, 2, 3, 4, 5]. Thus the available spacing will be 15kHz, 30kHz, 60 kHz, 120kHz, 240 kHz and 480 kHz (for example, $15 \times 2^0 = 15$ kHz with n = 0 and $15 \times 2^1 = 30$ kHz for n = 1). This spacing leads to the formation of mini-slots which provides an additional feature to the NR functionalities. The availability of mini-slots will result in the successful transmission of a very small packet. Mini-slots are the smallest Resource Blocks (RBs) that can be allocated to the user. It carries a control signal with it and used for enabling the low latency communication [8].

The frame structure of 5G NR is highly flexible and supports both FDD and TDD. In the time domain, the basic time unit T_b of NR is given by [17]:

$$T_b = \frac{1}{\Delta f_s \times N_f} \tag{1}$$

Here Δf_s is subcarrier spacing which is scalable as the factor of 15×2^n kHz, N_f is the FFT size of 5G NR, which is always assumed to be 4096. Each frame of 5G NR will last for frame duration of T_{fd} sec, which is calculated by using equation (1), such that:

$$T_{fd} = \frac{\Delta f_s \times N_f}{100} \times T_b = 10\text{ms}$$

The frame is then divided into 10 subframes of duration T_{sb} sec given as under:

$$T_{sb} = \frac{\Delta f_s \times N_f}{1000} \times T_b = 1\text{ms}$$

Thus each frame of 10ms duration is divided into 10 subframes of 1ms duration. 5 subframes together combine to form two equal size half frames. These subframes are self-contained, which means the information in one slot can be decoded without dependency on any other slot. Each subframe is then divided into a flexible number of slots based on $\frac{T_{sb}}{2^n}$. For n = 0, the slot duration will be 1ms, and the number of the slot will also be 1 and for n = 1, the slot duration will be 0.5 ms and the number of slots will be 2.

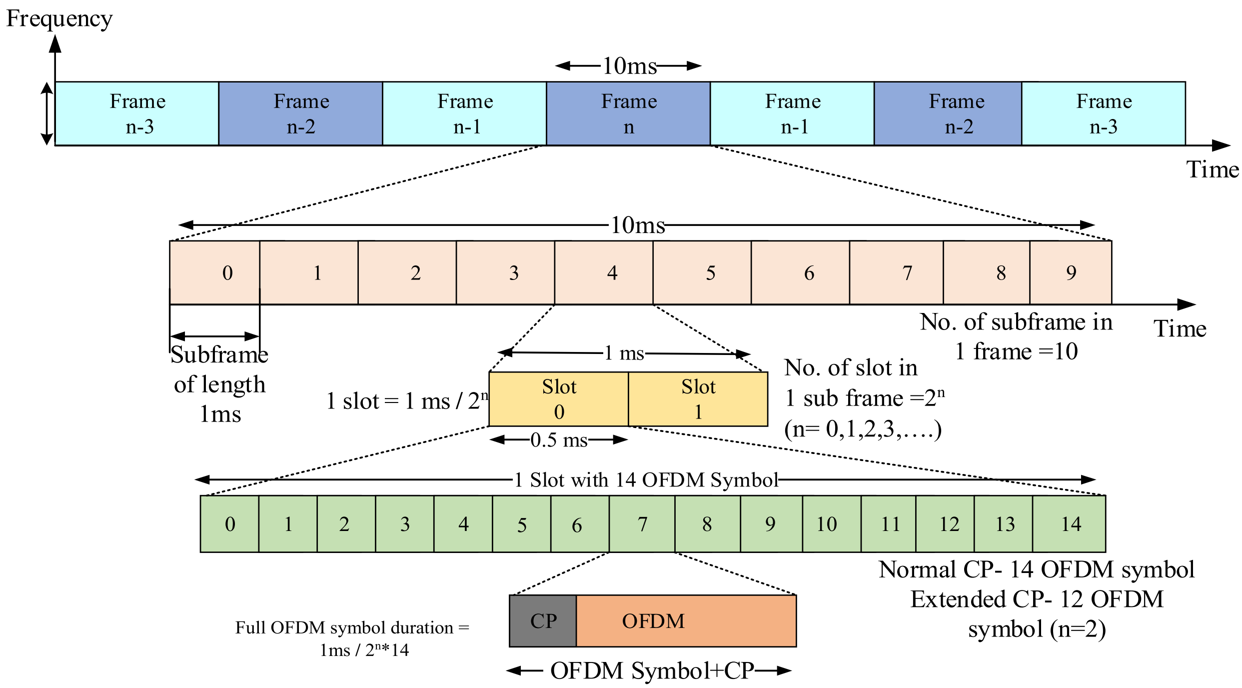

FIGURE 2. Structure of frame in 5G NR.

Each slot consists of 14 OFDM symbols with different subcarrier spacing and different CP lengths given in Table 4. Figure 2 shows the frame structure of 5G NR with subframe and slot durations. In the frequency domain, 12 subcarriers are combined to form 1 resource block. 5G NR will support flexible spacing of 15×2^nkHz between these subcarriers, depending on the frequency range as shown in Table 2. The Flexibility of NR design will help in:

- ✓ Providing minislots for enabling lower latency communication.
- ✓ Large subcarrier spacing for reducing the inter-carrier interferences.
- ✓ Support narrowband IoT with better power efficiency.

3) ULTRA-LEAN DESIGN

In the mobile communication system, some signals are termed as the 'always on' signals. These signals include synchronization signals, Broadcast signals, and the reference signal. These signals are transmitted in the cellular network after a regular interval of time, even if the user has no data for transmission. Due to the increase in the density of users, these signals may have some unacceptable effects on the performance of the system, as it can limit the achievable data rates and reduces the efficiency of the system by increasing the interferences. Thus the next generation networks are aiming at reducing these types of transmissions so that interferences can be minimized and the performance of the system can be enhanced [7]. Ultra-lean design of NR system will help in:

- ✓ Reducing the expenses for the operation of the network.
- ✓ Increases the energy efficiency of the system.
- ✓ Minimize the interferences in the high traffic load conditions.
- ✓ Enhances forward compatibility.

In ultra-lean design, four primary reference signals like Phase Tracking Reference Signals (PTRS), Channel State Reference Signals (CSI-RS), Sounding Reference Signals (SRS), and Demodulation Reference Signals (DMRS) will be transmitted only when it is required. The receivers use DMRS during channel estimations for performing demodulation. These signals can be beamformed towards the specified user only at the time of its requirement, both in UL and DL channels. DMRS is transmitted with the synchronization signals. PTRS is used for tracking the phases of the local oscillator and provides compensation at the receiver terminal so that any error in the phase noise of the signal can be removed. PTRS is used for the transmissions over high frequencies, generally mmWave. PTRS is also specific for the user and can be scheduled over the confined resources. These signals are present over both the uplink and downlink channel. SRS provides the scheduling and sounding of the UE. It is transmitted as part of the last 6 symbols in a slot. In 5G NR systems, these signals are made user-specific as compared to LTE. CSI-RS are used for performing beam measurements during the mobility of the user. Various parameters like Reference Signal Received Power (RSRP), SNR, etc. are estimated by using CSI-RS signals. In 5G NR, the configuration of the CSI-RS signal is highly flexible and occupies any slot in the OFDM symbol. These signals can be transmitted periodically or aperiodically depending upon the requirement.

4) FORWARD COMPATIBILITY

5G NR is expected to be evolved even beyond 2020, and forward compatibility implies the feature that will allow 5G NR to support various use cases that are not yet defined [19]. There are two design aspects of forward compatibility. First is keeping some frequency and time resources blanked and utilizing them flexibly for supporting those characteristics and requirements that are still unknown. Second is the decoding of data in a particular slot or beam is performed without any dependency on other slots or beam. Forward compatibility can be ensured by minimizing the always-on signals. It is necessary for future evolution. Various features of 5G NR that enables forward compatibility are as under:

- ✓ Blank subcarriers in the 5G NR framework.
- ✓ Self-contained structure of subframes.
- ✓ Scalable numerology and transmissions.
- ✓ Dynamic allocation of uplink/downlink resources based on the traffic conditions.

Forward compatibility ensures the system compatibility with the future systems or versions, likewise backward compatibility, which means that the system can process the information even from its previous versions. These types of systems are not resistant to any modification or any upgradation in the hardware or software. These upgradations are generally related to programming, protocols, signals, and interfaces. For example, the future version of some software may not be able to process the data from its previous version if its designing protocols are not backward compatible. Similarly, if the present version of some software is not able to process the information from its modified version then the software is not considered to be forward compatible.

The above-stated key features of 5G NR, imparts flexibility, extendibility, and novelty to the network. These added features help in enabling countless applications. Flexible numerology leads to the formation of minislots that will help in ensuring low latency communication. The ultra-lean design promotes green communication and reduces the excessive utilization of bandwidth. Forward compatibility provides a platform for those technologies that are not yet discovered.

B. USE CASES OF 5G NEW RADIO

5G New radio specifies three primary use cases that are specified as the Next Generation Key Performance Indicator (KPI). The three KPIs are eMBB, uRLLC, and mMTC has been shown in Figure 3. 5G NR will make use of the diverse spectrum with massive deployment and unparalleled services. The eMBB services will drive the requirement of high capacity, high data rates, and better coverage. The uRLLC will ensure prodigious reliability with very low latency. The service of mMTC will provide a platform that can handle a huge number of devices simultaneously. Various use cases with their features and enabling services are described as under:

1) ENHANCED MOBILE BROADBAND (EMBB)

It is one of the primary use cases of 5G NR. The eMBB is an extension of the existing services provided by LTE systems.

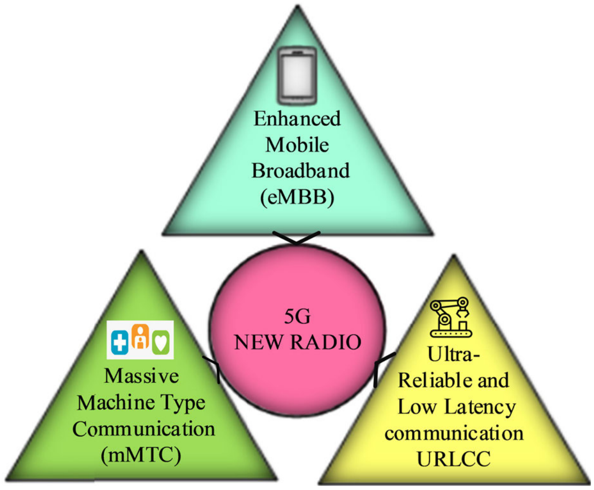

FIGURE 3. Three Use cases of 5G new radio (5G NR).

In future, the demand for mobile data traffic and video content will increase significantly. Presently, 4G has been supporting the video resolution of less than 720p HD with 50 ms mobility interruption time. Whereas 5G NR systems are expected to support 1080p, 2K, 4K, 8K full HD video resolution with less than 1ms mobile interruption time. In [20], it is stated that in 5G NR, some applications require eMBB services with hard latency requirements of 1ms and 99.999% reliability. These kinds of requirements may lead to the problems of scheduling due to the coexistence of eMBB and uRLLC that can be optimized by using a null space-based preemptive scheduler.

In [21] the problem of coexistence is removed by slicing the available resources on the basis of the demand of the users. A risk-sensitive based approach is used for the distribution of resources on the basis of the sensitivity of demand. The eMBB services will ensure faster data rates for better user experience and aim towards providing the required QoS that we are currently enjoying from fixed broadband internet services. The eMBB service will enable enhanced broadband access in highly dense areas like stadiums, offices, conference centers, and special venues. In moving vehicles or high-speed trains, eMBB will provide the user with consistent access everywhere at any time. Various services that are being enabled with eMBB are AR, VR, MR, 360° video streaming, immersive video conferencing, real-time virtual interactions, and HD screen display. Various features that are being supported by the 5G eMBB use case are as:

- The peak data rate of 20 Gb/s for DL and 10 Gb/s for UL.
- Area traffic capacity of 10Mbits/s/m^2.
- Increasing energy efficiency by 100 times.
- Provide peak spectral efficiency of about 30 b/s/Hz for DL and 15b/s/Hz for UL.
- The user experienced a data rate of 100 Mb/s for DL and 50 Mb/s for UL.
- Supports high mobility of about 500 Kmph and 1000 Kmph.

- Less than 1 ms of mobile interruption time.

Mobile broadband will provide better and enhanced connectivity, which does not only include smartphones but also involves connected IoT devices. It helps in resolving several issues related to the connection termination in highly mobile scenarios and crowded locations.

2) MASSIVE MACHINE TYPE COMMUNICATION (MMTC)

Machine type communication deals with communication between different machines without the intervention of human beings. It is anticipated that the total aggregate of connected devices will reach up to 50 billion in future. For communication between these massive numbers of connected devices, mMTC is presented as one of the primary use cases of 5G NR. Various applications of mMTC will include health monitoring, management of fleet and logistics, autonomous driving, factory automation, smart metering, surveillance and security. In mMTC, the data from the input device is automatically interpreted by intelligent devices and based on the input, the respective response is generated. The uplink flow of the data packet is generally much more than the downlink flow which includes only the query information. The size of data packets is very small but the connectivity of several devices increases the total traffic volume. Massive IoT (mIoT) is also categorized in mMTC services, which deals with the connection of numerous devices with the help of the internet so that autonomous functions can be performed. The 5G mMTC use case will support the following features:

- High connection density of 1M devices/Km^2.
- Wider coverage.
- Low-cost IoT
- High Mobility of 10Km/h for indoor, 30Km/h for dense urban and 500Km/h for rural.

Existing cellular networks are designed based on the techniques that can handle only Human to Human Communication (H2H). These techniques are not sufficient for providing Machine to Machine Communication (M2M). When the connection between the two machines is established, it always require reliability and security. There are various applications of mMTC, and each application will demand different QoS and QoE. In H2H communication, Radio Resource Management (RRM) procedures improves the spectral efficiency and energy efficiency, but it is not enough in M2M communication. In [22], various RRM techniques for different applications of mMTC are surveyed and various challenges regarding the implementation of mMTC are also reviewed.

The mMTC, however, can become the leading cause of network congestion when numerous devices try to access the network simultaneously. The massive deployment of devices may lead to the increased latency and packet loss during severe congestion problem in the network. These problems are not desired for the efficient working of 5G networks. In [23], an algorithm is proposed for controlling congestion in a distributed network of mMTC by which the available resources are allocated to the user within the specified contention period. The algorithm is helpful in scaling the resources so that they can be utilized effectively with low energy consumption, low overhead, and less delay. It provides better access in case of congestion than the traditional Random access procedure.

In [24], mmWave based NOMA technique is proposed for mMTC so that the drawback of the massive connectivity of devices and high delay can be eliminated. During the implementation of mmWave based NOMA for mMTC, it is assumed that multiple devices will share the same allocated resources provided by the base station. The devices that are sharing the resources are acting as pairs depending on the distance, either between the devices themselves or between the device and the base station. These type of scenarios thus results in improved outage probability and reduced overhead as compared to mmWave based OMA techniques.

3) ULTRA RELIABLE AND LOW LATENCY COMMUNICATION (URLLC)

The uRLLC is one of the most critical use cases of 5G NR, which provides novelty to the whole infrastructure of the next-generation system. It enhances the quality of the network and makes it potentially sufficient for supporting several applications. It enables the expansion of traditional boundaries of already existing machines and enhances its functionalities. In 4G, the network is associated with lower reliability and higher latency, due to which these network does not support various advanced applications. In 5G NR, the service of uRLLC ensures the lower latency and higher reliability of the system, which is typically less than 1ms per packet with 99.999% of reliability.

The uRLLC services can be enabled in two forms: 1) By replacing already existing wired link and 2) by native uRLLC applications [25]. In the case of link replacement, the already present links are replaced with a new uRLLC enabled link so that the quality of communication can be enhanced. For example the devices of industry 4.0, which deals with the replacement of traditional wired links by the uRLLC enabled wireless connections, like in cooperative robots. Whereas, the native uRLLC connections are not the replaced connections. They are fully designed for uRLLC applications. For example V2V communication. Various requirements that will be focused to be fulfilled by the 5G uRLLC use case are as under:

- User plane latency up to 1ms for uRLLC.
- Control plane latency up to 10-20ms.
- Reliability of 99.999% success probability.
- Mobility interruption time less than 1ms.

Latency and reliability plays a very crucial role in real-time applications and mission-critical services. Several applications of uRLLC include intelligent transportation, industrial automation and remote surgery [26]. Intelligent transportation generally refers to the management and synchronization of traffic. It generally involves drone delivery, autonomous car, remote driving and vehicle to everything communication. The importance of uRLLC in the area of intelligent transportation is self-explanatory. Industrial automation defines the controlling and monitoring of industrial processes with the help of robots. It includes industrial IoT, remote manufacturing and training. Similarly, Remote surgery involves the diagnosis or surgery of patients from distant places with the help of robots. In such applications, any latency or delay can cost the life of a person.

In 5G NR, the strict latency requirement and ultra-reliability are quite challenging to attain simultaneously. In [25], technologies like multi-connectivity and massive MIMO are proposed for accomplishing the targets of uRLLC. The author has focused on the application of machine learning techniques for getting the prior knowledge of the environment, which plays a vital role in achieving the required reliability. In [27], a prediction based resource optimization technique is used for maximizing the supporting uRLLC services. The future states of the devices are predicted in order to achieve reliability. The coexistence of uRLLC services with other use cases is also a critical issue. In [20], a null space-based preemptive scheduler is proposed for immediate scheduling of uRLLC without influencing the overall capacity of the system. The scheduler forcefully transmits the uRLLC traffic with the eMBB transmission and reduces the queuing delay, which is one of the major obstacles for ensuring low latency.

In 5G NR, the flexible frame structure leads to the formation of minislots. These minislots are helpful for small packet transmissions. These slots are self-contained which means they are not dependent on each other. The novel frame structure of 5G NR is responsible for the immediate scheduling of uRLLC transmissions [8]. For supporting uRLLC in a TDD system, a channel aware sparse transmission technique is proposed in [28] by which grant signals are transformed into the sparse vector. Further, the adaptation of LDPC coding ensures the high reliability of the communication link. In [29], the generalized LDPC codes are used for uRLLC transmission that outperforms the conventional techniques. The service of uRLLC is not limited to the 5G network only. It is also extended to beyond 5G networks, with more strict latency and reliability requirements.

At last, the three use cases eMBB, mMTC, and uRLLC impart novelty to the 5G NR architecture and differentiate it from previous wireless generations both qualitatively and quantitatively. In this section, all the three use cases and their potential deployment are overviewed, and it is discussed that future networks will provide a vast set of services and features that are summarized in Figure 4. The novel features of 5G network will enable numerous services and applications that were dormant. 5G NR bands and its flexible utilization helps in its extensive deployment in almost every region. Thus 5G networks will ensure extensive connectivity and coverage with high capabilities.

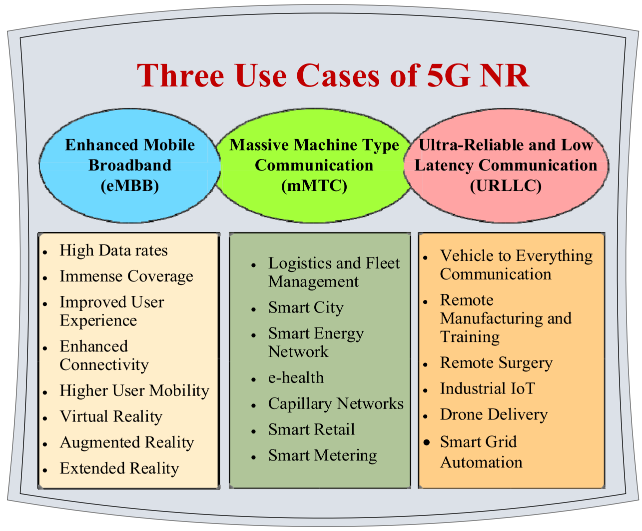

FIGURE 4. Various services and features provided by three use cases of 5G NR.

IV. NETWORK ARCHITECTURE FOR MIGRATION TOWARDS BEYOND 5G/6G NETWORK

The general 5G network architecture comprises of various essential technologies like D2D, NOMA, UDN, SCA, MIMO, massive MIMO, and Cognitive Radio (CR) [1]. These technologies will focus on fulfilling all the requirements of 5G that are regarded as the minimum 2020 requirements. UDN is helpful in handling the ultra-high density of users and increases the capacity of the network. SCA network increases the coverage and offloads the data traffic. MIMO is helpful in increasing the diversity gain so that the maximum number of users can be handled. Massive MIMO is an extension of traditional MIMO systems and is helpful in enabling massive connectivity in the network. Cognitive Radio is another useful technology that is helpful in utilizing the available bands in the spectrum by varying various parameters for concurrent communication.

According to the 3GPP release 15, 5G New Radio is the first standard air interface for the 5G network. 5G NR architecture involves the deployment of the three use cases eMBB, mMTC, and uRLLC, with the help of technologies demonstrated in 5G architecture. 3GPP has specified two frequency bands in 5G NR. These two frequency bands are sub 6 GHz (FR1) and above 24GHz (FR2) [17]. The FR2 band comprises the millimeter-wave band, which uses very high frequencies for enhancing data rates. There are various added features of 5G NR overviewed in section III. The flexible spectrum and scalable numerology ensures wide coverage and enhanced data rates. The High frequencies are generally associated with high propagation losses, due to which the mmWave implementation is limited to small areas. The limitation of mmWave can be removed by increasing the antenna gain through beamforming. Beamforming is a technique of focusing the maximum power of signal towards the direction

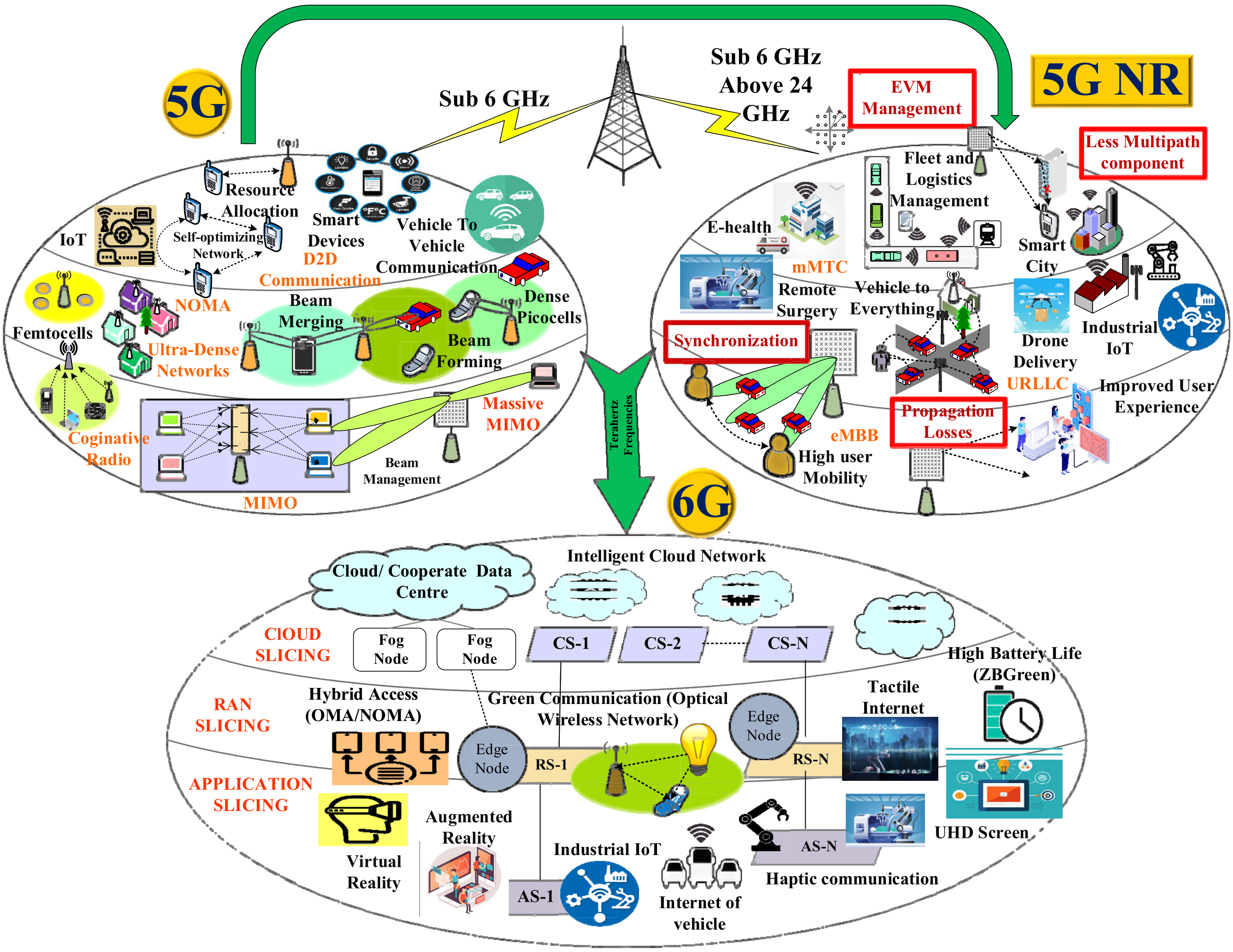

FIGURE 5. A proposed architecture for next-generation wireless communication.

of the user. Various other techniques of beamforming like beam merging (two beams merge for maximizing SNR) and beam broadening (for increasing the coverage) help in extending the concept of beamforming in 5G. Various applications enabled by 5G are e-health, fleet and logistics management, smart city, remote surgery, industrial IoT, vehicle to everything, drone delivery, high user mobility, ultra-high definition video and, 360° video streaming. 5G networks have focused on the massive connectivity of digital devices.

The architecture in Figure 5 presents a bridge from the 5th Generation network towards beyond 5G/6G networks. The architecture also defines the applications and services that will be offered by the 6G network. The 5G networks previously rely on sub 6GHz bands, but with the requirement of high data rate, the mmWaves are introduced. It is expected that the 6G network will operate on terahertz frequency for enabling the data rates up to terabits/sec [30]. These networks will use Optical Wireless Communication (OWC) for data transmission. In OWC, visible light bands are considered to be the most promising band. The communication enabled by these light bands are termed as Visible Light Communication (VLC). Visible light frequencies are advantageous in providing a high data rate (terabits/s) and promote green communication. Future networks will focus on low power consumption and extended battery life by deploying the techniques that are energy efficient. Adaptive allocation of resources will be helpful in reducing the power consumption level in the 6G network.

In [31], Artificial Intelligence (AI), Super IoT and ultra-broadband services are studied as three main aspects of 6G. These networks will deploy Machine learning and deep learning based algorithms and techniques for enabling automation. The intelligent cloud-based services will make the network an intelligent and smart network. In later Section VII of this paper, the virtualized network slicing based 6G architecture is proposed, and various services with enabling applications are also discussed. In the proposed architecture, the 6G network is divided in three different layers. These layers are Intelligent Cloud slicing layer, RAN slicing layer and Application Slicing layer. The layered architecture of 6G network will provide a platform for enabling numerous services that require different network functionalities. 6G will enable tactile based services that will revolutionize the existing wireless network. The integration of touch technology will direct the wireless network towards a new destination. Tactile internet is the evolution of the IoT network, which include human to machine and machine to machine communication. It enables the real-time control of IoT devices. The tactile supported network will enable haptic communication, which includes the human senses [32].

The proposed architecture shows the transaction of 5G to the 6G network. It forms a bridge between the two different generations of the network. Although the migration is challenging, it is expected that the 5G technologies will form the basis for new technologies of the 6G network.

TABLE 5. Various challenges for the deployment of 5G NR.

S.No.	Challenges	Description
1	Signal distortion due to higher modulation schemes	With the evolution of wireless technology, modulation schemes are also getting evolved. Adaptation of higher modulations will result in tighter packing of constellation points and hence increases the signal distortions.
2	Inter-RAT handover Synchronization	For highly mobile users, handover between two different Radio Access Technology will increase the computation time, which may result in poor synchronization of beams and leads to call drop.
3	Higher frequency Propagation losses	Higher frequencies like mmWave and terahertz are associated with high propagation losses. These losses include partition losses, absorption losses, and atmospheric looses. These losses affect the signal quality and results in lower SNR.
4	Coexistence of eMBB, uRLLC and mMTC services	The existence of three use cases of 5G NR altogether within the same RAN hinders the functionalities of each other. Massive connectivity of users leads to the violation of uRLLC requirements by increasing the queuing delay.
5	Coexistence of 5G NR with other wireless networks	Various frequencies of 5G NR from FR1 and FR2 band is overlapping with already assigned frequency bands. Thus prioritizing the frequency band is necessary for smooth coexistence.

V. RESEARCH CHALLENGES

5G networks are in the early phase of its deployment and now, everyone is talking about the development of the 6G network. These networks are expected to enable real-time interaction over the wireless system. The migration of the 5G network towards 6G is however, tricky. Various research challenges are needed to be mitigated for the easy ascend. These challenges are summarized in Table 5.

Many researchers have already emphasized some of the stated challenges. Numerous techniques are used for minimizing the losses due to higher frequencies. In [33], novel hybrid beamforming is used for multiple users in the mmWave MIMO system. The proposed algorithm is robust and has low computation complexity. Presently, the mmWave band is being used for enabling high data rates in 5G systems. These bands are associated with many propagation losses. These losses results in the reduction of gain at the receiver end which can be maximized by using beamforming. 6G networks will deploy frequencies beyond 100GHz (generally terahertz bands) for their operation. In [30], the scattering behavior of THz frequencies is studied, and novel antenna technology like the cone of silence is used to improve the performance of the system. The author has introduced the theory of directive scattering for measuring the scattering parameters at 140 GHz, and the effect of increasing frequency and surface roughness on the scattering behavior of radiations is also studied.

There are three main use cases of 5G NR, as already discussed in section III of this paper. The coexistence of these use cases altogether within the same RAN, can limit the services of one another. In [34], the non-orthogonal based resource sharing scheme is used for supporting the heterogeneous services offered by eMBB, mMTC and uRLLC. The author has presented a slicing based model for two services in two different scenarios. The first scenario includes eMBB and uRLLC, and the second will include eMBB and mMTC. In the case of eMBB and uRLLC scenario, the uRLLC requests will be decoded first and then eMBB. The slicing of the network is the best solution for the effective deployment of these use cases. In [35], the RAN slicing based offline-reinforcement technique is used for the flexible allocation of resources according to the user's requirement so that the available spectrum can be effectively utilized.

Likewise, several techniques are proposed by different researchers to mitigate the challenges for the deployment of 5G NR systems. However, some of the challenges like signal distortion due to higher modulation schemes and Inter-RAT handover synchronization are not yet addressed by any of the researchers. Thus these challenges are adequately discussed in this paper. For smooth ascend of 5G to 6G network, these challenges are required to be resolved that are stated as under:

A. SIGNAL DISTORTION DUE TO THE ADAPTION OF HIGHER MODULATION SCHEMES

The technique of immersing the information-carrying data on the radio frequency carrier wave is called Modulation. The characteristics of the carrier are varied according to the data that has to be transmitted. Nowadays, data transmissions are generally digital transmissions over the wireless channel. Since with the growing demand of users and limited availability of spectrum, the type of modulation that is being employed, has become critical. Higher modulation schemes are being implemented for increasing the bandwidth

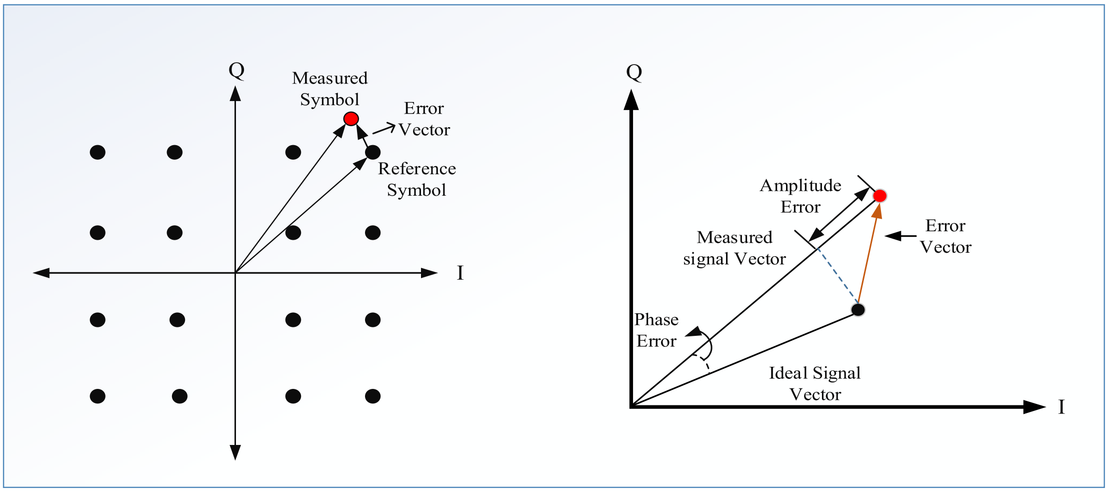

FIGURE 6. Error vector magnitude in 16 QAM.

efficiency of the system. The modulation schemes are also getting evolved with the evolution of wireless networks from 1G to 5G. The higher modulations help in providing higher data rates and better services.

Whenever the information-carrying signal travels through the wireless communication channel, the message bits in the form of symbols are mapped as the constellation points, and any change in the position of these points leads to signal degradation. These changes are due to phase noise, amplitude nonlinearity, distortions, and IQ imbalance. If a signal is supposed to be passed through the ideal system, then it would have all the constellation points at the ideal locations. However, if there are some degradation or imperfections in the system or channel, then these constellation points will also get deviated from their ideal location. These deviations in constellation points can be the source of the signal degradation.

For measuring these types of signal degradation, Error Vector Magnitude (EVM) is being used. EVM is defined as the vector that specifies the difference between the ideal position and the measured position of the constellation points [36]. The Error vector connects the I/Q reference signal vector with the I/Q measured signal vector, as shown in Figure 6. The determination of EVM is an essential factor for specifying the performance of the digital Modulation system. It is the ratio of the RMS power of the error vector to the RMS power of the reference signal constellation, which can be expressed as:

$$\%\text{EVM} = \sqrt{\frac{P_e}{P_{ref.}}} \times 100\% \tag{2}$$

$$\text{EVM(dB)} = 10\log_{10}\left(\frac{P_e}{P_{ref.}}\right) \tag{3}$$

Fourth Generation wireless systems such as LTE and LTE-Advance has been using QPSK, 16QAM, and 64QAM for the modulation of OFDM symbols. In Release 12 of 3GPP, implementation of 256 QAM has been discussed [37], and recently in release 15 of 3GPP, 1024 QAM is introduced [3]. 5G systems will operate on millimeter-wave frequencies and will use the higher modulation schemes such as 512 QAM, 1024 QAM, 2048 QAM, and 4096 QAM. These modulation schemes require tighter EVM, which is quite challenging to attain, for efficient working of a device.

Table 6 shows the required EVM for the modulation scheme of up to 256 QAM. From the Table, it is concluded that as the modulation is getting higher, the required EVM is falling down. For 256 QAM, the required EVM is 3.5% which is very small for a device to handle. In 5G systems, the modulation schemes higher than 256 QAM will be used. Thus the EVM requirement will become even more condensed and poses various critical issues for the proper working of devices at denser modulations.

TABLE 6. EVM requirements with the modulation scheme [36].

Modulation scheme	Required EVM
QPSK	17.5 %
16QAM	12.5 %
64QAM	8 %
256QAM	3.5 %

There are numerous techniques that were put forward for estimating the signal distortion in the system. Several algorithms and receiver designs are proposed for eliminating these errors. Some of the techniques for the estimation and elimination of signal distortions are given in Table 7.

Let $V_{I \text{ or } Q,1}$, $V_{IorQ,2}$, $V_{I \text{ or } Q,3}$, ——$V_{Ior\,Q,n}$ be the RMS voltages of the in-phase and quadrature components of the Ideal symbol point of the ideal constellation diagram and $V'_{IorQ,1}$, $V'_{IorQ,2}$, $V'_{I \text{ or } Q,3}$, ——$V'_{Ior\,Q,n}$ be the RMS

TABLE 7. Various techniques for the estimation and elimination of signal distortions.

Reference	Technique	Description	Observation
[39]	Blind, wide range IQ imbalance estimation.	The mixture of analytical models and clustering algorithms are used for estimating the imbalance of both transmitter and receiver separately with QPSK and 16 QAM modulation scheme.	Estimation of amplitude IQ imbalance ranged from -7 to 7dB is possible with 1dB estimation error. Phase IQ imbalance estimation ranges from -80° to 80° with 4° of estimation error
[40]	Specific Emitter identification	By using the received raw IQ imbalance information, the emitter is identified by using a conventional neural network.	Performance increases as the SNR increase both for QAM and PSK modulation scheme, but it is more significant in PSK modulation. The performance can be improved if the range of IQ imbalance parameters is smaller.
[41]	Novel pilot design	The technique helps in estimating the IQ Timing Mismatch (IQTM) for transmitter and receiver.	The technique for the estimation of IQTM is improved, and it is concluded to be directly related to BER. As the BER increases, IQTM increases.
[42]	Diversity Combining	The combiner combines the minimum EVM constellation of signals obtained from both direct and relay links at the destination to generate the new constellation. SNR, QoS, and outage probability are then analyzed based on the new constellation.	The QoS provided by EVM enabled constellation combiner increases with the increase in transmitter power.
[43]	Digital Predistortion	Common digital predistortion is cascaded with the auxiliary digital predistortion for reducing the distortion loss of each path so that the distortions can be fine-tuned.	Complexity is reduced to a great level, and the linear performance of the system is almost the same as that by parallel directional modulation with digital predistortion.

voltages of the in-phase and quadrature components of the measured symbol point in the measured constellation diagram. Error Vector is the difference between ideal symbol voltages and measured symbol voltages that is ($V_{IorQ,1}$- $V'_{IorQ,1}$), ($V_{I\ or\ Q,2}$- $V'_{IorQ,2}$), ($V_{IorQ,3}$- $V'_{I\ or\ Q,3}$) — ($V_{IorQ,\ n}$- $V'_{I\ or\ Q,\ n}$). Let N be the total number of unique symbols in the constellation that is N = 4 for QPSK or N = 16 for 16QAM. Then the Error vector magnitude [38] is given by

$$EVM_{RMS} = \sqrt{\frac{\frac{1}{N}\sum_{n=1}^{N}|V'_{IorQ,n} - V_{I\,or\,Q,n}|^2}{\frac{1}{N}\sum_{n=1}^{N}|V_n|^2}} \tag{4}$$

V_n is the total voltage of ideal constellation points. EVM defines as the ratio of error to the total signal power. Whereas SNR is defined as the ratio of signal power to noise power (η_0). Thus EVM and SNR bear an inverse relationship, which is given in equation 5.

Here the noise power is additive white Gaussian noise. SNR is one of the essential metrics for determining the performance of the system. Thus, the EVM can be inferred in terms of SNR (Υ) as below [43]:

$$EVM \approx \sqrt{\frac{1}{\Upsilon}} \approx \sqrt{\frac{\eta_0}{\varepsilon_s}} \tag{5}$$

Another performance metric like BER is generally calculated as the number of erroneous bits that are received, as compared to the transmitted bits. BER is directly related to the noise. So, the increase in signal distortion increases the BER [44]. It is calculated as the bit error probability, which is expressed as:

$$\acute{\rho}_B = 1 - \left(1 - \frac{2(\sqrt{M}-1)}{\sqrt{M}log_2M} Q\left[\sqrt{\frac{3\vartheta_b log_2 M}{M-1}}\right]\right)^2 \tag{6}$$

$$\acute{\rho}_B = 1 - \left(1 - \frac{2(\sqrt{M}-1)}{\sqrt{M}log_2M} Q\left[\sqrt{\frac{3\vartheta_s}{M-1}}\right]\right)^2 \tag{7}$$

where $\vartheta_s = \vartheta_b log_2 M$ and $Q[z] = \int_z^{\infty} \frac{1}{2\pi} e^{\frac{-v^2}{2}} dv$

Here ϑ_b is the SNR per bit given as $\vartheta_b = \frac{\varepsilon_b}{\eta_0}$, and ε_b is the energy per bit. ϑ_s is the SNR per symbol given as $\vartheta_s = \frac{\varepsilon_s}{\eta_0}$, and ε_s is the energy per symbol.For higher modulation, the probability of symbol error ($\mathfrak{p}_s$) will be higher and it is defined as the number of erroneous symbols received. Probability of symbol error is also known as Symbol Error Rate (SER) which is given as under:

$$\mathfrak{p}_s = 1 - \left(1 - \frac{2(\sqrt{M}-1)}{\sqrt{M}} Q\left[\sqrt{\frac{3\vartheta_s}{M-1}}\right]\right)^2 \tag{8}$$

Both BER and SER are essential for the estimation of error in the signals. In Table 8, various equations for the probability of symbol error and bit error probability are derived for different modulation order. For the given value of ϑ_b and ϑ_s, the probability of symbol error and bit error probability can be calculated.

Table 8 demonstrates that as the system is moving towards higher modulation, $\mathfrak{p}_s$ as well as $\acute{\rho}_B$ is also increasing. This can be explained by considering various examples of calculating $\mathfrak{p}_s$ and $\acute{\rho}_B$ for different modulation orders. For example, let ϑ_b = 15dB and $\vartheta_s = log_2 M * 10^{\frac{15}{10}}$ then $\mathfrak{p}_s$ and $\acute{\rho}_B$ for

TABLE 8. Symbol and bit error probabilities with higher modulation order.

Modulation Order (M)	Probability of symbol error (p_s)	Bit error probability ($\acute{\rho}_B$)
4	$1\text{-}(1\text{-}Q(\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.5Q(1.14\sqrt{\vartheta_b}))^2$
16	$1\text{-}(1\text{-}1.5Q(0.44\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.37Q(0.89\sqrt{\vartheta_b}))^2$
32	$1\text{-}(1\text{-}1.66Q(0.31\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.32Q(0.67\sqrt{\vartheta_b}))^2$
64	$1\text{-}(1\text{-}1.75Q(0.21\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.29Q(0.52\sqrt{\vartheta_b}))^2$
128	$1\text{-}(1\text{-}1.82Q(0.15\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.26Q(0.4\sqrt{\vartheta_b}))^2$
256	$1\text{-}(1\text{-}1.87Q(0.10\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.23Q(0.30\sqrt{\vartheta_b}))^2$
512	$1\text{-}(1\text{-}1.91Q(0.076\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.21Q(0.22\sqrt{\vartheta_b}))^2$
1024	$1\text{-}(1\text{-}1.93Q(0.054\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.19Q(0.17\sqrt{\vartheta_b}))^2$
2048	$1\text{-}(1\text{-}1.95Q(0.038\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.17Q(0.12\sqrt{\vartheta_b}))^2$
4096	$1\text{-}(1\text{-}1.96Q(0.027\sqrt{\vartheta_s}))^2$	$1\text{-}(1\text{-}0.16Q(0.08\sqrt{\vartheta_b}))^2$

M = 64 is $p_s = 7.54 \times 10^{-3}$ and $\acute{\rho}_B = 1.1 \times 10^{-3}$. For M = 2048 and keeping ϑ_b and ϑ_s same, the probabilities are given as $p_s = 0.97$ and $\acute{\rho}_B = 0.15$. This increase in error due to higher modulation becomes the cause of signal degradation, and hence several techniques are required for reducing these degradations. One of the optimal solution is to maintain EVM adaptively at higher modulations for carrying out high-speed transmissions.

B. INTER-RAT HANDOVER SYNCHRONIZATION

The Synchronization procedure in 5G NR involves two phases: the first phase is the phase of initial access which is carried out by the idle user. This phase confirms the establishment of a link between gNB and UE. The second phase is the phase of tracking mobile user once they are connected to the network. This phase involves the adaption of the beam with the changing channel conditions and the management of handovers for avoiding radio link failure [9], [45]. The initial access phase of the synchronization process follows the operations of Beam Management (BM). BM involves the establishment and maintenance of beam between the UE and gNB. The established beam is responsible for the exchange of information between them. The process of BM involves four different beam operations briefed as under:

1) BEAM SWEEPING

During beam sweeping, a set of beams are steered over the selected area after a regular interval. The steered beams involve the transmission of Synchronization Signal Blocks (SSBs) in the form of Synchronization Signal Burst (SS Burst). Each SS Burst consist of a different number of SSBs. Table 9 shows the number and the indexes of transmitted SSBs, depending on the subcarrier spacing and carrier frequency. Each SSB is transmitted with the periodicity of T_{ssb} = [5, 10, 20, 40, 80 or 160] ms in the form of a beam towards the specified direction. The beam sweeping procedure is shown in Figure 7.

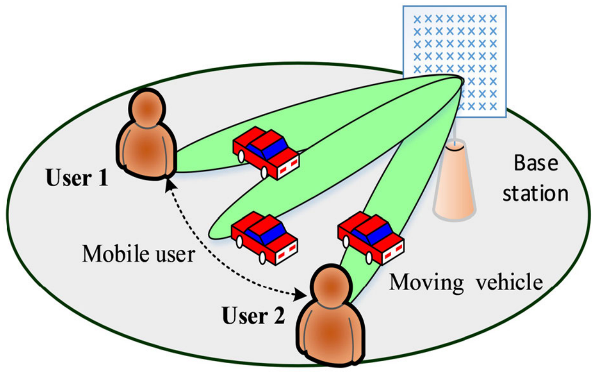

FIGURE 7. Beam sweeping in 5G new radio.

2) BEAM MEASUREMENT

It involves the measurement of various parameters that are required for estimating the quality of the received signal. These measurements include the determination of SNR, Reference Signal Received Quality (RSRQ), Reference Signal Received Power (RSRP), etc. These measurements are made on the basis of reference signals that are received with the SSBs. Measurement of beam parameters is essential for the determination of best beam and tracking purposes.

3) BEAM DETERMINATION

During beam determination, based on the measurements drawn from the beam measurement process, the best beam is selected. The selection of the best beam is made on the basis of a comparison between the calculated parameters of each beam. The beam with high SNR, RSRQ or RSRP is chosen as the optimal beam for subsequent transfer of data from the user to gNB and vice versa. Once the determination of the best beam is completed. The information about the chosen beam is reported to the gNB through beam reporting.

4) BEAM REPORTING

When the user equipment finds the best beam through which it can proceed with its transmissions and receptions. The next step involve the reporting of its decision to the RAN as a piece of information related to the quality of the beam. Based on the information, the serving gNB will optimally align its beam in an appropriate direction. After that, the gNB will Schedule the RACH opportunities in that direction determined by the user itself.

TABLE 9. Maximum number of candidate SSBs and its indexes with respect to SCS.

Subcarrier Spacing (kHz)	Indexes of candidate SSBs	Max. no. of candidate SSBs in SS Burst		
		fc≤ 3GHz	3 GHz < f_c ≤ 6GHz	f_c > 6GHz (upto 52.6)
15	{2,8}+14∗n	4 (n=0,1)	8(n=0,1,2,3)	SCS not supported
30	{4,8,16,20}+28∗n	4 (n=0)	8(n=0,1)	SCS not supported
60	{2,8}+14∗n	4 (n=0,1)	8 (n=0,1,2,3)	64(n=0,1,2,3,5,6,7,8)
120	{4,8,16,20}+28∗n	SCS not supported	SCS not supported	64(n=0,1,2,3, ….., 16,17,18)
240	{8,12,16,20,32,36,40,44}+56∗n	SCS not Supported	SCS not supported	64 (n=0,1,2,3,4,5,6,7 8)

On the basis of these four operations, the process of synchronization can be summarized as: during beam sweeping operation, the gNB transmits multiple SSBs in the form of SS burst. Within the SS burst, these SSBs are transmitted periodically with the interval of T_{SSb} = {5, 10,20,40,80, or 160} ms. Each SSB in the SS burst is transmitted as a beam, with an already defined direction and interval [17], [45]. The SSBs carries various Synchronization signals (SS signals) with it. These SS signals are PSS, SSS, PBCH and DMRS. The DMRS signals are transmitted along with PBCH and generally used for measuring beam parameters. One SS block spreads over four OFDM symbols in the time domain and 20 Resource Blocks (RBs) in the frequency domain as shown in Figure 8. PSS and SSS use 127 subcarriers and are transmitted as 1st and 3rd OFDM symbol respectively. Here 20 subcarriers, 10 on each side of the SSS signal is left vacant. PBCH is transmitted as 2^{nd} and 4^{th} symbol over 240 subcarriers and as 3^{rd} symbol over 96 subcarriers, 48 on each side of SSS. During initial access, these synchronization signals are essential for correct estimation of Frequency and Time Offsets (FTO).

In 5G NR, there are a total of 1008 cell IDs which are organized in 336 groups. These 336 groups have 336 different cell group IDs. Each group consists of three sectors, which are identified by the cell sector ID. UE will evaluate the cell ID as $N_{C-ID} = 3\,N_{C-Gr} + N_{C-Sec}$. Here N_{C-ID} is the cell ID, N_{C-Gr} is the cell group ID which is determined with the help of SSS such that $N_{C-Gr} \in \{0, 1, 2 \ldots 355\}$. N_{C-Sec} is the cell sector ID, which is detected with the help of PSS such that $N_{C-Sec} \in \{0, 1, 2\}$. During initial access, the user starts the procedure of cell search by using the SSBs received during beam sweeping operation. With the help of these SSBs, the user will be able to estimate the correct FTO and decode the physical cell ID by determining the cell group ID and cell sector ID with the help of PSS and SSS respectively. After the successful detection of cell ID, the user firstly detects the index of candidate SSB (shown in Table 9) in the SS burst. These indexes are estimated by decoding the respective PBCH and DMRS associated with that SSB. The UE then carries some blind trails for decoding the Master Information Block (MIB). The MIB enables the UE to successfully determine the sample timing. During the decoding of MIB, the UE also estimates the System Frame Number (SFN).

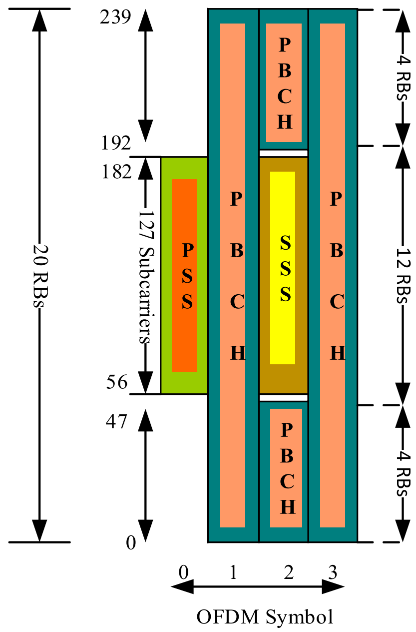

FIGURE 8. Synchronization signal block (SSB).

The decoded DMRS is helpful in performing beam measurements. It provides a piece of information that helps in estimating the RSRP and RSRQ measurements. Based on these measurements, an optimal beam is selected during beam determination operation. After the estimation of best beam, the information about the chosen beam is sent to the RAN with the help of RACH resources transmitted by gNB with PDSCH. The PDSCH also includes System Information Block (SIB) which is decoded with the help of MIB and provides information about the serving gNB. User equipment makes use of these RACH resources to transmit RACH preamble and after that, the gNB responds with Random Access Response (RAR) message. This step completes

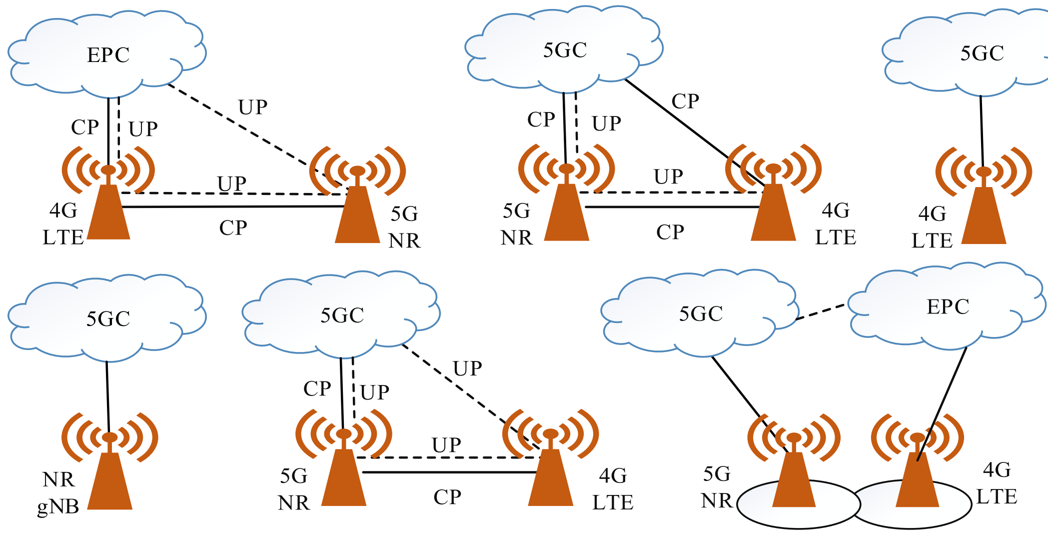

FIGURE 9. Non-Standalone and Standalone Configurations of 5G NR.

the establishment of a successful connection between the gNB and the UE. Once the connection is set up, for mobile users, the synchronization procedure proceeds with the second phase which is tracking the mobile user.

In the case of beam tracking, the user is in the connected mode. The beams are managed by using the CSI-RS for downlink and SRS for uplink [46]. These signals transfer the CSI information and control information between the connected user and gNB through the already selected beam and update the information about the connection through the selected beam.

C. NON-STANDALONE (NSA) AND STANDALONE (SA) DEPLOYMENT

NSA deployments involve the connection of gNBs with the EPC or the connection of eNB with 5GC. 3GPP has standardized the feature of multi-RAT DC (MR-DC) in 5G NR systems. Several configurations of MR-DC defined by 3GPP are E-UTRAN-NR DC (EN-DC), NR-E-UTRAN DC (NE-DC), NG-RAN-E-UTRAN DC (NGen-DC), and NR DC [47]. The option of dual connectivity ensures the mobility of users in different RATs at mmWaves. Several NSA and SA configurations of 5G NR with established Control Plane (CP) and User Plane (UP) are shown in Figure 9. NSA architectures provide a smooth transition between different generations of the wireless network. It helps in providing interconnectivity between different RATs and enhances the performance of the system by providing the reusability of already deployed infrastructure. NSA configurations provide high reactiveness in the case of link failures and also decrease the effect of overhead during the beam reporting process as compared to the standalone Configuration [48].

SA deployments involve the connection of gNBs with 5GC. SA modes are totally dependent on the core network which will be based on the specifications of the 5G systems. It will not use any previously deployed infrastructure. SA deployments will solely target the 5G architecture and enable the three use cases already specified in the previous section III. There are various challenges that are associated with NSA and SA deployment. NSA configurations are however, easy to be deployed, but for enabling the full potential of 5G applications, SA configurations are foremost required.

Some of the challenges related to the process of synchronization are summarized as under:

- Correct estimation of FTO during the handover operation so that the cell ID of the serving cell can be recovered. 3GPP has not provided any algorithm that can define the synchronization process at a wide range of frequencies that are operable in 5G NR systems. Moreover, In case of NSA and SA deployments, the FTO synchronization during handover is of primary concern as the device is moving between two different RATs that have different specifications (EPC with LTE specifications and 5GC with 5G specifications).
- Beam reporting is one of the essential operation in beam management. In the case of NSA scenarios, beam reporting is easy as the UE can easily send its information about the selected beam through the legacy connection provided by LTE. However, in the case of SA scenarios, the UE has to wait for RACH resources as UE may require a complete directional scan of multiple RACH opportunities that are directed by gNB 50].
- The frequency deviation in crystal oscillator is defined in parts per million (ppm), and the cost of the crystal oscillator is inversely proportional to its ppm value. Lower the ppm means lower the frequency offset and higher is the cost of the oscillator. In the LTE system, a 10ppm crystal oscillator is used for generating 3 GHz carrier frequency and provides the frequency error up to 30 kHz. Thus the frequency generated will be (3 GHz $\pm$30 KHz), which is tolerable and can

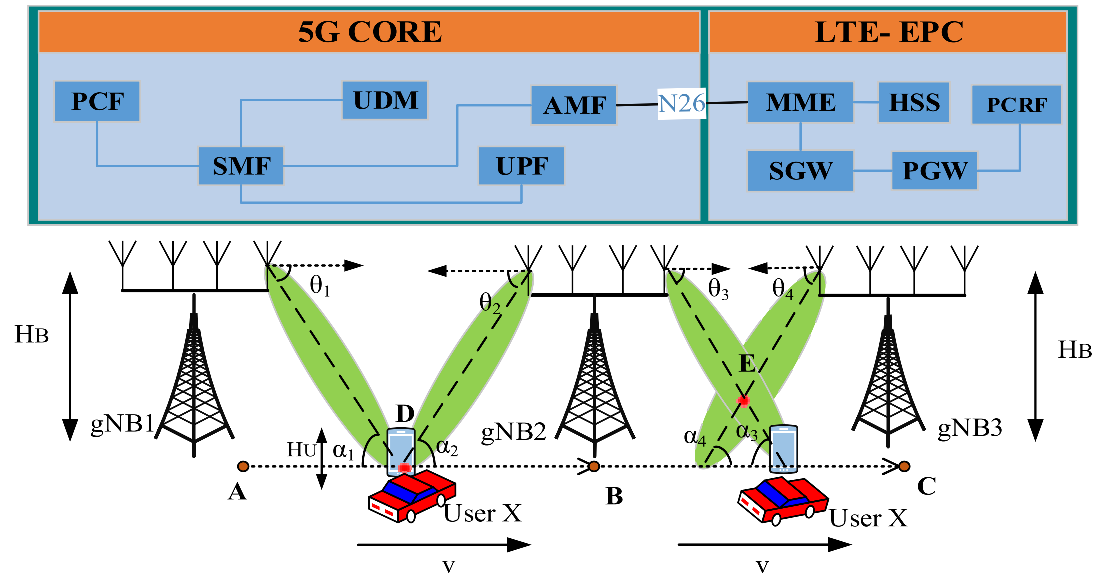

FIGURE 10. Synchronization problem in Multi-RAT scenario of 5G NR.

be estimated during FTO synchronization. However, in 5G NR systems, the carrier frequency will be very high (above 6 GHz). Thus crystal oscillator with very low ppm is required so that the low-frequency offset can be observed, which may result in higher deployment cost [45].

For easy ascend of 5G to 6G, it is required that these challenges will be removed. In this paper, we have addressed the problem of synchronization during inter-RAT handover in the 5G NR network. As it is already stated in the above section that 3GPP has standardized multi-RAT DC for providing better throughput and high mobility performance in 5G systems. Multi RAT involves the working of multiple radio access technologies together. It is an extension to the DC feature of LTE system through which one UE can be served by two RANs. This feature is helpful in connecting the user with two different RATs for ensuring reliability and quality of service. Multi-RAT DC, no doubt, will extend the functionalities of the system, but it requires a tight inter-networking among different RATs.

5G NR architecture is expected to deploy both NSA and SA mode. SA mode of deployment will not be dependent on the LTE core network. Instead of that, a new next-generation core network will be used that can operate on 5G specifications. NSA mode of deployment will be dependent on the LTE core network. NSA architecture has many benefits over SA architectures as it provides a smooth roll-out of 5G NR and combines two different spectrum (LTE and 5G) that will not only extends the coverage but also improves the data rates. For enabling NSA, the inter-working of 5G NR and LTE is required which is referred to as EN-DC/NE-DC. 3GPP has introduced an architecture in [49] for interworking of 5GC and EPC so that any user registered in any of the networks can easily access another network when it is out of the coverage of its parent network.

The architecture defines the combined modules that can perform the functions of both the networks for enabling interworking. Network Functions (NFs) like Home Subscriber Server (HSS) is combined with Unified Data Management (UDM), Policy and Charging Rules Function (PCRF) is joined with Policy Control Function (PCF), Packet Data Network Gateway (PGW) is aggregated with Session Management Function (SMF) and User Plane Function (UPF). Access & mobility management function (AMF) supports the mobility of the user and manages the connection, authentication, and authorization of users in 5GC. Similarly, in LTE EPC, the Mobility management entity (MME) manages the authentication of the user and keeps track of the mobility of UE. Both AMF and MME are responsible for managing the mobility of the user in the network. Thus by connecting these two NFs with the N26 interface, the mobility between two different RATs is possible. N26 interface is similar to the S10 interface of the LTE network which interfaces two MMEs. It works on GPRS Tunnel Protocol (GTP-C) and User Datagram Protocol (UDP) which provides a tunnel for signaling messages between MMEs during mobility of the user. For providing interworking, the N26 interface is introduced that connects MME and AMF [50].

In Figure 10, a Multi RAT system is considered in which 5GC and LTE EPC are two different RATs, and the user is considered to be moving between these two RATs. 5GC will provide all the functionalities and specifications of 5G and LTE-EPC is operating on 4G specifications. The connectivity between two different RATs is promoted by using the concept of interworking. A moving user is assumed and the concept of Beam merging is used for maximizing the SNR experienced by the user at handover regions. We have considered three different regions- Region A, Region B and Region C enabled with the services provided by gNB1, gNB2 and gNB3 respectively. The first two gNBs (gNB1, gNB2) are supposed to be connected to the same 5G core, and gNB3 is controlled by LTE- EPC. A user (say 'X') is moving with speed 'v' and starts from region A under gNB1 and driving towards region B which is under the coverage of gNB2. In between these two regions, the user will experience handover in region D. At this point, a smooth handover is needed for experiencing a reliable connection by the user. As the user is in the same access technology, beam synchronization between the gNBs is easy to attain. In 5GC, the AMF network function is responsible for keeping track of user mobility. So the information about the behavior of the user and its traffic pattern will be easily intimated from gNB1 to gNB2 as they belong to the same RANs. Thus gNB2 will get enough time for proper synchronization and will steer its beam according to the information intimidated by gNB1 for user 'X'. Now the user 'X' will travel through region B and get served by the gNB2.

In the second scenario, the user is considered to be moving from region B (served by gNB2) to region C (served by gNB3) with same velocity 'v' and will experience handover in region E. But in this case, the handover will be a bit difficult because both the base stations gNB2 and gNB3 will be of different RATs (gNB2 getting access from 5GC and gNB3 getting access from EPC). In EPC, the MME network function manages the mobility of the user. Similarly, during handover other network functions will also interact with each other and gather information about the user. The MME afterward, buffers all the information towards the gNB3, and it will steer its beams towards user 'X'. The exchange of information between different RATs will introduce an extra computation delay, and hence the gNB3 will not be able to get enough time for the synchronization of the beam within the required interval. Due to computational delay, the network will not be able to provide handover to the user moving with high speed and leads to call dropping. Thus, the inter-RAT handover synchronization is an open issue which can hinder the reliability of network.

To fulfill the promises of 5G NR, devices are required to operate in different frequency bands and different RATs. 5G NR not only needs to coexist with existing commercial wireless infrastructure but also with the upcoming future wireless network. 5G NR mmWave operating bands in FR2 is overlapping with already reserved frequencies of FSS earth station. These frequencies are 27.5 to 29.5 GHz for UL and 37.5 to 40 GHz for DL [51]. In these situations, the incumbent may have to priorities the frequency band and will need to sense the environment and modify the behavior based on the policies and requirements. It is a significant challenge during the implementation of the 5G NR network and presents a critical area for future research.

VI. THE ADVENT OF 6G NETWORK

5G networks, with all its services and use cases, are in the initial stage of its commercialization. However, these networks face various challenges during their effective deployment (Table 5). The challenges and paradigm shift of technologies have led to the development of the successor of the 5G network. It is expected that the next decade will be devoted to 6G networks (2030-35) with the realm of ''everything connected''. Various countries have already started their research on 6G networks. Finland in 2018, announced the 6Genesis flagship program for the development of a complete 6G ecosystem [52]. ITU has established a group named ''Network 2030,'' which is focusing on exploring new technologies for the systems beyond 2030.

Next-generation networks are expected to be associated with high bandwidths, terahertz frequencies (up to 3THz), and high data rates (up to 1Tb/s) for enabling various applications that includes the transfer of senses and emotions. In [53], the subsequent generation of wireless networks from 1G to 5G with the vision on 6G has been discussed with their innovations, services and issues. 6G networks will focus on improving the satisfaction of users. It follows the trajectory associated with the previous generation networks. It will include different communications modes, like satellite communication for extending the services and coverage. In 6G, the transmission networks will be modified to computing networks with AI and ML-based automatic information collection and decision making, for enabling personalized services [54]. Table 10 shows various comparable features of the 6G network with the 5G system.

In [55], the author refers the 6G network as a user and data-centric network that will provide customized services to users. Several applications of 6G like eMBB plus, big communication, 3D integrated communication, secure uRLLC and unconventional data communication are summarized as five slices of the network. 6G architectures will open a way to mobile-based AI applications. Approaches like Machine Learning and Deep Learning will play a critical role in optimizing various operations in 6G network. Advance Edge Computing with AI empowered edge nodes will integrate billions of smart devices. It will make the Internet of Everything (IoE) a reality [56].

6G will support ubiquitous intelligent society of devices that will integrate spaceborne, airborne and terrestrial networks for extending the coverage and enhancing the capacity of the network [57]. However, 6G is not limited to space, air and ground communication only. It will also provide coverage and services for underwater applications. In [58], a four-tier based cell-free network architecture is proposed that covers space, ground, air and water networks. Satellite mobile communication will extend the global coverage at a very low cost and will support high-speed mobility of users. 6G will incorporate AI and ML-based interfaces, extended-spectrum, specialized slicing based architecture, extreme networking and enhanced secured schemes for carrying out data transmission [59], [60].

Several use cases and technologies are discussed under 6G that are beyond eMBB, mMTC and uRLLC. In [61], use cases include Computation Oriented Communication (COC), Event Defined uRLLC (EDuRLLC) and Contextually Agile eMBB Communications (CAeC). These services will differ from conventional services in terms of their flexibility and

TABLE 10. Comparison of features of 5G and 6G network.

Features	5G NR	6G
Peak data rates	20Gbps	~1 Tbps
Latency	1ms	Less than 1ms
Area traffic capacity	$10Mb/s/m^2$	$1Gb/s/m^2$
Frequency bands	Sub 6GHz mmWave (24-52.6 GHz)	Sub 6GHz mmWave band Terahertz band (Visible light band)
Connection density	$1M$ devices/Km^2	$10M$ devices/Km^2
Device Services	Reliable connectivity of devices.	Physical interaction in real-time scenarios.
Network Type	SDN, NFV, Slicing	SDN, NFV, Intelligent cloud, AI-based Slicing. Machine Learning, Deep Learning.
Computing Technique	Fog Computing, cloud computing	Quantum Computing, Edge computing
Mobility	500 Km/h	> 700 Km/h
Technology	D2D communication, Ultra-dense Network, Relaying, Small Cell Access, NOMA.	Visible Light Communication, Quantum Communication, Hybrid Access, Haptic technology, Adaptive Resource Allocation.
Applications	360º Video, UHD video, AR, VR, IoT, Smart city, Smart Home.	Holographic imaging, Haptic communication, Telerobotics, Teledriving, AR/VR/XR, Tele-education, Internet of Everything

adaptability, and hence makes the network, flexible, agile and adaptable according to the changes in the network condition. In [62], services like the ultra-High Speed with Low Latency communication (uHSLLC), ultra-High Data Density (uHDD), and ubiquitous Mobile Ultra-Broadband (uMUB) are included as the three use cases of 6G networks. In order to realize these use cases, three leading technologies are illustrated. These are computational holographic radio, Artificial intelligence, and photonics-based cognitive radio. Photonics based systems are capable of providing high bandwidth and full spectrum capacity. It is an extension of microwave photonics. In 6G, the photonic technology is integrated with machine learning for supporting AI-based intelligent architecture. The author has presented an all photonic RANs based architecture for computational holographic radio. In [31], super IoT, mobile ultra-broadband and artificial intelligence are discussed as the main aspects of 6G network. Technologies like Terahertz (THz) communication, symbiotic radio, satellite communication and machine learning are demonstrated as the promising techniques.

Conventional networks has been using radio links for carrying out communication but next-generation networks will make use of Optical Wireless Communications (OWC). OWC generally includes the usage of visible light bands for wireless communication. Presently, the visible light spectrum is widely used for illumination purposes. But in 6G, it is expected that Visible Light Communication (VLC) will be deployed for achieving high data rates. Various 6G techniques with their drawbacks and use cases are discussed in [63]. Based on all the applications, performance metrics and use cases of 6G network, a new class of services is proposed in [64]. These services will include Mobile Broadband Reliable Low Latency Communication (MBRLLC) services, massive URLLC (mURLLC) services, human-centric services and multi-purpose convergence, computing, control, localization and sensing services. Several potential techniques of 6G network like holographic radio, THz communication, Large Intelligent Surface (LIS) and Orbital Angular momentum (OAM) Communication are summarized in detail in [65]. LIS is the large surface made up of electromagnetic materials. It is cost-effective and energy-efficient. In future, LIS based communication can provide the best solution for better energy efficiency with high data rates and low cost. Moreover, OAM based novel access techniques will also help in providing high spectral efficiency in 6G network.

VII. VIRTUALIZED NETWORK SLICING BASED 6G ARCHITECTURE

A virtualized 6G architecture based on the concept of network slicing is proposed in Figure 11. The architecture consists of three layers: Intelligent Cloud Slicing Layer, RAN Slicing Layer and Application Slicing Layer. The architecture is solely based on network slicing which provides flexibility to the network. It is one of the optimized solutions that can boost the efficiency of the system and helps in enabling the services that are required for providing vast applications and harness the capabilities of the network effectively. The concept of network slicing was described in [66]. It was introduced as an essential requirement of the 5G/IMT 2020 network, which involves the division of both control and data plan. But it is not limited to the 5G network only. The concept of slicing can be extended to 6G network for enabling network virtualization and ensuring flexibility. 6G will incorporate several technologies and services which may require different network functionalities. Network slicing will provide a platform to the 6G services like touch technology (haptic communication), that will incorporate ML and DL based techniques. The technology will enable the network to provide real time access to the product from anywhere at anytime. In order to utilize these distinctive services effectively, the virtualized slicing of network will be a promising approach. Network slicing defines the capability of the network to construct and manage the network slice according to the requested services. For efficiently handling the complicated task of slice management, machine learning is proposed as the best approach in [67].

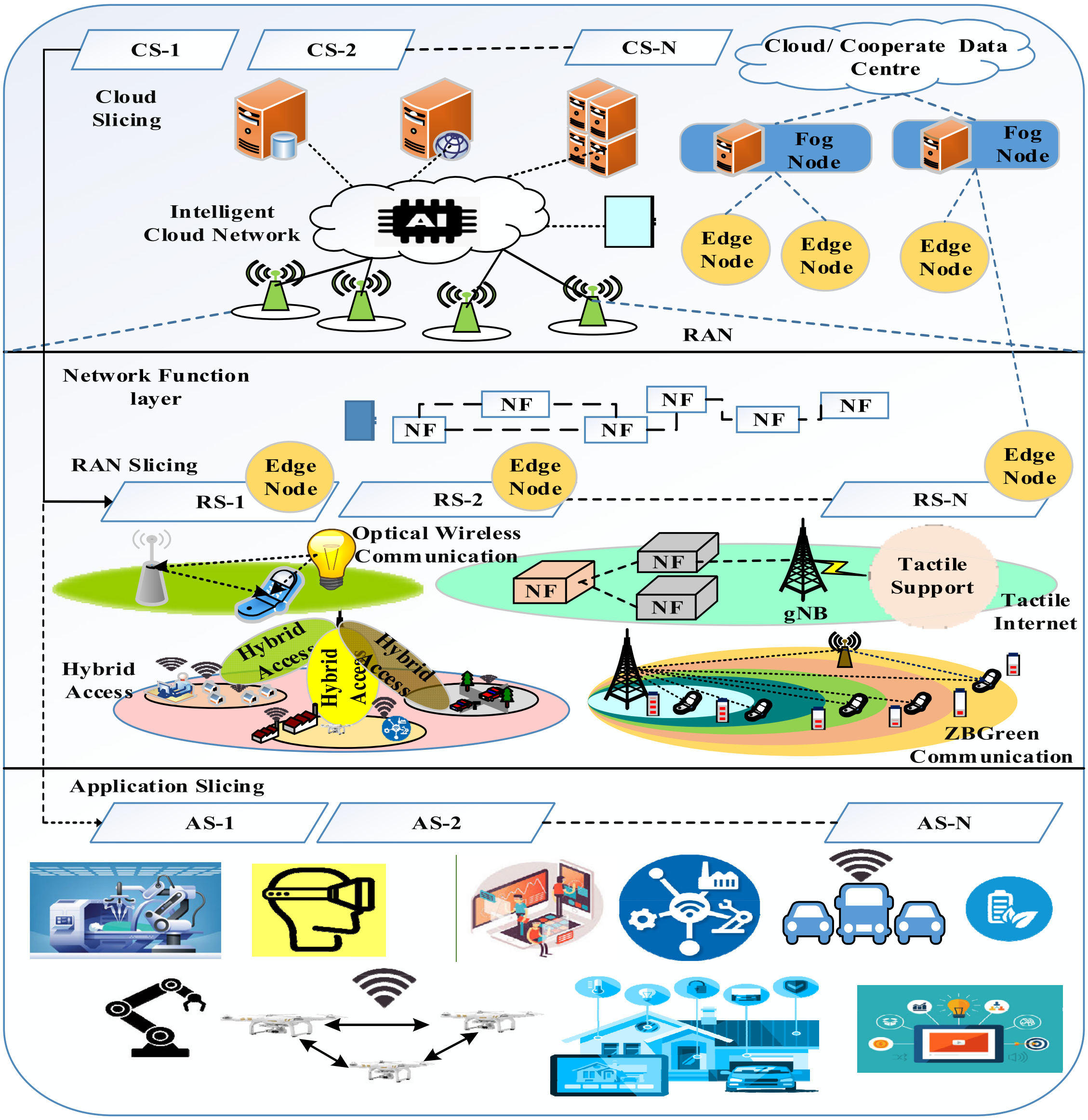

FIGURE 11. The virtualized network slicing based Architecture of 6G network.

In 6G, for enabling various potential applications, the network is divided into various slices, and each slice is configured with required protocols and policies. These protocols and policies are already defined and helps in enabling the specified service on a slice. Network slicing uses the concept of NFV and SDN for providing virtualization and flexibility [68]. NFV reduces the cost of the infrastructure and enhances its capacity. NFV is also termed as Virtualized Network Functions (VNF) which includes the chained network functions that are virtual to form an infrastructure which is generally referred to as the NFV Infrastructure (NFVI). The NFVI consists of storage blocks and network management blocks. It includes Management and Orchestration (MANO) which automatically configures, coordinates and manages the network. MANO architecture is much responsible for enabling the services and actualizing the NFVI. MANO architecture will include Resource Orchestrator within the network. It takes the help of Virtual Infrastructure Manager (VIM) and VNF Manager (VNFM) that manages the life cycle of different VNFs and also collects the information about the performance of NFVI.

SDN enables the network to be controlled intelligently and programmed by implementing software applications. This type of networking ensures flexibility, robustness, and virtualization. An SDN controller effectively controls the network slice according to the policies and apply rules and regulation when required. These controllers significantly affect the flexibility of the network. Various SDN features that help in enabling network slicing are:

(1) Centralized control makes the network to be controlled intelligently by using the centralized topology of the network so that each element of the network can be viewed holistically.

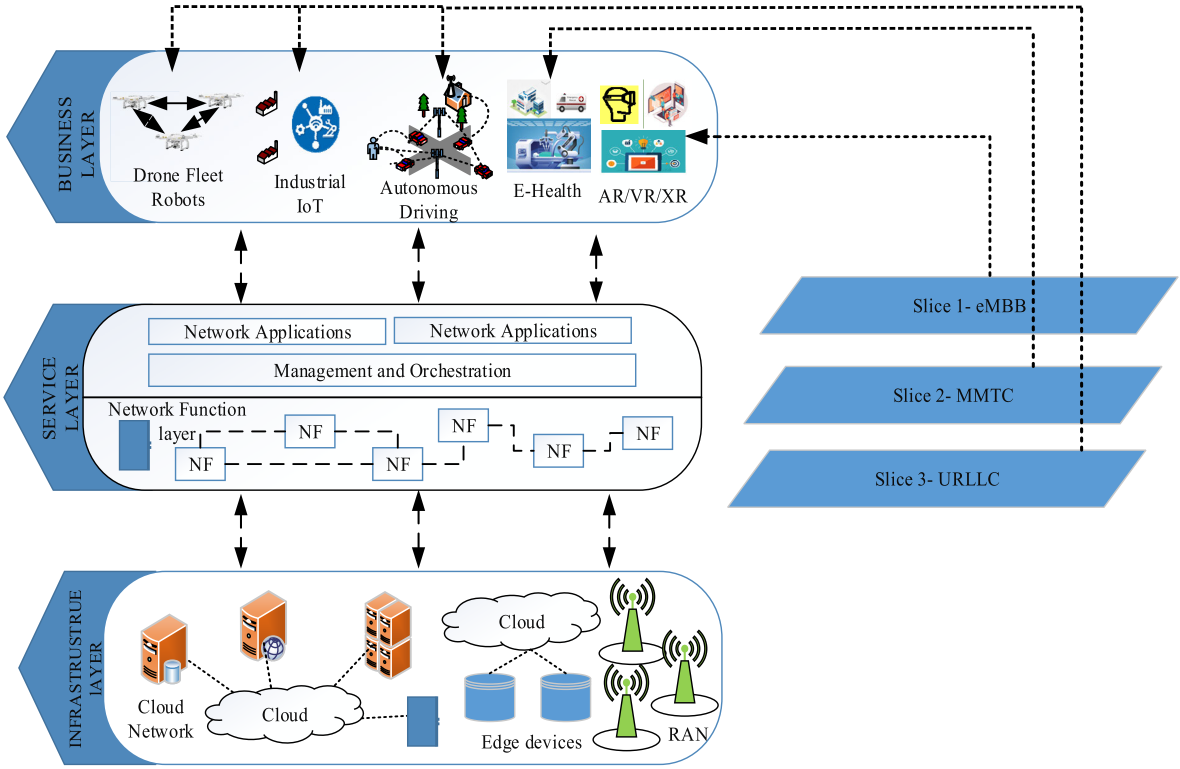

FIGURE 12. Virtualized network slicing architecture.

(2) Programmable Networking makes the network to be programmed according to the modified services. The changes in the hardware are merely required, and just by making some software changes, the operator can support various new services.

(3) Flexibility and Openness which makes the system to support numerous program interfaces and interoperability.

Figure 12 shows the virtualized network slicing architecture. There are three layers in slicing architecture: Infrastructure layer, Service layer, and Business layer [69]. The infrastructure layer accommodates edge cloud, Core Network (CN) and RANs. The service layer enables the services of the specific slice by grouping the NFs in the network function layer. It is directly connected to the business layer and enables various applications. The business layer works as an application layer. It provides support to the three use cases and collects all the details about the demanded application and encodes it. After encoding, all the information is transferred to the service layer for the detection of the slice for that particular service. Similarly, the concept of network slicing will be helpful in enabling AI-based 6G architecture. 6G architecture will be divided into three fundamental layers: Intelligent Cloud Slicing layer, RAN Slicing layer, and Application Slicing layer. These layers will be formed virtually on the basis of the demand of the user. The three layers are discussed as under:

Intelligent Cloud Layer Slicing: This layer is the same as the infrastructure layer of network slicing that provides virtualized resources for computing and increases the capability of the network. It helps in isolating the network slices, based on the services and establishes an interface with the service layer so that the respective service on the individual slice can be enabled. It enables the feature of resource orchestration based on the network resource request from the operators. Modern virtual technology needs infrastructure virtualization and intelligence, which can be accomplished by utilizing SDN based base station, virtualized RANs and intelligent CN.

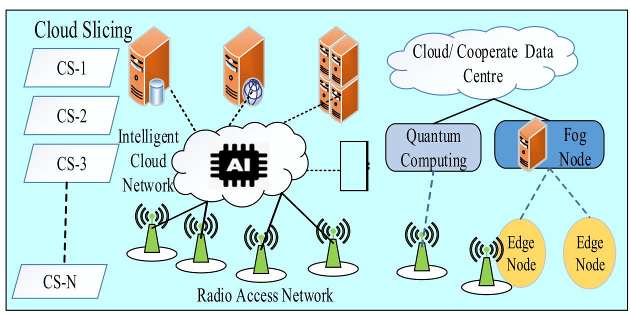

FIGURE 13. Intelligent cloud slicing layer.

An intelligent cloud consists of an AI-empowered cloud that has excellent computing power and extensive storage capabilities. It provides a platform for the functioning of a large number of advanced technologies and services. In 6G, cloud slicing provides a definite solution for enabling various functionalities of the network within one infrastructure. In Figure 13, the cloud is sliced into N number of cloud slices to support various RAN infrastructure. The computing power of the intelligent cloud is enhanced by using the technology of edge computing and quantum computing.

A. EDGE COMPUTING

Next-Generation networks are supposed to support the connection density of higher than 1M devices/km^2. The introduction of the massive number of devices has added several endpoints to the existing networks, and it becomes complicated to process such an immense data with less than 1ms round trip time. In [70], the author has broadly reviewed the edge technology in the 5G network. This technology will provide cloud services at the user's end. 6G network includes tactile internet services that require extremely high data rate, lower latency, and extended reliability. It will enable the physical interaction of human beings with the object at the remote place. For enabling these type of services, Edge Computing (EC) is incorporated as the technique for reducing the computational complexity. It processes most of the data at the network's edge rather than transferring it to the cloud network that is far away. It provides a local source for the number of devices where the data can be stored and processed for minimizing the access time and thereby reduces the latency. Edge computing is advantageous with respect to:

- Increasing the computational capability of the network.
- Reduces the computation time for handling the complex tasks in real-time applications.
- Reduces the latency and access time.
- Reduces the bandwidth requirement.
- Optimize the processing data for higher computing layers.
- Acts as a complement to Fog computing.

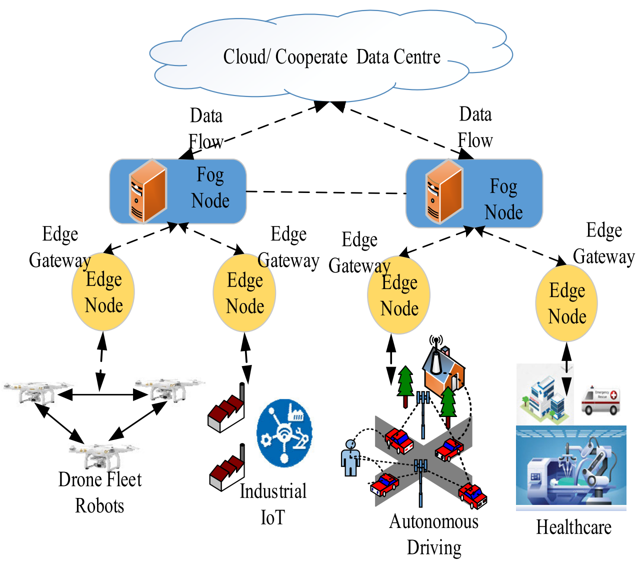

FIGURE 14. Edge computing with different applications.

Figure 14 shows the technique of edge computing for enabling various next-generation applications. The network consists of various Edge nodes. Each node has an edge gateway that connects the edge devices to the local edge processor and local edge processor to the centralized network /Cloud. Edge device includes various IoT devices like sensors, actuators, smartphones, cameras, smart devices, haptic devices etc. The local edge processor performs all the necessary processing near the network and then buffer only the necessary data to the cloud network for further processing, which is then sent back to the edge device as the response during real-time applications and hence reduces the bandwidth utilization with enhanced performance. Indifference to the Fog Computing, Edge computing is associated with the processing at the device end rather than processing at the local network provided by Fog computing.

6G will implement AI algorithms on the edge nodes, generally referred to as Edge AI. It enables the devices to perform specific tasks based on the information harvested locally. Edge intelligence will benefit the network with low latency communication. In [71], techniques of deep learning are used for enabling uRLLC. Federated learning is applied at edge nodes for effectively exploiting the limited capacity of edge nodes and devices for uRLLC. For competent working of an edge node with millions of connected devices, several mobile edge scheduling and offloading policies are required. In [72], a Computation Offloading Method for the Internet of Vehicle (IoV) named as CoV is proposed. The CoV will offload the data from an overloaded edge node to the idle edge nodes by estimating an appropriate destination with minimum delay and offloading cost.

B. QUANTUM COMPUTING

In 6G, conventional computing systems are going to be replaced by quantum computing for promoting parallelism, which is an inherent property of quantum mechanics. Quantum computing will enable parallel processing of multi-dimensional and large size data. It will enhance the algorithms and techniques of ML and AI that deal with a tremendous amount of data for training. Quantum communication can be useful in providing high security in 6G networks. It can be considered as the key enabler of 6G technology. It enhances the network efficiency for keeping the knowledge on a real-time basis and provides a rapid response to the user demand [73]. Quantum computing based networks can effectively support several applications over a long distance. Quantum processing and computing enhances data rates and reduces delay. It helps in achieving the ultra-low latency requirement of modern technologies. Quantum computing uses quantum mechanical phenomenon for manipulating quantum information (in qubits). General features of quantum computing are:

- It provides faster manipulation of a large number of data.
- Rely on qubit (quantum bit), which is the unit of quantum information.
- Promotes parallel processing for supporting millions of devices simultaneously.
- Helps in processing training data for Machine learning and deep learning models.

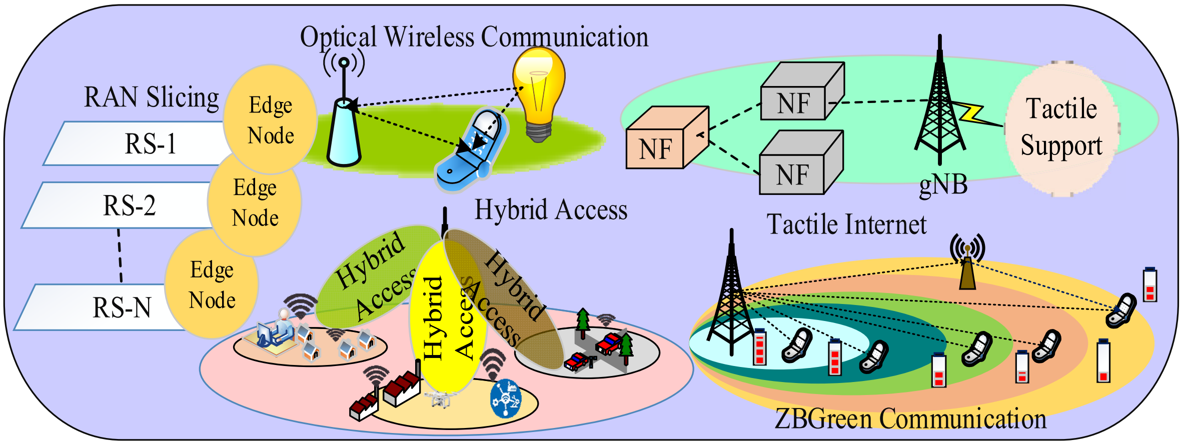

FIGURE 15. RAN slicing layer.

Ran Layer Slicing: RAN slicing is generally termed as the sliced RAN infrastructure for enabling those applications and services, which require different functionalities. It performs the same function as the service layer performs in network slicing. In the network slicing architecture (Figure 12), based on the demand of the user, the service is offered to the customer by using a virtual slice, which is being managed and operated by the Network Function Layer (NFL). NFL is also a part of the service layer. It deals with the network function orchestration and manages the life cycle of NFs [74]. It behaves like an end to end link that helps in meeting various functions that are required for enabling the service on a specific slice. NFL will chain the necessary NFs, based on the performance metrics. These chained NFs are then stored in a repository. The repository is like a storage block, which stores the complete set of NFs. The created slices are also stored in the repository for future usage. In 6G architecture, the service slicing is accomplished by slicing the RAN into N number of slices, as shown in Figure 15. Each RAN slice is supported by specific intelligent cloud slice to enable specific application slice.

6G networks will provide various new services that are beyond eMBB, mMTC and uRLLC. In [62], the services are classified as uHSLLC which deals with the extremely high data rate of 1 Terabit/sec and very-low latency of less than 1ms, uHDD for supporting the massive data requirements and uMUB for high-speed broadband services. In [61], the enabling services are defined as COC for computational accuracy, EDuRLLC for ensuring the spectrum flexibility and availability for uRLLC and CAeC for providing eMBB services that are agile in terms of network context. These services will help in providing support to the upsurging applications. In a network, each of the above-stated services require different functionalities and performance metric. It is difficult to effectively deploy each service within the same infrastructure. Thus RAN slicing will virtually slice the network into different RANs, such that each virtual RAN can effectively enable the specified service. Various novel techniques that are being used for RAN slicing are briefed as under:

C. TACTILE INTERNET

Tactile internet provides a platform for enabling real-time applications, which range from actuating robotics to haptic communications including telesurgery, autonomous driving, AR, VR, and XR. In the tactile enabled network, lower latency is combined with enhanced reliability and security. It is considered as the key enabler of haptic communication, which incorporates the actual immersion of human being in the virtual world empowered with the sense of touch and physical interaction from a remote place. It integrates the senses (touch) of the human being with an intelligent machine and has revolutionized IoT networks.

The conventional network doesn't support the transmission of haptic data with traditional systems. Thus tactile internet acts as the platform that provides support for the transfer of haptic data. It includes the transfer of feelings, touch, and motion through the network. In [75], [76], the author has divided the tactile architecture into three different zones: Master Zone, Network Zone and Controller Zone. Figure 16 shows the tactile internet-based architecture as an enabler of haptic communication.

1) MASTER ZONE

It consists of a Human-System Interface (HSI), where the haptic device converts the input from humans to the tactile input with the help of coding techniques. Haptic devices are the programmed device that permits the user to operate, to touch, and to feel the remote things from bidirectional haptic feedback through a haptic interface.

The haptic interface is of two types: Kinesthetic interfaces and tactile interfaces [77]. The kinesthetic interface acts on the basis of feedback which is related to force or movement. Any change in the position of the device is only because of this interface. Whereas, the tactile interface, acts on the basis of feedback which is related to the sense of touch or feel. The haptic devices have direct interaction with human skin and stimulate the nerves so that a person can feel the distant thing. Various new haptic devices are required to be developed so that the insights of tactile internet can be truly realized.

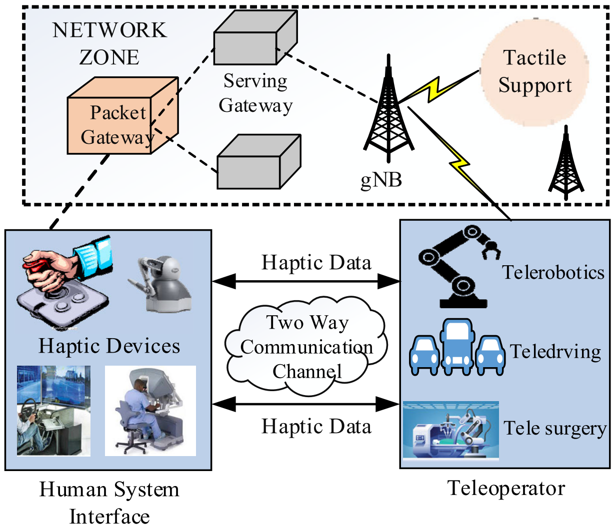

FIGURE 16. Tactile internet-based architecture.

2) CONTROLLER ZONE

This zone incorporates a teleoperator part of haptic communication, which interacts with the objects that are at the remote place. Any change in this zone is due to the command from the master zone. The haptic device in the master zone converts the human input into the tactile input. The tactile input in the form of haptic data travels through the network-enabled with tactile internet. Based on the haptic data, the required changes will be made. The haptic feedback is a bidirectional control link that helps in controlling the exchange of energy between these two zones through the tactile internet-enabled network.

3) NETWORK ZONE

In the network zone, the access network is supported by tactile internet which provides required functionalities for carrying out haptic communication. This zone connects the master zone with the controller zone. The traditional networks require a lot of modifications in terms of protocols so that it can support virtual interactions. For providing the real-time interactions, ultra-low latency and highly reliable links are required. The total immersion of operators in the virtual environment requires an exceptionally high data rate. Thus, the handling of high data for high performance needs an efficient network.

In 5G systems, uRLLC services are the enabler of lower latency and highly reliable communication links. Tactile internet is also based on the uRLLC service of 5G NR, where latency and reliability are its critical aspects. Some algorithms and techniques are put forward for improving system performance. In [78], the author has discussed that reducing Transmission Time Interval (TTI) and HARQ Round Trip Time (RTT) will enhance the network capabilities by reducing latency and improving reliability. The author has used the queueing model for studying the behavior of the Physical and Mac layer that operates on the concept of dropping the packet if the queuing delay exceeds the latency requirement. But, it will result in reduced reliability of the network. Thus by reducing the TTI and HARQ RTT, the time period for HARQ transmissions is extended, which results in reduced queuing delay and improved reliability. The short TTI is achieved by increasing the SCS and reducing the number of OFDM symbols in each slot. However, the reduced number of OFDM symbols in a slot will result in the utilization of more RBs, which indirectly increases the queuing effect. The queuing effect further reduces the reliability of the link and can cause jamming in the network. Thus, it is concluded that TTI and HARQ RTT time reduction should be made wisely so that it will not affect the system performance.

Tactile internet is itself very vast in terms of providing services and enabling applications. Tactile internet has its main advantage in enabling both haptic (deals with sense) and non-haptic (deals with force) communication. It incorporates almost each application field of automation. Various applications and challenges related to tactile internet are presented in [79]

D. OPTICAL WIRELESS COMMUNICATION (OWC)

In the future wireless networks, RF communications are being replaced by OWC. It includes the frequency bands of Infrared, visible light, and ultraviolet radiation. Among these three, OWC generally operates on the visible light band for data transfer. The type of communication through the visible light spectrum is termed as VLC. In VLC, visible light is used to offer both illumination and communication, along with energy harvesting. It provides an alternative for providing faster data rates to the indoor user with the help of LEDs. It uses visible light that is Terahertz (THz) bands for transferring information which does not have any harmful impact on human health and thus promotes green communication [80].

The upsurging applications of the 6G network will require extremely high data rates ($\sim$ in Tb/s). Such a huge demand for data rates can be fulfilled by extending the frequency range of wireless networks. Presently, in 5G NR, the mmWaves (up to 100GHz) are expected to be employed. These high frequencies are associated with various looses that are being compensated by using the technique of narrow beamforming. The frequencies above 100 GHz are expected to be utilized in 6G/beyond 5G networks. The frequency spectrum between 100-300GHz is defined to be the sub-THz band and 300GHz to 3THz as the THz bands [30]. However, the optical band/visible light band ranges from 430-730THz. THz communications are extremely secure because these communications use narrow beam and small duration of pluses for data transfer which reduces the probability of attack. The THz frequencies are non-ionizing and have less thermal hazards than RF radiations. These frequencies have a very less harmful effect on the health of human beings.

E. DYNAMIC MULTIPLE ACCESS TECHNIQUES

6G networks will provide a platform for AI-based applications and thus require a completely new framework with AI-based protocols and adaptable multiple access techniques. As it is already stated that 6G will integrate all the network domains including terrestrial network, airborne network, spaceborne network and underwater network. The collaboration of these networks will require a highly flexible and adaptable system. A new framework of protocols is mandatory that can adapt themselves according to the channel conditions. It requires several dynamic mechanisms for providing smooth handover in different mobility patterns of the 6G network. Thus, it becomes essential to develop novel AI-based protocols for providing access, handover, and authentication.

In [81], the author has reviewed various multiple access techniques for VLC. Among all the conventional techniques of multiple access, the NOMA ensures high system throughputs and gains. For magnifying its performance in VLC, the transmission angles and receiver's field of view are tuned by adding MIMO to NOMA. MIMO based NOMA further increases the system throughput and its spectral efficiency. However, several challenges like LED non-linearity, imperfect Successive Interference Cancelation (SIC) and imprecise Channel State Information (CSI) can affect the performance of NOMA based VLC system and thus requires novel techniques to be proposed. In [82], an extended technique named as Delta Orthogonal Multiple Access (D-OMA) technique is discussed for providing massive access in 6G, with improved outage capacity than NOMA. This technique can significantly help in boosting the required spectrum efficiency gain for 6G network but possess several implementation issues. These issues include power allocation among D-OMA devices, effective SIC and selection of cluster size. In [65], Orbital Angular Momentum (OAM) based multiplexing is discussed as one of the potential key technology for the 6G network OAM based access technique is advantageous for fulfilling the required demand of high spectral efficiency and high capacity with enhanced reliability.

In [83], a Rank based access technique is used for providing access to the user based on mobility. Pedestrian users are assigned as Rank I, mobile users with a medium speed of less than 30 Km/h are assigned as Rank II and the high-speed mobile users are assigned with Rank III. It is assumed that the user of group Rank I are highly susceptible to the security attack because these users are low mobility users and are under the influence of attack for an extended period of time than the other two cases. A proper access technique is provided to the user under each rank. The low mobile user of Rank I is provided with NOMA so that reliability and security can be ensured. The users under Rank II are medium velocity user and are assigned with Hybrid access (OMA+NOMA). Highly mobile users under Rank III are assigned with OMA as the multiple access technique.

The Rank based Hybrid access technique is helpful for enhancing the QoS of the vehicular user. The next-generation networks are expected to use these types of Hybrid Multiple Access (Hybrid MA) techniques so that the performance of the system can be improved by the effective utilization of available resources [84]. By grouping the users into different ranks on the basis of different parameters, as shown in Figure 17, the Hybrid MA technique is employed for providing access as per the user's requirement in 6G networks.

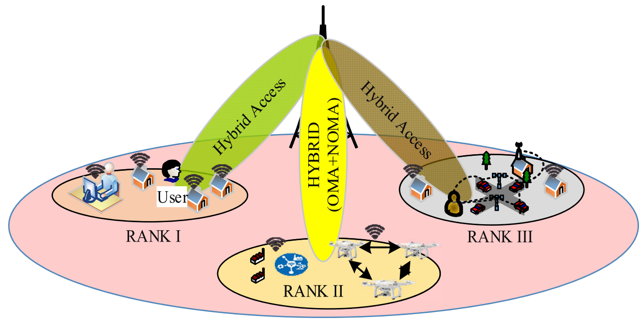

FIGURE 17. Rank based hybrid access technique.

F. BACKHAUL NETWORKS

With the emerging technologies and services that are being promised by 6G network, there is a requirement of feasible backhaul network. It is essential that the backhaul network must be sufficient enough to meet the requirement of capacity, latency, cost efficiency, availability, energy and long-distance reachability. With the exponential increase in the demand of bandwidth, further improvement in present backhaul network is an important requirement. Passive Optical Network (PON) technologies are being deployed widely nowadays, for realizing majority of the networks. PONs are point to multipoint networks which includes an Optical Line Terminal (OLT) that acts as a central station and connects a number of Optical Network Units (ONUs) through an optical splitter. OLT will perform downstream transmissions by sending modulated data (on specific bandwidth) to the optical distribution network. The optical splitter then splits the data signals into multiple ONUs. The ONU receives the signal and after demodulation, signal is transferred to the wireless frontend. The ONUs are also responsible for the collection of upstream data, upstream wavelength assignment and upstream data transmissions to the remote node that is OLT.

In [85], the author has focused on Hybrid optical-wireless networks as an optical backhaul for the next generation networks. The optical networks are advantageous for large bandwidth capacity but requires a lot of infrastructure for long transmissions. On the other hand, wireless access networks can provide flexibility with low infrastructure requirements, but cannot handle high bandwidth demand. Thus, by collaborating the features of both the technologies, hybrid optical-wireless networks are proposed as an optimal solution. The hybrid networks are capable of providing the requirement of high bandwidth and high mobility. In this paper, the author has suggested an architecture of hybrid optical wireless network using Time and Wavelength Division Multiplexing PON (TWDM-PON) as an optical backhauling network. Likewise, a lot of research is required for the development of efficient backhaul network that can effectivity support the growing demand of the users.

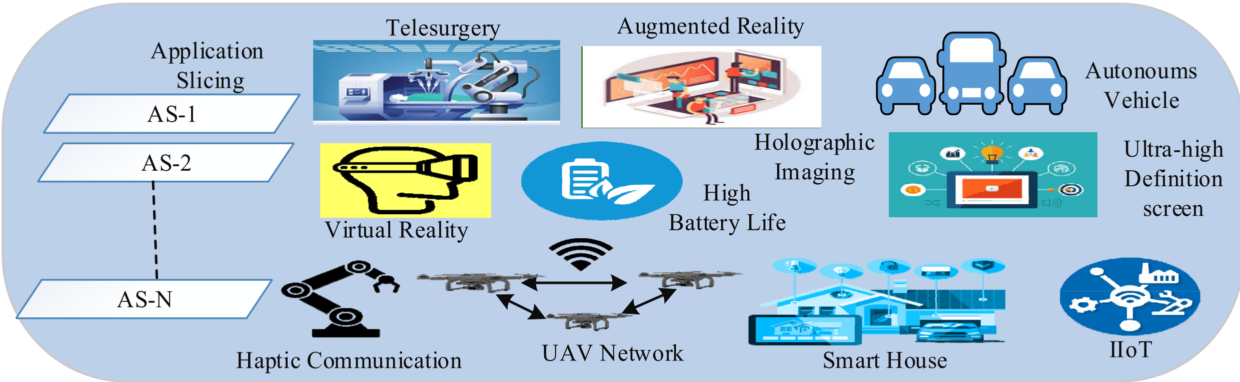

FIGURE 18. Application slicing layer.

G. ENERGY EFFICIENT TECHNIQUES

Massive connectivity of smart devices and the requirement of high data rates have increased the energy consumption levels. Various new applications like AR, VR, XR, Tactile applications, etc. require high data rates and high battery capabilities, which makes energy efficiency a critical issue of next-generation wireless systems. Various energy-efficient algorithms and techniques are required to be implemented so that the power utilization can be optimized and green communication will be promoted.

In [86], an energy-efficient scheme referred to as Energy-Efficient Adaptive Resource Block Allocation with Low Complexity (E2ARC) is implemented for adaptively allocating resources to the user. The scheme makes the system energy efficient by improving the throughput and reducing the power consumption. Along with it, the scheme is helpful in ensuring the extended battery life of the system. In [87], a Zonal Based Green algorithm (ZBGreen) is introduced for determining the energy consumed during the transfer of data from one transmitter to the number of receivers present in different zones. It is assumed that the increased distance between the transmitter and the receiver increases the required transmission power and battery life time for carrying out communication. When the transmitter fails to achieve the target rates, it will coordinate with relay. The relay simply amplifies the signal and reduces the transmission time. The ZBGreen algorithm thus extends the battery lifetime of the PT by up to 46.28%.

Therefore the schemes like E2ARC and ZBGreen helps to promote green communication and extending battery life in the next-generation wireless network. At Last, RAN slicing is performed on the basis of the demanded application. Different slices of RAN operates on different technologies for ensuring the services of 6G. Each RAN slice is connected with the intelligent virtual cloud for enabling various applications of the 6G network.

Application Slicing: Application Slicing is similar to the business layer in network slicing. It provides support to numerous applications like haptic communication, telesurgery, autonomous vehicle, AR, VR, IIoT, holographic imaging, IoV, U2X and IoR as shown in Figure 18. In Application slicing layers, N number of application slices are formed based on the different types of applications. These applications differ from one another in terms of performance and QoS requirements. The layer collects all the details about the demanded application and encodes it in the form of performance metrics. These metrics will include requested QoS, latency requirements, Packet Error Rate (PER) and required bandwidth. At the RAN Slicing layer, based on the performance metrics, a slice is selected from the already present slices, stored in the repository. If in any case, the required RAN slice is not present, then a new RAN slice is generated by NFL.

The Slicing architecture of 6G opens up various new applications that were dormant previously. Some of the revolutionary applications and services enabled by 6G network are briefed as under:

H. HAPTIC COMMUNICATION

Haptic deals with the human sense of touch. Haptic communication generally includes the control and management of the object from the distant place by using the sense of touch. Haptic communication also includes audiovisual communications. It provides an environment where a user can experience the actual immersion of the digital world with the real world for carrying out various tasks. These communications will enable the physical interaction of the user with digital devices that are placed remotely. In [77], Telepresence and Teleaction (TPTA) are considered as the main target of haptic communication. TPTA include the presence of a user in the remote environment without being there. The system that can enable these communications is generally referred to as Telehaptic systems. These systems include various technologies that are capable of providing a scenario to the user, which deals with the ability of a person to feel something from a remote place.

Telehaptic systems consist of two main components, Human system Interface (HSI) and a teleoperator (generally digital device/machine). In between these two components, there exist a two-way communication channel,

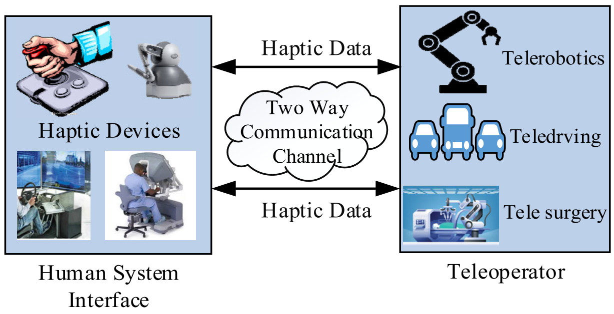

FIGURE 19. Telehaptic system.

as in Figure 19. At the user end, there is a haptic interface that contains sensors and the operator/human who will interact with these sensors. Each movement (in terms of velocity and position) of the operator is sensed by the sensors and is transmitted as the motion data to the teleoperator through the communication channel. As a result, any action at the remote digital device can be taken. These actions will include changing the position and direction of an object, telesurgery, teleoperations, etc.

Haptic links require very low latency of less than 1 ms with the least packet loss which is necessary for the reliability of the system. The stability of the network and communication link is of significant concern in haptic communication. Even small delay or data loss in the network can hamper the quality of the task or service [88]. Tactile internet is the key enabler of haptic communication. In this section, Figure 19 shows the interaction of humans with telerobots, teledriving, and telesurgery. Here the HSI is connected to teleoperators through a two-way communication link. Haptic communication is facing several challenges related to latency, reliability, stability, hardware, and security. Various novel applications enabled by haptic communication are mentioned below:

1) TELESURGEY

Telesurgery eliminates the barrier of distance in the absence of a surgeon and can save many lives. Robotics in medical science has already improved the quality of treatments by providing modified machines and devices that can operate more effectively than the previous systems. In case of serious accidents, if the surgeon is in some other country, then with the help of the telesurgery feature provided by haptic communication, the patient can be operated from distant places also. In [89], an architecture is presented for enabling the telesurgery with the help of tactile internet. It is concluded in this paper that low latency, less reliability, high packet loss can lead to the failure of these systems. Telesurgery is carried out by operating surgery on the virtual body image of the patient, where the surgeon can touch and feel the injured muscles and operate it more effectively, even from a remote place. These kinds of surgeries will require very low latency (less than 1ms) and high reliability (99.999%) of the system, which can be provided only through haptic technology.

2) TELEROBOTICS

Industry 4.0, the fourth industrial revolution, which generally includes digitalization and automation. It includes smart manufacturing where, with the help of robots, multiple functions can be performed. Telerobotics is very similar to smart manufacturing, with slight modification in the control system. In industries, Telerobotics controls the manufacturing units or industrial robots from remote places. It helps in operating any machine or instrument from a distant place by the professional and saves both time and money. It is also helpful in smart home automation for operating domestic robots and carrying out household activities from distant places. Telerobotics has its application in health care also, where medical instruments or robots are controlled from the distant place.

3) TELEDRIVING

Vehicle to everything communication lays out the way to autonomous driving, where various sensors and actuators interact with each other for driving a vehicle autonomously. But any failure in the functioning of any sensor or actuator due to weather conditions may lead to severe accidents. During any sensor failure, human interaction is required so that the best decision can be taken in time. Teledriving means to drive and controlling the operations of the vehicle from a remote place. It is helpful in the absence of driver where any driver from distance place feel the virtual environment of the road and take necessary decisions according to the traffic conditions.

I. HOLOGRAPHIC IMAGING

Holographic Imaging produces the holographic view of the remote place. The holographic view contains several holographic images that are projected in the form of a 3D hologram. For producing these images, a large number of cameras are used. These cameras operate on a very high data rate in the order of terabits per second. Nowadays, Holographic imaging is combined with telepresence, which will be helpful in enabling the interaction of human beings with the things that are at the remote place [90]. It enables the actual immersion of human beings into a distant environment and provides a platform for 3D video conferencing with a real-time 3D image of the person present at the remote place.

In conventional holographic communication, several cameras have been used for capturing the image of an individual and its surrounding objects. The images are then compressed and transferred through the communication channel. At the other end, the received images are decompressed and projected with the help of laser beams. In 6G, along with image transfer, motion and audio data will also be transmitted. These types of transmissions require high data rates and high computational power. Holographic imaging will help to enable real-time interactions in future networks by providing the hologram views for haptic communication.

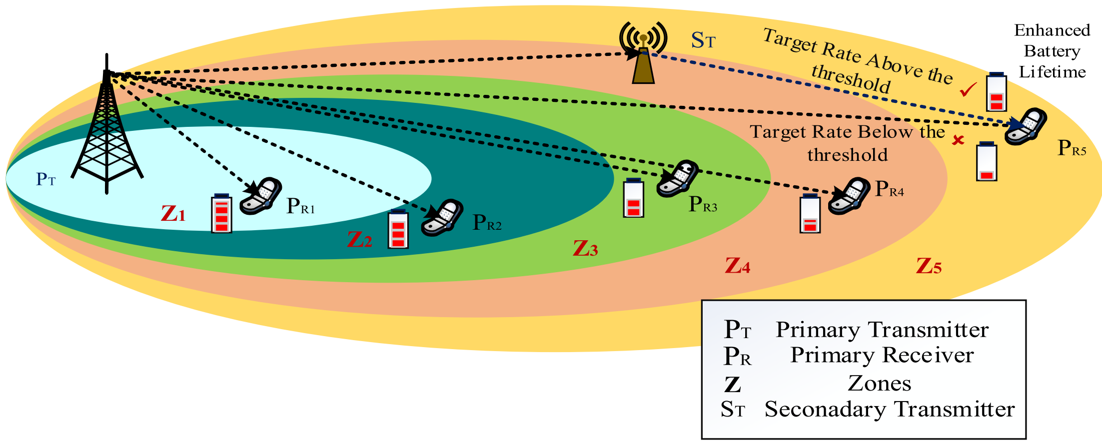

FIGURE 20. Zone-Based Green (ZBGreen) Algorithms.

J. LOW POWER CONSUMPTION

6G networks are expected to provide high performance with low power consumption and better efficiency. In the coming years, the user traffic will be very high with the massive number of connected users. New-sprung applications will consume high power for their operation. Thus, power optimization is foremost essential. It is required to implement various new techniques that can optimize the power consumption level of the devices and enhance the energy efficiency of the network. Techniques like E2ARC will help in optimizing the power consumption level of devices [86].

In E2ARC, the Resource blocks are adaptively allocated to the user on the basis of demand and thus optimize the power consumption level. Previously, in 5G networks, spectrum sharing has been promoted for effectively utilizing the available spectrum and increasing the spectrum efficiency. D2D and relaying have helped in optimizing power consumption by offloading the dense network demand. In 6G, several adaptive techniques must be adopted for ensuring low power consumption. Various AI based schemes and algorithms are required to be employed that will be low cost and less power consuming.

K. HIGH BATTERY LIFE

The limited battery life of devices puts a barrier in adopting modern applications. 6G networks are expected to facilitate an assorted range of new applications. Thus the researchers have to focus on enhancing the battery life of the devices so that with one-time charging, the device can sustain up to one week. Enhanced battery life will also make the network energy efficient. A technique like ZBGreen helps in extending the battery life of the device by deploying a secondary transmitter for a remote device [87]. In ZBGreen, a spectrum sharing based network is considered with a primary transmitter that can form multiple D2D pairs with different receivers distributed around it in different zones. These zones are formed on the basis of distance between the receivers and the transmitter as shown in Figure 20. Various primary receivers (PR1, PR2, PR3, PR4, and PR5) are distributed in different zones (Z1, Z2, Z3, Z4, and Z5) around one primary transmitter (PT). Secondary Transmitters (ST) (acting as a relay) are also considered. These STs will transmit in cooperation with the PT for fulfilling the target rates.

The Increasing density of users intensifies the requirement of transmission power, which further adds up with the successive zones. Thus the PT finally cooperates with the ST for maximizing the target rate and serves secondary receiver with the demanded application. ZBGreen improves the energy efficiency of the system and helps in optimizing power. Further, it also keeps a track on energy consumed by devices in different zones. The energy consumed while file transfer for 'j' application from PT to the 'p PRs' in zone 'k' is given by:

$$E^{p}_{consumed(p,j)} = \frac{E^{T}_{battery} T^{k}_{p,j}}{3600} Wh \quad (9)$$

where, $T^{k}_{p,j}$ is the transmission time in zone k and $E^{T}_{battery}$ is the battery consumption by PT in watt-hour (Wh). The energy consumed will affect the battery lifetime of the device, which is equivalent to the current drawn from the battery. The battery lifetime of PT for serving 'j' application to 'p PRs' in 'k' zone is given by the equation below:

$$L^{k,j}_{b} = \frac{C^{capacity}_{battery}}{C^{k}_{PT,j}} * 0.7(\text{in hours})$$

where $C^{k}_{PT,j}$ is the total amount of drawn current for serving 'j' application to 'p PRs' in zone 'k', $C^{capacity}_{battery}$ is the total battery available at the PT and the term 0.7 will include the external factors.

The ZBGreen algorithm is helpful in enhancing the battery lifetime of the PT to 46.28%. Similarly, several potential techniques and algorithms are required to be developed for extending the battery lifetime of the devices. Innovative techniques based on harvesting solar energy, utilizing radio waves and laser beams for device charging must be designed. Edge computing is another technique that can also help in enhancing the battery life of devices. It reduces the computation time and provide enhanced services at the device's edge.

L. AUGMENTED REALITY (AR), VIRTUAL REALITY (VR), AND MIXED REALITY (MR)

AR, VR, and MR are the critical applications of the next-generation system. VR comprises of complete immersion of the user in the artificial world or the digital world. 360° video streaming is an example of VR. AR deals with the employment of digital objects in real-world scenarios. Google Glass is an AR-based headset that will display digital content on a small screen. Moreover, MR anchors the real world with the virtual world. These technologies will require high data rates for uninterrupted services, which can be achieved with the help of terahertz frequencies or visible light bands. In 6G, AR, VR, and MR will become the critical enabler of haptic technology. VR with haptic technology will help in generating virtual environments of the remote place. It will produce an immersive environment where a person can feel the things that are virtually generated. AR combined with haptic communication will help in carrying out various operations from the distant place.

M. INTERNET OF EVERYTHING (IOE)

IoE is an extension of IoT, which will intelligently connect the persons, physical objects, processes, and data. IoE will be more complex with a large number of devices and humans connected to each other. It is based on the concept that everything surrounding us is intelligent. It is an autonomous and seamless coordination of a large number of computing devices. IoE includes various well-known applications like the Internet of Vehicles (IoV), Unmanned Aerial Vehicle (UAV) to everything, and the Internet of Robots (IoR), etc. These applications are discussed in detail as follow:

1) INTERNET OF VEHICLES (IOV) OR VEHICLE TO EVERYTHING (V2X)

It refers to the connection between two vehicles and vehicles to the surrounding environment. It will assist the real-time traffic management for facilitating autonomous driving and intelligent transportation system. The real-time management of traffic requires enormous data collection and accurate decision making. 6G will incorporate Edge AI for providing advanced computing techniques. The information about the road activities is collected on the edge nodes of the network and based on the collected data, specific tasks will be performed. However, the increasing number of vehicles may result in overloading of edge nodes that can hamper the performance of the system. In [72], the author has focused on offloading the collected data from the overloaded edge node to the idle node. A Computation Offloading Method for IoV (CoV) is proposed for appropriate determination of destination node with optimized offloading delay and cost. In order to realize these objectives of optimization, an algorithm named as strength pareto evolutionary algorithm 2 is adapted. It is noted that CoV can provide a fair distribution of load and helps in better utilization of resources with very less wastage.

2) UAV TO EVERYTHING (U2X)

U2X is a collaborated term of the internet of UAV with wireless network. The networking of UAV to everything relies on three communication modes: UAV to UAV, UAV to device and UAV to network. A UAV can switch from one communication mode to another based on the location and networking environment. UAV to UAV is beneficial for broadcasting data in various directions. UAV to device mode provides an offloading option in case of low latency applications. UAV to network mode can benefit the network by providing a high data rate and reducing transmission delay [91]. U2X is an example of an airborne network that integrates the terrestrial network. It extends the capabilities of 6G network by providing access to the inaccessible places.

3) INTERNET OF ROBOTS (IOR)

It will integrate autonomous robots with IoT. The IoR will interconnect sensors and actuators with the network. Here autonomous machines will collect data from sensors and perform several tasks based on the gathered information. Robotics and automation have revolutionized the field of manufacturing and processing in Industry 4.0 but in 6G, it will be combined with AI. The combination of AI with robotics will help in automating the tasks outside the factories that are in the surrounding environment. AI will improve the learning capability and accurate decision-making feature of robots in real-time applications. Briefly, the IoR will ensure an autonomous society of smart robots in future networks that will make human life much easier.

In short, Network slicing has its relevance in 6G/beyond 5G networks also. It lays out a manifesto for enabling various new services. In Network slicing based 6G architecture, Application Slicing works on the differentiation of the slices on the basis of demanded services and requirements. For providing support to the specific Application Slice, RAN slicing is made functional by connecting necessary network functions according to the requirement. Cloud slicing provides cloud services to the virtual resource mapping to the demanded service. The intelligent cloud layer controls and manages the resource allocation for ensuring automation services. Figure 21 shows some of the enabling slices in 6G architecture. Different network slices enable different applications.

The Haptic communication slice, utilizes the Tactile empowered RAN network and AI-based intelligent cloud for enabling haptic technology at the user end. Haptic communication has various requirements in terms of latency and reliability that can be imparted only by operating it on a dedicated slice. Applications based on AR, VR, UHD streaming, etc. required ultra-broadband services and hence required RAN slice that is empowered with mobile broadband services.

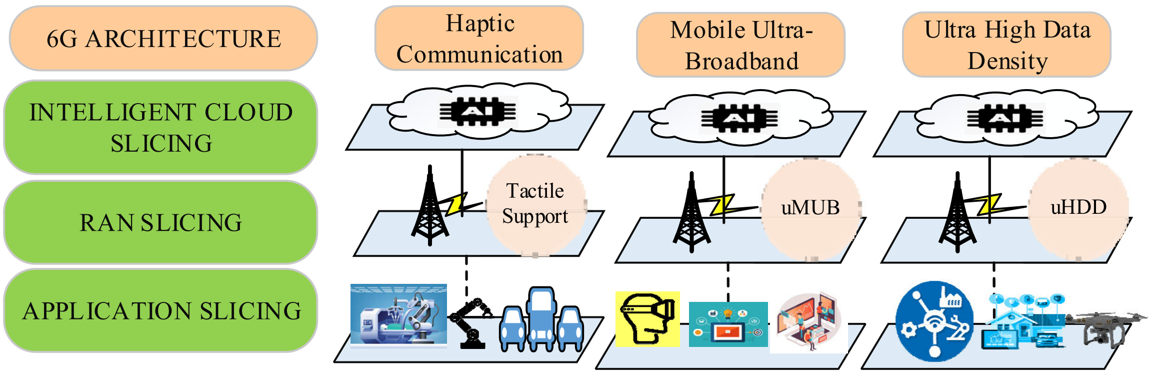

FIGURE 21. The Various application enabled with proposed 6G architecture.

Similarly, Ultra-high density of users generally in the case of IIoT, UAV network, smart cities and smart homes etc. requires RAN with high computation and manipulation capabilities.

6G networks will lead to the advancement of present technologies and layout many ways to develop new technologies [92]. Holographic telepresence is presently becoming very popular which combines holographic imaging with haptic technology. Tele-education is another future application that deals with the generation of virtual environments like a classroom where students from different areas can study in a group. 6G networks will be solely dependent on AI-based applications with machine learning and deep learning algorithms for enabling automation and various new services. It will provide support to complex tasks that require a large set of data manipulation and computation. In short, 6G networks basically incorporates the sense of touch and feeling with the virtual environment. It provides a platform for enabling a lot of future applications that are yet to be explored.

VIII. CHALLENGES AND FUTURE SCOPE

The research on 6G network is in its infant stage. Therefore, there are numerous issues and challenges that are required to be resolved. 6G networks are presumed to be intelligent and flexible with several potential techniques and use cases. In this section, some issues related to the technologies of 6G network are discussed:

- Recently, THz communication is emerging as the tempting technology of 6G network that will extend the capacity of the system by providing more spectrum ranges. However, these frequencies are susceptible to blockages and high absorption losses, which may limit its deployment to short-range communications only. Moreover, for supporting such high frequencies advance devices, miniature circuitry and small-sized transceivers design with low noise and reduced inter-component interferences are required [93]. Therefore, researchers should focus on investigating the abilities of devices to operate at such high frequencies and modify it accordingly so that high-performance gain can be obtained.
- Present models for channel estimations are not sufficient enough for determining the uncertain and highly varying nature of higher frequencies. Thus, it is foremost essential to develop new channel and propagation models for estimating the behavior of such complex environments. 6G is presumed to collaborate space, air, ground and water networks. Therefore, flexible schemes and dynamic protocols are needed to be designed that can adapt themselves according to the environment for providing seamless connectivity and network interoperability.
- 6G will integrate different networks, like terrestrial and satellite networks for achieving extensive coverage and high mobility. However, realizing satellite communication with ground communication is quite challenging in terms of large delay, apparent Doppler shift and inter-satellite links [60]. These challenges can affect the processes of synchronization, random access, signal detection, receiving performance and so on. Thus, for successfully deriving the advantages of an integrated communication system, advanced techniques must be furnished that can minimize the challenges related to them.
- Edge computing or edge intelligence will drastically increase the computational capacity of the network. But with the limited availability of resources and storage, it is very difficult to operate highly complex AI-based algorithms that require enormous data collection on edge nodes. Thus, researches are required to design fine and novel AI algorithms for edge nodes. Moreover, the development of effective mobile edge scheduling and offloading techniques for enhancing the system's performance is also needed.
- 6G will be AI-driven which requires high power from computing and manipulating complex data. Thus, energy efficiency and power optimization will be the important aspects of 6G network. Various applications like holographic imaging, haptic communication, AR, VR and MR are power-hungry applications. Power optimization and energy-efficient techniques for next-generation networks are required to be developed.

TABLE 11. 6G related ongoing projects and working research groups and institutes.

Research Project/Research Group	Research Area	HTTP Location
6Genesis Flagship (by university of Oulu)	Development of fundamental technology of 6G Networks	http://cscn2018.ieee-cscn.org/files/2018/11/AriPouttu.pdf
Intelligent Environments for Wireless Communication for 6G	Envision of 6G networks as intelligent systems	https://bwn.ece.gatech.edu/projects/6G/index.html
Electronics and Telecommunications Research Institute (ETRI), South Korea (collaborated with University of Oulu)	Terahertz band for 6G and technologies for 6G network	https://www.etri.re.kr/eng/main/main.etri
Ministry of Industry and Information Technology (MIIT) China	6G research and development	http://www.miit.gov.cn/n11293472/index.html
EPIC - Enabling Practical Wireless Tb/s Communications with Next Generation Channel Coding	Forward Error Correction (FEC) codes for enabling Tb/s communication	https://epic-h2020.eu/
TERAPOD: Terahertz based Ultra-High Bandwidth Wireless Access Networks	Feasibility of Terahertz bands for wireless network	https://terapod-project.eu/
WORTECS: Wireless Optical/Radio Terabit Communications	Combines Radio Communications with Optical Wireless Communication	https://wortecs.eurestools.eu/

LIS communication is presently in discussion for its low cost, simple installation, lightweight and high energy efficiency. It is suggested as one of the tempting technology for 6G network.

- Data security and privacy are the primary issues of wireless networks. The prominent technologies of 6G network require enormous data collection and transmission. In order to ensure security and privacy, several PHY security techniques and encryption algorithms are required to be developed. 6G networks are presumed to provide immunity against new threats. In future, the economy and society will be totally dependent on the digital world. Thus, a trusted architecture with required secrecy and privacy is mandatory.

IX. CONCLUSION

In this paper, a detailed survey of various novel features and use cases of 5G NR systems is done. The features like scalable numerology and flexible spectrum impart extensive coverage and flexibility to the network. Forward compatibility and ultra-lean design of 5G NR enable the

TABLE 12. List of abbreviations.

Abbreviations	Meaning
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
5GC	5th Generation Core
6G	6th Generation
6Genesis	6G-Enabled Wireless Smart Society and Ecosystem
AI	Artificial intelligence
AR	Augmented Reality
BER	Bit Error Rate
CP	Cyclic Prefix
CSI	Channel State Information
CSI-RS	Channel State Reference Signal
D2D	Device to Device communication
DC	Dual Connectivity
DL	Downlink
DMRS	Demodulation Reference Signals
eMBB	Enhanced Mobile Broadband
eNB	Evolved Node B
EPC	Evolved Packet Core
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
FR	Frequency Range
FSS	Fixed-Satellite Services
gNB	Next-Generation Base Station Nodes
HD	High-definition
IoR	Internet of Robots
IoT	Internet of Things
IIoT	Industrial IoT
ITU	International Telecommunication Union
IoV	Internet of Vechicles
LDPC	Low-Density Parity-Check
LIS	Large Intelligent Surface
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
Massive MIMO	Massive Multiple Input Multiple Output
MIB	Master Information Block
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine Type Communication
mmWave	Millimeter Wave

TABLE 12. *(Continued.)* List of abbreviations.

MR	Mixed Reality
NF	Network Function
NFV	Network Function Virtualization
NGC	Next-Generation Core
NOMA	Non-Orthogonal Multiple Access
NR	New Radio
NSA	Non-Standalone
NTN	Non-Terrestrial Networking
OAM	Orbital Angular Momentum
OFDM	Orthogonal Frequency Division Multiplexing
OMA	Orthogonal Multiple Access
OOBE	Out of Band Emission
PAPR	Peak to Average Power Ratio
PBCH	Physical Broadcast Channel
PDSCH	Physical Downlink Shared Channel
PSS	Primary Synchronization Signal
PTRS	Phase Tracking Reference Signal
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RACH	Random Access Channel
RAN	Radio Access Network
RAT	Radio Access Technologies
RF	Radio Frequency
RMS	Root Mean Square
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SA	Standalone
SCA	Small Cell Access
SCS	Subcarrier Spacing
SDN	Software-Defined Network
SIB	System Information Block
SNR	Signal to Noise Ratio
SRS	Sounding Reference Signal
SS	Synchronization Signal
SSB	Synchronization Signal Block
SSS	Secondary Synchronization Signal
TBCC	Tail Bit Convolution Coding
TDD	Time Division Duplex
U2X	UAV to Everything

TABLE 12. *(Continued.)* List of abbreviations.

UDH	Ultra-High Definition
UDN	Ultra-Dense Networks
UL	Uplink
URLLC	Ultra-Reliable and Low Latency Communication
V2X	Vehicle to Everything
VLC	Visible Light Communication
VR	Virtual Reality
XR	Extended Reality

system to be compatible with the future technologies and makes it energy-efficient by reducing the interferences due to "always-on" signals. In this paper, an architecture for next-generation wireless network is proposed. This architecture connects the 5G network with beyond 5G/ 6G network. Presently, the 5G technology is on the verge of its commercialization. But its deployment has various issues in terms of effective utilization of services. The heterogeneous deployment of three different use cases poses various issues that can be handled by using the technique of network slicing on the basis of service demanded. In this paper, challenges due to the adaptation of high modulation schemes and inter-RAT connectivity are well addressed. For the migration of the 5G network to the 6G network, these challenges are required to be resolved. A virtualized network slicing based 6G architecture is proposed. The architecture comprises of three sliced layers: intelligent cloud layer slicing, RAN slicing and Application slicing. The proposed architecture will be capable of enabling various technologies and applications of 6G network. Tactile internet is incorporated as the essential service provided by 6G and it is termed as the enabler of haptic communication. At last, various challenges related to the technologies of 6G network are discussed. This paper may provide a platform for further research in the next generation of the wireless system.

APPENDIX

A. LIST OF ONGOING RESEARCH PROJECTS

A list of current research projects and research institutes/ groups working on 6G technologies are given in Table 11.

B. LIST OF ABBREVIATIONS

A list of abbreviations used in this paper has been shown in Table 12.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support provided by 5G and IoT Lab, DoECE, Shri Mata Vaishno Devi University, Katra, Jammu

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