Exploring the Future of Communication Technology :6G Development, Applications, and Related Technologies

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Abstract. The rapid evolution of communications technology has brought us from 5G to the cusp of 6G, heralding a future of enhanced connectivity and efficiency. This article explores the evolution of communication technologies, focusing on the contrast between 5G and 6G technologies and the unique characteristics of 6G communications. It begins with an overview of the evolution of communications technology, highlighting key mile-stones and advances that have shaped the current landscape. The comparison of 5G and 6G technologies will be discussed, as well as the unique features and benefits of 6G communication. While, the application of 6G communication is deeply discussed, and how this advanced technology is applied in various fields is explored. Industrial automation, telemedicine operations, and smart city projects are just a few examples of how 6G communications can revolutionize industries and improve efficiency. Fi-nally, the technologies and challenges associated with the implementation of 6G communications has be studied to provide a comprehensive under-standing of the complexities involved in deploying 6G communications networks. By exploring the evolution, applications, and challenges of 6G communications, we can better understand the future of communications technology.

Keywords: Communication technology evolution, 5G vs. 6G, 6G unique characteristics, application areas, technical challenges

1 Introduction

The rapid development of mobile communication networks over the past few decades has seen advancements from 1G to 5G. However, by 2030, it is anticipated that 5G will reach its limits, necessitating the introduction of new paradigms to address the challenges faced by previous generations of mobile networks. This has led to the advancement of sixth-generation (6G) mobile network technologies. which will set new standards in meeting the performance requirements that 5G networks are unable to fulfill. With the increasing demand for smarter networks, ultra-low latency, and extreme network communication speeds, 6G technology will support a wide range of connected applications.

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This paper will explore the evolution of communication technologies, focusing on the contrast of fifth-generation and sixth-generation technologies and the unique characteristics of 6G communication [1]. The second section of the paper will provide an overview of the evolution of communication technologies, highlighting key milestones and advancements that have shaped the current landscape. The contrast of 5G and 6G technologies will be discussed, along with the distinctive features and benefits of 6G communication. The third section will delve into the applications of 6G communication, exploring how this advanced technology can be utilized in various sectors. Industrial automation, remote medical operations, and smart city initiatives are just a few examples of how 6G communication can revolutionize industries and improve efficiency. The final section will examine the relative technologies and challenges associated with implementing 6G communication. IRS technology and its challenges, as well as OWC technology and its challenges, will be discussed in detail to provide a comprehensive understanding of the complexities involved in deploying 6G communication networks.

Overall, this paper aims to shed light on the potential of 6G communication technology and the impact it could have on various sectors. By exploring the evolution, applications, and challenges of 6G communication, we can better understand the future of communication technology and its role in shaping a more connected world.

2 Advancements in Mobile Communication Technologies

2.1 Evolution of Communication Technologies

Nippon Telegraph & Telephone, or NTT, debuted the first generation of mobile networks, or 1G, in Tokyo in 1979. It was limited to analog speech transmission at first. The Dynamic Adaptive Total Area Coverage of 8000X telephone, which was demonstrated by Motorola's Martin Cooper, was the world's first cellular device. It was approved for commercial use by the U.S. Federal Communications Commission in 1983.This led to the development of AMPS, or the Advanced Mobile Phone System, which became the dominant technology throughout the 1980s until the arrival of the second generation, 2G [2].

In 1991, Finland launched 2G wireless telephone service based on Global Mobile Communications System (GMS) specifications. This marked a significant advancement in mobile technology, as digital signaling replaced analog and allowed for encrypted calls. Additionally, users could now send and receive text messages and multimedia content, such as pictures and videos, through SMS and MMS. These technological advancements set 2G apart from its predecessor, with improved voice quality, data encryption, and the introduction of text and multimedia messaging [2].

The third generation of mobile communications, 3G, began in the early 2000s and marked a shift towards higher data rates and expanded frequency spectrums. With data rates surpassing 2 Mb/s, 3G offered increased voice and data capacity, as well as enhanced transmission security through encryption [1]. Unlike 2G, which still used analog voice signals, 3G digitized both voice and data transmissions, paving the way for faster and more efficient communication [2].

4G, the fourth generation of wireless communications, introduced a significant leap forward in technology, requiring new devices to fully utilize its capabilities [1]. Devices like Apple's iPhone played a crucial role in driving the growth of 4G technology, which was first introduced in 2009 as Long-Term Evolution (LTE) in Sweden and Norway. This marked another milestone in the evolution of wireless communications, with faster data rates and improved network capabilities [2].

The next stage of wireless technology was introduced with the launch of the first 5G network in South Korea in April 2019 [1]. With projections indicating that by 2025, 5G internet might be available to up to 65% of the global population, efforts to create and deploy 5G networks and technologies are continuing. As standards evolve and technologies advance, the development of 5G is expected to continue well into the 2020s [2]. The timeline of the evolution of communication technology is shown in figure 1.

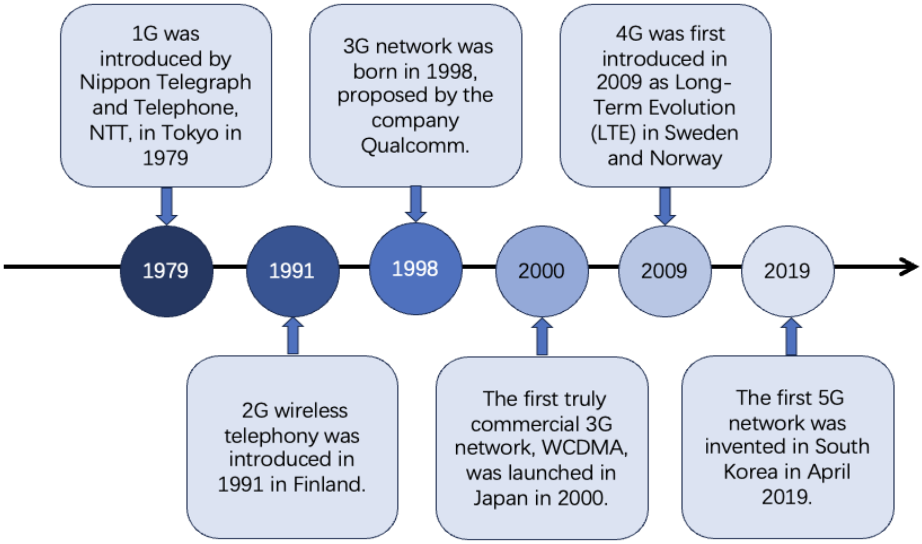

Fig. 1. Timeline of the evolution of communication technology (Photo/Picture credit: Original)

2.2 The Contrast of 5G and 6G Technologies and Characteristics of 6G Communication

The widespread availability of 5G is expected to set the stage for the development of 6G, which aims to provide global coverage. The key factors that differentiate 6G from its predecessors are the integration of AI applications and the establishment of an autonomous network that will serve as the foundation for 6G technology. Data rates, security quality, and latency are all anticipated to improve significantly in 6G compared to 5G [1]. With a projected speed of 1–10 Tbps and a higher frequency than any previous generation, 6G is expected to offer high transmission rates using THz frequencies. It is anticipated that latency will be in the range of 10μs-100μs, connectivity density will be ten millon devices/km2 [3]. In addition, 6G is anticipated to enhance coverage percentage, reliability, positioning accuracy, and receiver sensitivity, as well as significantly increase spectrum and energy efficiency when compared to 5G [3]. Communications, Global Position System, imaging, and navigation can all be supported by this next-generation communication network, which provides unlimited wireless connectivity [1]. Table 1 shows the difference between 6G and the previous two generations of communication technology. The contrast of 4G, 5G and 6G is shown in table 1.

Table 1. The contrast of 4G, 5G and 6G

Key Performance Indicators	**4G**	**5G**	**6G**
Maximum data rate /device	1 Gbps	10 Gbps	1 Tbps
latency	100 ms	1 ms	0.1 ms
Max. spectral efficiency	15 bps/Hz	30 bps/Hz	100 bps/Hz
Energy efficiency	< 1000x relative to 5G	1000x relative to 4G	>10x relative to 5G
Connection density	2000 devices / km2	1millon devices /km2	>10millon devices/km2
Coverage percent	< 70 %	80 %	>99 %
Positioning precision	Meters precision (50 m)	Meters precision (20 m)	Centimeter precision
End-to-end reliability	99.9 %	99.999 %	99.9999 %
Receiver sensitivity	Around −100dBm	Around −120dBm	< −130dBm
Mobility support	350 km/h	500 km/h	≥1000 km/h
Satellite integration	No	No	Fully
AI	No	Partial	Fully
Autonomous vehicle	No	Partial	Fully
Extended Reality	No	Partial	Fully
Haptic Communication	No	Partial	Fully
THz communication	No	limited	Widely
Service level	Video	VR, AR	Tactile
Architecture	MIMO	Massive MIMO	Intelligent surface
Max. frequency	6 GHz	90 GHz	10 THz

3 Applications of 6G Communication

Numerous essential elements are offered by 6G mobile technology, such as high bandwidth, very dependable communication links, faster data transfer rates, reduced latency, and an atmosphere that is ideal for AI applications. These factors form a platform for many new application areas that can replace the former 5G mobile technology, making it a more suitable choice for future use cases [1].

3.1 Industrial automation

Recently, with the arrival of Industry 4.0, the concept of industrial automation has gradually received attention [4]. Every sector of society is focused on maximizing the automation of manufacturing processes, and while the services provided by each sector may vary, the ultimate goal of each sector is to eliminate the human element in production and thus mitigate potential risks [2, 4]. However, the process of achieving full automation emphasizes the importance of low latency to prevent system outages and ensure seamless operation of numerous devices, and only 6G mobile technology can provide the ability to respond quickly to every module within the system [1]. At the same time, AI-driven 6G technology is capable of improving energy efficiency, simplifying wireless channel modeling, optimizing transmission power, and lengthening battery service time of Internet of Things devices [4]. It is necessary to facilitate and investigate the implementation of smart and accommodative 6G robotization systems to decrease computational complexity and human involvement, in order to unify industrial automation [5].

3.2 Remote medical operations

The current healthcare system's weaknesses have been brought to light by the COVID-19 pandemic. The increase in COVID-19 patients has resulted in insufficient medical services due to the shortage of medical staff. While transportation is a crucial aspect of the healthcare system, it is evident that current technology is unable to fully meet the demands [1]. Many patients unfortunately pass away before reaching the hospital due to delays in ambulance arrival [6]. Telemedicine, specifically tele-surgery, presents a targeted solution to address healthcare and transportation challenges without the need for physical presence. However, real-time communication is essential for remote surgery, which is currently not achievable with 5G technology. The 6G mobile technology, which has data rates that exceed 1 Tbps, utilizes terahertz signals for data transmission, offers the potential to enable telemedicine effectively by providing high data rates and stable communication connections [1].

3.3 Smart City

The concept of smart cities was initially introduced in 1994, but has gained increased significance following the COVID-19 pandemic. The pandemic has necessitated the transition of many activities to digital platforms in an effort to stop the virus from spreading, underscoring the importance of smart city initiatives. Enhancing city intelligence may involve implementing cashless systems in traffic management, recognition systems in finance, as well as integrating self-driving cars, sensors, and cameras. However, these advancements require faster connectivity speeds, which can be facilitated by 6G [1].

6G is projected to provide significantly faster connectivity compared to 5G, where current users experience speeds ranging from 1-10gbps [3]. While 5G technology supports communication advancements like the Internet of Things, 6G is poised to unlock additional possibilities for leveraging artificial intelligence (AI) technology. The Internet of Things' customer service capabilities are predicted to be revolutionized by the combination of 6G and AI, providing seamless access to personal and environmental data related to weather, food quality, and urban air pollution. This integration will not only expand the range of interactions between devices and individuals, but also facilitate more cost-effective and rapid access to personal and environmental data [1]. Given the current circumstances brought about by the pandemic, the imperative to transform our cities into smarter hubs that can efficiently leverage personal and environmental data has never been more pressing [7].

4 Relative Technology and Challenges

4.1 IRS technology and challenges

Intelligent Reflective surfaces (IRS) is a key technology development direction. Reconfigurable Smart Surfaces (RIS) have developed as an energy conservative and high efficiency technology to serve the requirements expected for years to come, with the ability to enable a smart radio environment [8]. A phase shift in the impact signal is introduced by RIS by utilizing a large number of cheap passive reflective elements, which creates a good transmission path between the transmitter and receiver [8]. IRS is employed because the wireless channel is the least monitored component of a network [9]; Therefore, in 6G system, by addressing the channel part, finding a way to accelerate the overall performance of the wireless system is the better option [9]. Intelligent Reflecting Surfaces (IRSs) can be seen as simple signal-scattering devices placed amidst the nodes involved in network communication. They can also be embedded within walls to form intelligent indoor radio environments, which are capable of frequency-selective signal transmission and energy absorption, as well as passive beamforming that augments wireless power transfer efficiency [10, 11].

Despite these advantages, the deployment of IRSs presents certain challenges, including precise estimating channels to mitigate interference and align with the line-of-sight (LoS) for peak system performance. Additionally, the coordination of numerous IRSs, especially within diverse and rapidly changing networks such as those in smart factories and vehicular-to-vehicle (V2V)/vehicle-to-everything (V2X) communications, demands thorough inquiry [9]. This issue also make preparations for research into the optimal disposition of IRSs in various situations within the realms of 5G and future 6G networks.

4.2 OWC technology and challenges

Unprecedented advancements in fast data rates, low latencies, and high reliability are expected to support various services of 6G in the future. Optical wireless communication (OWC) is anticipated to play a crucial role in 6G networks, offering exceptionally high data rates in short indoor ranges thanks to the abundance of unlicensed spectrum [9]. Compared to traditional communication, OWC provides advantages like zero electromagnetic interference and a high frequency-reuse factor, achieved by confining light within enclosed spaces [12]. Moving beyond millimeter waves to smaller wavelengths in the terahertz-frequency range is predicted to unlock data rates surpassing 1 Tbps, as discussed earlier. However, because transmitted signals have shorter wavelengths, there may be obstacles to this development, most notably increasing air absorption at higher frequencies [9].

Concerns arise regarding wireless channel modeling for tasks like synchronization and channel estimation, particularly in unstable atmospheric conditions [13]. Extreme link reliability, a critical requirement for 6G, may limit OWC usage to indoor settings, as outdoor environments and dynamic scenarios pose vulnerabilities. Furthermore, employing ultra-high frequencies and massive MIMO arrays complicates beam management tasks important for network operations, such as the transition of mobile users. To handle massive volumes of data from end devices, ultrahigh data rates at the network require transceiver designs that may operate at frequencies as high as several terahertz [14].

5 Conclusion

In conclusion, 6G communication, the next generation of communication technology, has numerous advantages over its predecessor 5G. With its promises of higher coverage, reduced latency, and faster speeds, it is ideally suited for usage in a variety of applications, including as smart cities, remote medical operations, and industrial automation. Furthermore, 6G communication is expected to integrate with other emerging technologies such as IRS and OWC to further enhance its capabilities and address current and future challenges.

But even with these encouraging possibilities, a number of issues still need to be resolved before 6G communication can be completely adopted and widely used. These include ensuring reliable and secure communication in challenging environments, optimizing network planning and management to maximize efficiency, and developing cost-effective solutions that are appropriate for a wide range of applications.

Efforts to address these challenges and explore new opportunities offered by 6G communication will be the focus of research and development efforts in the future. This will lead to further progress in the field of communication technology and ensure that 6G becomes a key enabler for a range of industries and applications in the coming years.

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