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Review Article

From 1G to 6G: Review of history of Wireless Technology Development, Architecture, Applications, and Challenges

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ABSTRACT

Understanding the concentrations of Carbon Dioxide (CO2) and greenhouse gases is very important in solving the problem of climate change. The advent of 6G technology will point to the start of a new revolution in wireless communication and networking. There have been great achievements in terms of networks and transmission of information. This review article provides a comprehensive assessment of 6G, it is equally important to track the evolution process of this technology starting from the conceptual stage up to now. This article explores new features that may potentially transform the global landscape for 6G; identifies major historical events that have shaped the evolution of 6G and stressing the importance equity in terms of technological enhancements and novelties that define it from the preceding generations. Although 6G has promise, it also faces issues, which includes the scarcity of spectrum, and the need for relatively more complex equipment and software integration and the call for enhanced energy efficiency. And goes on to understand the use of 6G, such as reliable and high-speed transmission without delay, transmission between a large number of machines. This review is to provide an analysis of 6G and to take a look at all the features in order to understand the new technology. trend and how it affects various fields in the society.

1. INTRODUCTION

The advancements in highly developed Wireless communication technology referred to as 6G is a great achievement toward the invention ability in changing the process of human interaction, sharing and usage of information in the digital realm.[1]. 6G, the next generation of telecommunication technology beyond the present 5G technology, is capable of being advanced in terms of speed, capacity and connectivity compared to 5G and operating at terahertz (THz) frequencies to provide [2]. This would enable prospective developments that need instant and large bandwidth data communications. The design and implementation of other technologies that are recent innovations include artificial intelligence (AI) and machine learning (ML) will be important for the development of 6G [3].

These technologies will be vital in sustaining and optimising network utilisation and identifying when to perform maintenance. managing resources. The use of edge computing will improve this by allowing computation where the data is collected. starts which means that undue time is not spent while also enabling an instantaneous decision to be made. Additionally, 6G technology aim to lessen the distinction between communication and sensing by putting forward the Integrated Sensing and Communication (ISAC) systems. They will assist in the execution of the measurement of the prevailing environmental conditions and also the operation of the remote control[4].

Multiple research have been carried out in this field. In [5], The paper mainly focuses on the future development of 6G networks with a focus on sustainability and energy efficiency. The text discusses architectural ideas and the latest technologies while pointing out the hardware and power, renewable energy consumption, and networks optimization. It also examines the applications of AI/ML in the utilization of resources and the challenges and prospects of developing the future green 6G environment.

Besides the study[6], discuss the application of innovative technologies like Terahertz transmission, Massive MIMO and Reconfigurable Intelligent Surfaces in 6G technology in assuring high data rate and low latency along with energy

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efficiency. These technological advancements give enhanced accessibility in several environments, as well as set elevated standards as to the velocity, reliability, and resilience of intercontinental communicational systems. They are indispensable for the interaction and networking of the organization and with the global environment.
In [7], it provided an overview of 6G wireless networks and key technologies including Terahertz transmission, Massive MIMO, and Reconfigurable Intelligent Surfaces. These technologies bring the possibility of high-speed data transfer, more efficient utilization of the existing radio frequency bands, and effective communication in many circumstances. The complexity of the strategy is aimed at creating networks, which can work at a very high speed and with minimum time loss and still would be easy on electricity and other resources. The essay also explores prospective uses and the revolutionary effect of 6G on global communications infrastructures.
Moreover In [3],explores the incorporation of land-based and non-land-based networks, the virtualization of networks, and the administration of SDN. Significant progress has been made in the fields of Terahertz communication, reconfigurable intelligent surfaces, increased massive MIMO, and AI. Some examples of applications include the implementation of advanced technology in urban areas, the use of technology in the medical field, self-driving cars, and the use of augmented reality (AR) and virtual reality (VR) in many industries. The challenges encompass signal propagation, energy usage, security, privacy, and worldwide standards.
In the era of 6G, researchers are prioritizing sustainability and energy efficiency. They are researching the green communications technology and techniques for energy harvesting with a view of minimizing the impact of an extensive network formation on the environment [5]. In addition, the demand for 6G to support global coverage and cover remote areas becomes a challenge that needs the seamless integration of satellite networks into terrestrial networks. In this paper, the inherent advancements and issues in the development of the sixth generation, also known as 6G technology are analysed and the ability of this new technology to revolutionize the digital space is assessed. Thus, the goal of this paper can be defined as providing a comprehensive introduction to the innovative field of 6G research for scientific, social, and economic developments as well as for multiple applications in various sectors. This will give a comprehensive idea of how 6G is revolutionizing connectedness in the different countries.

2. HISTORY OF 6G DEVELOPMENT.

The development of 6G technology may be understood by examining the progression of wireless communication technologies across time. The initial iteration, known as the first generation or 1G, was launched in the 1980s and brought about analogue voice communication. However, this technology was hindered by its subpar quality, restricted capacity, and absence of security measures
Depending on the development of wireless communication technology through time, one can explain the development of 6G technology. The first generation or 1G was introduced in the 1980s which introduced the idea of voice communication using analogue. However, this brought about this technology which had a poor quality, limited capacity and lacked security features[8]. Thus, the second generation of mobile communications that began in the early 1990s extended the use of digital voice communication and provided other services such as SMS and very basic internet access [9]. The 3G that came to the market around the 2000s improved the rate at which data is transferred thus supporting mobile Internet access and multimedia services. The fourth generation also referred to as 4G was launched in the 2010s and it added high-speed data transfer that facilitated services such as streaming of videos in high definition and playing of games. Cellular based internet access technology referred to as LTE, which stands for Long Term Evolution, has become today's dominant internet technology offering higher bandwidth and better dependability [10].
The fifth generation or 5G which was first rolled out from 2020 is characterized by extremely high data transfer rate, minimal latency in transmitting information and ability to connect a huge number of smart devices[11]. It offers backing to complex solution concepts like IoT, self-driving cars, smart cities, and augmented reality. The idea about 6G appeared around the middle of the 2020 when experts and managers analysed the limitations of 5G as well as future requirements. The initial informal discussions and academic papers stressed the possibility of the use of terahertz frequencies and the application of artificial intelligence, as well as the convergence of communicating and sensing [1].
Table 1. includes all the basic details related to development, functionality, advantages and limitation of every phase of wireless technology. In addition, it describes the development status, functionalities, data transference rate, the bandwidth, coverage area, possible conflicts with the other signal sources and general applications of the technology. ln addition, it prescribes basic technologies and standards that form the current network's basis, stressing the shift from analogue to digital patterns and integrating such technologies as AI and quantum communication in the future 6G networks.

TABLE I. THE DIFFERENCES AMONG DIFFERENT GENERATIONS START FROM 1G TO 6G TECHNOLOGY [1], [2], [11]–[20], [3], [21]–[27], [4]–[10].

Generation	**1G**	**2G**	**3G**	**4G**	**5G**	**6G (expected)**
Years of Development	1980	1990	2000	2010	2020	2030
Applications	Analog voice	Digital voice, SMS	Mobile internet, multimedia	Mobile broadband, HD video	Enhanced mobile broadband, IoT, AR/VR	Holographic telepresence, XR, autonomous systems
Speed	2.4 kbps	64 kbps to 1 Mbps	Up to 2 Mbps	100 Mbps to 1 Gbps	1-20 Gbps	100 Gbps to 1 Tbps
Bandwidth	30 kHz	200 kHz	5 MHz	20 MHz	100 MHz to 800 MHz	Up to 1 THz
Coverage Area	Local to regional	Regional to national	National	National to Global	Global, including remote areas	Global, including remote and underserved areas
Interference	High	Moderate	Low	Very low	Ultra-low	Ultra-low
Uses	Voice calls	Voice calls, SMS, essential internet	Mobile internet, video calls	Internet browsing, streaming, gaming	IoT, smart cities, autonomous vehicles, AR/VR	Advanced IoT, AI-driven applications, intelligent environments
Key Technologies	Analog cellular	GSM, CDMA	UMTS, WCDMA, HSPA	LTE, WiMAX	NR (New Radio), mmWave, massive MIMO	THz communication, AI integration, RIS, ISAC, quantum communication
Advantages	Basic mobile communication	Improved voice quality, better security	Faster data rates, global roaming	High-speed internet, low latency	Extremely high speeds, massive device connectivity	Ultra-high speeds, intelligent connectivity, global coverage
Disadvantages	Poor voice quality, low security, limited coverage	Limited data services, moderate speed	Higher cost, variable speeds	Battery drain, network congestion	High deployment cost, initial limited coverage	Developmental challenges, high infrastructure cost, potential security issue
Hybridization Technologies	None	GPRS, EDGE	HSPA, Wi-Fi integration	LTE-A, LiFi, Carrier Aggregation, Wi-Fi offloading	Dual Connectivity, Network Slicing, NB-IoT, mmWave integration	THz/VLC, LiFi, AI/ML for network optimization, quantum communication, RIS

3. 6G SYSTEM COMPONENT AND ARCHITECTURE.

Its actual tutti refers to the design of 6G technology that includes the elements like advanced antenna systems, the technology of MIMO technology and network slicing capacity which creates the higher data rates, lower latency and increased network capacity. further, it is expected that the use in Artificial Intelligence (AI) and Machine Learning (ML) algorithms support the enhancement of the network situation and or the enhancement of the user experience of the user. However, when considering the higher generation such as 6G, new application such as holographic communication and remote surgery are likely to be implemented that require highly dependable and minimal delay connection. The upcoming generation of wireless technology is anticipated to bring about a significant transformation in sectors like autonomous cars and smart cities, necessitating uninterrupted and dependable connectivity for instantaneous data transfer. The ongoing development of 6G networks is expected to have a significant impact on the future of global communication and connection. Figure 1. Illustrate the main component of the 6G technology

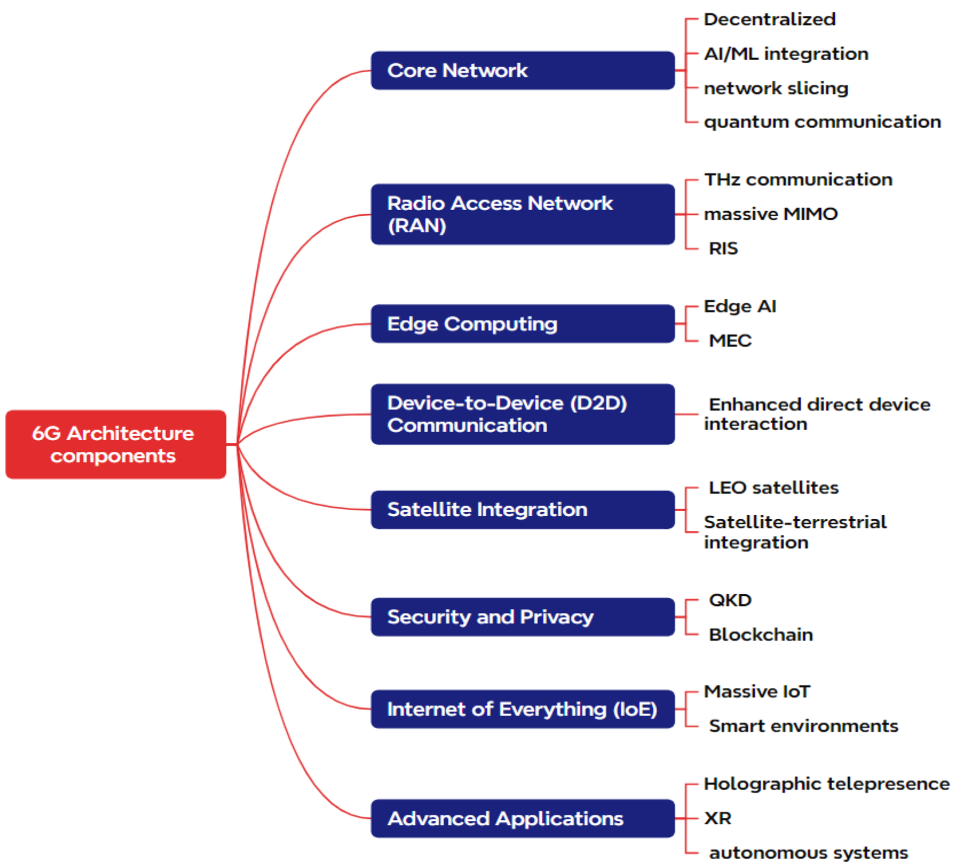

Fig. 1. 6G Architecture components

The first component is the core network) The 6G core network is anticipated to exhibit more decentralization, intelligence, and flexibility compared to previous generations. The essential elements comprise network slicing, integration of artificial intelligence and machine learning for dynamic network administration, and quantum communication for secure data transmission and improved processing capacities. These technologies facilitate the improvement and repair of networks on their own, boosting their skills and enabling more efficient and secure communication[28].

The second component is Radio Access Network (RAN): RAN is an innovative upgrade in wireless communication infrastructure that integrates multiple technologies such as Terahertz (THz) transmission, Massive MIMO (Multiple Input Multiple Output), and Reconfigurable Intelligent Surfaces (RIS)[29].

THz communication provides increased data rates and capacity, allowing for transmission speeds of up to 100 Gbps or more excellent. In fact, Massive MIMO technology uses a large number of antennas at both the transmitter and recipient side so that it provides increased capacity and coverage while it enhances the spectral efficiency and provides support to the beamforming methodologies. RIS technology enhances the signal quality, coverage, and lessens the impacts that might cause interference by creating interference constructive patterns[30]. This feature can go a long way in improving performance of the network especially in urban and central places and interior where standard antenna solutions can pose challenges. It therefore can be concluded that the RAN will be used in 6G to offer a wireless network platform that is very adaptable, efficient and robust. This infrastructure will also be able to support new applications and services that require high rate data transfer, low latency and continuity in different environments[28]–[30]. The third component is (Edge computing) is a distributed computing approach under which computations and data storage techniques and systems are shifted to the edge, inflating the system's reaction rate and bandwidth [31]. Exceeding the efficiency level and promulgating the opportunities are the key demands for the 6G technology. Also, it deploys AI algorithms on the edges of devices, reducing latency and increasing privacy. In addition, it includes Multi-access Edge Computing (MEC) that moves beyond edge computing by providing a cloud computing facility on the edge of the network.[32]. This environment has benefits like no delay experienced, access to larger bandwidth to transfer data, flexibility to manage higher loads and serving specific areas. This also allows for the evolution of new fields like autonomous automobiles and industrial robotic systems.

The fourth component is (Device-to-Device (D2D) communication); in fact, the D2D communication will be improved in 6G, where devices will be able to make direct contact without the need for the core network. This will cause increased additional speed and decreased latency. This way the properties of data transmission will be brought to higher levels and networks will utilize its extent more actively and as a consequence, the existence and technical characteristics of the networks will be increased in terms of their efficiency and usability for users. Further, 6G D2D communication can also have complex security measures to protect the information exchanged between various devices [33].

The fifth component is (satellite integration). 6 G technology makes the utilization of satellites paramount in order to ensure connection to the global population especially in regions that may not have access to any services. This integration includes the application of satellites in Low Earth Orbit (LEO) and incorporation of satellite with other terrestrial networks. Since LEO satellites orbit close to the Earth and the satellites are numerous, LEO has fast connection and full coverage and data transfer delay will be minimal. Satellite-terrestrial integration enhances coverage and reliability by combining satellite and terrestrial system [34]. This approach ensures that communication services are always available regardless of the location and thus consumer continues to connect with his friends and family in the lucrative business zones, remote villages or even deserts. In addition, it provides improvements to networking durability in terms of natural disasters, network, or communication disruption, for further data relaying optimization. The objective of the 6G satellite integration plan is to provide universal access to fast and dependable connections worldwide, facilitating the use of modern technologies such as the Internet of Things (IoT), autonomous systems, and immersive experiences, regardless of geographical constraints[35].

Moreover, the sixth component is (Security and Privacy)The primary emphasis of 6G technology is on safeguarding security and privacy to shield valuable data and guarantee dependable communication within a data-centric setting[36]. There are many essential methods, such as i)security methods such as Quantum Key Distribution (QKD), which is a decentralized and unchangeable ledger system used for securely managing, authenticating, and verifying data[37]; ii)blockchain technology, a distributed and unchangeable record, eliminates weak spots, decreases susceptibility to cyberattacks, and guarantees the accuracy and openness of data without centralized authority[38]. Privacy concerns encompass the implementation of advanced data encryption, privacy controls that prioritize the user, and techniques that anonymize data to ensure the usability of services and apps. The objective of these solutions is to augment security and privacy in 6G technology.

Another crucial component is (the Internet of Everything (IoE)) the main difference between the IoT and IoE is that IoT involves the connection of devices for data exchange. In contrast, IoE is a more comprehensive and interconnected network that integrates devices, data, people, and processes, enabling more extensive and interlinked applications[38]. In 6G, It allows the connection of a large number of IoT devices using efficient communication protocols, assuring long-term viability and the capacity to handle increasing demands. These developments will result in progress in the areas of smart cities, industrial automation, healthcare monitoring, and environmental sensing. The integration of IoT capabilities with AI will be revolutionized by 6G in bright surroundings. These settings will evolve into intelligent and responsive systems capable of automatically adjusting to changes and optimizing operations in real time. AI algorithms will analyse large volumes of data collected from IoT sensors. This will enable the prediction of maintenance needs, improvements in energy efficiency, and the enhancement of user experiences. These areas, including transportation, energy management, agriculture, and urban planning, will be fundamentally transformed, resulting in improved quality of life and increased sustainability[39].

The last component is (Advanced Applications). 6 G technology will change advanced uses like holographic telepresence[40], extended reality (XR), and self-driving systems[41]. It will make high-speed, low-latency communication possible for 3D and augmented reality experiences that are genuinely immersive.

4. CHALLENGES

The development of 6G technology faces several challenges, which include Technological Complexity, Spectrum Availability, Energy Efficiency, Security and Privacy, Global Standardization., Cost and Investment, and Regulatory and Policy Frameworks. To tackle these problems, industry leaders, governments, and academics need to collaborate in order to foster innovation, overcome technical obstacles, and develop a robust framework for the future of wireless communication using 6G technology.

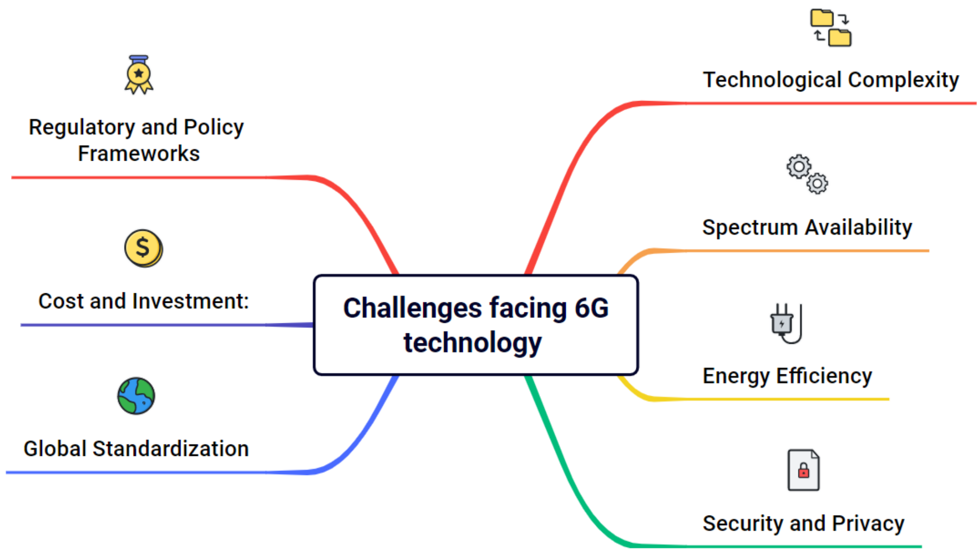

Fig. 2. Challenges facing 6G technology.

As seen in Figure 2. these challenges can be illustrated as the following:

1.Technological Complexity

Introducing advanced technologies, like terahertz communication (RIS) and AI for networks, poses certain major technical obstacles regarding HW design, signal processing, and network structure.[30].

2.Spectrum Availability

The opportunity of spectrum for 6G networks especially in the terahertz frequency band comes with challenges because the regulatory boards on frequencies made available to the networks limit the numbers permissible for usage, propagation gets difficult further, and there are challenges due to atmospheric absorption in such bands. [42][16]–[20], [22].

3.Energy Efficiency

The energy efficiency is a challenge in powering the ultra-high speed and highly demand equipment's. interconnected networks and an almost uncountable number of IoT devices[43].

4.Security and Privacy

The energy efficiency is a major concern in the availability of the power that fuels the ultra-high speed and highly demanding equipment interconnected networks and almost an infinite number of IoT devices[36].

5.Global Standardization

Integration and global standardisation remain crucial for the success and integration of 6G to the global network. This includes attaining an agreement of the international spectrum on a range of factors including spectrum bandwidth, structure of networks and compatibility[44].

6.Cost and Investment

The development and implementation of 6G infrastructure incur enormous expenses, such as research and development expenditures, spectrum licencing fees, and network deployment expenses. These costs necessitate significant investments from governments, telecom operators, and industry players[45].

7.Regulatory and Policy Frameworks

Adapting regulatory frameworks to include new technology, manage spectrum, safeguard data, and ensure fair competition is crucial for the effective implementation of 6G networks on a global scale[46].

5. APPLICATION OF 6G AMONG DIFFERENT SECTORS

6G technology is expected to be utilized in various environments, each benefiting from its advanced capabilities, with critical applications in multiple sectors

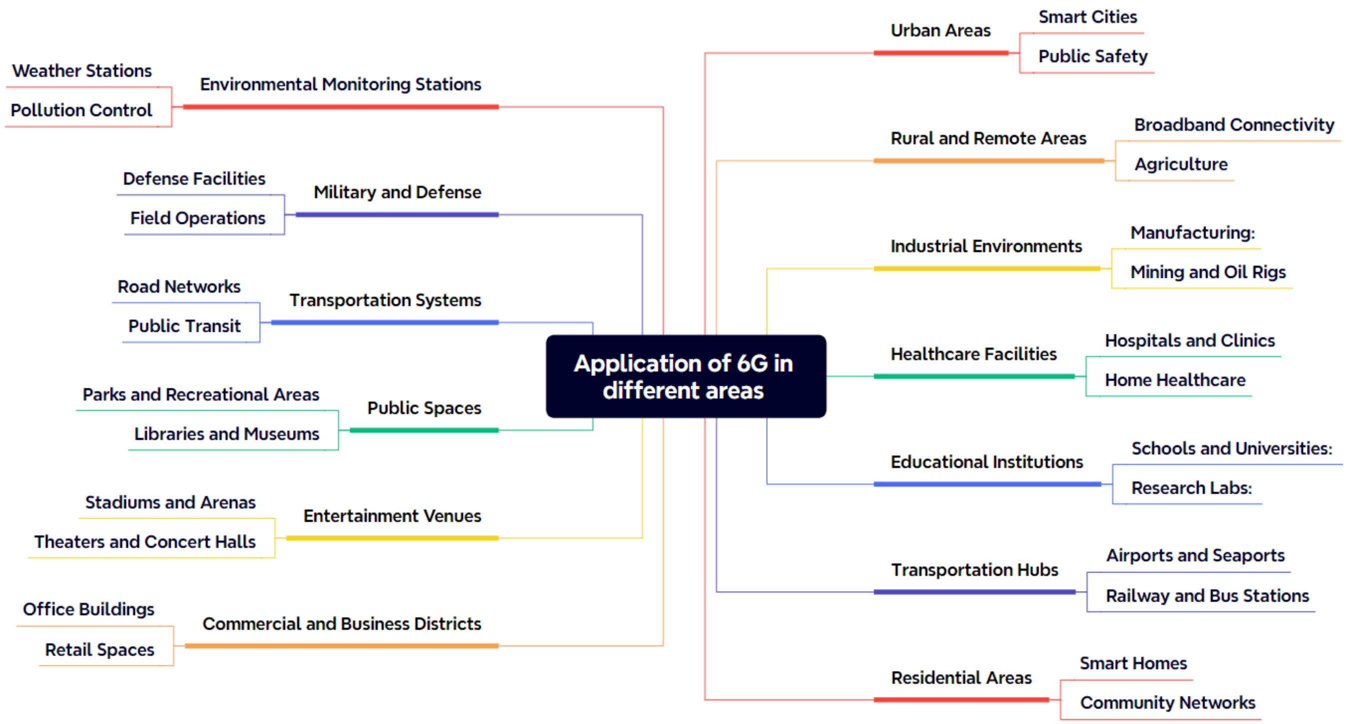

Fig. 3. Application of 6G among different sectors.

The use of 6G technology is anticipated in many contexts, with each environment reaping the advantages of its improved capabilities. As seen in Figure 3. This technology is particularly crucial for vital applications across several sectors. Anticipated to bring about a change in several sectors, such as healthcare and transportation, 6G technology is expected to facilitate quicker data throughput, reduced latency, and enhanced connection. The upcoming iteration of wireless technology holds the capacity to improve communication networks and stimulate innovation in several industries significantly.

These sectors can be illustrated and explained as follows:

1) Urban Areas: In metropolitan regions, the use of 6G technology will improve smart cities by optimising urban infrastructure through intelligent traffic management, energy-efficient structures, and advanced public services [47]. Additionally, it will enhance public safety through the implementation of enhanced emergency response systems, real-time monitoring, and efficient catastrophe management.

2) Rural and Remote Areas: In rural and isolated regions, the implementation of 6G technology would provide fast and reliable internet connectivity, therefore reducing the gap between places with and without access to digital resources[36]. And it will facilitate the advancement of precision agriculture through the use of real-time monitoring and automated agricultural equipment. This will improve the level of connection and operating efficiency in areas that now lack sufficient services.

3) Industrial Environments: 6G technology will facilitate the development of smart factories in industrial settings, allowing for the seamless integration of machinery, real-time data analysis, and automation[48]. This will result in a substantial improvement in efficiency and production. Moreover, it would improve operational safety and efficiency in industries like as mining and oil rigs by enabling real-time monitoring and remote control of equipment.

4) Healthcare Facilities: Within healthcare institutions, the use of 6G technology will facilitate the utilisation of advanced telemedicine, remote surgery, and continuous patient monitoring, hence enhancing the accessibility and quality of care. Additionally, it would assist in monitoring patients' health at home and offering telehealth services to improve patient management and convenience[49][13], [15], [21], [23].

5) Educational Institutions: Within educational institutions, the use of 6G technology will provide immersive learning encounters through the utilisation of augmented reality/virtual reality, remote education, and intelligent classrooms. This will promote heightened engagement and customised learning experiences[50]. Furthermore, it will facilitate cutting-edge scientific study by enabling rapid data sharing and providing tools for real-time collaboration[24].

Moreover,6) Transportation Hubs: 6G technology will optimise operational efficiency, security, and passenger services at transportation hubs such as airports, seaports, railway stations, and bus terminals by facilitating real-time data interchange

and automation. This encompasses enhanced logistical operations, intelligent transportation systems, and enhanced passenger experiences facilitated by uninterrupted connection[51].
7)Residential Areas: The use of 6G technology will enable the integration of IoT devices into smart homes, facilitating home automation, energy management, and enhanced security. Additionally, it will provide high-speed internet and intelligent services to residential neighbourhoods in order to enhance quality of life. 8) Commercial and Business Districts: In commercial and business districts, 6G technology improves connectivity to facilitate advanced telecommuting, real-time collaboration, and smart building management, thereby contributing to the optimisation of efficiency and the smooth operation of digital operations[52].
In addition, 9) Entertainment Venues: By providing real-time statistics, immersive augmented reality (AR) and virtual reality (VR) features, and improved connectivity, 6G technology has the potential to transform spectator experiences, ensuring that interactions are enhanced and personalised content is delivered. Additionally, theatre rooms utilise 6G for high-definition streaming and interactive performances[53].
10) Public Spaces: 6G technology is implemented in public spaces to provide improved connectivity and intelligent services, such as interactive digital experiences, smart lighting, and IoT-based environmental monitoring, that are beneficial to both residents and visitors[46], [48].
Finally 11)Military and Défense: The operational efficiency, surveillance capabilities, and communication reliability of 6G technology in military and defence applications are improved, thereby supporting critical missions and ensuring national security in diverse and challenging environments[53].

6. CONCLUSION

This article examines the 6G technology, which represents a significant increase in wireless communication, by focusing on its historical evolution and notable progress. The goal of this review paper was to provide a thorough analysis of current research on the subject. 6G has significant opportunities, despite the challenges like as spectrum management, energy efficiency, and hardware integration. These opportunities include dependable and fast communication with low latency, extensive machine-to-machine connectivity, improved mobile broadband, and the expansion of the IoT. Tackling these challenges is essential for fully harnessing the capabilities of 6G.

Conflicts Of Interest
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