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Evolution of wireless communication networks: from 1G to 6G and future perspective

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ABSTRACT

Since about 1980, a new generation has appeared approximately every decade. Mobile phones started with first-generation (1G), then the successful second generation (2G), and then mixed successful auctions since the launch of 3G. According to business terms, 1G and 2G were providing voice and gradually include data (3G is unsuccessful, 4G is very successful). Today, we are seeing a stir over what 5G will provide. Key expectations currently being discussed include an ultra-high 20 Gb/s bit rate, an ultra-low latency of just 1 millisecond, and a very high capacity. Given the enormous potential of 5G communication networks and their expected evolution, what should 6G include that is not part of 5G or its long-term evolution? 6G communication networks should deliver improved range and data speeds, as well as the ability to connect users from anywhere. This article details possible 6G communication networks. More specifically, the primary influence of this research is to deliver a complete synopsis of the development of wireless communication networks from 1G to 6G.

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1. INTRODUCTION

One of the most successful technology advancements in contemporary history has always been mobile communication. To date, five wireless communication networks have been adopted. Since about 1980, a new generation has appeared about every decade. Mobile devices started with a monopoly (1G), followed by a successful attractiveness spectacle (2G), followed by the success of 3G. Regarding services, 1G and 2G delivered voice service only and gradually contain data which increased gradually (unsuccessful on 3G, successful on 4G). Cellular networks have advanced dramatically in the last five years, enabling data-driven applications such as multimedia, multiplayer services, and high-definition streaming media. Consequently, the number of mobile users' number, besides the amount of data traffic, has skyrocketed [1]. The number of smartphone subscribers reached 7.75 billion in January 2020, with each subscriber requesting an average of 10 GB of data per year. Data traffic will climb to 82 GB per user per year, accounting for over half of worldwide mobile data traffic, due to record requests for streaming video data. Moreover, the rise of the internet of things (IoT) concept will cause a massive increase in network traffic. This extraordinary surge in traffic causes a noteworthy expansion of wireless network capability. These issues are important motivators for the development of 5G mobile wireless networks.

The International Telecommunication Union (ITU) defines the vision and standards; 5G ought to meet three common scenarios and eight key performance indicators (KPI) [2]. Millions of connections/kilometer square (1 M/km^2) huge machine challenge technology in three scenarios enhanced mobile broadband (eMBB) Gb/s data rate, ultra-reliable low-latency communication (URLLC) milliseconds (ms) air interface delay, massive machine challenge technology in three scenarios Indicator type communication (mMTC). Many enabling technologies have been developed, considered in standardization, and implemented in technical trials in order to achieve these KPIs [3]. Massive multiple input multiple output (MIMO), sophisticated coding and modulation, millimeter-wave communications, ultra-dense networks (UDN), non-orthogonal multiple access, flexible frame structure, dual connectivity architecture, and other wireless technologies are only a few examples [4], [5]. However, the exponential growth of data traffic is because of the substantial growth in the number of connected devices, which can grow to hundreds of devices /m^3; Aside from the growing number of innovative applications, like virtual reality/augmented reality (VR/AR), self-driving cars, integrated 3D communications, and new applications that have not yet been conceived [4], [6] will require data to provide higher and lower latency than 5G networks. These problems are regarded as the primary motivators for the development of 6G communication technologies; they are expected to be deployed in 2030 [7], [8].

Depending on the revelation and expansion of 5G, 6G will be improved and extended further to accomplish up to 100 times the throughput, higher system capacity, greater spectrum efficiency, lower latency, and coverage that is both wider and deeper to support the increased speed of movement. Serving the internet of things and completely supporting the smart life expansion and industrial ubiquitous smart mobile society. The following paragraphs will provide a detailed description of the expected requirements related to the vision.

This article aims to discuss the substantive issues of the evolution of wireless communication networks and to cover the latest developments in the industry in the context of the main application areas and challenges. For this reason, this research attempts to merge as many addresses as possible. Due to space limitations, this article investigates disputed research subjects in depth based on their various sub-fields in order to obtain proper, precise, and succinct recommendations. For researchers, this article will support the exploration of the realization of 6G networks by providing some new reference materials, thereby opening up new possibilities for future research avenues.

The remaining of this article is structured in the following manner: section 2 looks at the evolution of wireless communication networks from 1G to 5G. Section 3 looks at the prospects for 6G wireless communication networks. Section 4 summarizes the work.

2. WIRELESS NETWORKS EVOLUTION: 1G TO 6G

Starting from 1980, every 10 years a new wireless communication network generation appears [9], [10] to date they are 5 generations. Figure 1 reviews the main signposts of the five generations (1G to 5G) wireless communication networks. Moreover, here's a quick rundown of how wireless technologies are growing.

2.1. First-generation mobile communication 1G

In the 1970s, 1G mobile communications were declared. North America's advanced mobile phone system (AMPS), Scandinavia's Nordic mobile telephone (NMT), the United Kingdom's total access communications system (TACS), and Japan's total access communications system (JTACS) are the principal users. 1G technology is a simple analog system with data speeds of up to 2.4 kbps optimized for voice conversations. It has a 30 kHz bandwidth and uses frequency modulation (FM) and frequency division multiple access (FDMA) communication technologies (BW). But 1G has many shortcomings, such as i) due to the use of analog modulation, no encryption, poor quality, and security; ii) limited users because of the use of FDMA technology; iii) insecure base station power radiation, lack of transfer procedures; iv) supports voice services only; and v) divergent systems because of inadequate of consistent international standards [11]–[13].

2.2. Second-generation mobile communication (2G)

The global mobile communications (GSM), which was introduced in the 1990s, was the first second-generation system. GSM is a straightforward digital cellular system that uses Gaussian minimum frequency shift keying (GMSK) modulation, time division multiple access (TDMA) transmission technology, with bandwidth=200 kHz for voice communications. The characteristics of this generation are i) formulated a unified international mobile communication standard, promoted the development of global mobile communication technology; ii) improved services; iii) improved network security through encrypted numbers; and iv) improved the capacity of the system; and v) the mobile phone battery life is longer because the radio signal uses less power. However, the lower data rate of GSM has prompted improvements in cellular systems that use general packet radio service (GPRS) technology [11]–[13].

GPRS is classified as 2.5G. It employs GSM's packet switching and circuit switching technologies. Its data rate can be raised by up to 50 kbps, and it uses transmission and modulation that is similar to GSM. Fundamentally, GPRS is the first phase on the way to the GSM environment that supports enhanced data (EDGE). EDGE is a radio technology that predates 3G. Users can transmit and receive data at a rate of up to 200 kbps. The EDGE technology is based on the previous GSM standard, and it employs an identical transmission mechanism and BW as GSM, but it employs eight phase-shift keying (8PSK) and GMSK modulation instead of GSM. 8PSK has a higher data rate but a narrower coverage area, whereas GMSK is a reliable model for wide coverage. It was developed to enhance packet switching services and to enable future applications for high-speed data like multimedia [12], [13].

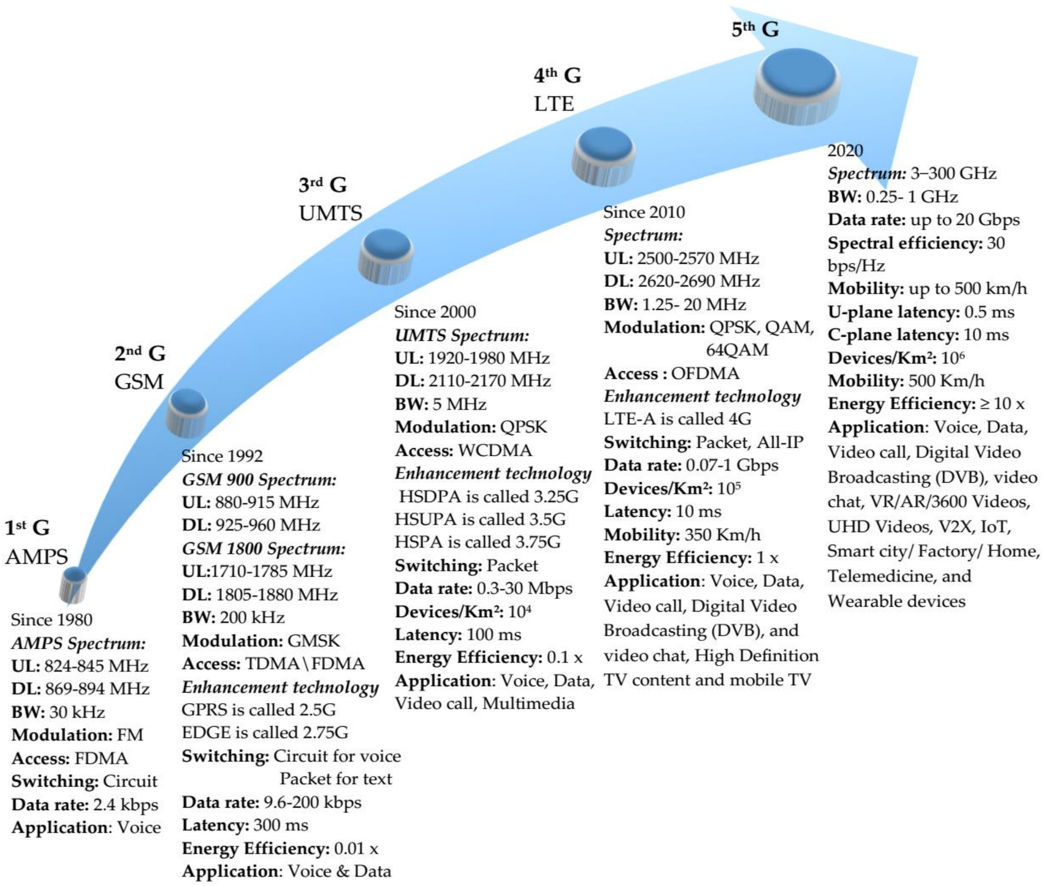

Figure 1. Leading communication achievements for several generations (1G to 5G)

2.3. Third-generation mobile communication (3G)

The 3G system employs wideband code division multiple access (WCDMA) and high-speed packet access (HSPA) technology to deliver fast Internet access, as well as significantly improved video and audio transmission capabilities. HSPA combines two mobile phone protocols, high-speed downlink packet access (HSDPA) and high-speed uplink packet access (HSUPA), to enhance and improve the 3G mobile telephony networks performance using the WCDMA protocol. Developed HSPA (commonly known as HSPA+) is an upgraded 3rd generation partnership project (3GPP) standard that was launched at the end of 2008 and was used internationally in 2010. 3.9G long term evolution (LTE), on the other hand, contains characteristics that go beyond those found in ordinary 3G mobile communications [12], [13]. However, the ITU and the 3GPP eventually concluded that the LTE can be called the 4G technology [14].

2.4. Fourth generation mobile communication (4G)

LTE is a wireless access technology based on orthogonal frequency division multiplexing (OFDM), which allows for sophisticated multi-antenna transmission as well as expandable transmission bandwidths of up to 20 MHz. MIMO is a critical system technology that allows for higher data rates and multi-stream transmission to achieve great spectral efficiency, improve connection quality, and alter radiation patterns for signal gain and mitigation. The antenna's adaptive beamforming is used to create the interference array. The LTE technology boosts data speeds through mobile to 100 megabits per second (Mbps). The wireless technology roadmap has been extended to LTE advanced (LTEA) [14], which can theoretically reach a peak throughput rate of more than 1 gigabit per second, in response to the tremendous increase in demand for mobile broadband communication capacity year after year (Gbps).

By delivering a comprehensive and consistent solution based on the Internet protocol IP, the 4G system improves the current communication network. The wireless community has investigated three primary research topics in-depth to satisfy 4G mobile network capabilities:

– Densification of the network: This technology is used in situations where there are a lot of people, such as stadiums, concerts, public places, and retail malls. By deploying compact, low-power, and low-cost cells, this technique intends to shorten the distance between mobile terminals and base stations (BS), hence increasing spectrum reuse and boosting network coverage. Due to the use of low-loss routing, the small base station has a coverage radius of 50-150 m and transmits at low power (0.110 W), which improves energy efficiency and signal interference plus noise ratio (SINR). Furthermore, operators are working to make small base stations plug-and-play, meaning they can configure all the essential parameters themselves and don't need to be maintained regularly [15], [16].
– Improved spectral efficiency: Coordinated transmit/receive methods and solutions to reduce inter-cell interference use modern signal processing and spatial diversity to reduce co-channel interference and improve spectrum efficiency [17], [18].
– Carrier aggregation is used in LTEA to syndicate separate component carriers, which can be of diverse sizes and are in a non-contiguous spectrum, to facilitate bandwidth increase (up to 100 MHz). Although the combined execution of these technologies can theoretically provide fixed customers with data rates exceeding 1 Gbps, further expansion is limited because of the limited number of frequencies accessible [14], [19].

2.5. Fifth-generation mobile communication (5G)

The 5G communication standardization process is now complete, and it is being implemented on a global basis [20]. The ITU defines the vision and specifications; 5G should meet eight KPI and three common scenarios [21]. Millions of connections/square kilometer (1 M/km^2) massive machine challenge technology in three scenarios eMBB Gb/s data rate, URLLC milliseconds (ms) air interface delay, and massive machine challenge technology in three scenarios Indicator type communication (mMTC). Many enabling technologies have been developed, considered in standardization, and implemented in technical trials in order to achieve these KPIs [2]. Dual connectivity architecture, massive MIMO, UDN, sophisticated coding and modulation, millimeter-wave communications, flexible frame structure, non-orthogonal multiple access, and other wireless technologies are only a few examples [4]. As shown in Figure 2, the main backbone in the 5G network includes several elements widely fitted all over the network, like multi-access edge computing (MEC) data center, next generation core (NGC), and active antenna system (AAS) (with 5G NR support) Source antenna system) [22].

The organization employed for the 5G AAS, that is, the radio access network (RAN) Fronthaul network of mobile networks, requires the common use of multiple technologies, such as the next generation passive optical network (NGPON), lengthy division of thick wave multiplexing (CWDM), dense wavelength division multiplexing (DWDM), and enhanced common public radio interface (eCPRI). All of these techniques necessitate a fiber optic infrastructure that is compatible. Because 5G mobile networks require a lot of bandwidth and speed [23], the infrastructure needs fiber optic cable to be installed to the antenna. As a result, in addition to boosting the capacity of the backbone fibers [24], it is also required to deploy the 5G mobile network as close to the fiber infrastructure antennas as feasible, as well as to install new fiber optic cable infrastructure for extra antennas when capacity is insufficient.

However, due to the substantial growth in the number of associated things, the data traffic has increased exponentially, which can grow to hundreds (s) of devices per m^3; in addition to the rapid increase in new applications, like virtual reality/augmented reality (VR/AR), self-driving cars, integrated three dimensional communications, and new applications that have yet to be imagined [6], they will still need data rates. Will provide higher and lower latency than 5G networks. These challenges are thought to be the key driving factors for the realization of 6G communication systems. Given the huge potential of 5G networks and their foreseeable evolution, what features of 6G should be included that are not present in 5G? Research, Academia, and industry have worked on describing and determining the main qualifying technologies that can define 6G; it is expected to be deployed by 2030 [7].

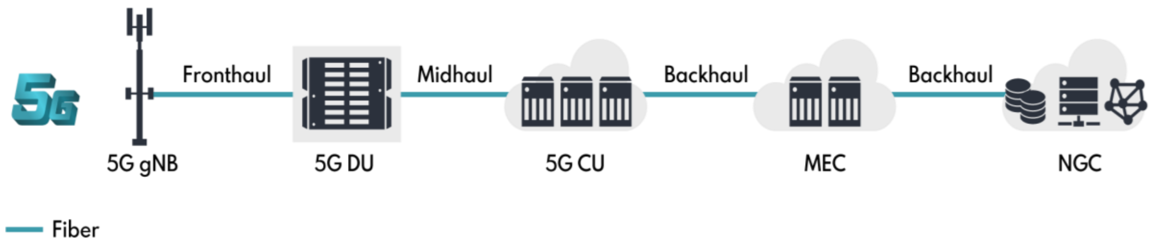

Figure 2. 5G-infrastructure-fronthault-midhaul-backhaul

3. FUTURE PERSPECTIVE OF 6G WIRELESS COMMUNICATION NETWORKS

6G will be updated and enlarged based on the visualization and expansion of 5G to reach up to 100 times the data throughput, higher system capacity, reduced latency, higher spectrum efficiency, and wider and deeper coverage. To enable faster movement, to serve the internet of everything (IoE), and to completely promote the evolution of intelligent life and the industrial omnipresent intelligent mobile society. Figure 3 summarizes the top 6G wireless network milestones in terms of technology, applications, and KPIs.

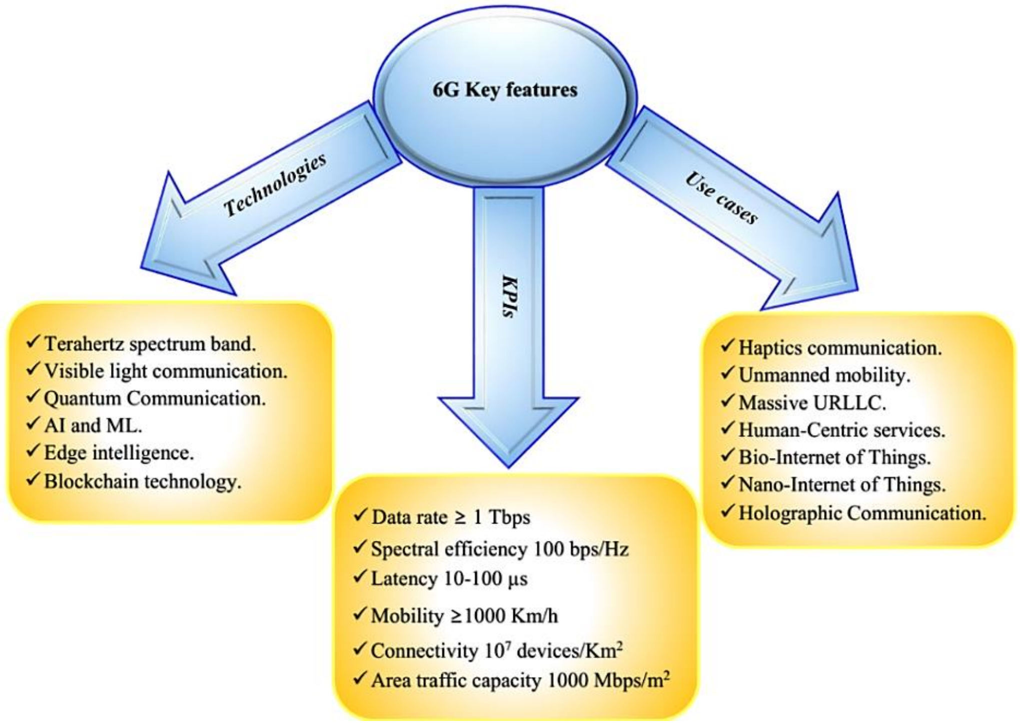

Figure 3 Major milestones of 6G wireless networks in terms of technologies, KPIs, and applications

The following paragraphs describe in detail the foreseeable requirements related to vision:

- 6G should be a comprehensive network with broader and wider coverage, including terrestrial, satellite, and short-distance device-to-device communication. Thanks to sophisticated mobile management technologies, 6G can service a wide range of situations, including airspace, land, and sea, resulting in the world's first ubiquitous mobile broadband communication system [25].
- In order to attain a broader bandwidth, 6G is planned to operate at higher frequencies, such as millimeter-wave, terahertz [26], and visible light. In comparison to 5G, data rates can be enhanced in 6G by up to one hundred times, allowing for the greatest data rate of Tb/s and a user experience data rate of 10 Gb/s. Furthermore, 6G can take advantage of flexible frequency sharing technologies to boost frequency reuse efficiency even more [27].
- 6G is a smart grid that may be customized. When combined with artificial intelligence technology, 6G will enable the virtualization of mobile communication [28], the network will transfer from a classic

centralized network type to a new type 3 centralized network, which is user-centric, data-centric, and entirely centralized content.

- An endogenous security solution or an integrated functional security design will be used in the 6G network. 6G has self-perception capabilities, real-time dynamic analysis capabilities, risk adaptation capabilities, and confidence assessment capabilities. You will help achieve cyberspace security by introducing trust and security mechanisms.
- Computing, navigation, and detection are all combined in 6G. 6G will, for example, comprise satellite communication systems as well as positioning systems and satellite navigation, as well as radar detection systems. more open architecture will be used in 6G, with a core network using software-defined algorithms, and a wireless access network; it will be able to achieve rapid autonomous intelligent development as well as rapid and dynamic deployment of network capabilities.
- The internet of things can generate vast volumes of data, and 6G can be integrated with new technologies like edge computing, cloud computing, artificial intelligence, and blockchain [29]. 6G has the ability to actualize multiple intelligences as well as group intelligence. 6G may finally support the ubiquitous smart mobile society.

Table 1 summarize the technologies, features, and challenges of 6G wireless networks. 6G communication accesses various forms of data through unconventional communication networks and sends it over traditional and upgraded radio frequency networks, resulting in a new communication experience of virtual presence and involvement at any time and from any location. Holographic calls, flying nets, remote control driving, and tactile Internet are among the future communication scenarios predicted for 2030 [6], [25]. Furthermore, future wireless communications are expected to deliver the same level of reliability as traditional communications. However, terahertz (THz) communications [30], artificial intelligence (AI), and reconfigurable smart surfaces offer the most promise of all the technical efforts connected to 6G [31].

Table 1. 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. – Restricted coverage, need for radio frequency (RF) uplink. – Path loss model.
Intelligence	– Learning for the value of informal assessment. – User-centric network architecture.	– Autonomous selection and intelligent information transmission. – Intelligent distribution to network endpoints.	– Complexity, unsupervised learning. – Real-time and energy-efficient processing.
PHY	– Full-duplex Out-of-band channel estimation sensing and localization	– Continuous relaying and transmitter (TX)/received (RX). – Flexible multi-spectrum communications. – Innovative services and context-based control.	– Management of interference and scheduling. – Reliable frequency mapping is needed. – Efficient communication and location multiplexing.
Network architectures	– Cell-less architecture and multi-connectivity. – 3D architecture for the network. – Virtualization. – Advanced access-backhaul integration. – Energy-harvesting and low-power operations.	– Smooth movement and integration of different types of links. – Omnipresent 3D coverage, unified service. – Economy costs for operators for tremendously dense deployments. – Flexible deployment options, outdoor-to-indoor relaying. – Energy-saving grid operation, flexibility.	– Scheduling, need for new network design. – Energy efficiency, modelling, and topology optimization. – High performance for medium access control (MAC) processing and physical (PHY). – Scalability, interference, and scheduling. – The characteristics of the power supply need to be integrated into the protocol.

4. CONCLUSION

We analyzed the major triumphs and difficulties from 1G to 5G in this article. This is accomplished by discussing all areas of legislation, services, innovation, and other themes relevant to each generation. In terms of innovation, analog systems (1G) gave way to fully digital systems based on TDMA (2G), followed by code division multiple access (CDMA) (3G), and finally, the successful 4G and wireless local area network (WLAN) that employed OFDM. Today, there is a lot of buzzes about what 5G will bring. When it comes to 6G, we see optical communication in open spaces, energy harvesting, wireless charging, and machine learning to promote novel services as the primary innovative offerings.

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