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TOPICAL REVIEW

Integration of Hybrid Networks, AI, Ultra Massive-MIMO, THz Frequency, and FBMC Modulation Toward 6G Requirements: A Review

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ABSTRACT The fifth-generation (5G) wireless communications have been deployed in many countries with the following features: wireless networks at 20 Gbps as peak data rate, a latency of 1-ms, reliability of 99.999%, maximum mobility of 500 km/h, a bandwidth of 1-GHz, and a capacity of 10^6 up to Mbps/m^2. Nonetheless, the rapid growth of applications, such as extended/virtual reality (XR/VR), online gaming, telemedicine, cloud computing, smart cities, the Internet of Everything (IoE), and others, demand lower latency, higher data rates, ubiquitous coverage, and better reliability. These higher requirements are the main problems that have challenged 5G while concurrently encouraging researchers and practitioners to introduce viable solutions. In this review paper, the sixth-generation (6G) technology could solve the 5G limitations, achieve higher requirements, and support future applications. The integration of multiple access techniques, terahertz (THz), visible light communications (VLC), ultra-massive multiple-input multiple-output (um-MIMO), hybrid networks, cell-free massive MIMO, and artificial intelligence (AI)/machine learning (ML) have been proposed for 6G. The main contributions of this paper are a comprehensive review of the 6G vision, KPIs (key performance indicators), and advanced potential technologies proposed with operation principles. Besides, this paper reviewed multiple access and modulation techniques, concentrating on Filter-Bank Multicarrier (FBMC) as a potential technology for 6G. This paper ends by discussing potential applications with challenges and lessons identified from prior studies to pave the path for future research.

INDEX TERMS 6G, multicarrier modulation technique, terahertz communication, ultra-massive multi-input multi-output, visible light communication.

I. INTRODUCTION

The 3GPP (Third Generation Partnership Project) met the requirements for the standalone (SA) and non-standalone (NSA) versions of the fifth generation (5G) mobile

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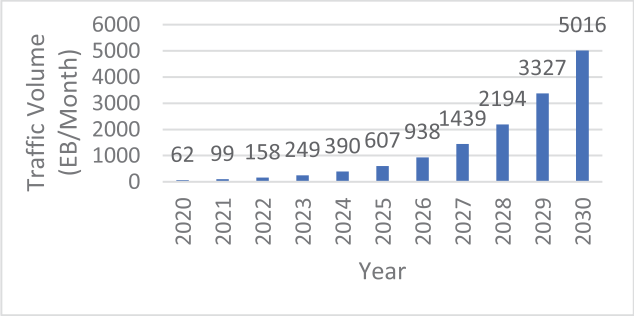

FIGURE 1. **The anticipated global mobile connectivity is from 2020 to 2030 [12].**

communication system, respectively, at the end of 2017 and mid-2018 [1]. Compared to the previous 4G networks, 5G marks a technical revolution [2]. High reliability, data rates, energy efficiency, and low latency enhance 5G networks [3]. These enhancements are reflected in the primary 5G service scenarios, such as enhanced Mobile Broad Band (eMBB), Ultra-Reliable and Low-Latency Communications (uRLLC), and massive Machine-Type Communications (mMTC) [4]. Even though 5G has added significant technologies, such as millimetre wave (mmWave), optical spectral, software-defined networking (SDN), and massive multiple-input multiple-output (MIMO) [5], studies and research on 5G are still continuing [6], [7]. Industries and researchers have begun focusing on the 6G concept since 2018 [8], as the wireless communications sector is growing at a rapid pace with widespread new applications such as the Internet of Everything (IoE), extended reality (XR), and blockchain technology, in addition to data-hungry applications such as tactile and holographic communications [9]. Which require lower latency, higher capacity, higher data rates, and better system performance [6], [7], [8], [9], [10], [11], [12]. Because 5G networks can't build a fully automated, integrated network that provides service anywhere, anytime [11], Figure 1 illustrates that the above applications can increase worldwide mobile traffic volume to 5016 EB/month in 2030, up from 7.462 EB/month in 2010. Meanwhile, 39 EBs of data traffic per user are anticipated in 2025 and 257 EBs in 2030 [12], [13].

6G vision can turn cities into ultra-intelligent metropolitans with lots of smart services, along with widely used humanoid robots that are intelligent enough to make decisions with minimal participation of people [14]. The 6G network expects to provide wireless communications With faster data rates of up to 1 Tbps, a latency of 1 ms, ultra-high reliability, ultra-high connectivity, coverage provision, and more excellent key performance indicators (KPIs) than the 5G network. Also, 6G supports rapid mobility up to 1000 km/h [11], [15]. Table 1 shows the comparison between 5G and 6G KPIs [11], [12], [15], [16], [17]. Therefore, 6G wireless communications networks require a novel modulation approach and an improved multi-access technique to increase data rates.

TABLE 1. **KPI comparison between 6G and 5G communication systems.**

KPI	5G	6G
Peak data rate	20 Gb/s	1 Tb/s
Experienced data rate	1 Gb/s 100 Mbps	10 Gb/s 1 Gb/s
Latency	1 ms	0.1 ms
Maximum bandwidth	1 Gb/s	Up to 400 Sub 6 G band 10-100 Gb/s THz band
Peak Spectrum efficiency	30 b/s/Hz	60 b/s/Hz
Experienced spectrum efficiency	0.3 b/s/Hz	3 b/s/Hz
Mobility	500Km/h	1000 Km/h
Area traffic capacity	10 Mb/s/m^2	1 Gb/s/m^2
Connection density	106 Device/Km^2	107 Device/Km^2
Reliability	99.999%	99.99999%
Frequency band	3-300 GHz	-Sub-6 GHz -mm-wave -THz band (above 300GHz) -Visible light band
Receiver sensitivity	-120 dBm	<-130 dBm
Satellite integration	No	Yes

Therefore, the ultra-massive MIMO (um-MIMO) and intelligent reflecting surface (IRS) can be deployed to enhance spectrum efficiency. The network needs to integrate with non-terrestrial communications for ubiquitous coverage and artificial intelligence (AI) [18], [19], [20], [21]. Sub-Terahertz and VLC could be implemented to increase spectrum frequency in 6G [22]. Many studies have examined new technological spectrums, challenges, and solutions for 6G systems [6]. In [2] demonstrated instances, deployment options, novel network designs, and many potential 6G technologies (e.g., terahertz (THz) communication, intelligent reflected surfaces, and orbital angular momentum). Meanwhile, the focus in [3] was on the evolution of generations from the 1G to 5G system. Also, the study outlined the limitations of 5G networks.

Some studies [4], [5], [7] looked into AI as a novel paradigm for creating and perfecting highly intelligent 6G networks. Another study [8] proposed a 6G architecture as an integrated system with network coverage and network-type integration. The 6G architecture is illustrated in four typical urban scenarios: secure and private businesses, intelligent traffic systems, and large-scale smart homes. The authors in [9], [11], and [12] concentrated on 6G KPIs and outlined proposed technologies that can accomplish the KPIs, like modulation technologies and um-MIMO. The research in [23] focuses on machine learning (ML) and quantum communication in the upcoming 6G network. The study papers listed above mostly concentrated on specific technologies and elements of 6G wireless communications networks.

TABLE 2. Comparison of the previous survey on 6G.

Reference [Year]	6G vision & KPI	Multiple Access Technique	THZ communication	VLC	Um-MIMO	Beamforming	AI	Hybrid Network	Potential Application	Lesson Learned	Challenges
[24], 2019	√	√	x	√	√	x	x	√	x	x	x
[3], 2020	√	x	√	√	x	x	√	√	√	x	X
[8], 2020	√	x	√	x	√	x	√	√	x	x	√
[9], 2020	√	x	√	√	√	√	√	√	x	x	X
[12], 2020	√	x	√	√	√	x	x	√	√	x	√
[13], 2020	√	x	√	x	x	x	√	x	√	x	√
[15], 2020	√	√	√	√	√	√	√	√	x	x	√
[19], 2020	√	x	√	√	x	x	√	x	√	x	√
[25], 2020	√	√	√	√	√	x	x	x	x	x	√
[26], 2020	√	x	√	x	√	x	√	√	x	x	√
[27], 2020	√	x	√	√	√	x	√	√	√	x	x
[28], 2020	√	x	√	√	x	x	√	√	x	x	x
[18], 2021	√	√	√	√	√	x	√	√	√	x	√
[22], 2021	√	√	√	√	√	√	√	√	x	x	√
[29], 2022	√	x	√	√	√	x	√	x	√	x	√
[30], 2022	√	x	x	x	√	x	x	√	√	x	√
[31], 2022	√	x	x	√	x	x	x	x	√	x	√
[32], 2022	√	x	√	√	√	√	√	√	√	x	√
[33], 2023	√	x	√	√	√	x	√	√	√	√	√
[34], 2023	√	x	√	√	√	x	√	x	x	x	√
[35], 2023	√	√	√	√	√	√	√	x	√	x	√
This Study	√	√	√	√	√	√	√	√	√	√	√

The main contribution of this article is a comprehensive discussion about the potential development and KPIs of 6G communication systems. Based on the latest modulation techniques, we have identified FBMC as the potential 6G modulation due to its pulse shaping filter featuring low out-of-band emissions (OOBEs), lowest intersymbol interference (ISI) and cyclic prefix (CP) free transmission which improves spectral efficiency and data rate. Besides, it is highly potential for Terahertz (THz) band adopted as 6G's frequencies owing to its unlimited bandwidth and freedom from RF interference. However, such frequencies require ultra-broadband and highly directed antennas to cope with propagation issues such as higher path losses. Satellites, unmanned aerial vehicles (UAV) and high altitude platforms as base transceiver stations (BTS) in space are thoroughly investigated as infrastructure to support 6G's full coverage. The roles of AI and the research challenges needed to meet the 6G demands are discussed as well. Table 2 summarizes those requirements. The columns show the references and year, 6G vision and KPI, multiple access and modulation techniques, THz communication, visible light communication (VLC), um-MIMO, beamforming, AI, hybrid network, potential application, lessons learned, and challenges. The symbol shows that the subject is covered in the respective survey. This paper reviewed the idea of 6G as a successor to 5G. Here, recommended technologies, ideas, requirements, benefits, and challenges of leading technologies are discussed. The contributions of this paper are as follow:

- Our review explains the KPIs, visions, and requirements of 6G, as well as a detailed shortcoming of 5G to support the new applications.
- This study enhances understanding of the main proposed technologies applicable for 6G, including their applications and role in meeting the requirements. The benefits and challenges of the technologies are listed as well. We highlight some technologies that may be essential for 6G, including AI and Hybrid networks.
- Also, this work highlights the role of multicarrier modulation (MCM) in achieving high data rate and spectrum efficiency. Proposing Filter-Bank Multicarrier (FBMC) as a potential 6G candidate. It compared FBMC with other candidates based on spectrum efficiency, advantages, drawbacks, and MIMO flexibility.
- This survey focused on recent studies on 6G technologies to identify the key challenges that demand attention as future research opportunities.
- Future applications that 6G networks will fully support are addressed in this study.

- Lessons learned, challenges and future work are also provided from an in-depth critical review based on the proposed technologies of the paper.

The rest of the paper is organized as follows: Section II discusses the evolution of cellular generation. Section III presents several proposed technologies, multiple access and modulation techniques, VLC, THz communications, AI, um-MIMO, hybrid networks (integration of terrestrial network (TN), and NTN), cell-free massive MIMO, and AI, all applicable in 6G. In Section IV, a detailed description of applications for 6G motivation are presented. Section V presents findings and lessons learned from the 6G technology enabler. Section VI covers the summaries of the 6G network challenges and future work. This review paper is concluded in Section VII. Figure 2 illustrates the structure of this review paper.

II. EVOLUTION OF CELLULAR GENERATION FROM 1G TO 5G

A new wireless generation system has been released every decade since the advent of the first-generation system in the 1980s [26]. Developing a new generation needs alterations in the complexion of the framework (e.g., spectrum, infrastructure, algorithmic, multiple access, modulation, and protocol) are required. To realize the function and goals of the new generation, besides improving the quality of service (QoS) metrics and supporting new services or features [27]. Initially, 1G was the root of all mobile generations, which only offered voice service with a 2.4 kbps data rate [36]. The 2G era had more competition techniques than the 1G era. Despite the presence of IS95 and Personal Digital Cellular (PDC), GSM was the dominating system standard. 2G was the best option for mobile voice communication, with a 64 kbps data rate [37]. In 2000, the 3G aimed to provide a wireless network with a 2 Mbps data transfer rate and high-speed internet access, thus enabling television (TV) streaming, web browsing, navigational maps, and video services. In 2010, 4G was launched. But 4G become the most effective mobile internet option. However, 3G was the first to describe the mobile internet regarding increased bandwidth (BW) and data speed. Because there was more communication in the 4G era, intelligent options and other new technologies grew [36]. The goal of 4G is to increase the amount of voice and data that can send and received while also improving the quality of experience (QoE). 4G is provided by two systems: WiMAX and LTE [37]. The Evolved Node B (eNodeB) is the 4G LTE base station that links user equipment (UE) to the core network [24]. The characteristics of 4G are an IPV6-based core IP network and OFDMA as an air interface to provide scalable transmission bandwidths of up to 20 MHz [38]. Many services were available to 4G users, such as high-definition voice, SMS, mobile TV, MMS, wearable devices, high-definition streaming, global roaming, and gaming services [39]. Next, 5G communication technology aims to provide higher reliability, better security, lower latency, improved spectral efficiency, and increased capacity [40]. This offers new value as a fundamental technology that helps society and industry, besides mobile broadband services and the Internet of Things (IoT). Unlike the previous generations, 5G architecture uses licensed and unlicensed frequency bands from 3 GHz to 300 GHz with high data rates of up to 1.0 Gbps. Meanwhile, VLC, massive MIMO, cognitive radio networks (CRN), mmWave, and software-defined networking (SDN) are all part of the technology that underpins 5G [41], [42], [43]. Table 3 and Figure 3 display the progress of cellular generations and the specifications of each generation [24], [36], [37], [38], [39], [40], [41], [42].

III. THE 6G POTENTIAL KEY TECHNOLOGIES ENABLER

The 6G KPIs pave the way for new features and technologies proposed to address the current wireless communication bottleneck and realize the 6G vision. Multiple access and modulation approaches, VLC, um-MIMO, THz communication, and IRS, were among the anticipated new technologies for 6G, which would also concurrently integrate NTN, TN, and AI [8], [44]. Multiple access techniques are introduced to maximize data rates and spectrum efficiency.

A. MULTIPLE ACCESS AND MODULATION TECHNIQUES

Multiple access techniques have become crucial to developing wireless networks over the past few decades. The techniques make sending much data over a channel possible while keeping communication systems resilient against varying channel defects [45], [46]. Multiple access lets more than one user use the same communication channels at the same frequency, time, or code [47]. These techniques have been deployed in many wireless systems to meet the demand for spectrum effectiveness, increased data rate, and enhanced system capacity [48], [49]. Cellular networks are designed to give wireless connectivity to multiple users. The three multiple access techniques are OMA (Orthogonal Multiple Access), NOMA (Non-Orthogonal Multiple Access), and Delta-OMA (D-OMA) [40], [41]. This section presents the working principle, types, advantages, and challenges of each technique mentioned above.

1) ORTHOGONAL MULTIPLE ACCESS (OMA)

In wireless systems, the OMA scheme has been used to connect many users [52]. It allows concurrent users to share system resources orthogonally. Frequency division multiple access (FDMA), code division multiple access (CDMA), time division multiple access (TDMA), and Orthogonal Frequency Division Multiple Access (OFDMA) are the main OMA techniques [53]. With simple single-user identification, the conventional OMA was a solid choice for high throughput performance [45]. The secret of successful OMA in previous generations lies in its ability to be implemented in a low-complexity manner. The multicarrier modulation (MCM) approach divides a wide-band frequency-selective fading channel into numerous narrow-band frequency nonselective flat fading subchannels. 4G and 5G use OFDM as MCM

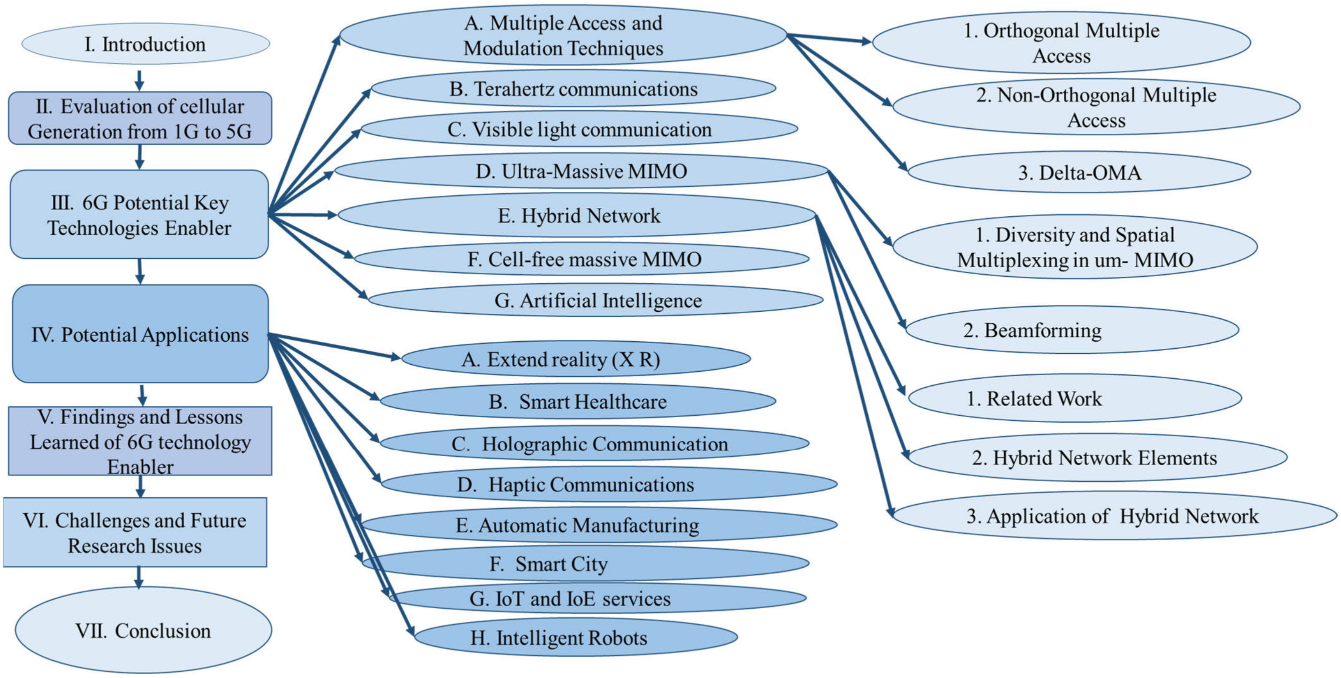

FIGURE 2. The structure of this paper.

TABLE 3. Mobile wireless generation evolution from 1G to 5G.

Features	1G	2 G	3 G	4 G	5 G
Years	1980-1990	1990-2000	2000-2010	2010-2020	2020-2030
Technology	AMPS	GSM, IS-90	CDMA2000, UMTS	LTE, LTE-A	NR
Data rate	2.4 kb/s	14.4-150kbs	3.1-14.7 Mb/s	100 Mb/s-1 Gb/s	1 Gb/s
System	Analog	Digital	Digital broadband	Digital broadband	Digital broadband
Frequency band	800 – 900 MHz	850,900,1800,1900 MHz	850,900,1800,1900, 2100 MHz	2-8 GHz	3-300GHz
Bandwidth	150kHz	5-20 MHz	25 MHz	100 MHz	1-2 GHz
Core network	PSTN	PSTN	Packet network	Internet	Internet
Multi-Access	FDMA	TDMA, CDMA	WCDMA	OFDMA	OFDMA, BDMA
Main service	Voice	Voice, SMS	High speed Voice, Data	High-speed access, Video, VOIP	IoT
Antenna type	SISO	SISO	SISO	MIMO	Massive-MIMO
Handoff	Horizontal	Horizontal	Horizontal	Horizontal, Vertical	Horizontal, Vertical
Switching	Circuit	Circuit	Packet	IP Network	IP Network
Advantages	Mobility	Secure, better power consumption	High internet speed	High data rate	Higher data rate Lower latency
Drawback	High energy consumption, lack of security	Low data rate	Increases power consumption to reduce the battery life of a device	More battery usage, limits the use of spectrum	Limited resources with high traffic volume

based techniques [47]. As the most widely used MCM, it has been applied in numerous applications, such as WiMAX, ADSL (asymmetric digital subscriber line), and WLANs (wireless local area networks). OFDM divide the available spectrum into many non-overlapping sub-channels. It uses the spectrum efficiently and is appropriate for high-speed data

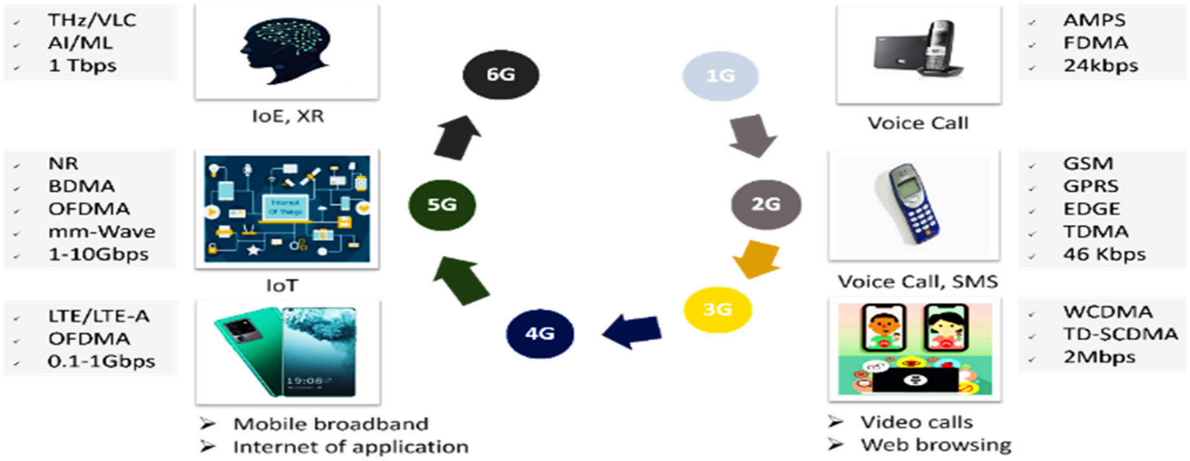

FIGURE 3. Development of mobile generation from 1G to 6G.

transmission [54]. The main KPIs of MCM are resistance against multipath fading, spectrum efficiency, out-of-band emissions (OOBEs), peak average power ratio, implementation complexity, and compatibility with MIMO [39]. OFDM has achieved many of the above KPIs as a simple equalizer, simple MIMO implementation to increase channel spectrum efficiency, immunity to ISI, and low complexity [55]. The cyclic prefix (CP) is used to reduce ISI. This method involves copying the final part of the symbol and then adding it to the beginning of the sequence. The network delay spread should exceed the CP, although the CP is regarded as redundant in information and affects bandwidth efficiency [56]. Besides, CP OFDM has many drawbacks, including high OOBE, as well as orthogonality, which necessitates precise time and frequency synchronization to prevent timing and frequency offsets, which can result in inter-carrier Interference (ICI) [57], and high PAPR, which dismiss the conventional OFDM to be a candidate for a future generation [55], [58]. Researchers have attempted to reduce these drawbacks and enhance the performance of OFDM to be deployed in 6G [59], [60], [61], [62]. Many research suggested new waveforms, including filtered OFDM (F-OFDM), Generalized Frequency Division Multiplexing (GFDM), Filter-Bank Multicarrier (FBMC), and Universal Filtered Multicarrier (UFMC) to address current and upcoming wireless issues and address the shortcomings of OFDM. [63]. GFDM can fix OFDM's problems with its improved multicarrier technologies. But, PAPR limits the performance of GFDM despite its higher spectral efficiency and lower OOBE than OFDM [64], [65]. Besides, interference cancellation techniques to mitigate ICI and ISI due to non-orthogonality are sought, but they increase computational complexity [66]. By combining the benefits of OFDM with FBMC, the Universal Filtered Multicarrier (UFMC) system is created. As a result, not used CP, and it is easier to implement than FBMC. Because a prototype filter known as the Chebyshev was utilized, it resulted in improved spectral efficiency and less spectral leakage [67]. Moreover, ICI, ISI, and inter-block Interference (IBI) are embedded into the UFMC, even if there is just a minor offset [68]. One of the waveforms that effectively addresses OFDM problems is filtered OFDM (F-OFDM). This F-OFDM uses the same OFDM design, but it also includes an additional, carefully constructed filter based on the sub-band that keeps the subcarriers inside the allotted spectrum, and it is used a cyclic prefix. Because F-OFDM reduces OOBE [60] while maintaining an acceptable ISI [69], it offers greater spectrum efficiency allocation. However, its high PAPR is the main problem [70].

The FBMC is an alternate waveform to OFDM. The FBMC system has often been linked with three advantages: 1) CP-free transmission, 2) lower OOBE, and 3) asynchronous environment resilience [71]. FBMC is an excellent contender for 6G due to these fundamental advantages. Therefore, it will be further explored.

a: FILTER-BANK MULTICARRIER (FBMC)

It is the waveform candidates that are best suited for use in wireless communications in the future. To overcome the drawbacks of the multicarrier approach, Saltzberg and Chang proposed FBMC in 1971 [62], [72]. Since it is an OFDM advancement [72], FBMC inherits most of the OFDM features. So, FBMC is a most promising candidate to substitute for conventional CP-OFDM. Additionally, the FBMC minimizes ICI using specially developed pulse shaping filters and is not susceptible to multipath fading without CP. As a result, FBMC offers higher spectral efficiency [73].

In contrast with previous multiple carrier approaches, high spectral efficiency for the wireless network is what the FBMC promises, low side-lobe radiation, a higher data rate, and flexible receiver signal processing [73], [74]. It is also robust against multipath channel fading [75]. Side lobes of the signal must be eliminated, so the filtering mechanism is used in FBMC for each sub-carrier [76].

The three types of FBMC cosine modulated multi-tone (CMT) A set of PAM symbols are bandlimited to VSB signals and modulated to different frequency bands using a synthesis filter bank. CMT is usually used to improve bandwidth efficiency. However, the transmission of real-valued symbols leads to inefficient practical implementation. In essence, VSB filtering is carried out via a frequency-shifted low-pass filter. The second type is Filtered multi-tone (FMT); unlike CMT, the sub-band overlap is not allowed in FMT. In addition to offering some uncommon benefits in spectrum management, unbundling, and duplexing, it offers an intriguing alternative to existing single-carrier and multicarrier systems proposed for very high-speed digital subscriber line transmission. In other words, compared to other noise signals, ICI becomes insignificant thanks to the tremendous amount of spectrum confinement achieved by PF. The final type refers to Staggered Multi-Tone (SMT)or FBMC/OQAM. Based on QAM symbols with in-phase and quadrature components and the size spaced by half the symbol period, OQAM/FBMC operates. [77], [78].

Both polyphase networks (PPN) and frequency spreading (FS) can be used to make FBMC transceivers [79]. Each design has benefits: the PPNFFT method reduces hardware complexity, and the size of the FFT in PPN can be maintained the same as in OFDM. The FSFBMC method achieves good equalization and timing offset compensation performance [80].

b: OFFSET QUADRATURE AMPLITUDE MODULATION (OQAM)

It is comparable to QAM, and it is orthogonal. OQAM separated the digital signal's components into real and imaginary. Imaginary and real symbols are not simultaneously transmitted in OQAM [81]. There is a half-symbol time delay in the imaginary component [82].

The OQAM modulation is applied to each subcarrier to keep the orthogonality in the real domain. The ICI and ISI are eliminated from the FBMC system by the OQAM [83]. Thus, FBMC-OQAM has a better spectral shape and improves mobility [84]. The first step in OQAM modulation is to apply a QAM map to the input signal. Next, the output signal is up-sampled by a factor of two, and a delay is used to the signal's imaginary or real components [85].

c: PROTOTYPE FILTER (PF)

PF is introduced to achieve the best time and frequency localization. It fits the Nyquist theory, according to which its impulse response crosses zero at multiples of Ts, thus resulting in the frequency domain symmetry condition. Phydyas and Hermite are the most common filters of FBMC [86]. The Overlapping factor, K, indicates the number of filter coefficients, representing how many symbols overlap in time. The coefficients H and k of the Phydyas prototype filter are listed in Table 4 for various K values [87].

TABLE 4. Frequency coefficients of Phydyas Filter [87].

K	H_0	H_1	H_2	H_3
2	1	$2\sqrt{2}$	-	-
3	1	0.911438	0.411438	-
4	1	0.971960	$2\sqrt{2}$	0.235147

A synthesis filter bank follows the OQAM pre-processing unit of the FBMC transmitter. IFFT, a polyphase filter, makes up the two parts of a synthesis filter bank and, finally, a parallel-to-serial converter. A serial-to-parallel converter is followed by analytical filter banks on the FBMC receiver side divided into two main blocks: polyphase filter and FFT and OQAM post-processing [88](see Figure 4).

The imaginary value in OQAM introduces intrinsic Interference. This Interference is the main obstacle that hinders the FBMC-OQAM system from being integrated into conventional MIMO techniques [89]. Although FBMC is employed to improve the wireless network's performance, some of its disadvantages are:

- High computational cost compared to OFDM [90].
- And it has an exceptionally high PAPR [91].

Table 5 briefly compares future waveform candidates regarding spectral efficiency, latency, a cyclic prefix (CP), OOB, filter type, PAPR, complexity, MIMO, and orthogonality.

More research is being done on improving precoding, equalization, and channel estimation to use FBMC in future wireless systems with better quality and fewer problems [92]. For instance, a novel short filter implemented for FBMC/OQAM receivers was proposed in [92]. The simulation revealed that the suggested filter was more robust to various channel impairments and had lower complexity than the prototype filters (long filter). Next, a new pulse-shaping filter prototype in FBMC/OQAM systems was proposed to enhance system performance [93]. Based on the results, FBMC/OQAM displayed better spectrum characteristics than OFDM. In [94], a combined equalizer and precoder design for the MIMO-FBMC-OQAM system was suggested. Power allocation algorithms, such as the water-pouring algorithm (WPA) and error balance algorithm (EBA), were applied in the design. The results exhibited that the combination could substantially increase downlink spatial multiplexing system performance. The FBMC technique, however, revealed a more complicated implementation than the conventional OFDM technique. In [89] and [95], the focus was on free interference transmission; [89] proposed a linearly processed FBMC (LP-FBMC), and [95] presented a QAM-FBMC interference-cancelling algorithm using an MMSE receive filter.

Even though the PAPR issue was high, FBMC got the lowest score of all the candidates. Due to PAPR, the power amplifier's efficiency was lower, affecting signal quality and coverage area. Thus, high-power amplifiers must be operated at the transmitter. The FBMC system uses an OFDM-based PAPR reduction approach, such as absolute exponential

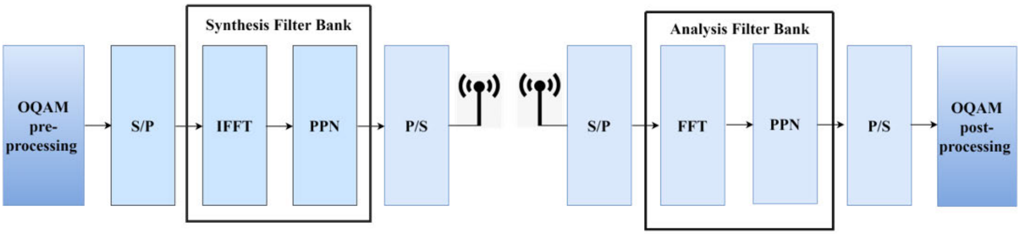

FIGURE 4. Block diagram of PPN-FBMC.

TABLE 5. Comparison between future OMA candidates.

KPI	OFDM	F-OFDM	UFMC	GFDM	FBMC	Reference
Spectral Efficiency	Lower	Much Better	Good	Enhanced	Best	[96]–[98]
Latency	Low	high	Low	High	High	[97]
CP	Used	used	Not used	Used	Not used	[96]–[98]
Out-of-Band	High	Reduced	Reduced	Low	Extremely small	[96], [97]
Filter length	Whole Band	Sub-Band	Sub-Band	Subcarrier	Subcarrier	[96], [97], [99]
Peak-to-Average-Power Ratio	Highest	High	High	Low	Lower than the rest	[97], [99]
Computational complexity	Lower	High	Very high	High	High	[97], [98]
Introduction Of MIMO Techniques	High flexibility	High flexibility	Flexibility	Less flexibility	Less flexibility	[97], [98]
Orthogonality	Orthogonal Subcarriers	Orthogonal subcarriers	Orthogonal subcarriers	Non-orthogonal subcarrier	Real field Orthogonal	[96]–[98]

companding, logarithmic rooting, tangent rooting, the A-law, and rooting [100], [101]. The objective outlined in [76], [100], and [101] is to reduce the PAPR issue. In [101], PAPR reduction is enabled by using logarithmic rooting companding. Meanwhile, the authors in [100] applied discrete cosine (DCT) and sine transform (DST) as precoding schemes to reduce PAPR via clipping and companding. In [76], phase reordering (PR) was initiated. These studies revealed a significant reduction in PAPR, but [101] observed a lower bit-error rate than conventional in OQAM/FBMC, just the symbols for the real field are orthogonal. Thus, the receiver will be even on a distortion-free channel suffering from intrinsic imaginary interferences that can affect channel estimation [102], [103], [104]. The channel estimate is crucial for data symbol recovery in MIMO-OQAM/FBMC systems [105]. Because of intrinsic Interference, efficient channel estimation is difficult in FBMC systems, increasing the design and implementation complexity compared to CP-OFDM approaches [106], [107], [108], [109], [110]. There are two channel estimation types. The scattered pilot-based approach reduces pilot overhead by improving channel estimation performance [96] and tracking channel changes in fast-fading settings. Besides, preamble-based methods are effective in channel estimation over time-invariant channels [103]. In [103], the authors proposed a great preamble strategy for OQAM/FBM based on intrinsic interference utilization by building a preamble with triplets of subcarriers. The study in [102] reflects the findings of investigating the errors made by a conventional pair of pilots to create a new, superior POP for use in OQAM/FBMC systems.

A periodic preamble pattern was developed to lower the MSE of CE and find the connection among preambles and imaginary interferences from surrounding symbols to gain the least MSE [105]. In [106], a sparse adaptive CE technique is based on a dynamic threshold with minimal complexity. The sparse adaptive CE showed superiority over the conventional preamble-based CE in accuracy and computational complexity. The study in [107] developed an approach based on line fitting in which the properties of the demodulated OQAM were examined. Later, a pilot optimization issue was devised using intrinsic interferences to increase line-fitting accuracy. In [108], a new channel estimate model was initiated for a quasi-static mmH-MFO (mmWave hybrid MIMO-FBMC-OQAM) system that could reconfigure radio-frequency circuitry during zero symbol transmission. Following that, a (BL) Bayesian learning approach for sparse channel estimation was developed, which applied many measurement vectors in conjunction with selective subcarrier grouping to enhance the estimate. In doubly-selective mmWave hybrid MIMO-FBMC-OQAM systems, an online BL-based tracking was deployed. In the MIMO-FBMC, to reduce the overhead of CS, two Kalman filters (OBL-KF) were designed for sparse channel low-overhead CS approaches SPM and DFT, for block-repetition based

MIMO-FBMC system [109]. Compared to the usual way of doing things, the ways that were suggested were much better for pilot overhead. By modifying the iterative termination conditions for FBMC in [110], the simulation showed that fast Bayesian matching pursuit (FBMP) did better than traditional compressive sensing methods in terms of MSE and BER. Traditional estimating techniques may have difficulty capturing complex patterns and correlations in wireless channel data that deep learning algorithms, particularly neural networks, can. This review proposed to use deep neural network (DNN) channel estimation in 6G FBMC. As DNN channel estimators have the advantage of just requiring data that may be obtained directly from received signals. In conclusion, improving FBMC technique's by optimizing channel estimation will lead to higher data rates and low latency as required by 6G and one of the proposed techniques is to deploy deep neural network (DNN) as DNN channel estimators have the advantage of acquiring data that can be obtained directly from received signals.

2) NON-ORTHOGONAL MULTIPLE ACCESS (NOMA)

The NOMA is a technique that can be applied to existing resources efficiently without affecting the users QoS [111] by increasing the number of served subscribers. The NOMA is proposed as a candidate technique to satisfy the stringent requirements of 6G networks [112]. By broadcasting data at the same time and frequency but with different power levels or by allocating codes, it enables users to consume resources efficiently without affecting the users QoS [111] by increasing the number of served subscribers. The NOMA is proposed as a candidate technique to satisfy the stringent requirements of 6G networks [112]. By broadcasting data at the same time and frequency but with different power levels or by allocating codes, it enables users to consume resources on a subcarrier concurrently (see Figure 5) [113]. It also unveiled better spectrum efficiency, throughput, low latency, user fairness, significant connection, and future system compatibility [114].

The two NOMA schemes are power- and code-domain [115]. In power-domain NOMA, the superposition of multiple user messages uses different transmit signal powers at transmitters. In contrast, receivers use successive interference cancellation (SIC) to distinguish between the received superposed signals [116]. NOMA allocates high or low power signals to users with poor or good channel conditions [117]. Before decoding its message, the user with a good channel will always decode the message of other users. A weak signal has a high signal-to-noise ratio (SNR) [118]. Thus, conventional NOMA has low-level internal security. Distant users consider the close user's Interference as noise [114]. This scheme requires judicious power allocation signals for users to have perfect multi-user detection (MUD) in the receiver. This is because insufficient power difference between users causes inter-user Interference (IUI), and due to the low SINR (signal-to-interference noise ratio), signal separability becomes a challenge for the receiver [119]. The code-NOMA uses distinct spreading codes to allow multiple users to share the same subcarrier with varied received power [120]. Utilizing SIC in NOMA improves capacity and cell-edge user throughput even if there is no frequency-selective channel quality indicator (CQI) at the BS (base station). Using SIC in the receiver affects receiver complexity [121].

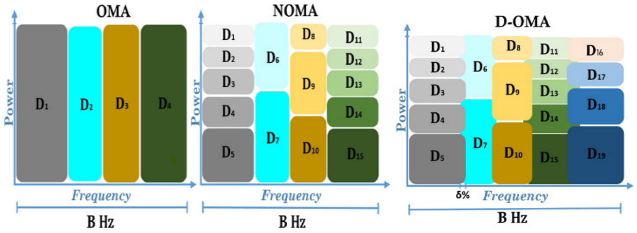

FIGURE 5. Concepts of OMA, NOMA, and D-OMA [125].

Two main challenges hamper the use of NOMA. The first challenge is intra-cell Interference (ICI), where a strong user's receiver suffers from interferences from weak users [122]. Second, high receiver complexity led to higher power consumption at the terminal devices [123]. Many techniques such as interleave division multiple access (IDMA), sparse code multiple access (SCMA), and multi-user shared access, can enhance the traditional NOMA [124].

3) DELTA-OMA (D-OMA)

The 6G networks are designed to carry many users in a limited geographic area. This demands massive APs/BSs, allowing overlapping coverage regions that require careful handoff, frequency allocation, and interference control [126]. The D-OMA refers to a new technique that overcomes the setbacks of NOMA and permits different NOMA clusters with adjacent frequency bands to overlap by an amount of δ per cent of the maximum allocated sub-band (i.e., $\delta = 0$ will be conventional power-domain NOMA) (see Figure 5) [125]. Although partial overlapping of neighbouring sub-channels improves spectral efficiency, it causes more Interference. This depicts the importance of proper sub-channel scheduling [127].

B. TERAHERTz COMMUNICATIONS (THz)

The evolution of wireless communication systems has increased system capacity and data rates. THz communication has been suggested to help 6G wireless networks handle more data rates [128]. This is because there aren't enough spectral resources allotted in mmWave bands for applications that need Terabits per second of capacity and are data-hungry [129]. Many applications are likely to arise as a result of THz communications shortly, such as Tbps WLAN system (Tera-WiFi), ultra-broadband THz space communications (Tera SpaceCom), and Tbps internet-of-things (Tera-IoT) in the wireless data centre [130].

The IEEE 802.15.3d (WPAN) is the first wireless communications standard that runs at 300 GHz and has supported wireless networks at 100 Gbps and more since 2017 [131]. The terahertz range is between 0.1-10 THz (see Figure 6). It is offered as a solution to the spectrum scarcity issue by unlimited bandwidth, besides enhancing the system capacity [132], where the data rates exceed 100 Gbps, low complexity, tolerance to hardware impairments, Doppler spreads, and high-power efficiency [133]. They can conduct wireless data communications without experiencing RF interference because the bands between 275 and 300 GHz are still not globally assigned to specific services [134]. Many years ago, THz was suggested for wireless systems. However, due to the high-power THz transmitters, enter energy efficiency, low noised, extremely sensitive receivers, its practical application is still limited [134]. The importance of THz technology is increased by the advancements in semiconductor technologies, that is provide numerous advantages such as cost-effectiveness and transistor operating frequencies reaching 1 THz. Improvements in THz transceiver architecture have made signal generation more efficient [135]. The electronic solutions that use metal-oxide-semiconductor (CMOS) circuits are candidates for implementing THz communication technologies up to 300 GHz [132]. THz, however, requires small and high-density cells due to limited area coverage. This increases the capital and operating costs, energy consumption, complexity, and scale of backhaul infrastructure [136].

These bands only use outdoor on-point-to-point links. The first outdoor transmission experiment was conducted using 120 GHz, covering over 170 m [137]. However, some factors prevent the use of THz links in commercial systems. First, the THz transceivers should have a large bandwidth, so broadband antennas should be designed [134]. Second, small-scale PIN diodes, varactors, triodes, and other devices are difficult to produce and costly [128]. Third, the THz band has high-frequency attenuation due to high path loss (reflective, spreading loss, diffuse scattering, atmospheric loss, shadowing diffraction, signal blockage, and molecular absorption), which has a great impact on its coverage [128], [133], [134], [135], [137].

The signal blockage should also be considered since THz signals cannot penetrate the most common materials. A highly directed antenna radiation pattern must be adopted to overcome significant path losses [133]. When the space of the THz coverage increases, the path loss also increases. Hence, THz is better for short distances of 10-20 [137]. Rain and snow significantly attenuate the THz wave propagation, so their effect on propagation is a popular topic. The experiment showed minimal rain effects at 90-225 GHz and 313GHz, and 355 GHz frequency bands. For microwave-band frequencies below 50 GHz, the attenuation increased. A peak at roughly 100 GHz signified that the attenuation stayed largely constant or decreased. Rain attenuation increased in direct proportion to the rainfall intensity [138]. To date, THz links have been investigated via actual tests, which revealed that at 200 GHz and 8 m of propagation, 2-dB attenuation was observed during dry snowfall. The results showed that snow caused more loss than rain at the same rate of precipitation [139].

When the snowfall rate increased, wet and dry snow attenuation also increased. However, the experiment showed larger attenuation for wet snowfall [22]. There is a need for advanced channel transmission theory, signal coding, modulation techniques, antenna, radio frequency system technology, and specific hardware for better outcomes. 6G is expected to use um-MIMO and reflected surfaces, which will help in THz communication to minimize path losses. This integration modelling will be an exciting research topic for future 6G.

C. VISIBLE LIGHT COMMUNICATION (VLC)

VLC has been suggested for future 6G mobile and short-range communication [140]. It is expected to overcome spectrum shortage issues, achieve high speed, possess an abundant spectrum, licensed-free bandwidth, pose no health risk, low cost, low consumption of power and Interference, and serve as highly secure wireless communications [141], [142]. The VLC is crucial for gigabit networks to meet consumers' demand for higher-speed connections, which are not viable via RF technology. It is also safe and can accelerate the progress of future communications [143]. The VLC is safe to use in delicate locations, such as chemical plants, hospitals, and aircraft, mainly because no harmful radiation is emitted. Only light-emitting diodes (LEDs) are deployed as the light transmitter source. Frequency reuse is possible due to the limited reach of transmitter signals in VLC systems [144]. The VLC transmits data via light wave wavelengths ranging from 380-750 nanometers (400 and 800 THz). Japan adopted the first VLC standard in 2007 as JEITA CP-1221 [145]. The primary motivation behind VLC technology is the invention of LED [146]. White LEDs are low in cost, small in size, and light in weight. They are also quite effective at converting electrical energy into optical form, have a high operational speed, good modulation performance, and a long-life span. When comparing the power consumption of LED lamps to that of other optical sources, VLC consumes $\sim 20\%$ and 0.5% of the power consumed by fluorescent bulbs and conventional light sources, respectively [144]. Lasers (LDs) and LEDs are the two light sources used in VLC systems. LD systems support long-distance transmissions and high data speed with massive bandwidth. However, LDs and receivers must be aligned accurately. Due to their greater divergence compared to LDs, LEDs can be employed in the shorter-range link for both point-to-multipoint and point-to-point communications. LEDs' lower complexity and good power efficiency [145] make them more attractive for VLC commercialization. However, the main weakness of LED is poor spectral efficiency due to the limited modulation bandwidth [147]. The receiver has a photodetection device (e.g., photodetector (PD)). Early studies assessed the VLC band where many other

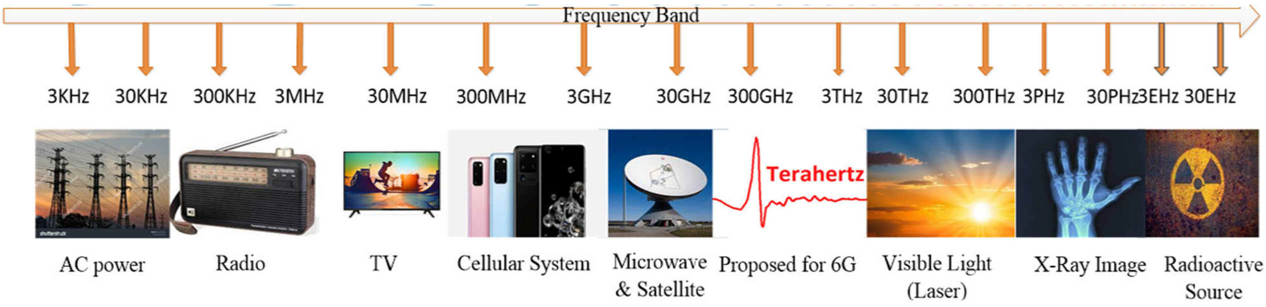

FIGURE 6. The electromagnetic spectrum and application.

technologies, such as indoor positioning systems and light fidelity, have already been implemented [148].

The VLC has many advantages compared to other radio communication bands, as VLC offers a wide spectrum range (THz-level bandwidth). The VLC does not emit electromagnetic radiation and is less susceptible to external electromagnetic interference, making it ideal for applications sensitive to electromagnetic Interference. Finally, VLC is more secure as the transmission channel is visible light and cannot pass through walls or other impediments. Since the transmission is only accessible to the users in sight and is restricted to specific buildings, it prevents harmful behaviour from outsiders and ensures data security [141], [143], [144], [149].

However, VLC networks suffer challenges that must be overcome to enable their use in future wireless systems. The challenges are listed in the following [144]:

- Small bandwidth of LEDs.
- The fast reduction in light intensity with distance increases makes VLC more suitable for indoor communications.
- The potential for adjacent lighting sources to cause noise and Interference.
- Small cell size causes significant infrastructure costs [150].

Since the intensity of natural light can affect the transmission signal, the primary applications for VLC should be made indoors [141], [151]. Short-range communication, light-sources interference, signal modulation, and detection are some of the VLC problems. Research on practical interference reduction strategies and accurate channel models is an interesting area that needs to be explored.

D. ULTRA-MASSIVE MIMO (um-MIMO)

Connection density and high-peak data rate are imperative in 6G, where THz can meet those requirements. However, due to high frequencies, the THz range suffers from massive propagation loss [152]. Hence, due to high-frequency range constraints, um-MIMO compensates for the significant path loss [141], atmospheric absorption, rapid channel changes, and combat communication distance limits [153]. The MIMO technology uses many antennas at the sender and receiver to service a group of UE on the same resource [154]. The massive MIMO channel model was deployed in mmWave bands. However, it appeared unsuitable for THz communication systems since lower frequency propagation processes differ from THz bands [155]. Hundreds or thousands of antennas with high array gains and narrow beams are employed for um-MIMO [156].

The um-MIMO supports the wireless network through higher capacity, higher data rates, and improvement of the communications systems' quality [157]. THz frequencies have a crucial role in creating high antenna gain with small physical dimensions, thus enabling spatial multiplexing [158]. More antennas were required to boost the system's capacity. As a result, um-MIMO technology can reach 6G capacity. But when RF network signal processing becomes more complex due to the requirement for more antennas, deployment costs rise and power consumption [159].

1) DIVERSITY AND SPATIAL MULTIPLEXING IN MIMO

Diversity refers to using multi-antennas to transmit duplicate versions of the data. Diversity can increase the reliability of detection and improve the quality of the wireless link [160]. Concurrently, spatial multiplexing focuses on increasing the throughput and spectral efficiency so that different data streams can be sent independently [161]. The mix of diversity and spatial multiplexing is a new approach proposed to meet massive-MIMO requirements. Depending on the channel condition, the embedded switching technique can shift between spatial and diversity multiplexing for each cluster of two data streams. This method reduces the system's bit error rate without sacrificing the data rate [160].

2) BEAMFORMING

It is a technique for increasing system capacity by making up for the substantial path loss. It creates beams in the physical directions of the channel path components. While concurrently avoiding interference from other users. It sends signals from BSs with many antennas to UE, as shown in Figure 7 [162]. According to the radiation type, the beamforming systems could be adaptive arrays or switched- beam systems. Switched-beam systems rely on fixed beamforming to create specified beams, while adaptive construct a specific beam for

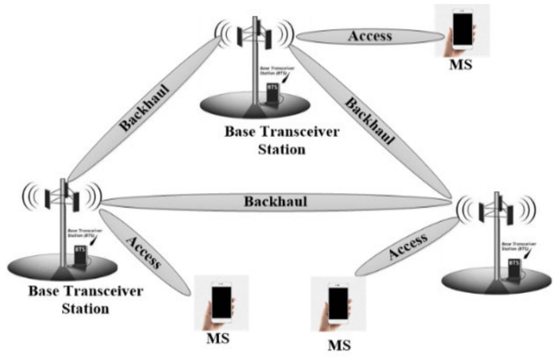

FIGURE 7. Beamforming in MIMO systems.

each user. Adaptive beams eliminate user interference, gain significantly increased power resources, and cover a larger area than switched beamforming for the same power level beamforming [163].

In [164], beamforming techniques are classified as analog, digital, and hybrid (analog, digital) beamforming. In the high-frequency spectrum, MIMO beamforming is very narrow and described as a pencil beam [163]. Analog beamforming can create high directional gain beams using phase shifters as used in massive MIMO [165]. Although fully digital beamforming is more accurate in um-MIMO, it is costly and consumes high power [166]. Hybrid beamforming is a promising solution to the issues stated above. Hybrid beamforming was initiated in the mid-2000s, which refers to a mix of analog beamformers in the RF domain with digital beamforming in the baseband. The antenna element numbers provide the beamforming for both gain and diversity order [167]. In analog beamforming, all antennas are controlled by a single RF chain and digital-analog-converter analog-digital-converter (DAC/ADC). Meanwhile, each antenna in digital beamforming has its own RF chain and DAC/ADC. Thus, digital beamforming is intricate and consumes more power. Thus, the hybrid applies a limited number of RF chains and DAC/AD [168].

In 6G, um-MIMO is proposed to support varying scenarios for long travelling paths (distances of a few millimetres to tens of meters) and large bandwidths [155], [169]. In conclusion, um-MIMO could lead to improved spectral efficiency and reliability. However, novel channel estimation techniques that explicitly account for the time-varying nature of the wireless channel are exciting areas that need to be explored. In addition this study suggested a learning architecture using the Deep MIMO dataset, which will built using precise ray-tracing channels. Besides, AI algorithms proposed to enhance higher directional beamforming to compensate for the high radio-channel attenuation in THz communications.

E. HYBRID NETWORK (TERRESTRIAL AND NON-TERRESTRIAL NETWORK)

The 6G network offers a host of services anywhere and anytime. Thus, 6G denotes a novel, intelligent, reliable, and scalable communication network that provides seamless network coverage, while supporting the connection for IoT [10]. In the smart world, billions of sensors, vehicles, machines, drones, and robots are linked [170], [171] in the ocean, mountainous areas, forests, and sensors in remote areas but not covered by terrestrial cellular networks [172]. Hence, a hybrid network is highly recommended by the integration of TN (Terrestrial Network) and NTN (Non-Terrestrial Network) [173]. Utilising this combination 6G provide a full coverage, cost-effective high-speed data-rate internet access can be achieved anywhere [18]. With this kind of integration, the 6G network can be used indoors, in rural areas, in cities, by the sea, and in the mountains [174]. The NTN offers services to these areas that TN cannot cover. In addition, satellite networks function as backup networks to provide reliable on-demand wireless communications; natural disasters (e.g., snowstorms, earthquakes, and tsunamis) destroy ground communication infrastructures [175].

The aerial components or NTN of 6G systems are unmanned aerial vehicles (UAVs), geostationary, medium, and low earth orbits (GEO/MEO/LEO), and high altitude platform systems (HAPS) [10], [176], [177]. Satellites are essential to these hybrid networks because they offer wide-area coverage and guarantee connectivity even in difficult-to-reach places. Drones, or UAVs, play a role by serving as mobile communication relays and dynamically adjusting coverage and capacity in real time. The system is enhanced by the terrestrial component, which provides high-density connectivity in urban areas and improves the overall resilience of the network [178]. (see Figure 8). Hybrid network including NTNs and TNs is greatly facilitates a wireless system that functions as a single entity using the same radio technology and to create a seamless and robust communication system [177].

The idea of integration was proposed for 5G as part of 3GPP standardization work for Release17, which can cover unserved and isolated areas to achieve 5G ultra-high reliability and seamless connectivity demands [179].

To enable the integration with NTNs, the Next-Generation Radio Access Network (NGRAN) demands new interfaces and protocols. The NTN system serves as a space reflector or gNB in the sky [180]. The 3GPP supports various NTN designs based on integrating airborne and spaceborne elements. The 3GPP envisions 1) a radio access network (RAN) design based on satellites that are transparent. In a regenerative satellite payload, the satellite transfers the user's signal from the feeder link to the service link and back again (a regenerative satellite-based RAN attains signal regeneration from the earth while enabling an inter-satellite connection). And 2) a multiple connections manner with two transparent RANs that allows for integrating TN and NTN access. In addition, a number of industrial initiatives have been started to use this kind of design. As an illustration, Integrated Space. The Transformational Satellite Communications System (TSAT) [18] and Infrastructure for Global Connectivity (ISICOM) [181] seek to offer worldwide

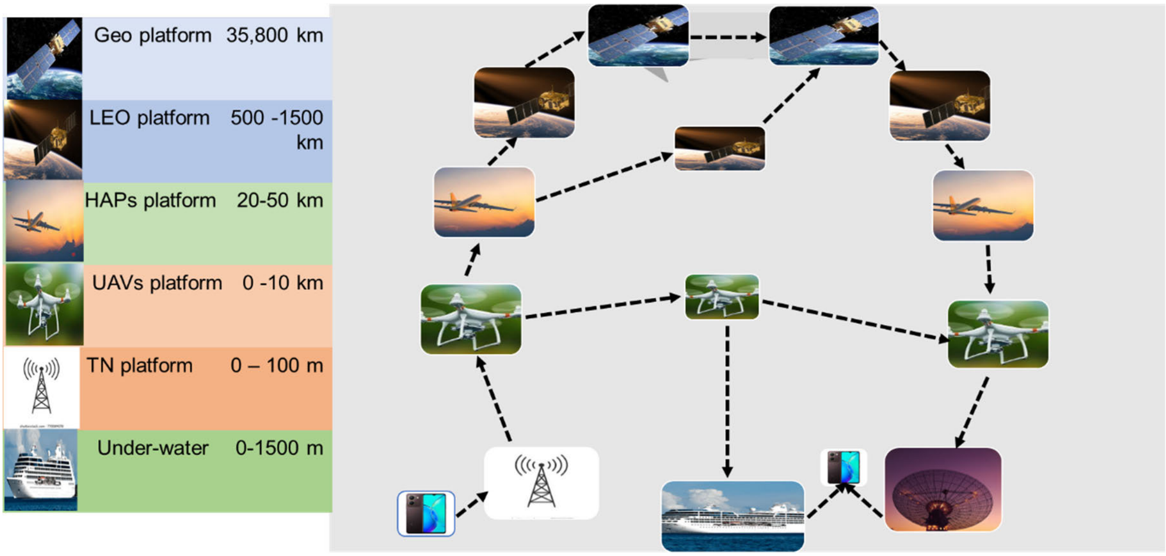

FIGURE 8. The architecture of hybrid network for 6G.

connectivity via land, sea, and space. The communications links between the satellites may then be divided into four categories: HAP-to-HAP links (HHL), UAV-to-UAV links (UUL), satellite-to-satellite links at different levels (SSLD), and satellite-to-satellite links at the same layer (SSLL) [182].

1) RELATED WORK

The wireless communication networks have seen a radical change in recent years, focusing on hybrid networks to satisfy the increasing needs for high capacity, significant data rates, and ubiquitous connectivity. Therefore, Various studies have investigated the challenges and opportunities associated with integrating these technologies, addressing issues such as resource allocation, and interference management, such as Nguyen. Nguyen et al. [183] considered a network of IoT backed by several satellites and various UAVs with cache assistance. The long-distance transmission and unfavourable transmission environment can cause a very high delay, mainly when backhaul congestion occurs. In order to minimize the overall network delay, they define an optimization problem. In order to break down the original problem's complexity, it is split into three smaller challenges: allocating power to satellites and UAVs, placing cache in UAVs, and clustering ground users connected to UAVs. Li et al [172] proposed iterative multi-domain resource allocation algorithms for the cognitive satellite-UAV network (CSUNs) that increase network coverage efficiency while ensuring user fairness. The simulation results show the suggested algorithms superiority and effectiveness in serving wide-area IoT devices in the future 6G era.

The study optimizes cache placement, UAV resource allocation, and trajectory to maximize minimum achievable throughput per ground user in [184]. It decomposes the problem into three sub-problems: cache placement, UAV resources optimization, and UAV trajectory optimization. Simulation results show enhancement in max-min throughput. Lin et al. [185] outlined common use cases for integrated satellite-mobile edge computing (MEC) networks, which can potentially provide globally dispersed customised services, and we address the key obstacles in this regard. Tirmizi and co-author [186] examined the extensive number of IoT solutions that are now on the market or in the process of standardisation, which will require integration into the 5G framework. They used UAVs and satellites as potential alternatives to terrestrial infrastructure due to limited coverage and device density [187]

Besides, 5G cellular networks primarily operate on terrestrial networks, and maritime communication networks (MCNs) as of right now depend on on-shore base stations (BSs) and maritime satellites. Li et al. [188] explored the integration of UAVs with existing MCNs for on-demand maritime coverage. It explores the potential gains of hybrid satellite-UAV-terrestrial networks, highlighting the challenges of complex maritime progation environments and mutual interference interfering with each other's UAVs, current satellites and shore-based terrestrial based stations (TBSs). Wang et al. [189] goal is to optimised the rate of users that TBSs and UAVs can service, while ensuring that satellite users experience minimal leakage interference. The non-convex issue is solved by combining consecutive convex optimisation techniques and random matrix theory. In addition, Wang et al. [190] investigated the potential of deployable BSs for improving marine coverage in order to bridge the gap in the next sixth-generation (6G) era. Deployable BSs are configured using movable vessels and UAVs. This results in an oceanic hierarchical satellite-UAV-terrestrial network. For this hybrid network, they tackle the combined link scheduling and rate adaptation problem in order to minimize overall energy usage while maintaining QoS assurances. They employ the large-scale CSI, which is reliant on location and may be estimated using each vessels or UAVs position data. Fang and co-others [191] examined a hybrid satellite-UAV-terrestrial network based on NOMA in the maritime domain. In particular, they have coordinated with TBSs using connected UAVs. They organize into virtual clusters and provide user-centric service; the NOMA technique has provided diverse users with quick service. They have put out a cooperative power allocation approach to address the difficult interference between various users, clusters, and various network segments. They only optimize to lower system overhead by using large-scale CSI.

2) HYBRID NETWORK ELEMENTS

As mentioned, the hybrid network includes wireless BTS, satellites, unmanned aerial vehicles (UAVs), and high-altitude platform systems (HAPS). This section explains the hybrid network element in detail. In these hybrid networks, satellites play a pivotal role in providing wide-area coverage, ensuring connectivity in remote and challenging. Satellite communication systems use radio technologies that are not part of the terrestrial cellular network. With more people using satellite communication services like in-flight internet, asset tracking, vessel tracking, and disaster monitoring, the price of launching a new satellite into orbit becomes less. In addition, reusable rockets and small satellites, such as cube satellites targeted at LEO with low power and a smaller antenna [172] have opened new opportunities to integrate independent satellite and terrestrial networks [192]. The satellite network is divided into GEO (altitude: 35,800 km), MEO (altitude: 8,000-12,000 km), and LEO (altitude: 500-2,000 km) [193]. We can summarise the satellite architecture as the following: (i) a terrestrial terminal, such as a smartphone or the cellular network; (ii) a satellite station carrying a payload that may use a bent-pipe or regenerative configuration (in the latter case, the satellite functions similarly to a terrestrial base station); (iii) a service link connecting the terrestrial terminal and the satellite station; and (iv) a gateway that joins the satellite access network to the core network [192]. There are two kinds of satellite services: mobile satellite services (MSS) and stationary satellite services (FSS). In FSS, customers can connect with satellites using fixed equipment on the ground, but it needs large antennas. GEO satellites provide FSS services, such as TV transmission and VSAT connectivity. For MSS, users talk to satellites through portable mobile devices that can be put in cars, ships, planes, or on the users themselves. To ensure mobility, the antenna size in MSS is limited. The LEO satellite networks are used in MSS systems with relatively smaller signal attenuation [187]. The greatest option to supplement terrestrial networks is a constellation of low-Earth orbit satellites [194]. LEO satellites are a critical component in developing a communication network with global coverage and ubiquity. Unlike GEO satellites, LEO satellites use lower orbits at 600-1,200 km, with less propagation delay, low deployment cost, and affordable manufacturing. However, LEO satellites' footprints cover a limited area and travel at a fast rate relative to Earth. Thus, numerous satellite constellations are required for LEO systems to ensure continuous coverage. In the end, the satellite has a large footprint. A single LEO satellite can cover an area of one million km^2 area [195].

Many channel impairments can affect a typical satellite, which is the cause of variances between NTN and TN systems. The impairments are: [192], [196], [197], [198], and [199]:

- Higher complexity due to a massive number of LEO satellites can increase complexity in management, control, and operation.
- Location management and terminal handover are covered under mobility management. As LEO's footprint is large, many users may simultaneously initiate handovers.
- Doppler shift, since it moves more quickly than the earth's rotation.
- LEO-transmitted signal path loss and transmission delays are significantly larger than the terrestrial system.

Several satellite systems were built and used for international communications in the previous decades. Satellite networks in previous decades did not perform successfully in the Communication sector. Globalstar is a LEO satellite. Motorola runs the Iridium LEO, and O3b Networks runs. Due to the building expenses, most of these satellite networks eventually went out of business [200]. Recently, satellite Internet has been presented as a way to allow global access to the Internet via satellite networks, spurred by the development of Internet applications, microsatellite manufacturing, and low-cost launch technologies [187]. Typical satellite projects include Telesa [194], OneWeb [201], and Starlink [187]. The roughly 42,000 LEO satellites in the Starlink network, which operate in orbits ranging from 340 km to 1150 km, are intended to give high-speed Internet connectivity to the whole planet. Using the Ka-band and Ku-band, each satellite can sustain a transmission rate of 20 Gb/s. 300 LEO satellites in a 1000 km orbit make up the Telesat LEO network [194]. One Web has suggested a LEO satellite network. 648 LEO satellites in 18 orbital planes with a 1200 km orbit make up the OneWeb network [201]. Satellites have significantly contributed to the development of various remote sensing image analysis methods, such as remote sensing index methods, object-oriented analysis methods (OBIA), and deep neural network methods, all based on the multi-spectral and high-resolution images produced [202].

In satellite networks, low elevation angles, obstructions, rain/fog attenuation, and other factors might cause unreliable communication lines between the satellite and users, which could result in a masking effect. In this scenario, there won't be any direct connections from the satellite to users, which will cause a breakdown in satellite users' ability to communicate. The hybrid satellite-terrestrial relay network (HSTRN), which introduces terrestrial relays into satellite networks, is proposed to overcome the masking effect. Due to the masking effect, the HSTRN's fundamental design prevents a direct connection from the satellite to the user [203].

With the aid of the terrestrial relay, the satellite sends the signal to the user. Signal to the terrestrial relay will make up the entire transmission process. The satellite sends the desired signal in the initial phase. The received signal is then sent to the satellite user through the terrestrial link during the second phase via the terrestrial relay. The system's stability is improved since the satellite user may interact with the satellite even when the direct link is obscured, thanks to the terrestrial relay. The amplify-and-forward (AF) and the decode-and-forward (DF) protocols are typically the two forwarding protocols used for relay communication [204].

The fundamental design of the HSTRN was examined in [205], where just one relay and one user were considered. The symbol error rate (SER) was examined. For multiusers was then investigated in [206] and [207]. In preparation for the advancements of 6G and to enhance user service quality, integrated terrestrial-satellite networks (TSN) will play a pivotal role. Mobility control for satellite location management and handover control are the fundamental components of the mobility control of satellite networks. Effective management of caching, computation, and communication (3C) gains significance as data traffic expands within TSN for 6G integration. It is essential to provide equitable and secure services in TSN while considering actual consumer data transfer needs. Current TSN literature is primarily divided into two categories.

TSN transmissions are classified into uplink and downlink categories. Specifically, in the uplink scenario, each ground station (GS) engaged in TSN transmission conveys information collected from the users it serves. This occurs during instances when the satellite's orbital configuration adheres to specific geocentric restrictions [208].

Recently **Unmanned aerial vehicles (UAVs)** are new flying wireless communications that can be used at low cost and robustly during large temporary social events, military operations, agricultural precision, cellular communication, and natural disasters [209]. However, it suffers from Interference generated by other UAVs [210]. The UAVs are located in the aerial region at random locations (10-100 m in height), as each UAV communicates with a ground receiver using an unlicensed band (2.0, 2.4, and 5.8 GHz) [186]. UAV-assisted vehicle-to-everything (V2X) communications, UAV swarm networks in disaster areas, UAV-enabled smart city development, traffic offloading in hotspots, and surveillance and IoT network applications are just some of the many wireless networks that use UAV technology [211]. UAV-based base stations (gNB) are primarily used for two purposes: (i) to improve data rates and capacity and (ii) to give user equipment (UEs) an acceptable network acquisition, particularly in shaded zones. Similarly, line of sight (LoS) aerial to ground link and controllable manoeuvrability in three-dimensional (3D) space are promising advantages of UAV-aided gNB. It can offer an ad hoc, affordable cellular network, such as supplying network connectivity for connected and autonomous vehicles in mountainous or shady environments [207].

UAVs are available in a wide range of specifications, tools, shapes, and sizes. Fixed-wing, single-rotor, fixed-wing hybrid, and multirotor UAVs are among the several varieties. Fixed-wing UAVs are made up of a main body, wings, motor, and propeller [209], [212]. In many cases, UAVs are less costly than manned platforms, self-organization, rapid and easy deployment, scalability, adaptability, and excellent mobility [212]. A number of factors constrain the practical use of UAVs in various application situations. The primary significant restriction on UAVs is flight endurance, which is constrained by the limited power source of batteries. By employing internal combustion engines or hybrid systems to construct various types of batteries, this problem can be reduced. A docking station, which can store and execute communication activities with UAVs and recharge or replace batteries, is another possible alternative [209]. Docking stations can help UAVs advance in autonomous systems by resolving the problem of battery longevity [213]. UAV performance is also constrained by harsh surrounding weather, and the size of the fixed-wing aircraft UAVs can travel between 30 and 460 km/h. And it isn't easy to identify and track UAVs because of their tiny size and changing locations and speeds. This could lead to issues like disconnecting and link failure. In addition, creating a UAV interference mitigation system is an impressive topic for study that should be taken into account in 6G.

Airships, balloons, and other high-altitude platform stations (HAPS) can be integrated with satellites and TN [198]. The HAPs enable users to communicate with other cellular and fixed networks on demand, and more importantly, they do not get damaged by disasters [214]. In order to provide access to a large number of mobile and IoT users, HAPs are essential parts of space-air-ground networks, particularly in rural areas where ground BTS coverage is poor. It is anticipated to include capacity expansion, delay reduction, and cost savings in the communication channel between Low Earth Orbit (LEO) satellites and base stations. The base station-to-HAPS channel and the HAPS-to-satellite channels are the two distinct communication channels for the anticipated HAPS system [215]. It can fly at a fixed position above the ground for several months with an altitude of ~ 20 km. The HAPs can cover a wide area and provide stable network connectivity for terrestrial users. Because of this, HAPs are equivalent to an aerial wireless base station with low launch and maintenance costs [216]. The HAPS has become a crucial part of the future generation of wireless networks due to technical advancements in autonomous avionics, array antennas, solar panel efficiency levels, and battery energy densities. The predominant method of supplying energy for HAPS systems has been solar power coupled with energy storage since they have wide surfaces that can hold solar panel films despite the fact that the choice of energy source was thought to be a critical challenge in HAPS research. A HAPS can also immediately offer wireless services to customers of terrestrial networks due to its low-delay features compared to the upcoming satellite networks [217]. The electromagnetic wave is refracted and attenuated when it travels through the ionosphere's layers. Two models, the Appleton-Hartree model for the refractive index and the Chapman model for the ionosphere layers, have been used to compute the overall loss [215].

HAPS will be used as a new wireless access platform for future wireless networks because it has great potential [218], such as

- Fast, dependable, and effective long-distance communication between satellites is made possible by the HAPS layer, acting as a large-scale intelligent entity, negating the need to set up millions of ground and offshore relay stations.
- In order to control the movement of a swarm of UAVs, the HAPS layer offloads complex calculations, handles extensive sensing and monitoring, and provides edge intelligence.
- The HAPS layer reduces dependency on terrestrial and satellite networks by offering quick Internet access and wireless communication capabilities.

Despite the efforts of hybrid network many issues were observed in the deployment [192], [219].

- Doppler, multipath components, and fading effects are very high at high frequencies.
- Lack of comprehensive model of the ground-space-air channel.
- Integrating different network elements (TN and NTN) may cause different process information rates that delay overall communication. The ground-to-satellite transmission distance causes a significant propagation delay, resulting in a longer response time.

Using UAVs, HAPs, satellite networks, and TNs makes it much easier to make a wireless system that works as a single unit and uses the same radio technology [177]. We can summarize the benefits of using the hybrid network as follows:

- It can offer connectivity anywhere, anytime, with notable socioeconomic effects [170].
- NTN networks are backup networks that provide reliable on-demand wireless communications; natural disasters (e.g., snowstorms, earthquakes, and tsunamis) destroy ground communication infrastructures [175].
- Cover unserved and isolated areas for reliability and seamless connectivity [179].
- To ensure continuous service (access to the Internet) for people travelling by aircraft, ships, high-speed trains, and highways.

3) APPLICATION OF HYBRID NETWORK

This section concludes the common use cases for hybrid satellite-UAV-HPA-terrestrial networks, which traditional networks cannot provide. There are many applications of 6G hybrid networks and promise to revolutionise several industries as well as daily life. Here are a few important places where widespread 6G coverage might have a substantial impact, including on-shore base stations and marine satellites, the primary data sources for MCNs. Deployable BSs are configured using mobile vessels and UAVs. This results in an ocean-hierarchical satellite-UAV-terrestrial network [190]. Additionally, in order to meet passengers urgent communication needs, communication on aeroplanes is necessary. Furthermore, UAVs may be effectively paired with HAPSs and satellites to facilitate continuous information broadcasting and enable more precise data processing [14]. A hybrid network in 6G ensures a consistent and lag-free connection, allowing users to seamlessly engage in augmented reality (AR) and virtual reality (VR) environments for applications ranging from gaming to professional training [220]. Given the rapidly increasing number of linked devices, 6G hybrid networks will be essential in ensuring dependable connectivity for IoT applications. Pervasive coverage guarantees seamless device communication, from industrial IoT to smart cities and homes [178], [221], [222]. Ubiquitous coverage and low latency are necessary to communicate in real time for autonomous vehicles, infrastructure, and other connected objects on the road. Transportation networks are made safer and more effective [223]. With its ability to facilitate remote collaboration and isolated rural communities, immersive learning, and global access to educational resources, 6G has the potential to transform the educational landscape completely. For seamless online learning, ubiquitous coverage guarantees dependable connectivity for educators and students. 6G hybrid network can facilitate enhanced healthcare applications, telemedicine, and remote patient monitoring. Via virtual consultations and monitoring equipment, ubiquitous coverage guarantees that patients can obtain high-quality healthcare services even in remote places [28]. For 6G, Cell-free massive MIMO systems can be effectively combined with UAVs to provide cell-free networks with comparatively low latency; therefore, it will be discussed below in detail [14].

As the world journeys towards 6G, 'hybrid satellite-UAV-terrestrial' networks emerge as a critical enabler, promising ubiquitous coverage and meeting the diverse and evolving demands of future communication technologies. However, the methods created for conventional networks do not apply to hybrid networks because of the significant differences between the two networks. Interference between terrestrial and non-terrestrial platforms, resource utilization, and spectrum utilization are challenges in 6G networks. New communication protocols are needed for seamless transmissions. Despite the potential for ubiquitous coverage, several challenges must be addressed for effective 6G network utilization.

F. CELL-FREE MASSIVE MIMO (CFmMM)

This advanced wireless communication technology represents a significant departure from traditional cellular network architectures. It is designed to enhance wireless networks' capacity, coverage, and efficiency by leveraging a distributed and cooperative approach. The traditional cellular network splits the network into cells according to topology theory. Few access points with huge co-located antenna arrays are used by each cell. This results in poor communication and significant interference for users near the cell's edge and also demands complicated co-processing and expensive deployment [25]. Recent studies have indicated that cell-free delivers a viable solution to efficiently support huge access for IoE devices in the upcoming 6G networks, overcoming the cost-ineffectiveness of traditional cellular design [18]. In the cell-free network design, cellular grids are no longer used to split up regions. Massive MIMO antenna arrays and access points are geographically dispersed across a wide region and managed by a single central processing unit (CPU), sharing the same resources with user terminals. Due to its wide network coverage, cheap cost, high macro-diversity gain, and low path loss, the cell-free massive MIMO architecture appears promising in next-generation systems [33]. Each access point has many antennas that can work together to create a scalable MIMO cell-free network supporting numerous mobile devices across a wide geographic region. Each user's equipment (UE) may use several APs and neighboring antennas with less path loss as the number of APs rise; see Figure 9. With low-complexity signal processing, the proposed CFmMM systems guarantee that UEs may achieve comparable traditional performance independent of location [224]. Due to improved service quality, practically uniform attainable rates throughout the coverage area, and smooth handover for all mobile users regardless of their network position [225]. The CSI estimation's precision, acquired by training sequence transmission among the access points and UE, determines how well cell-free massive MIMO performs. However, the pilot resources must be shared across users because the channels vary in their timing and frequency. Therefore, this pilot's reuse may result in pilot contamination, which lowers the performance of cell-free massive MIMO. It's also necessary to find suitable resource allocation methods in CFmMM. Additionally, it's crucial to consider how to effectively communicate system information and signal synchronisation and how to optimise locations of access points. It is intended to increase the capacity and coverage of wireless networks; however, accurate CSI calculations are required. Future research should focus on the use of DL and ML in CFmMM systems as well as it can integrate with FBMC systems, which is additionally a fascinating.

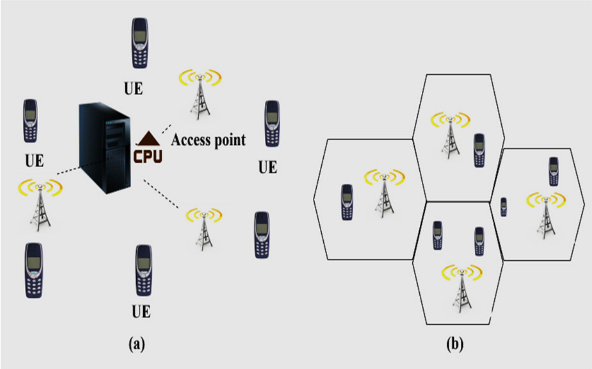

FIGURE 9. (a) Cell-free massive MIMO with a distributedaccess points (APs) (b)Traditional cellualar system.

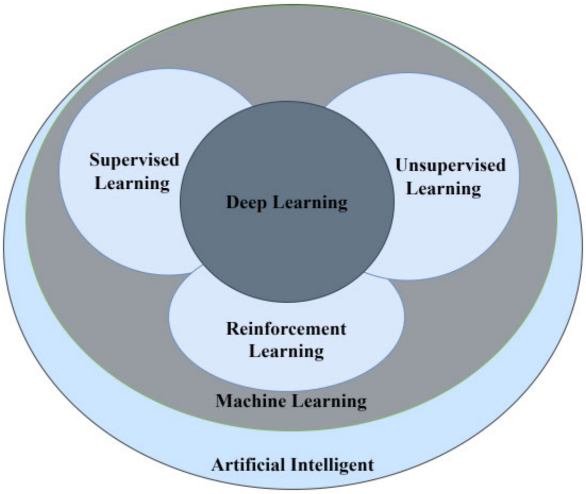

FIGURE 10. The relationships between AI and ML [226].

G. ARTIFICIAL INTELLIGENCE (AI)

The 6G networks are integrated with satellite networks, UAVs, drones, and HAPs to attain exceptional performance [1]. Therefore, it is likely that 6G networks will be more complex, diverse, dynamic, and automated in how they are managed and how they are put together. With the growth of big data, it's getting harder and harder to use resources well and give users consistent experiences. So it is only natural to use AI to solve intricate 6G network challenges [226], [227]. The AI network is required to manage, analyze, and optimize various resources besides supporting 6G wireless networks [227]. AI and machine learning (ML) have gained attention and become critical technologies affecting our lives, society, and industry. ML is supposed to play a crucial role in radio resources, control, and mobility management in 6G networks [228]. AI simulates human intelligence to develop theories and techniques. Hence, AI simulates the human brain's information processing by making machines think like humans. ML is a sub-branch of AI that makes predictions and decisions based on data learning [226], [229]. The AI features are as follows [230]:

- Intelligent service identification: AI techniques are used to learn service characteristics to enable the powerful medium access control (MAC) scheduler to use more smart policies and algorithms.
- Intelligent physical layer functions.
- Powerful MAC scheduling is more efficient and smarter depending on channel prediction, data traffic, and QoS.

ML can overcome the complexity of mathematical formulas and solve complex problems [227]. Moreover, ML algorithms can analyze communication data and predict signal loss in a wireless setting. Therefore, various algorithms can be used in a 6G network [226]. The ML algorithm was used to enhance resource allocation and design pilot signals [231] for channel estimation [232], as well as for power allocation and rapid beamforming [23]. In addition, ML was applied to decide handover timings [233], channel coding in the physical layer, ranging and obstacle detection, as well as for security [234]. ML is developed in four branches: 1) supervised learning, 2) unsupervised learning, 3) reinforcement learning, and 4) Deep learning (DL) [199], [200], [201], [202], [203], [204], [235], [236], [237], [238], [239], [240].

Supervised learning needs a supervisor to train the system. The supervisor tells the system what inputs to take and what outputs to expect. It needs massive datasets. Supervised techniques include logistic regression, naive Bayes, k-Nearest Neighbor (kNN), Artificial Neural Network (ANN), random forest, and decision tree. It has been used for channel estimation. The output can be generated using experience, but it suffers from low accuracy in huge datasets

Unsupervised learning does not need a supervisor and is used when the expected output is unknown. The system must learn by itself. It lets the agents learn from their experiences. Unsupervised techniques include), the hidden Markov model (HMM), K-means, and self-organizing maps (SOMs). The advantages of this technique are 1) less complex as it dismisses data labelling. 2) It works in real-time because users label and analyze all input datasets at the beginning of the algorithm. However, It isn't as accurate as other ML techniques because the data used aren't labelled and have higher computational complexity.

Reinforcement Learning (RL) works similarly to the unsupervised scenario. It makes accurate decisions based on the situation's actions and later evaluates which actions must be considered to increase a long-term reward. The techniques of RL are the Markov decision process (MDP), Q-Learning, policy learning, actor-critic (AC), and the multi-armed bandit (MRB). The advantage of RL is its ability to manage delayed rewards. Besides, stochastic decision-making and data set modifications can be maintained for a long. However, RL suffers from overloading in much usage.

Deep learning (DL) is a promising ML technology that is a powerful method as it adds intelligence to wireless networks with complex radio conditions and large-scale topology. Computers need to learn from experiences in the DL process and then build up certain training models that allow computers to specify the accurate weight values between neural nodes by extracting features from input data [241]. The DL allows the model to make predictions, decisions, and classifications depending on big datasets. Since the technology is closer to humans, it can learn from scenarios and decide which access point can be connected to 6G. But DL has a lot of problems because it needs a lot of memory and processing power to work. It can be applied to search optimal routing paths. In higher layers, DL can be useful in multi-session scheduling and data compression [240], [241] in some IoT applications [242].

The DL techniques include a convolutional neural network (CNN), recurrent neural network (RNN), deep neural network (DNN), and long short-term memory (LSTM) [242]. relationships between AI and ML. The success of AI and ML algorithms encourages many quarters to use them in 6G networks. The ML algorithms are usually assessed by how much their performance has improved in 6G. Issues that might arise when using AI and ML are: 1) computation overhead and storage, 2) system requirement, 3) compatibility, 4) data privacy, 5) type of information that can be collected and provided to network operators [243], [244] and 6) ML algorithms with long convergence times that could diminish their usefulness in highly dynamic wireless [243] More studies should integrate AI and ML methods for mobile networks, channel estimation with high mobility settings, and THz wave channels. Table 6 lists the benefits and setbacks of the proposed 6G technologies. The tradeoff between AI prediction accuracy and ML algorithms' training complexity is crucial, along with technical challenges like long convergence times. Developing efficient algorithms for dynamic wireless networks is also essential.

IV. 6G POTENTIAL APPLICATIONS

Every decade a new generation has been introduced. These new generations always enhance the quality-of-service metrics, offer new services, and introduce new applications. As 6G is expected to provide the network with ultra-high-speed, extremely low-latency communications, ubiquitous connectivity, coverage, and network intelligence, it will enhance the overall user experience and offer advanced applications. Many applications are expected to achieve perfection in 6G, such as XR usage, real-time interactive applications (e.g., holographic, haptic, and tactile communications), automatic manufacturing, smart cities, IoE, and robotics.

A. EXTEND REALITY (X R)

XR, as a catchword for AR, VR, and MR, is one of the valuable applications of this decade. It has been classified as a supportive application for different areas of applications, but it demands very low latency and a higher data rate. Hence, 6G might face challenges in XR applications [246]. XR technology offers a unique opportunity to create spatial experiences. With recent software advancements, spatial computing has evolved as a strong paradigm that enables users to map their surroundings in real-time using their smartphones in both the visual and aural realms [247]. The XR systems are capable of delivering incredibly realistic synthetic experiences. The XR systems, which use low-cost HMD-based, have progressively stimulated other senses. The most common multimodal technique uses hand-held controllers with rudimentary vibrotactile haptics. Besides HMD, many technologies can be used to view XR scenes, including cutting-edge visual technologies, 3D to light fields, and

TABLE 6. Summary of benefits and challenges of the proposed technologies.

Technology	Benefits	Techniques	Challenges	Ref
Multi-carrier Modulation Techniques	Higher data rate High spectrum efficiency	FBMC	Computational complexity High PAPR	[88], [90].
Terahertz Communications	The higher data rate, spectrum efficiency, and capacity	Frequency range 0.1-10 THz	High-frequency attenuation Blockage Infrastructure expenses	[132], [128] [123]–[127].
Visible Light Communications	Maximize the Bandwidth. Increase the data rate.	Ranging from 380 to 750 nanometers (400 and 800 THz),	Small bandwidth of LEDs Noise and Interference from adjacent lighting systems Infrastructure costs	[145] [150]. [131], [132]
Ultra-massive MIMO,	Increased capacity, data speeds, and spectrum efficiency	Hundreds or even thousands of antennas. Beamforming	Increase the signal processing's complexity Increase the power used Deployment expenses	[145], [148] [151]
Hybrid Network	Ubiquity Coverage Seamless connection	Satellite Networks. Unmanned Aircraft Systems. High Altitude Platform Systems.	Large propagation delay Different process information rates Doppler effects	[10], [192], [219]
Cell-free massive MIMO	Increase the connectivity and provide full-coverage	Arbitrarily distributed access point manged by CPU unit	The accuracy of the CSI estimation	[18], [33]
Artificial Intelligence and Machine Learning	Intelligent Network	Supervised learning algorithms. Unsupervised algorithms Reinforcement Learning algorithms Deep learning Algorithms	Computation overhead Storage Compatibility Machine-learning algorithms have a long convergence time	[227] [243], [244]

holographic displays CAVE virtual rooms fog screens to augmented spatial reality [246], [248].

Virtual Environment (VR) users have a high sense of immersion in computer-generated surroundings [249] that apply computer technologies and reality headsets to create believable experiences. Augmented Reality (AR) extends the real world by combining virtual content [250]. Due to the powerful smart devices with cameras and tiny sensors being widely available, as are augmented reality glasses, AR applications are rapidly expanding [5]. This has enhanced their elements through various computer-generated sensor inputs, including video, audio, and visuals [246], [248]. Mixed Reality (MR) merges real and imaginary worlds, which creates an intricate environment and virtual objects sensationalized in 3D in one's real space [251], as portrayed in Figure 11. XR technologies have the potential to combine real and virtual environments. They are supportive in various application areas and may be implemented to receive contextual data on demand for the duration of training or maintenance duties [249], telemedicine [252], and education [253]. Users can play games, watch sports events, etc, without time and place restrictions [254]. Recently, XR systems have embedded AI systems, specifically ML, to reduce their high computational power and cautious manual work. The AI can boost some aspects, such as motion sickness prediction and stability, as well as tracking and gesture recognition, mainly because AI can learn from data via XR interactions and technologies [247].

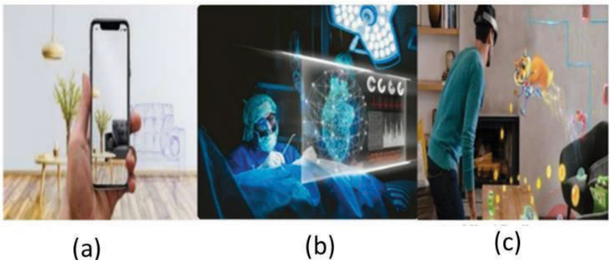

FIGURE 11. (a) Augmented reality, (b) Virtual reality, and (c) Mixed reality.

B. SMART HEALTHCARE

The progress in healthcare is looking toward telemedicine systems and smart remote health services shortly. The 6G technology is bound to support smart healthcare with new services for an advanced, reliable, and remote monitoring system, evaluation, as well as treatment of human beings. Remote surgery is made possible via XR, robotics, and AI to eliminate time and space barriers [251]. Healthcare relies on three main technology areas for developing sensing areas applicable to collecting large data for data processing [252]. The enabling factors for communication are ubiquitous connectivity, high reliability, low latency, and data analytics [253]. The Internet of Medical Things (IoMT) can make decisions, identify risks, and take precise actions automatically [18]. Smart healthcare systems can analyze and summarize medical data related to patients' information (e.g., age, gender, and condition of patients) [236]. The systems allow clinicians to monitor patients remotely, collect data from various sensors, and store and forward devices to a micro interface (e.g., cell phone) so clinicians can easily access patients' records. This enables the patients to be treated remotely [18]. One advantage of using smart healthcare is that it can help people in both cities and rural areas. It can also cut down on the number of trips to the hospital, the time it takes to get treatment, and the money it costs. It supports the control of the spread of dangerous diseases [236].

C. HOLOGRAPHIC COMMUNICATION

For both professional and social communication types, holographic is an imminent application in 6G because it enables people to communicate with tactile communication while they are in various locations, thus providing a truly exciting experience. However, holographic communication is a data-hungry application [254]. It relies on visual transmission from multiple-view cameras, so it needs ultra-high accuracy and data rates (Tbps) [255].

D. HAPTIC COMMUNICATIONS

Haptic communications use nonverbal communication through the sense of touch and add a new dimension to audiovisual interactions in remote places and settings. However, the 6G network will have to put in plenty of effort to provide this real-time interactive experience [255]. The tactile Internet can be used in human-machine interaction-based applications, such as industry, cooperative automated driving (CAD), e-commerce, etc. [25].

E. AUTOMATIC MANUFACTURING

Automatic manufacturing requires as little human intervention as possible in industrial processes. In order to perform highly accurate manufacturing automation control systems, ultra-high reliability and extremely low latency time are needed [25]. Smart manufacturing demands IoT to connect manufacturing systems for controlling and data analytics approaches, which can enhance manufacturing functioning. The 6G network will facilitate the connection of sensors and machinery, thus realizing the smart manufacturing system [256]. Smart factories strive to maintain an appropriate supply-demand balance, create sophisticated product planning and development, sell and distribute products in the best possible way, as well as monitor their operations automatically [18].

F. SMART CITY

The population density is growing rapidly, especially when more than 70 percent of areas in the world are estimated to become metropolitan areas by 2050, as stipulated in the United Nations report [256]. This highlights the importance of facilitating the needs of the citizens. Creating a smart city aims to improve residents' quality of life, efficiently use public resources, and reduce operating expenses. Hence, smart cities need an intelligent approach to control systems in metropolitan areas, such as health, transportation, energy, education, and housing [257].

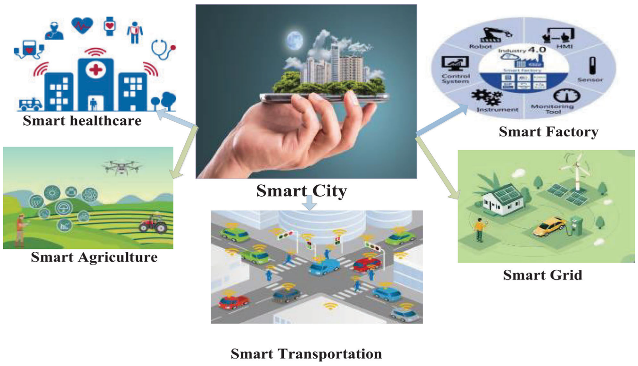

FIGURE 12. The smart city elements.

Millions of sensors are used in buildings, houses, factories, roads, vehicles, and other facilities to realize the smart city concept. As these sensors gather data from the devices, it is crucial to enable reliable and high-speed communication to maintain massive data [258]. The 6G expect to implement an integrated network architecture to manage varying administrative departments since most urban public infrastructure's information perception, sending, analyzing, and control will still be under their control. Besides, an inexpensive and real smart green city could be realized with the help of IoT and AI [259].

Smart transportation is a subset of smart cities that permits self-driving cars to connect and share information. Smart transportation, such as bikes, cars, metro trains, metro buses, and trains, is also part of the smart transportation system [260], [261]. An efficient urban transportation system depends on reliable mobile wireless networks and IoT [262]. Operators must gather transactional records and vehicular locations using wireless networks and sensors for transportation. Advanced communication is required with ubiquity, connectivity, and very low latency. Exploring data validity in transportation systems for smart cities [261]. Smart transportation improves road safety (from traffic congestion) and efficiency, assists drivers and passengers, saves energy, and makes good use of the existing infrastructure [263]. Figure 12 illustrates some components of the city.

G. IoT AND IoE SERVICES

The IoT refers to objects or devices capable of communicating with each other using specific addressing schemes via the Internet while concurrently supporting helpful information for a wide range of physical parameters. The number of IoT devices is growing; by 2030, the number will reach 24 billion due to the rapid growth of applications, including the industrial Internet of Things (IIoT) and smart cities [264]. The IoT can be connected via the internet to Bluetooth, wireless sensor networks (WSN), long-term evolution (LTE),

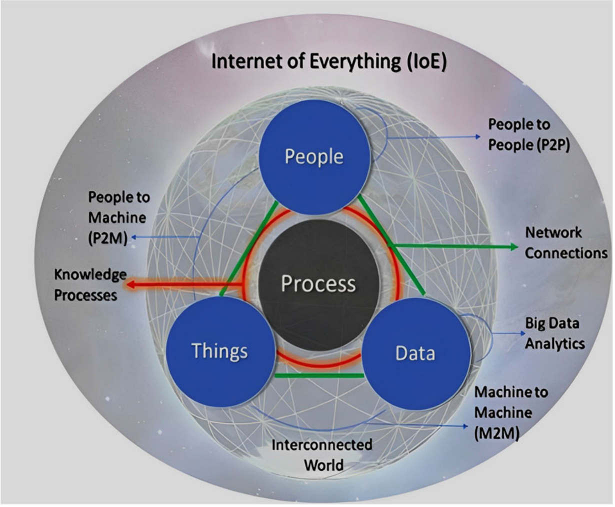

FIGURE 13. Internet of everything concept [266].

radio-frequency identification (RFID), and various other smart communication technologies [265].

The IoT can be employed in numerous applications, including transport, agriculture, healthcare, private residence, manufacturing, and industry. Perception, network, and application are the layers that make up the architecture of the IoT. The perception base layer extracts data from objects and converts them to a digital format. The responsibility of the network layer is to transport digital signals. Finally, the application layer puts transmitted digital signals to use in multiple contexts [267]. The IoE, another service that enriches people's lives by extending the concept of the IoT, was first defined by CISCO in 2012 [266]. The IoE has broadened the scope of the IoT, creating a hyper-connected world where data, objects, and people are all interconnected to facilitate the automation of corporate and industrial procedures to simplify human lives. The IoE sensors can monitor many parameters, including pressure, velocity, temperature readings, and biosignals. They can be used in smart cities, health care systems, and industrial domains to promote accurate system decision-making [268]. Trillions of intelligent devices worldwide have sensors to measure, verify, and estimate – all connected through public or private networks [269]. The growth of Internet-connected devices is a significant hurdle for the 5G network stemming from data volume increment up to 1000 times, which demands End-to-End (E2E) latency to be in milliseconds [270]. Since the IoE needs a massive amount of data from heterogeneous IoE devices, it requires a seamless connection supported by the 6G network to enable a smooth transition from the IoT to the IoE [268]. However, the IoE suffers from several technological issues, including accurate analysis and action, standards, compatibility, marketing, and customer satisfaction [269].

H. INTELLIGENT ROBOTS

Intelligent robotics, which eases one's daily living, demands multiple innovations in electronics, maturity in robotics technology, and a wireless communication system with higher data rates – an expectation to be realized within the next ten years. The 6G network is expected to tackle the infrastructure in enabling intelligent robotic solutions [271], [272]. MIMO and OFDM are used in 5G to achieve a higher data rate, but they require high energy consumption [271]. To date, an intelligent robot can be used for dull and tedious work. It can involve people in dangerous industrial activities that need plenty of attention. Thus, robots need to be able to react rapidly, especially when dealing with people and other machines in a dynamic setting. Suppose the hospital is overburdened with patients and the majority of the nurses are otherwise busy, or the patients have a potentially life-threatening illness (dangerous disease). Medical robots can step in to provide care [25]. Medical robots can assist surgeons during operations. Hence, the 6G wireless network will precisely enable robots to accomplish complicated jobs [21].

An intelligent robot can communicate with other intelligent robots about their experiences and share pictures and videos. Robot-to-Robot (R2R) communication necessitates mobile communication connection with smooth and high-speed dependable connectivity [273].

V. FINDINGS AND LESSONS LEARNED OF 6G TECHNOLOGY ENABLER

This section summarizes the significant lessons learned from the review and in-depth investigation of the techniques, requirements, and challenges of the envisioned 6G connectivity. The lessons learned are as follows:

Lesson One: In summary, the 6G network is expected to revolutionize communication systems, with numerous new applications emerging. The 6G is expected to boost data rates to multiples of Tbps, increase capacity to 107 Mbps/m2, and lower latency to 0.1 ms. The reliability and coverage area may reach 99.99999% and 1000 km/h, respectively, effectively enhancing the user's mobility.

Lesson Two: Over 70% of data traffic derives from indoor settings. Modern technologies have been assessed to offer high QoS, data rates, and spectral efficiency for mobile communication in 5G and beyond 5G (B5G) networks. To meet the 6G network demands, integrating various technologies (e.g., multiple access techniques, VLC, THz, beamforming, um-MIMO, IRS, and AI/ML) is crucial to improve network performance. Many 6G challenges, such as spectral efficiency, security, energy consumption, and interference control, may be resolved due to these integration efforts.

Lesson Three: Multiple access techniques allow several users to share the same communication resources at the same time, frequency, or in the same code. This has been included in many wireless systems to attain high data rates, spectral efficiency, and better system capacity. New intelligent multiple access techniques are required to enhance the QoS with limited resources, besides dealing with the resource constraints between heterogeneous devices for 5G and 6G networks.

Lesson Four: 6G could increase spectrum resources, data traffic, capacity, and security by utilizing THz and VLC communications. Based on the nature of electromagnetic wave propagation, the fading amplitude in free space is proportional to the frequency squared. Therefore, these frequency bands possess more attenuation in free space. Moreover, both VLC and THz links can be obstructed by the movement of objects or users in indoor settings.

Lesson Five: Rapid improvements, new ideas, and growth in mobile communications toward 5G and 6G have led to a lot of different kinds of networks. From heterogeneous 6G networks with big data processing, efficient resource allocation and administration have become more complicated. Hence, it is only natural to use AI and ML to solve complications and significantly improve 6G network efficiency. The ML may greatly facilitate the realization and optimization of 6G network applications.

Lesson Six: NTN technology utilization in 6G is attractive; it has garnered attention from researchers. The NTN offers service connections anywhere and anytime for IoT applications, besides serving as a backup network to offer reliable on-demand wireless communications during disasters such as snowstorms, tsunamis, and earthquakes. Many questions on a viable network design for NTN demand answers, such as radio resources, propagation delay, mobility management, and coverage area, to assess the role of NTN in 6G systems.

VI. CHALLENGES AND FUTURE RESEARCH ISSUES

The section explores the challenges and future research issues in 6G applications. It highlights the complex landscape of 6G, including advanced modulation techniques, satellite communication complexities, dynamic mobility scenarios, ultra-high data rates, massive IoT adoption, terahertz spectrum utilization, AI-driven network optimization, and environmental sustainability. These challenges present opportunities for innovation and research in the evolving field of 6G, shaping the future of wireless communication networks.

- Intelligent radio (IR) According to IR, RANs can use advanced AI chip capabilities at user and network devices to choose the best algorithms for spectrum sharing, radio frequency planning, channel modulation, coding, and estimation, as well as multiaccess schemes.
- Advanced Modulation and Channel Estimation: Developing advanced MCM techniques and channel estimation methods to accommodate the complex and dynamic propagation environments in 6G networks. These technologies must adapt to the intricate and dynamic propagation environments expected in the future.
- Satellite Communication: Addressing the unique challenges of satellite communication in 6G, such as Doppler fluctuation, Doppler shift, high bit error rates, path loss, and transmission delays. Researchers must explore error correction coding, adaptive modulation, and delay-tolerant networking solutions to address these concerns effectively.
- Security in wireless networks constitutes a pressing concern, and this paper underscores the necessity of regarding security as a fundamental performance requirement for 6G wireless computing. Further research is essential to comprehensively unravel the role of chaotic synchronization in cyberattacks and security vulnerabilities. In this context, blockchain technology emerges as a promising avenue, facilitating resource-saving and sharing, including spectrum and data, through distributed blockchain transactions. It offers cryptographic security without the reliance on a centralized authority. Additionally, the potential of quantum computing to expedite information processing, thereby enhancing the efficiency of 6G systems, is also acknowledged.
- Dynamic Mobility Scenarios: Managing the complexities of rapidly moving satellites in 6G networks, which affect inter-satellite links, network topology, and handover procedures. To ensure continuous connectivity and efficient management, the development of dynamic mobility management strategies, predictive algorithms, and seamless handover mechanisms becomes essential. Ultra-High Data Rates: Achieving ultra-high data rates, a central objective in 6G, is essential to support bandwidth-intensive applications like augmented
- reality and real-time 8K video streaming. Researchers must delve into advanced modulation schemes, interference management techniques, and spectral efficiency enhancements to achieve unprecedented data rates while minimizing latency.
- Massive IoT Adoption: As 6G networks strive to accommodate billions of IoT devices for applications in smart cities, autonomous vehicles, industrial automation, and healthcare, energy-efficient IoT communication protocols, scalable network architectures, and edge computing solutions must be developed to cater to diverse IoT requirements effectively.
- Terahertz Spectrum Utilization: Leveraging the untapped potential of the terahertz spectrum opens up new horizons in 6G. This involves exploring terahertz antenna design, modulation techniques, and propagation characteristics to enable reliable and efficient communication, paving the way for applications like high-resolution imaging and medical diagnostics.
- AI-Driven Network Optimization: Artificial intelligence-driven network optimization is poised to play a central role in 6G. Developing AI algorithms for dynamic resource allocation, predictive maintenance, network self-healing, and real-time anomaly detection is necessary to create self-optimizing 6G networks capable of adapting to changing conditions and optimizing performance autonomously. However, researchers must grapple with the technical intricacies associated with the often slow convergence of ML algorithms. Developing efficient algorithms with rapid convergence times emerges as a critical imperative, with due consideration

to the inherent complexity of training processes. Moreover, the deployment of DL approaches for channel estimation in high-mobility scenarios warrants extensive exploration.

- Environmental Sustainability: Finally, environmental sustainability is an increasingly critical concern. Researchers must investigate energy-efficient hardware design, renewable energy integration, and environmentally conscious network operation practices to reduce energy consumption, minimize the carbon footprint, and ensure the long-term sustainability of 6G networks.
- Finally, the paper accentuates the significance of electromagnetic (EM) and information theories in the realm of wireless communications. EM theory elucidates the genesis and propagation of electromagnetic waves, while information theory plays a pivotal role in the efficient transmission of information while conserving power and bandwidth. Bridging the physical aspects of wireless communication with information transmission, the amalgamation of antenna theory and wireless propagation channel modeling complements the convergence of EM and information theories. In conclusion, this paper underscores the transformative potential of 6G in the domain of wireless communication. It also casts a spotlight on critical domains that warrant further research and development efforts.

VII. CONCLUSION

This paper has provided an in-depth exploration of the forthcoming 6G wireless communication networks and their potential to surpass the capabilities of 5G. 6G holds the promise of revolutionizing communication among individuals, organizations, and smart devices, underpinned by intelligent networks, ubiquitous coverage, and seamless connections facilitated by the integration of Artificial Intelligence/Machine Learning (AI/ML) and Non-terrestrial Networks (NTN). The paper has furnished an insightful overview of AI and NTN, delineating their advantages and the formidable challenges that must be surmounted. Furthermore, it has delved into proposed technologies for 6G, with a particular emphasis on their capacity to expand bandwidth, curtail latency, amplify data rates, enhance system capacity, and optimize spectrum efficiency. Each technique has been presented along with its main fundamental advantage and prospective applications. Notably, multicarrier modulation techniques have been highlighted for their potential to propel data rates and spectrum efficiency to new heights. Focusing on FBMC as the most candidate for 6G, we compare FBMC with other candidates based on spectrum efficiency, advantages, drawbacks, and MIMO flexibility. Collectively, the paper posits that 6G networks will be ideally poised to cater to the evolving needs of individuals and businesses.

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