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Review

Milestones of Wireless Communication Networks and Technology Prospect of Next Generation (6G)

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Abstract: Since around 1980, a new generation of wireless technology has arisen approximately every 10 years. First-generation (1G) and second-generation (2G) began with voice and eventually introduced more and more data in third-generation (3G) and became highly popular in the fourth-generation (4G). To increase the data rate along with low latency and mass connectivity the fifth-generation (5G) networks are being installed from 2020. However, the 5G technology will not be able to fulfill the data demand at the end of this decade. Therefore, it is expected that 6G communication networks will rise, providing better services through the implementation of new enabling technologies and allowing users to connect everywhere. 6G technology would not be confined to cellular communications networks, but would also comply with non-terrestrial communication system requirements, such as satellite communication. The ultimate objectives of this work are to address the major challenges of the evolution of cellular communication networks and to discourse the recent growth of the industry based on the key scopes of application and challenges. The main areas of research topics are summarized into (i) major 6G wireless network milestones; (ii) key performance indicators; (iii) future new applications; and (iv) potential fields of research, challenges, and open issues.

Keywords: Wireless networks; beyond 5G; 6G communications; terahertz frequency; terahertz communications; holographic calls

1 Introduction

One of the most influential technological advances in recent history has been mobile communication. Five (AMPS, GSM, UMTS, LTE, and 5G) wireless networking networks have also been adapted to date. Approximately, in every decade since 1980, a new generation has appeared. 1G and 2G began with voice and eventually added more and more 3G data and highly popular 4G data [1]. The tremendous growth in mobile networks, which provide data-oriented services that consist of, but are no longer constrained to, multimedia, online gaming, and high-quality video streaming, has been seen in the last five years. As a consequence, there has been an explosive rise in the number of mobile subscriptions. This surge is equally experienced in the volume of mobile data traffic. Moreover, the introduction of the Internet of Things (IoT) paradigm would result in an exponential increase in network traffic [2]. This unparalleled traffic increase is considered a core driver of 5G wireless networks. 5G networks standardization is now in the final stage, being implemented across the globe [2].

The International Telecommunication Union (ITU) defines the vision and specifications; three standard scenarios, high data rate (Gb/s), minimum delay (ms)) and dense device connections (one million/sq-km), should be met by 5G [3]. Moreover, another requirement is to satisfy eight key performance indexes (KPIs). To attain the objective, varieties of supporting technologies were suggested and introduced [4], such as massive MIMO, mmWave, non-orthogonal multiple access (NOMA), and so on [5]. However, due to the significant increase in the number of connected objects, much higher data rates and less latency would be needed than would be offered by 5G networks [6]. Such problems are seen as a key driver for 6G communication systems, which are planned to be implemented within 2030 [7].

6G will be further improved and extended on the foundation of 5G. 6G aims to increase data rate 10 to 100 times higher than 5G. Bare minimum delay for delay-sensitive applications, advanced system capacity and higher spectrum efficiency will some other features. Moreover, 6G will promote improvements in coverage, facilitate higher mobility with mass interconnection, and uphold the development of an overall intelligent mobile Society [8]. Additionally, 6G communications use unconventional communication networks to access and transmit various forms of data via conventionally enhanced RF networks, permitting new connection experiences of virtual life as well as participation anywhere. Holographic calls, flying networks, tele-operated driving, and palpable internet are the potential connectivity scenarios planned by 2030 [9].

The goal of this work is to address the significant challenges of the evolution of mobile cellular communication networks and to keep the focus on the recent growth of the industry dealing with the key areas of application and challenges. The major factors of this work are summarized into (i) major milestones of 6G wireless networks; (ii) key performance indicators; (iii) potential emerging applications; and (iv) potential research areas, challenges, and open issues. To achieve an accurate, concrete, and succinct conclusion, these areas are analyzed grounded on their particular sub-domains. This article will greatly contribute to introduce new pathways for future research guidelines for researchers through presenting some novel sources that could help in the development of 6G networks.

The rest of the article is organized as follows. The evolution of wireless networks is provided in Section 2. The major milestones of 6G wireless networks are provided in Section 3. The open research issues are discussed in Section 4. Finally, Section 5 concludes the work.

2 Evolution of Wireless Networks: from 1G to 5G

The main achievements of the five generations (1G−5G) of wireless communication networks are summarized in Fig. 1. The key technologies and developments in wireless communication networks are presented in the following subsection.

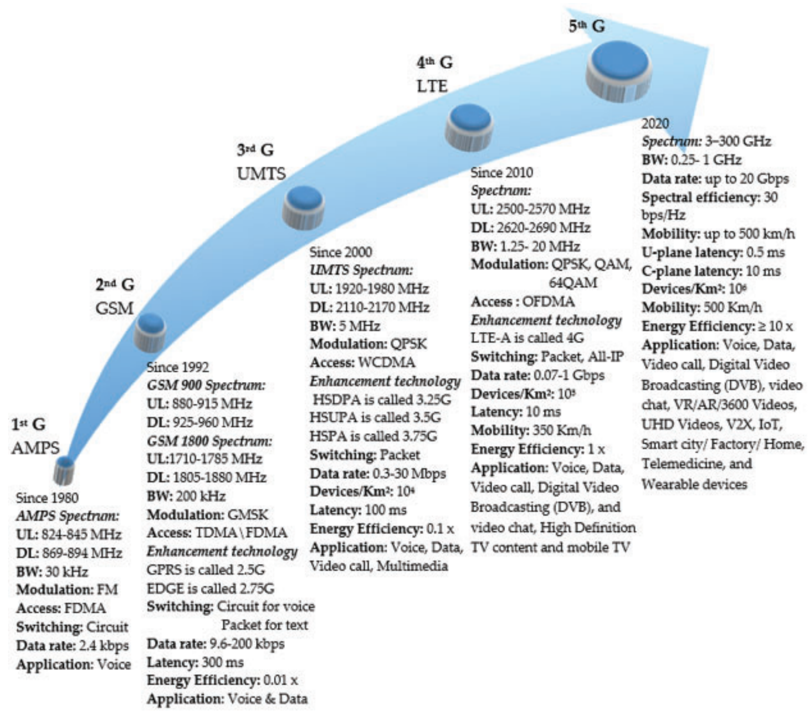

Figure 1: Major milestones of the five generations (1G–5G) of wireless communication networks [2]

2.1 First Generation (1G)

In the last part of the 1970s, the 1G of wireless cellular technology was uncovered. It, an analog telecommunication standard designed for audio transmissions, was mainly available in Scandinavia, UK, and Japan. The throughput was up to 2.4 kbps. In 1G, Frequency Modulation (FM) and Multiple Access Frequency Division (FDMA) transmission technology was used. The total dedicated bandwidth was 30 kHz. Nevertheless, it had a lot of drawbacks, for instance (i) insecure or no encryption because of analog modulation scheme, (ii) can handle inadequate subscribers because of the FDMA technique used, (iii) insecure radiation, and absence of a handoff and so on. Overall, it was a limited-service and not unique worldwide [10].

2.2 Second Generation (2G)

The first system of the 2nd generation, Global Systems for Mobile Communications (GSM), was revealed in the first part of the year 1990. 200 kHz bandwidth was dedicated for 2G and achieved a data rate up to 9.6 kbps. It used Gaussian Minimum Shift Keying (GMSK) modulation and Time Division Multiple Access (TDMA for creating a very basic phase of voice communication. It was the era when global mobile communication came under a unified standard. Secrecy due to digital encryption, prolonged battery life due to less power consumption, and enhanced device capacity are some mentionable achievement of 2G. 2G faced problems due to lower data rate, 2.5G or GPRS overcome that drawback [11].

A new feature, packet switching, started through GPRS. 2G uses this technology along with circuit switching that was adopted in GSM, which able to increase the data rate up to 50 kbps with keeping similar GMSK, TDMA, and 200 kHz BW used in GSM. The next evolutionary step is Enhanced Data GSM Environment (EDGE). It is well known as pre-3G radio technology and is the target to provide up to 200 kbps of data rate. Using the same transmission technology and BW, the EDGE standard is based on the current GSM standard but the difference is in the modulation technique. It uses Eight-Phase Shift Keying (8PSK) along with GMSK. 8PSK provides higher data rates but a lower coverage area compared to GMSK. To boost packet-switched services, the EDGE was introduced to allow a multimedia application that is an example of a high-speed data application [1].

2.3 Third Generation (3G)

3G, the result of research carried out by the International Telecommunication Union (ITU), is the 3rd generation of wireless cellular technology. The spectrum between 400 MHz to 3 GHz was assigned for 3G. It uses the Wideband Code Division Multiple Access (W-CDMA) and High-Speed Packet Access (HSPA) technologies to give improved internet access with audio and video streaming competencies. HSPA is a combination of two protocols, High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA), which expands as well as enhances the performance of in effect W-CDMA protocols for 3G mobile telecommunication networks. Evolved HSPA (also known as HSPA+), an enhanced 3GPP (3rd Generation Partnership Project) standard, was launched in the last part of 2008, with consequent wide-reaching use starting in 2010. 3.9G Long Term Evolution (LTE) contains features that surpass those of 3G mobile communications [1].

2.4 Fourth Generation (4G)

LTE is a radio access technology based on orthogonal frequency-division multiplexing (OFDM). It supports up to 20 MHz BW and Multiple-Input Multiple-Output (MIMO), which is the key technology behind high data rates and spectrum efficiency. It guarantees enhanced connection quality. Adaptive beamforming ensures the adaptation of radiation patterns for signal gain and mitigates interference. The peak mobile data speeds were increased by LTE technology to 100 Megabits per second (Mbps). This technology roadmap is extended to LTE-Advanced (LTE-A) [12], which targets to ensure a peak data rate exceeding 1 Gigabit per second (Gbps) to cope up with the continuously increasing demand.

By providing a complete and reliable solution based on IP, a 4G system enhances the predominant communication networks. The wireless community has extensively investigated three main lines of research to ensure the features of 4G wireless networks:

i. *Network densification*: In crowded areas, where a lot of subscribers are present at a time, this method is deployed. This approach aims to increase bandwidth reuse by dividing a big coverage area into small cells. These small BSs need low cost and consume low power. By reducing the distance between user devices and BS it improves spectrum efficiency and signal-to-interference-plus-noise ratio (SINR). Normally these cells have a coverage radius of 50–150 m and transmit power is 0.1 to 10 W. In current technology, these cells are deploying on an urgent basis and that's why do not need frequent maintenance [13].
ii. *Enhanced spectral efficiency*: In order to decrease inter-cell interference and enhance spectral efficiency, coordinated transmission/reception and inter-cell interference mitigation solutions can be applied with advanced signal processing and spatial diversity [14].
iii. *Spectrum extension*: In LTE-A, spectrum extension is supported up to 100 MHz. It can be done by combining various component carriers which are known as carrier aggregation. This mechanism will provide a very high data rate up to 1 Gbps [15].

2.5 Fifth Generation (5G)

5G wireless networks have attracted considerable interest from both academia and industry since the fourth quarter of 2014 [16]. The primary challenge was to achieve multiple objectives, (i) increased data volume per area, (ii) increased typical user data rate, (iii) increased number of connected devices and massive machine communication, (iv) reduced End-to-End latency, (v) reduced power consumption and extended battery life, and (vi) reduced cost.

These overwhelming 5G network specifications have already given rise to a whirlwind of innovative thinking with an intellect of perseverance to bring revolutionary novel technology to practice. Only five years ago, mm Wave mobile networks were thought of as imaginary; they are now considered to be unavoidable. Moreover, the use of massive MIMO techniques incorporated with mm-wave along with small cell geometries seems to be a symbiotic fusion to maximize throughput [10]. On the other hand, for future studies, several technological obstacles remain. Fig. 2 presents a complete overview of the specifications and challenges of 5G, main innovations, and fundamental architecture.

As of April 2019, South Korea was the leading country to implement a significant large-scale 5G deployment for around 85 cities. The total number of 5G BSs was around 86,000. Overall, it is estimated that nearly 65% of the global population will gain access to the coverage of superfast 5G internet within 2025 It is mentionable that 85% of the 5G BSs were positioned in six cities, including Seoul, Busan, and Daegu, where a distributed architecture spectrum of 3.5 GHz with data rate speed deployed tested speeds ranging from 193 to 430 Mbit/s [2]. The architecture of the SK Telecom 5G network is presented in Fig. 3.

The following subsections highlight the major milestones of 6G wireless networks such as potential technologies, key performance indicators, potential emerging applications, and potential research areas.

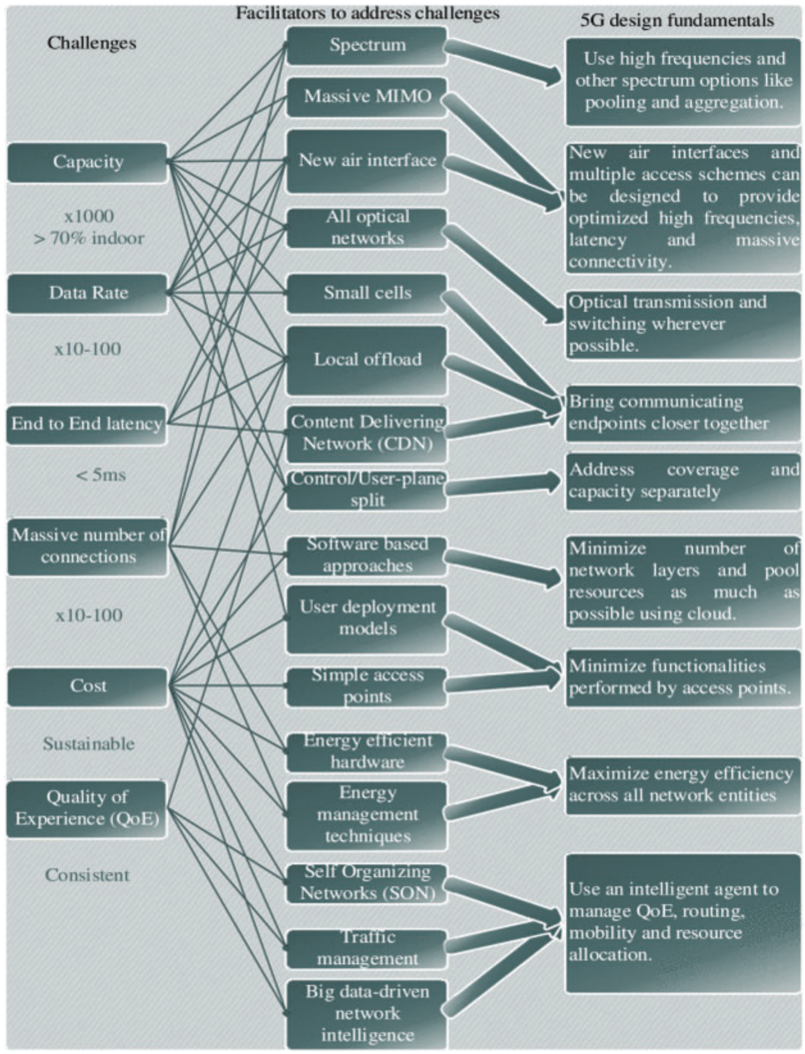

Figure 2: 5G requirement and challenges, key technologies, and design fundamental [17]

3 Major Milestones of 6G Wireless Networks

In general, 6G will go further than the internet Services and it will be provided from the core to the end devices of the network to support universal AI services. In the design and optimization techniques of 6G frameworks, protocols and operations, AI will perform a very important character [18]. Besides, data-rate intensive situations, like the transmission of holographic videos, require bandwidth is not adequate even in the existing mmWave spectrum that was used to address the lack of spectrum in 4G communication systems. This imposes strict criteria on a site or spatial-spectral efficiency and the necessary connectivity frequency bands. Wider radio bandwidths, which can only be available in the sub-THz and THz bands, are therefore required [6]. This success involves a structural shift within the mobile telecommunications industry in design standards and implementation practices. The potential technologies, features, and challenges related to the 6G mobile communications are presented in Tab. 1.

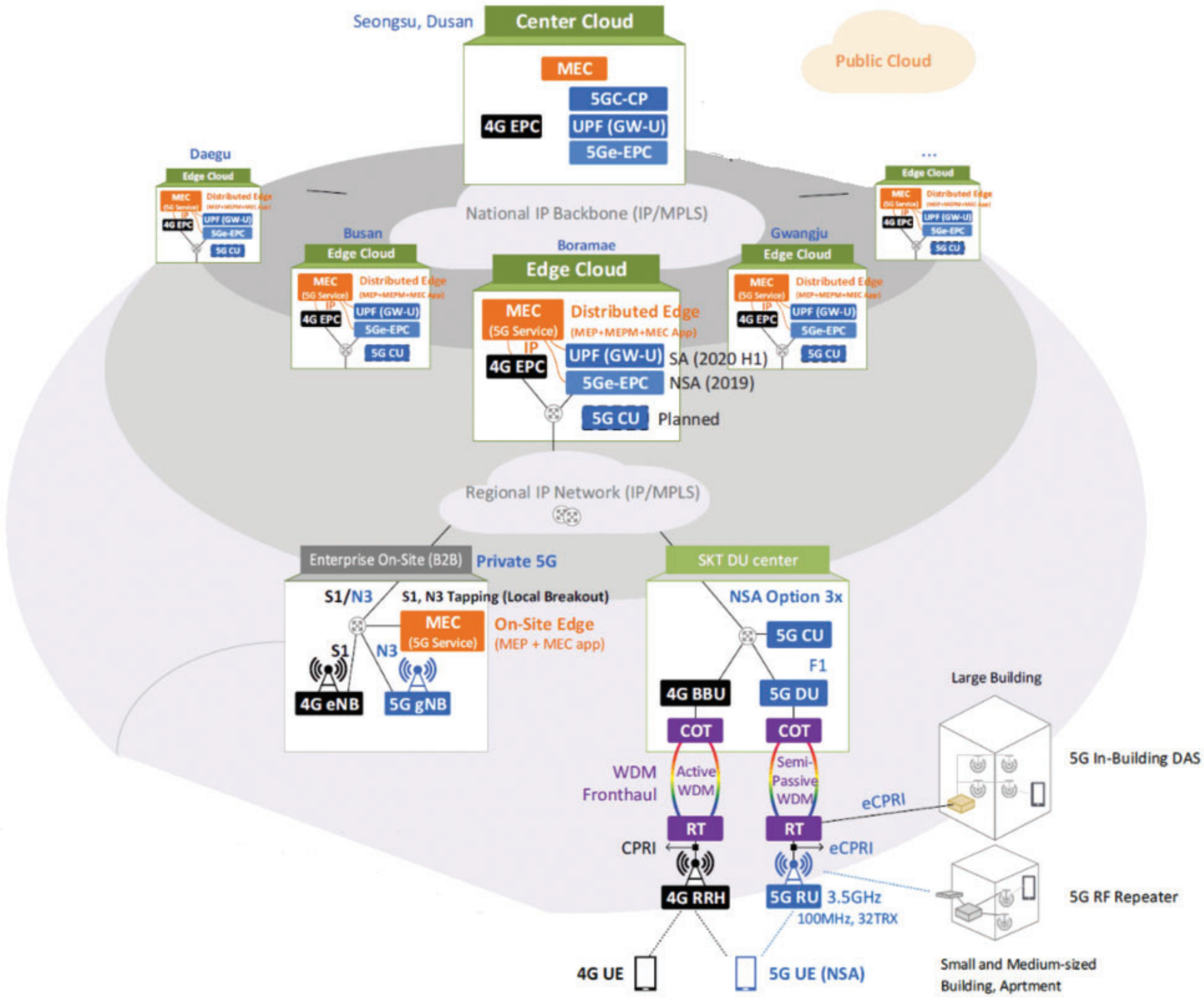

Figure 3: SK telecom 5G network architecture

Table 1: Potential technologies, features, and challenges of 6G wireless networks

	Enabling technology	Features	Challenges
Spectrum	✓ Terahertz (THz). ✓ Visible-light communication (VLC).	✓ High bandwidth, ✓ Small antenna size and focused beams, ✓ Low-cost hardware, and low interference.	✓ Circuit design, high propagation loss. ✓ Limited coverage, need for RF uplink. ✓ Path loss model.

(Continued)

Table 1: Continued

	Enabling technology	Features	Challenges
Intelligence	✓ Learning for value of information assessment. ✓ User-centric network architecture.	✓ Intelligent and autonomous selection of the information to transmit. ✓ Distributed intelligence to the endpoints of the network.	✓ Complexity, unsupervised learning. ✓ Real-time and energy-efficient processing.
PHY	✓ Full duplex Out-of-band channel estimation Sensing and localization	✓ Continuous TX/RX and relaying. ✓ Flexible multi-spectrum communications. ✓ Novel services and context-based control.	✓ Management of interference and scheduling. ✓ Need for reliable frequency mapping. ✓ Efficient multiplexing of communication and localization.
Network architectures	✓ Multi-connectivity and cell-less architecture. ✓ 3D network architecture. ✓ Virtualization. ✓ Advanced access-backhaul integration. ✓ Energy-harvesting and low-power operations.	✓ Seamless mobility and integration of different kinds of links. ✓ Ubiquitous 3D coverage, seamless service. ✓ Lower costs for operators for massively-dense deployments. ✓ Flexible deployment options, outdoor-to-indoor relaying. ✓ Energy-efficient network operations, resiliency.	✓ Scheduling, need for new network design. ✓ Modeling, topology optimization and energy efficiency. ✓ High performance for PHY and MAC processing. ✓ Scalability, scheduling and interference. ✓ Need to integrate energy source characteristics in protocols.

3.1 Key Performance Indicators

The key KPIs of 6G wireless networks are addressed in this section, namely peak data rate, mobility requirements, connected devices/Km^2, area traffic capability, latency, reliability, spectral network, and energy efficiency. In addition, a detailed study of KPIs between the 5G and 6G networks is provided in Fig. 4.

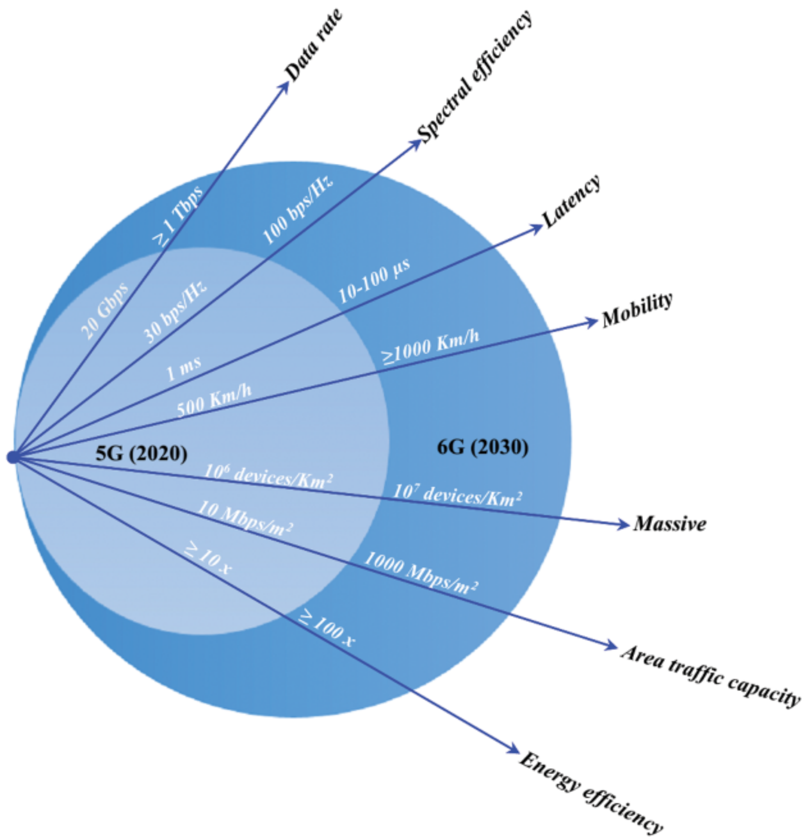

Figure 4: KPIs for 5G *vs.* 6G

3.1.1 Data Rate

Since the beginning of telecommunications, consumer data rate demands have been rising. The data rates of the 1G were a few kbps that increased to a few Gbps in 5G. To obtain wider bandwidth, terahertz, visible light, and so on, 6G is indeed to operate on a higher frequency. 6G will facilitate a data rate of up to 10 to 100 times relative to 5G, promoting the Tbps maximum bit rate. The expectation is that the data rate will increase to 1 Tbps to allow the future smart city to autonomously handle different activities. The data rate is projected to grow from 1Gbps in 5G to at least 10 Gbps per user for individual users, and up to 100 Gbps in certain circumstances in evolving 6G networks [19]. By using the flexible frequency sharing technology the performance of frequency reuse can be increased in 6G [20].

3.1.2 Spectral Efficiency

In order to boost wireless communications, 6G will use smart frameworks to provide an additional degree of freedom (DoF), providing an unparalleled power. Smart reflective surfaces will be installed on a wide scale in buildings [21]. The smart surfaces would improve the antenna aperture efficiently to capture as many radio signals as possible for better energy and spectral efficiency that may not have been achievable earlier. Also, it has been shown that very large capacity wireless mobile networks can be constructed to operate over a distance of a few meters by leveraging polarization diversity and orbital angular momentum (OAM) mode multiplexing. It is possible to design multiple separate transmissions of data streams over the same spatial wireless channel, which improves the spectral efficiency of the system by several times. At a relatively short distance, the performance is gaining significance that can be beneficial for industrial automation. In [22], the mmWave OAM system was stated to attain a spectral efficiency of more than 2.5 Tbps with a massive 95.7 bps/Hz. For Industry 4.0, this can be an attractive technology that is considered one of the main causes of the 6G implementation. On the other hand, to have worldwide mobile coverage, 6G is planned to be combined with satellites. As compared to the commonly used area spectral efficiency (bps/Hz/m^2), volume spectral efficiency (in bps/Hz/m^3) would be more appropriate in 6G to better calculate system performance in a three-dimensional operating space.

3.1.3 Latency

Low latency means communication is quick and rapid. We want to transmit our packets very quickly and there shouldn't be much delay in processing. The allowable 6G latency limit is 10 µSec [23]. A potential network of intelligent mobiles and robots will need high reliability and ultra-low latency. Smart houses, smart vehicles, smart factories, smart schools/colleges, and smart industries will be part of future cities. It will be essential for airplanes, ships, bullet trains, and UAVs to be connected to smart cities. Ultra-reliability and low latency are essential for some of the important applications such as health care, security, tracking, and surveillance [24].

High reliability and low latency are also needed for online gaming. The eRLLCS can combine the protection features with mMTC and uRLLC in 5G with higher reliability criteria greater than 99.999999999% (Nine 9's) in 6G wireless communication systems [25]. Autonomous vehicles will be connected to each other and the communication between them should be ultra-reliable, otherwise, the loss of life in accidents will result. Many households as well as other sensors communicate with each other in 6G systems would also need ultra-reliability to prevent any mishap among them.

3.1.4 Mobility

A range of heterogeneous radios in the equipment can support 6G applications. This allows multiple connectivity techniques, with users connected to the network as a whole (i.e., through various complementary technologies) and not to a single cell, that can increase the existing borders of cells. The devices will be able to seamlessly transition among different heterogeneous links (e.g., sub6 GHz, mmWave, Terahertz, or VLC) without manual intervention or configuration, which will provide QoS guarantees that are in line with the most challenging mobility requirements envisioned for 6G, low latency even in ultra-high mobility scenarios (up to 1000 km/h) [25].

3.1.5 Massive Connectivity

Another use case for next-generation wireless communication is mMTC. This is the domain at which IoTs come in without the presence of human beings. It is machine type communication where the calls, texts, and commands go from one machine to another machine. No human interactions are required and the machine can communicate with each other by following the instructions. It is expected that future mobile technology will accommodate 10^7 devices/Km^2 [18].

Sensor networks and IoTs will be linked to one another in a cooperative manner and with many base stations to boost the performance of the system such as wearable devices, control and tracking devices, self-driving vehicles, smart grids, industrial automation and control devices, and medical and health-related devices. Communication between these devices can be through peer-to-peer or multi-hop cooperative relay methods. A different communication network architecture that can handle different content-driven applications/network needs various applications or devices. Therefore, with all of these criteria in mind, preparation and optimization of next-generation wireless networks would require a unique approach [20].

3.1.6 Area Traffic Capacity

The world is entering into a new era of technology. Demand for better channel capacity and back-hauling has also increased as the number of connected devices per meter square area has increased. The extremely dense sensor network generates more data regularly than Tara-Bytes (TB) [26]. To handle this higher volume of traffic, the data production requires a higher capacity backhauling channel.

Wireless protocols have been developed for many unique applications in previous wireless generations (1G-to-5G). Nevertheless, to build massive IoTs or mMTCs, designers need to develop some power-efficient and cost-effective devices. This massive IoT connection contributes to the growth of vehicular communication called V2X (vehicle-to-infrastructure), such as autonomous driving [20]. The vehicle will communicate with some other vehicle, with the vehicle's pedestrian system and several other sensors. For ensuring the guaranteed quality of services all of these communications should be extremely reliable along with small latency and security. Another example where several sensors communicate and produce large volumes of data is industrial automation. For 6G, the minimum traffic capacity limit is 1000 Mbps/m^2 [27].

3.1.7 Energy Efficiency

6G will meet and exceed many demands, including high energy efficiency distribution, most importantly from the viewpoint of widespread use of the Internet of Things (IoTs) and with a multi-minute sensor eco-system. Besides, the expansion of smartphones' battery-recharge capability must be discussed in line with the suggestion that their capacity and ability to cope with advanced multimedia signal processing leap increases as their electricity consumption increases [28]. Therefore, low energy consumption and long battery charge life are two 6G fields of research to address the frequent re-charging challenges for most wireless devices and increase communication requirements. As a consequence, 6G must evoke a holistic strategy for a communication system that is sustainable and energy-efficient. The main objective of the 6G technology is to achieve battery-free communications whenever and wherever possible, aimed at 1 Pico-Joules per bit energy-efficiency [29]. 6G communication has the advantages of high power THz-waves, apart from directional beam communication with MIMO antenna arrays, enabling devices to send power beams in a certain direction. This technique has enough potential to provide adequate power to the IoT devices and sensors that remain in the coverage area. Authors in [30], the 6G vision and directions suggest that the researcher give emphasize the lifetime of the battery and services classes instead of bit rate and latency. The computational operations of user nodes should be moved to modern base stations fitted with a secure power supply or universal smart radio space to minimize power consumption [31]. To minimize the transmission power of mobile nodes by reducing the per-hop signal propagation distance, cooperative relay communications and network densification may also be of prime significance [32]. In the case of 6G, the lifetime of the battery involves a combination of different methods of energy harvesting that not only extract energy from ambient RF signals but also produce electricity from micro-vibrations and solar [33]. A strong substitute for extending battery lifespan will be long-range wireless power charging [34]. Furthermore, the distributed laser charging technology can securely supply about 2 W of power and reach up to 10 m for mobile devices [2].

3.2 Potential Emerging Applications

5G use cases have three main classes, such as URLLC, enhanced mobile broadband (eMBB), and massive machine type communication (mMTC). However, new communication scenarios in the future networks in the 2030s, which encompass holographic calls, haptics, autonomous connected vehicles, massive URLLC (mURLLC), human-centric services, Bio-Internet of things (B-IoT), nano-Internet of things (N-IoT), and mobile broadband reliable, low-latency communication, which require bandwidth not available even in the current millimeter wave spectrum, are considered be a critical driver towards the new era of the wireless networks (6G). In addition, consider XR (i.e., combining mixed reality, augmented reality, and virtual reality) and brain-computer interaction that requires 5G-eMBB high data rates, low-latency, and high reliability [2]. Novel 6G potential emerging applications are provided below:

3.2.1 Human-Centric Services

Although 5G offers numerous advantages, there is a need to propose services that are more human-centric. 6G is expected to widely support the human-centric communication concept, where the human can access and/or share physical features. The human-bond communication concept is proposed to allow access to the five human senses. It is foreseen that there will be an increasing number of new communication devices in the 2030s. These new communication devices can be wearable devices, integrated headsets, and implantable sensors [35]. Recently, the concept has been expanded with the help of a 'communication through breath' scheme to allow reading the human bio-profile using exhaled breath, and even interaction with the human body by inhalation using volatile organic compounds [36]. As a result, it is possible to diagnose diseases, detect emotions, collect biological features and interact with the human body remotely. Developing communication systems that can replicate the human senses and human biological features requires interdisciplinary research. Such systems are expected to have hybrid communication technologies that are able to sense different physical quantities and then share them with the intended receiver in a secure manner. However, there must be strict constraints on transmit power and frequency band used in these devices for health reasons. The device weight will become more sensitive when designing wearable devices and integrated headsets. Reliable power supply and security for implementable sensors are of high importance. In addition, there should be major dissimilitude in mathematical modeling between these emerging communication devices and classic mobile phones and tablets.

3.2.2 Holographic Communications

This use case is based on a remote connection with an ultrahigh accuracy [7]. In fact, transmitting three-dimensional images along with voice is not sufficient to convey the in-person presence. There is a need to have a three-dimensional video with stereo audio that can be reconfigured easily to capture several physical presences in the same area. In other words, one can interact with the received holographic data and modify the received video as needed. All this information needs to be captured and transmitted over reliable communication networks that should have an extremely large bandwidth [28]. Holographic communication will be based on multiple-view camera image communication that requires substantially higher data rates (Tbps) [37].

3.2.3 Haptics Communications

After using holographic communication to transfer a virtual vision of close-to-real sights of people, events, environments and so on, it is beneficial to remotely exchange the physical interaction through the tactile internet in real time [8]. Haptic communication, a form of non-verbal communication, deals with enabling sense of touch from a remote place [38]. Specifically, the expected services include teleoperation, cooperative automated driving and interpersonal communication, where it should be possible to apply haptic control through communication networks. However, enabling this type of real-time interactive experience using 6G requires substantial design efforts. Efficient cross-layer communication-system design has to be conducted to meet the stringent requirements of these applications. For example, new physical layer schemes need to be developed, such as to improve the design of signalling systems, waveform multiplexing and so on. As for the delay, all delay sources should be treated carefully, including buffering, queuing, scheduling, handover and the delays induced from protocols. Existing wireless communication systems cannot fulfill these requirements, and there is a necessity for over-the-air fibre communication systems [39].

3.2.4 Unmanned Mobility and Smart Applications

With the This use case deals with fully autonomous connected vehicles that offer complete unmanned mobility, safe driving, smart infotainment, and enhanced traffic management [40]. In addition, it is expected a massive number (more than $10^6/km^2$) of nodes for cyber-physical system-enabled smart factories and smart grids in the future [41]. Accordingly, a trade-off between reliability, scalability, and latency are required. Thus, must scale the classical 5G URLLC to a massive URLLC (mURLLC) to meet the requirements of these new applications [42]. mURLLC denotes IoE applications and will be based on merging massive machine-type communication and 5G URLLC [43].

4 Research Areas and Open Issues

Tab. 2 summaries briefly the potential research areas, challenges, and open issues of 6G wireless networks.

Table 2: Potential research areas, challenges, and open issues of 6G wireless networks

Research areas	Challenges and open Issues
Radio frequency (RF) link integration	✓ Design of RF hardware. ✓ System-level analysis of RF systems. ✓ Use of RF systems for various 6G services.
AI	✓ Reinforcement learning for SON. ✓ Big and small data analytics. ✓ AI-powered network management. ✓ Edge AI over wireless systems.
3D networking	✓ 3D propagation modelling. ✓ 3D performance metrics. ✓ 3D mobility management and network optimization. ✓ 3D performance analysis of rate-reliability-latency region.
Holographic radio	✓ Design of holographic MIMO. ✓ Performance analysis of holographic RF. ✓ Network optimization with holographic radio.

(Continued)

Table 2: Continued

Research areas	Challenges and open Issues
Reliability-latency	✓ Characterization of energy and spectrum needs for rate-reliability-latency targets.
6G protocol designs	✓ Design of scheduling, coordination, and signalling protocols that do not require pre-determined, rigid frame structures. ✓ Development of adaptive multiple access protocols. ✓ Design of proactive and dynamic handover mechanisms that can cope with different mobility patterns in 3D space. ✓ Introduction of new authentication and identification protocols tailored to 6G devices. ✓ Design of distributed, edge AI-inspired protocols for executing multiple 6G functions.

5 Conclusion

This article discussed the substantial issues of the evolution of wireless communication networks. We first reviewed the major successes and challenges of 1G through 5G. We did this by discussing, for each generation, aspects of regulation, services, innovations, and other issues. The major milestones of 6G wireless networks including key performance indicators, potential emerging applications, and potential research areas have discussed. Looking at 6G, key proposed innovations we foresee are optical free-space indoor communications, wireless charging, and energy harvesting, and extensive use of machine learning to facilitate innovative services.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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