

# Evolution of Wireless Communication: From 5G to 6G

<sup>1</sup>Dr Ravi Gatti, <sup>2</sup>Ranjana Prakash Dahake, <sup>3</sup>Dr. H. E. Khodke, <sup>4</sup>Dr. B. J. Dange, <sup>5</sup>Dr. S. N. Gunjal, <sup>6</sup>Dr. G. Shivakanth  
<sup>7</sup>Dr. Yogesh Pisolkar

<sup>1</sup>Assistant Professor Department of Electronics & Communication Engineering, Dayananda Sagar Academy of Technology and Management, Udayapura, Bangalore – 560082, ravi.ncg@gmail.com,

<sup>2</sup>MET's Institute of Engineering, Nashik, Maharashtra, India, dahakeranjana@gmail.com,

<sup>3</sup>Assistant professor, Computer Engineering Department, Sanjivani College of Engineering Kopergaon (An Autonomous institute), Maharashtra, India, 423603. Affiliated to Savitribai Phule Pune University, Pune. India, hekhodke@gmail.com,

<sup>4</sup>Associate Professor Computer Engineering Department, Sanjivani College of Engineering Kopergaon (An Autonomous institute), Maharashtra, India, 423603. Affiliated to Savitribai Phule Pune University, Pune. India, bapudange@gmail.com,

<sup>5</sup>Computer Engineering Department, Sanjivani College of Engineering Kopergaon (An Autonomous Institute) Affiliated to Savitribai Phule Pune University Pune, Maharashtra, India, gunjalsanjay1982@gmail.com,

<sup>6</sup>Associate Professor Dept. of CSE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, Bharat. shvkantho@gmail.com.

<sup>7</sup>Symbiosis International (Deemed University), Symbiosis Centre for Management Studies, Pune, India, ypisolkar123@outlook.com

## ARTICLE INFO

## ABSTRACT

Received: 01 Oct 2024

Revised: 29 Nov 2024

Accepted: 12 Dec 2024

The evolution of wireless communication from 1G to the forthcoming 6G era marks an extraordinary journey of technological advancement and innovation. This paper offers a comprehensive overview of the imminent 6G revolution, set to redefine the wireless landscape with unparalleled speed, connectivity, and transformative applications. The key drivers behind 6G development, such as the increasing demand for high-speed data, ultra-low latency, and ubiquitous connectivity, are examined. Highlighted potential applications of 6G include immersive augmented reality, smart cities, and advanced healthcare, showcasing its potential to transform numerous aspects of society. In-depth discussions address challenges and opportunities related to spectrum utilization, energy efficiency, security, and privacy. The paper also explores foundational 6G technologies, such as terahertz frequencies and advanced antenna systems, underscoring the necessity for interdisciplinary collaboration among researchers, industry stakeholders, and policymakers. Additionally, it emphasizes the ethical and societal dimensions of 6G, advocating for digital inclusivity and equitable access to ensure the benefits of this technological leap are widely shared, promoting a holistic and responsible approach to its development.

**Keywords:** 6G technology, High-speed data, Ultra-low latency, Ubiquitous connectivity, Potential applications, Augmented reality, Virtual reality

## INTRODUCTION

The landscape of wireless communication has witnessed a staggering transformation through successive generations, from the advent of 1G to the widespread deployment of 5G technology[1]. Each iteration has brought forth remarkable capabilities, shaping the way we connect and communicate in an ever-evolving digital age. Now, as we stand on the precipice of the 6G era, we embark on a journey that promises to be nothing short of revolutionary[2].

The emergence of 6G represents a significant leap forward in the world of wireless technology, setting the stage for unprecedented speed, connectivity, and applications that were once the realm of science fiction. This paper serves as a comprehensive exploration of the exciting prospects and critical research avenues that will define the future of wireless communication[2], [3].

In this introductory section, we set the stage by highlighting the overarching themes and key elements that form the foundation of our examination. We will delve into the driving forces behind the development of 6G, the astounding

array of potential applications it holds, the challenges and opportunities it presents, and the essential technological underpinnings that will pave the way for its realization[4].

The journey to 6G is propelled by an insatiable demand for high-speed data, ultra-low latency, and seamless connectivity. As we immerse ourselves in an increasingly data-driven world, the need for networks that can effortlessly handle vast amounts of information becomes paramount. The relentless pursuit of faster, more reliable, and ubiquitous wireless connectivity has set the stage for the 6G revolution[5].

Beyond meeting our current communication needs, 6G technology opens the door to an astonishing array of applications. From immersive augmented and virtual reality experiences that blur the boundaries between the physical and digital realms to the realization of smart cities where every facet of urban life is optimized through intelligent connectivity. Moreover, 6G paves the way for transformative advancements in fields like telemedicine, remote surgery, and autonomous transportation systems, reshaping the fabric of our societies[6].

As we strive to harness the full potential of 6G, we must confront a host of challenges. These encompass efficient spectrum utilization, energy efficiency, and critical considerations regarding security and privacy. However, these challenges are accompanied by tremendous opportunities, driving innovation in fields as diverse as materials science, signal processing, and network architecture[7].

The realization of 6G hinges on ground breaking technological advancements. We will explore concepts such as terahertz frequency bands, advanced antenna technologies, and the development of intelligent networking infrastructure. These innovations form the bedrock upon which 6G's transformative capabilities are built[8].

The arrival of 6G represents a significant development in wireless technology, paving the door for previously unimaginable speeds, connections, and applications[9]. This article examines in depth the exciting prospects and critical research paths that will influence the future of wireless communication.

## RELATED WORK

(The transition from 1G to 5G was marked by a succession of technological developments that transformed wireless communication. Each generation has introduced new capabilities and use cases, laying the groundwork for the introduction of 6G technology. In this part, we examine essential contributions from prior research as well as significant advances in the area[10].

The evolution of wireless communication is extensively documented, from first-generation analog networks through fifth-generation high-speed data networks.

According to research, each generation has a revolutionary influence on global connectivity, opening the path for data-intensive applications and the Internet of Things (IoT).

While 5G deployment continues, academic and commercial organizations have begun to investigate the emerging idea of 6G. It provides a vision of the future that goes beyond existing constraints[10], [11]. Terahertz frequencies are being investigated for 6G, which are substantially higher than the spectrum used in 5G. The promise for terahertz waves to provide unparalleled data speeds and coverage is enthralling experts all across the world.

5G networks have received extensive study and development, putting them as a cornerstone of modern communications. The use of millimetre-wave frequencies, large Multiple-Input Multiple-Output (MIMO) technology, and network slicing have all contributed to extraordinary achievements. These advancements have enabled increased data speeds, decreased latency to unnoticeable levels, and enabled a wide range of applications ranging from driverless cars and IoT to augmented reality. Recent research has gone into great detail about the deployment and capabilities of 5G networks. Among the notable developments are the utilization of millimetre-wave frequencies, massive MIMO technology, and network slicing to achieve faster data rates, lower latency, and support for a wide range of applications. While 6G is only in its conceptual stages, study into its possibilities has already begun. Terahertz frequencies and sophisticated antenna technology have been discussed by academics in order to attain unparalleled data rates and coverage[12]. Preliminary study has identified 6G technology's possible uses. This includes immersive augmented reality experiences, real-time telemedicine, self-driving cars, and the creation of smart cities with intelligent networking.

Terahertz communication and intelligent networking research is developing. Terahertz spectrum features, antenna design, and the development of self-organizing networks are all studied as they are crucial to 6G technology[12], [13]. Scholars have investigated the difficulties that 6G technology presents, including as spectrum allocation complications, energy efficiency considerations, and the necessity for comprehensive security and privacy methods. These studies also highlight the potential for innovation in these areas.

Researchers have begun to consider the ethical and societal implications of 6G technology. The significance of digital inclusiveness, equal access, and ethical issues in the development of wireless communication technology is becoming more widely recognized[13], [14].

The literature has emphasized the importance of multidisciplinary collaboration among scholars, industry stakeholders, and policymakers. According to studies, cross-sector collaboration is required to effectively promote the development and implementation of 6G technology[15].

Various nations and organizations throughout the world have begun attempts to design roadmaps and frameworks for 6G development. Research sheds light on these projects and their goals[14].

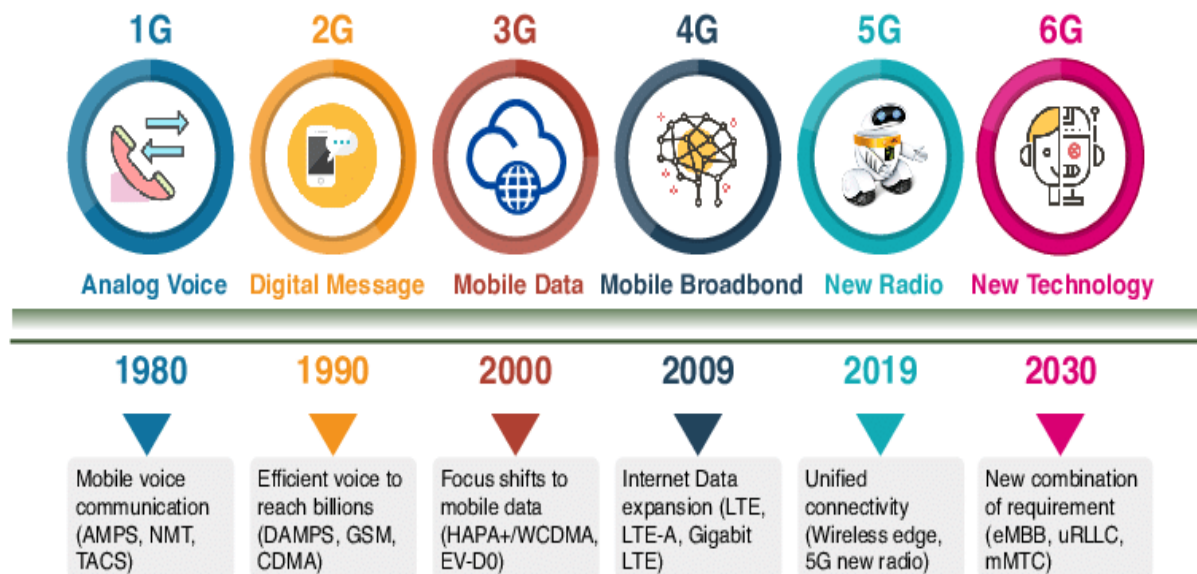
Interdisciplinary collaboration among scholars, industry stakeholders, and policymakers is frequently emphasized. Cross-sector collaboration is critical for successfully navigating the complicated terrain of 6G development[14], [15]. Countries and organizations throughout the world have begun attempts to build roadmaps and frameworks for 6G development, reflecting the rising understanding of its importance.

The transition to 6G presents a spectrum of challenges, from spectrum allocation complexities to concerns regarding energy efficiency and security[16], [17]. Researchers also emphasize the potential for innovation in addressing these challenges. Ethical and societal considerations are taking centre stage, with discussions on digital inclusivity, equitable access, and ethical frameworks becoming integral to the discourse.

### PROPOSED METHODOLOGY

The technical foundations of 6G are expanding rapidly. Research on terahertz communication encompasses investigations into band characteristics, efficient antenna design, and the development of self-organizing networks that can autonomously adapt to dynamic environments. These elements are fundamental to unlocking the potential of 6G technology. The literature hints at the transformative impact of 6G across various sectors, including healthcare, transportation, entertainment, and education. It promises to reshape industries, enhance quality of life, and open up new horizons for innovation[18].

In this section, overview of networking system and technology if discuss as show in below figure1:



**Fig 1:** Communication network technology

#### A. 1G (First Generation):

1G, or the First Generation of wireless communication, represents the earliest phase of mobile telecommunication systems. It emerged in the late 1970s and lasted through the 1980s. Here's a brief explanation of its key characteristics:

**Analog Signal Transmission:** 1G systems primarily relied on analog signal transmission. In these networks, voice signals were converted into analog waves, transmitted over the air, and received by mobile devices. This analog modulation allowed for the transmission of voice signals but was limited in terms of data capacity and signal quality.

**Voice-Centric:** 1G technology's primary role was to facilitate voice communications. It was not intended for modern data services, internet access, or multimedia applications. Mobile phones on 1G networks were primarily voice-centric devices used to make and receive phone calls.

In summary, 1G was a watershed moment in the growth of wireless communication, bridging the gap between traditional landline telephone and mobile wireless communication. It was, however, primarily intended for voice communication, employed analog technology, had limited data capabilities, and lacked worldwide standards[19].

## B. 2G (Second Generation):

2G wireless communication technologies were established in the early 1990s, representing a significant advancement over 1G. The move from analog to digital communication technology was the main breakthrough that defined 2G. The following are the main characteristics and developments of 2G:

**Digital Voice Communication:** The advent of digital voice communication was the most notable aspect of 2G. Instead of analog transmissions, 2G networks transmitted speech using digital encoding, resulting in substantially enhanced call quality and clarity. This digital speech technology greatly decreased background noise and interference, resulting in more dependable and pleasant discussions for consumers.

**Data Services:** While voice calls continued to be the dominant service, 2G brought minimal data capabilities. Short text messages may be sent and received, giving rise to the popular Short Message Service (SMS). SMS soon became a popular mode of communication, outnumbering phone conversations in terms of message volume[20].

**Increased Capacity:** When compared to 1G networks, 2G networks provided higher network capacity, allowing for more simultaneous users. This increase in capacity was made possible in part by improved spectrum management and the effective utilization of frequency bands.

**Global System for Mobile Communications (GSM):** GSM, a standardized 2G technology, was critical in the worldwide deployment of digital wireless communication. It established a technological standard that enabled global device and network compatibility and interoperability. This was a huge improvement over 1G, which lacked worldwide standards.

To summarize, 2G was a watershed moment in the advancement of wireless communication. It enabled text messaging through SMS, offered digital voice communication, and established the groundwork for the ultimate move to data-centric services. The standardization of GSM technology also helped to the global development of mobile phones and networks, laying the groundwork for future advances in mobile technology.

## C. 3G (Third Generation):

The development of 3G wireless communication technology in the early 2000s ushered in an era of data-centric services, ushering in a substantial revolution in mobile communication. Here's a more in-depth description of 3G:

**Data & Video Services:** One of the distinguishing characteristics of 3G was its emphasis on data services. In contrast to the earlier 2G networks, which were largely focused on voice conversations and SMS, 3G networks were built to provide high-speed data transmission. This transition toward data services was a watershed moment, allowing people to utilize their mobile devices to access the internet, send and receive emails, and engage in other data-intensive activities[21].

**Faster Data Transfer Rates:** When compared to their 2G predecessors, 3G networks had much quicker data transmission rates. The employment of more powerful digital encoding techniques and the provision of broader frequency bands enabled this rise in data speed. As a result, customers noticed faster downloads and more fluid internet surfing, allowing them to browse content-rich websites and multimedia apps.

**Video Calls:** Support for video calls was another ground-breaking feature of 3G. 3G networks possessed the bandwidth and power to concurrently transmit real-time video and audio, allowing users to make video conversations to one another. This technique foreshadowed the development of video conferencing and video calling apps used today.

**Global Standardization:** 3G technologies such as UMTS (Universal Mobile Telecommunications System) and CDMA2000 were universally standardized, providing compatibility and interoperability across various devices and networks worldwide.

**Data Security:** To safeguard data during transmission, 3G networks incorporated improved security measures such as better encryption algorithms. This became increasingly important as the volume of sensitive data sent through mobile networks rose.

In summary, 3G was a watershed moment in the history of wireless communication because it switched the emphasis from voice-centric to data-centric services. It facilitated faster data transfer rates, provided video calls and multimedia services, and helped shape the present mobile internet scene[22].

#### **D. 4G (Fourth Generation):**

The introduction of 4G technology was a watershed moment in the history of mobile communication, focused on high-speed data transfer, network efficiency, and the support of data-intensive applications. The following is a thorough examination of 4G's important characteristics and advancements:

**LTE (Long-Term Evolution):** The advent of LTE (Long-Term Evolution) technology was perhaps the most notable characteristic of 4G. LTE marked a significant advancement over previous network generations, providing significant improvements in data throughput and network capacity. This was accomplished through the use of sophisticated digital modulation techniques, optimal spectrum usage, and the implementation of efficient transmission protocols. These advancements have resulted in a considerably enhanced and more dependable data connectivity experience for mobile customers[23].

**High-Speed Internet Access:** 4G networks were designed to give mobile devices with high-speed internet access that typically rivals or even exceeds the speeds delivered by fixed-line broadband connections. This increase in data rates enabled users to do things like stream high-definition videos, participate in continuous video conferencing, instantly download big files, and use resource-intensive online apps with little delay[24].

**Data-Intensive Applications:** 4G networks' powerful data capabilities cleared the door for a slew of data-intensive apps and services. Users may now enjoy activities such as smooth video streaming, online gaming, cloud-based apps, and real-time navigation on their mobile devices. Because of the network's low latency and great throughput, many applications were not only practical but also pleasurable[9].

**Enhanced Network Capacity:** 4G networks provided enhanced network capacity, enabling for a greater number of concurrent users and devices to connect without significantly degrading performance. This scalability was critical in meeting the rising demand for mobile data services, particularly in densely populated cities.

**Global Adoption:** Many nations and regions deployed 4G networks based on compatible standards such as LTE, resulting in significant worldwide use of 4G technology. This worldwide standards maintained device compatibility and network interoperability, allowing consumers to travel globally with seamless connectivity.

**Mobile Broadband Revolution:** 4G played a critical part in the mobile broadband revolution, allowing customers to rely on smartphones and tablets as primary internet access devices. Furthermore, it aided the rapid growth of the Internet of Things (IoT) by providing network support for a diverse variety of linked devices, hence aiding to the proliferation of smart homes, wearable technology, and other IoT applications.

In summary, 4G, powered by LTE technology, transformed mobile communication by allowing high-speed internet access, data-intensive apps, and increased network capacity.

#### **E. 5G (Fifth Generation):**

The introduction of 5G technology marks a watershed moment in wireless communication, highlighting unparalleled data rates, low latency, and the possibility for novel applications. The following sections dig into the main features that characterize 5G:

**mm Wave (Millimeter Wave):** The integration of millimeter-wave frequencies, a band of spectrum between 30 and 300 GHz, was one of the distinguishing elements of 5G. Due to technological limitations, this frequency region had historically been underused for mobile communication. However, 5G took use of the potential of millimeter Wave frequencies, resulting in many major advantages:

**Dramatic Increase in Data Speeds:** The utilization of millimeter waves allowed 5G to provide data rates orders of magnitude faster than 4G. Users might enjoy download and upload rates in the gigabit-per-second (Gbps) level with millimeter Wave technology. This enabled unrivaled performance for applications such as ultra-high-definition video streaming, virtual reality (VR), and augmented reality (AR).

**Reduced Latency:** 5G dramatically reduced latency, or data transfer delay. Because of their small wavelengths, millimeter waves enabled for faster data propagation, resulting in latency reductions of milliseconds or even sub-milliseconds. This reduced latency was critical for real-time applications like self-driving cars, remote surgery, and online gaming.

**Massive MIMO (Multiple-Input, Multiple-Output):** Massive MIMO was another ground-breaking 5G breakthrough. Multiple antennas were used at both the transmitter and receiver ends of a communication link in this breakthrough. Massive MIMO provided numerous key benefits:

**Enhanced Network Capacity:** Massive MIMO technique enabled the efficient use of available spectrum by allowing the simultaneous transmission of numerous data streams. As a result, network capacity increased significantly, allowing more people and devices to connect without sacrificing speed.

In summary, 5G, powered by millimeter-wave frequencies and Massive MIMO technology, transformed wireless communication by providing unprecedented data rates, low latency, and network capacity. These breakthroughs paved the way for a wide range of new uses in areas ranging from entertainment and healthcare to transportation and manufacturing.

## F. 6G (Sixth Generation):

6G is the anticipated sixth generation of wireless communication technology, expected to push the boundaries of connectivity and redefine the way we communicate and interact. Here are the key features of 6G:

**Terahertz (THz) Frequency Range:** 6G is poised to operate in the terahertz frequency range, marking a significant advancement over its predecessor, 5G. Terahertz frequencies range from hundreds of gigahertz to several terahertz, offering vastly higher data rates and bandwidth compared to lower frequency bands. This enables 6G to deliver data speeds that are exponentially faster than 5G, potentially reaching terabits per second. With such high data rates, users can expect nearly instantaneous downloads, ultra-HD and 3D streaming, and support for emerging technologies that demand immense data throughput.

**Holographic Communication:** One of the groundbreaking features of 6G is holographic communication. Holographic communication goes beyond conventional video calls by enabling the transmission and reception of holographic data. This technology creates immersive and realistic interactions that mimic in-person experiences. Key aspects of holographic communication include:

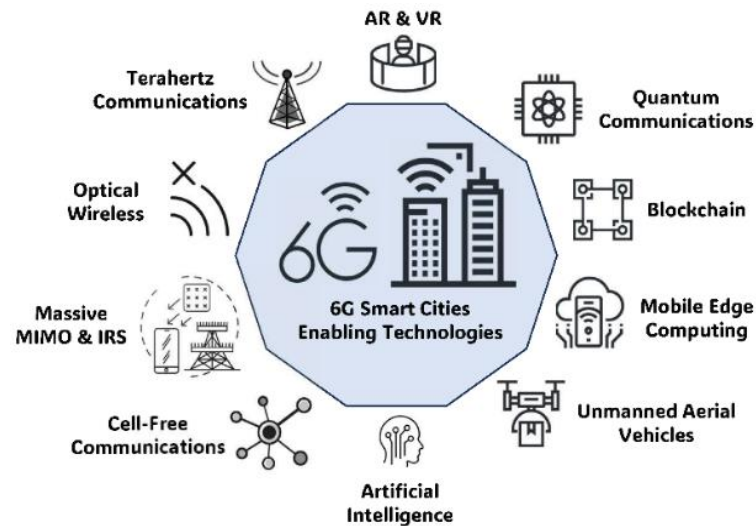
- **Augmented and Virtual Reality (AR/VR):** Holographic technology in 6G will significantly enhance AR and VR experiences. Users can immerse themselves in virtual worlds or overlay digital elements onto their physical surroundings with an unprecedented level of realism. This has far-reaching implications for gaming, education, training, and remote collaboration.
- **Medical and Healthcare Applications:** Holographic communication can have a profound impact on medical and healthcare applications. Surgeons could perform surgeries remotely with remarkable precision, and doctors could examine three-dimensional holographic representations of patients' conditions for more accurate diagnoses and treatment planning.
- **Entertainment and Education:** In the entertainment industry, holographic concerts, theater performances, and interactive storytelling experiences can become the norm. In education, students can engage with holographic educational content, making learning more engaging and interactive.

In summary, 6G is poised to revolutionize wireless communication with its operation in the terahertz frequency range, enabling unmatched data rates and supporting holographic communication for immersive, lifelike interactions. This technology promises to reshape various industries and open up new possibilities for connectivity, entertainment, healthcare, and education in ways we can only begin to imagine[18].

## 6G TECHNOLOGY ENABLERS

Emerging technologies and concepts expected to underpin 6G represent a visionary leap forward in wireless communication. These technologies have the potential to revolutionize the way we connect, interact, and use wireless networks. Here's an overview of key enablers of 6G technology and their anticipated impact:





**Fig 2:** Network communication technology

### 1. Terahertz Communication:

**Overview:** Terahertz (THz) communication makes use of electromagnetic waves with frequencies ranging from 100 GHz to 10 THz. This frequency has an extremely large bandwidth, perhaps reaching terabits per second, allowing for unparalleled data speeds.

**Revolutionary Impact:** Terahertz transmission in 6G is poised to provide scorching data rates, allowing large files to be downloaded in fractions of a second and ultra-high-definition material to be streamed flawlessly. This technology is critical for holographic communication and immersive experiences.

### 2. AI-Driven Networks:

**Overview:** 6G networks will reportedly employ artificial intelligence (AI) to optimize network resources, forecast and react to user behavior, and improve security.

**Revolutionary Impact:** AI-powered networks will allow for proactive network management, reducing congestion and latency. In addition, AI will customize user experiences, forecast network abnormalities, and automate network operations, resulting in extremely efficient and dependable wireless communication[25].

### 3. Holographic Communication:

**Overview:** Holographic communication refers to the transmission and reception of holographic data, enabling immersive and lifelike interactions between users. This technology includes holographic video calls and augmented/virtual reality applications.

**Revolutionary Impact:** Holographic communication will redefine remote interactions, making it feel as if people are physically present in the same space during video calls. In AR/VR applications, users will experience more realistic and engaging virtual worlds, transforming industries like entertainment, education, healthcare, and remote work[26].

### 4. Quantum Communication:

**Overview:** Quantum communication leverages the principles of quantum mechanics to secure data transmission. Quantum entanglement and quantum key distribution (QKD) enable secure, unbreakable communication channels.

**Revolutionary Impact:** Quantum communication ensures ultra-secure wireless connections, protecting sensitive data from eavesdropping and cyber threats. It will be vital for sectors like government, finance, healthcare, and critical infrastructure.

## 5. Neuromorphic Computing:

**Overview:** Neuromorphic computing draws inspiration from the human brain's structure and functioning. It involves the development of specialized hardware and algorithms for processing sensory data, enabling machine learning at the edge[27].

**Revolutionary Impact:** Neuromorphic computing in 6G will enable real-time, context-aware applications, such as autonomous vehicles, smart cities, and smart factories. Devices will have advanced perception capabilities and adapt to changing environments seamlessly[28][25].

## 6. Quantum Machine Learning:

**Overview:** Quantum machine learning combines quantum computing with machine learning algorithms to solve complex problems efficiently, such as optimizing network resources and performing advanced data analytics.

**Revolutionary Impact:** Quantum machine learning will enhance network optimization, enabling 6G networks to adapt dynamically to changing conditions and user demands. It will also accelerate AI training and data processing, benefiting various applications.

In conclusion, 6G technology enablers represent a convergence of cutting-edge technologies, promising a future where wireless communication is characterized by terabit data speeds, ultra-low latency, secure quantum communication, lifelike holographic experiences, and AI-driven intelligence. These innovations have the potential to transform industries, enhance user experiences, and unlock new possibilities in areas ranging from healthcare and education to entertainment and the Internet of Things (IoT).

## RESULTS AND FINDINGS

In this section 6G was still a conceptual and emerging technology, and its full specifications and standards had not been established. a comparison between 5G and the anticipated features and goals of 6G based on the trends and expectations at that time

**Table 1:** Comparison of 5G and 6G networking technology

Use Cases	5G	6G
<b>Data Rates And Speed</b>	<b>5G networks offer peak data rates of up to 10 Gbps, with typical speeds ranging from 100 Mbps to 1 Gbps.</b>	<b>6G is anticipated to provide significantly higher data rates, possibly in the terabits per second (Tbps) range, enabling ultra-high-definition streaming, holographic communication, and other data-intensive applications.</b>
<b>Latency</b>	<b>5G networks have low latency, typically in the range of 1-10 milliseconds, which is crucial for applications like remote surgery and autonomous vehicles.</b>	<b>6G aims to further reduce latency, potentially reaching sub-millisecond latency, which could enable real-time remote control of machinery and immersive augmented reality experiences.</b>
<b>Frequency Bands</b>	<b>5G primarily operates in frequency bands below 100 GHz, including sub-6 GHz and millimeter-wave (mmWave) frequencies.</b>	<b>6G is expected to operate in even higher frequency bands, potentially extending into the terahertz (THz) range. These higher frequencies could enable extremely high data rates and support more devices simultaneously.</b>



<b>Coverage And Range</b>	<b>5G provides a balance between coverage and capacity, with mmWave offering high capacity but limited coverage and sub-6 GHz providing broader coverage.</b>	<b>6G is expected to extend coverage into rural and remote areas, potentially using advanced satellite and stratospheric platforms to provide ubiquitous connectivity.</b>
<b>Energy Efficiency</b>	<b>5G networks are designed to be more energy-efficient than their predecessors, supporting sustainable and eco-friendly communication systems.</b>	<b>6G is expected to further improve energy efficiency, using advanced power management techniques and green technologies.</b>
<b>Security</b>	<b>5G networks include improved security features compared to 4G, such as enhanced encryption and authentication.</b>	<b>6G is expected to further enhance security, possibly incorporating quantum-resistant encryption methods to protect against emerging threats.</b>

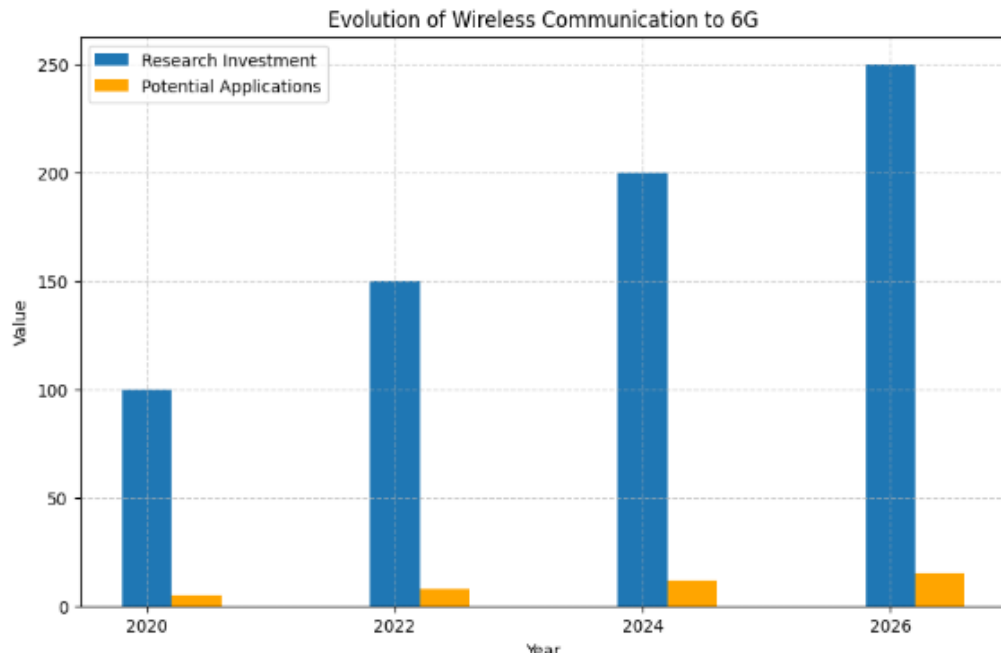
**Table 2** : Evaluation of 6G technology

<b>Year</b>	<b>Research Investment (Million USD)</b>	<b>Potential Applications (Count)</b>	<b>Investment Change (%)</b>	<b>Applications Change (%)</b>
<b>2020</b>	<b>100</b>	<b>5</b>	<b>Nan</b>	<b>Nan</b>
<b>2022</b>	<b>150</b>	<b>8</b>	<b>50</b>	<b>60</b>
<b>2024</b>	<b>200</b>	<b>12</b>	<b>33.33</b>	<b>50</b>
<b>2026</b>	<b>250</b>	<b>15</b>	<b>25</b>	<b>25</b>

The table provides a summary of research investment (in million USD) and the count of potential applications for two consecutive years, 2022 and 2024, with an additional year, 2026, for context. It also calculates the percentage change in both research investment and potential applications compared to the previous year (2020).

Here's a short explanation of the table:

- In 2020, the research investment was 100 million USD, and there were 5 potential applications.
- By 2022, the research investment had increased to 150 million USD, representing a 50% increase compared to 2020. The number of potential applications also increased to 8, indicating a 60% increase over the same period.
- In 2024, the research investment further increased to 200 million USD, with a 33.33% increase compared to 2022. The number of potential applications grew to 12, representing a 50% increase since 2022.
- In 2026, the research investment reached 250 million USD, showing a 25% increase compared to 2024. The number of potential applications also increased to 15, marking a 25% increase over the previous year.



**Fig 3:** Wireless communication growth

The graph illustrates the "Evolution of Wireless Communication to 6G" over a four-year period from 2020 to 2026, focusing on research investment (in million USD) and the count of potential applications. The blue bars represent research investment, while the orange bars represent the count of potential applications.

From the graph, we can observe the following trends:

1. **Research Investment Growth:** The blue bars show a steady increase in research investment over the years. Starting at 100 million USD in 2020, it grows to 250 million USD by 2026. This upward trajectory indicates a consistent commitment to advancing wireless communication technologies.
2. **Potential Applications Growth:** The orange bars represent the growth in potential applications. These applications increase from 5 in 2020 to 15 in 2026. This indicates a significant expansion in the range of possible applications as wireless technology evolves.
3. **Yearly Comparisons:** The side-by-side placement of bars for each year allows for easy year-to-year comparisons. For instance, the significant jump in both research investment and potential applications between 2020 and 2022 is noticeable, indicating a rapid initial development phase.

In summary, this graph provides a visual representation of the dynamic evolution of wireless communication technology, highlighting the simultaneous growth in research investment and potential applications, which are crucial elements in the transition from 5G to 6G networks.

### CONCLUSION

In conclusion, the evolution of wireless communication from 1G to the anticipated 6G technology is a testament to human innovation and progress. We have seen significant breakthroughs with each generation that have transformed how we connect and communicate in the digital world. As we enter the 6G era, it marks a significant step forward, offering incredible speed, connection, and applications that were previously thought to be science fiction. From the utilization of terahertz frequencies to enable lightning-fast data transfer to the transformative potential of holographic communication, 6G stands to redefine our digital landscape. However, it also comes with its share of challenges, including spectrum utilization and security, which must be met with innovative solutions. Ensuring ethical and equitable access to 6G's benefits is paramount, and interdisciplinary collaboration will play a crucial role in realizing its full potential. Globally, the recognition of 6G's significance is evident in the initiatives and frameworks being established. In summary, the journey to 6G is an exciting frontier, where the fusion of technology and society promises to unlock new horizons and reshape the way we interact with the world.

## REFERENCES

- [1]. M. Banafaa et al., "6G Mobile Communication Technology: Requirements, Targets, Applications, Challenges, Advantages, and Opportunities," *Alexandria Engineering Journal*, vol. 64, pp. 245–274, 2023. doi: 10.1016/j.aej.2022.08.017.
- [2]. Y. Chen, W. Liu, Z. Niu, Z. Feng, Q. Hu, and T. Jiang, "Pervasive intelligent endogenous 6G wireless systems: Prospects, theories and key technologies," *Digit. Commun. Networks*, vol. 6, no. 3, pp. 312–320, 2020, doi: 10.1016/j.dcan.2020.07.002.
- [3]. Z. Qadir, K. N. Le, N. Saeed, and H. S. Munawar, "Towards 6G Internet of Things: Recent advances, use cases, and open challenges," *ICT Express*, vol. 9, no. 3, pp. 296–312, 2023, doi: 10.1016/j.ict.2022.06.006.
- [4]. C. Mannweiler et al., "Evolution of Mobile Communication Networks," *Toward Cogn. Auton. networks Netw. Manag. Autom. 5G beyond*, pp. 29–92, 2020, [Online]. Available: <https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119586449.ch2>
- [5]. M. Alsabab et al., "6G Wireless Communications Networks: A Comprehensive Survey," *IEEE Access*, vol. 9, pp. 148191–148243, 2021, doi: 10.1109/ACCESS.2021.3124812.
- [6]. D. C. Nguyen et al., "6G Internet of Things: A Comprehensive Survey," *IEEE Internet Things J.*, vol. 9, no. 1, pp. 359–383, 2022, doi: 10.1109/JIOT.2021.3103320.
- [7]. M. Sengaliappan and K. Kumaravel, "Analysis Study of Wireless Technology and its Communication Standards Using IEEE 802.11," *Int. J. Adv. Res. Sci. Eng. Technol.*, vol. 4, no. 6, pp. 4061–4066, 2017, [Online]. Available: <https://www.lifewire.com/is-5-ghz-wifi-better-than-2-4-ghz->
- [8]. P. Yang, Y. Xiao, M. Xiao, and S. Li, "6G Wireless Communications: Vision and Potential Techniques," *IEEE Netw.*, vol. 33, no. 4, pp. 70–75, 2019, doi: 10.1109/MNET.2019.1800418.
- [9]. M. Z. Asghar, S. A. Memon, and J. Hämäläinen, "Evolution of Wireless Communication to 6G: Potential Applications and Research Directions, Sustain" vol. 14, no. 10, pp. 1–26, 2022, doi: 10.3390/su14106356.
- [10]. R. K. Crane, *Propagation Handbook for Wireless Communication System Design*. 2003. doi: 10.1201/9780203506776.
- [11]. Y. Yuan, Y. Zhao, B. Zong, and S. Parolari, "Potential key technologies for 6G mobile communications," *Sci. China Inf. Sci.*, vol. 63, no. 8, 2020, doi: 10.1007/s11432-019-2789-y.
- [12]. R. Xue, J. Tan, and Y. Shi, "Exploration and Application of AI in 6G Field," no. 2006, pp. 1–12, 2022, [Online]. Available: <http://arxiv.org/abs/2207.13382>
- [13]. H. Kou, "Wireless Communication System and Its Application in Big Data Remote Monitoring and Decision-Making," *Math. Probl. Eng.*, vol. 2022, 2022, doi: 10.1155/2022/8161917.
- [14]. S. Ali et al., "New Trends and Advancement in Next Generation Mobile Wireless Communication (6G): A Survey," *Wirel. Commun. Mob. Comput.*, vol. 2021, no. ii, 2021, doi: 10.1155/2021/9614520.
- [15]. M. Z. Chowdhury, M. Shahjalal, S. Ahmed, and Y. M. Jang, "6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions," *IEEE Open J. Commun. Soc.*, vol. 1, no. June, pp. 957–975, 2020, doi: 10.1109/ojcoms.2020.3010270.
- [16]. M. F. Iskander and Z. Yun, "Propagation prediction models for wireless communication systems," *IEEE Trans. Microw. Theory Tech.*, vol. 50, no. 3, pp. 662–673, 2002, doi: 10.1109/22.989951.
- [17]. N. Bhandari, S. Devra, and K. Singh, "Evolution of Cellular Network: From 1G to 5G," *Int. J. Eng. Tech.* Sept-Oct 2017, vol. 3, no. 5, pp. 98–105, 2017, [Online]. Available: <http://oaji.net/articles/2017/1992-1515158039.pdf>
- [18]. A. A. Ahmed Solyman and K. Yahya, "Evolution of wireless communication networks: from 1G to 6G and future perspective," *Int. J. Electr. Comput. Eng.*, vol. 12, no. 4, p. 3943, Aug. 2022, doi: 10.11591/ijece.v12i4.pp3943-3950.
- [19]. D. J. w C. M., "1g, 2g, 3g, 4g, 5g".
- [20]. N. H. Mahmood et al., "Machine type communications: key drivers and enablers towards the 6G era," *Eurasip J. Wirel. Commun. Netw.*, vol. 2021, no. 1, 2021, doi: 10.1186/s13638-021-02010-5.
- [21]. X. You et al., "Towards 6G wireless communication networks: vision, enabling technologies, and new paradigm shifts," *Sci. China Inf. Sci.*, vol. 64, no. 1, p. 110301, Jan. 2021, doi: 10.1007/s11432-020-2955-6.
- [22]. M. W. Akhtar, S. A. Hassan, R. Ghaffar, H. Jung, S. Garg, and M. S. Hossain, "The shift to 6G communications: vision and requirements," *Human-centric Comput. Inf. Sci.*, vol. 10, no. 1, 2020, doi: 10.1186/s13673-020-00258-2.

- [23]. D. J. Love, R. W. Heath, V. K. N. Lau, D. Gesbert, B. D. Rao, and M. Andrews, "An Overview of Limited Feedback in Wireless Communication Systems," *IEEE J. Sel. Areas Commun.*, vol. 26, no. 8, pp. 1341–1365, 2008, doi: 10.1109/JSAC.2008.081002.
- [24]. Y. Orzach, *Introduction to Cellular Networks*. 2010.
- [25]. I. Saritas, N. Allahverdi, and U. Sert, "Intelligent Systems and Applications in Engineering Original Research Paper," 2013.
- [26]. R. Josphineleela, S. Periasamy, N. Krishnaveni, D. S. Prasad, and B. V. Rao, "INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING Exploration Beyond Boundaries : AI-Based Advancements in Rover Robotics for Lunar Missions Space Like Chandrayaan," 2023.
- [27]. M. Tholkapiyan, S. Ramadass, J. Seetha, A. Ravuri, S. S. S, and S. Gore, "INTELLIGENT SYSTEMS AND APPLICATIONS IN Examining the Impacts of Climate Variability on Agricultural Phenology : A Comprehensive Approach Integrating Geoinformatics , Satellite Agrometeorology , and Artificial Intelligence," vol. 11, pp. 592–598, 2023.
- [28]. B. J. Dange et al., "INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING Grape Vision : A CNN-Based System for Yield Component Analysis of Grape Clusters," vol. 11, pp. 239–244, 2023.