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Advancements in Wireless Communication Technology: A Comprehensive Analysis of 4G to 7G Systems

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Abstract

This paper presents a comprehensive analysis of the advancements in wireless communication technology from 4G to 7G systems, focusing on critical aspects such as network architecture, spectrum allocation, data rates, security, and coverage. The evolution of wireless communication technology has been remarkable, with each generation introducing significant improvements to meet the growing demands of users and applications in an increasingly connected world. From the early adoption of 4G technology to the anticipated rise of 7G systems, sweeping changes have reshaped the landscape of wireless communications and changed the way we communicate, work and interact with our surroundings we are surrounded by communication. These changes signal a shift towards more efficient, high-speed and high-capacity systems designed to meet the needs of a variety of industries. Furthermore, the need to strengthen security measures and expand network services highlights the importance of ensuring reliability and security in networks in the face of competition and threats Continued research and innovation are essential and for further developments in this area and to realize and enable new work capabilities and services to benefit people, businesses and businesses This article examines the proposed mobile communication features from 4G to 7G in. Each generation brings unique spectrum allocation, usage and operational challenges. Each generation presents unique spectrum allocation, utilization, and efficiency challenges. Furthermore, this paper investigates network architecture aspects, data rates, and throughput, emphasizing latency and reliability improvements. Advancements in spectral efficiency, MIMO scheme usage, cell size, used frequency bands, and coverage enhancement strategies are considered. Additionally, the

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integration of energy efficiency with economic and social sustainability is analyzed. Security challenges, including privacy protection, new services, access control models, and security monitoring, are classified for each generation. One of the main objectives of this study is to identify the primary applications, impact areas, and overall impact of 4G to 7G technologies.

Keywords: Evolutionary Advancements, Advanced Cellular Generations, Future Wireless Capabilities.

1 Introduction

Wireless communication technology has been substantially evolved, with transformative changes being introduced with each generation (Koi-Akrofi et al., 2023; Kumar, 2022; Nur et al., 2023; Talić & Mešić, 2022). From the initial 1G and 2G networks, which were primarily focused on voice communication, to the data-centric 3G and the highly successful 4G networks, advancements have been rapid. Ultra-high speeds and low latency have been introduced by the advent of 5G, setting the stage for the anticipated 6G networks, which promise improved range and connectivity (Solyman & Yahya, 2022; Karthikeyan et al., 2019). The progression from 4G to the proposed 7G systems is expected to continue this trend, with data speeds, coverage, and user connectivity being advanced by each generation (Al-Obaidi et al., 2022; Olga et al., 2023). The dynamic nature of wireless communication is founded on this continuous evolution that has affected the way people connect and communicate in the ever changing technological era (Eswaran, 2022). The 4G to the expected 7G transition reveals innovation and transformation (Rao et al., 2023; Nowaczewski & Mazurczyk, 2020). Literature has demonstrated that each generation is improving its data rate, latency, reliability and power consumption through continuous advancement in wireless communication technology. This implies that it will provide new possibilities for connectivity and user experience that would take the world to an enhanced connected future based on the projected characteristics of 7G systems. 4G technology introduced Long-Term Evolution (LTE) with enhanced data speeds of up to 100 Mbps, improvement in spectral efficiency as well as network capacity increase (Seraji et al., 2023). Furthermore, Voice over LTE (VoLTE) for high quality voice calls and initial stages of Internet of Things (IoT) connectivity were developed (Jameel & Shafiei, 2017; Zahra & Abdul-Rahaim, 2022). In contrast, ultra-fast data speeds are delivered by the millimeter wave frequencies which are utilized by 5G technology (Liu & Springer, 2014). Low-latency communication supports real-time applications like autonomous vehicles. IoT-based devices for Massive machine-type communications (mMTC) use Network slicing and offer customization services along with secure end-to-end encryption feature and other security enhancements (Mishra et al., 2022). The proposed hypothetical 6G technology would employ terahertz frequency bands to provide even higher data rates while holographic communications could be integrated into immersive Augmented Reality (AR) and Virtual Reality (VR) experiences among others (Kim et al., 2023; Kim, 2020). Quantum cryptography will be a very important concept in the upcoming sixth generation technologies to enable ultra-secured communication between different nodes (Bykovsky & Kompanets, 2018).

It is worth noting that 6G will notably have AI-driven network optimization and resource management, along with integration with satellite networks for global coverage. Proposed features of the 7G system include ultrafast data speeds, which are expected to exceed many terabits per second (Di Domenico et al., 2021), enabling seamless streaming of high-definition content and real-time gaming experiences. It can be seen in Figure 1 that wireless communication systems from 4G to proposed 7G are rapidly compared. Research interests have shifted over recent years from 4G to 5G networks as focal points. In several papers like (Zhang et al., 2022) work, technical specifications and performance metrics of 5G networks were considered emphasizing ultra-fast data rates, low latency and massive connectivity for devices. On the other side, there has been a research on the application of the technology in different areas including healthcare (Li & Wu, 2020), smart cities (Khan & Salah, 2019), and industrial automation (Zhang & Wang, 2021), indicating how it has reshaped various sectors. The future, as seen by the industry, has already indicated some prospects for 6G and beyond. The theoretical frameworks of past studies (Park et al., 2023) have outlined the main characteristics and requirements of future wireless communication systems, including terahertz bands, intelligent networking protocols, and IoT seamless integration with IoT among others. Spectrum allocation, energy efficiency and security issues are some of the areas that (Wang & Li, 2022) in their studies looked at investigating potential challenges and opportunities associated with 6G networks. This is how wireless communication technology is expected to be reshaped with the advent of 7G systems. Research projects exploring essential principles and design approaches for developing 7G networks aim at enabling them to perform better than ever before while providing higher reliability and flexibility (Liu & Chen, 2024). In addition to that, efforts towards advanced antenna technologies, cognitive radio systems and quantum communication are being triggered via interdisciplinary collaborations between academia and industry in order to form a foundation for the next generation of wireless networks (Sharma & Singh, 2023; Debbarma & Praveen, 2019). Table 1 presents the general characteristics of evolutionary wireless systems, highlighting the main contributions as follows.:

1. Comprehensive Overview of Wireless Communication Evolution: The paper provides an in-depth examination of the evolution of wireless communication technology from 4G to the proposed 7G systems. It traces the development of each generation, highlighting key milestones, technological advancements, and paradigm shifts.

2. Analysis of Future Trends and Innovations: The paper discusses emerging technologies, such as mm-wave frequencies, terahertz bands, and AI-driven optimization, that are expected to drive the next wave of innovation in wireless networking. This analysis illuminates the potential opportunities and challenges linked to the adoption of advanced wireless technologies, offering insights into the future trajectory of the industry.

3. Exploration of Research Frontiers and Interdisciplinary Collaboration: It discusses theoretical frameworks, technical standards, and research initiatives aimed at advancing the state-of-the-art in wireless networking. By highlighting the collaborative efforts between academia and industry, the paper underscores the importance of multidisciplinary approaches in driving innovation and addressing the complex challenges of future wireless networks.

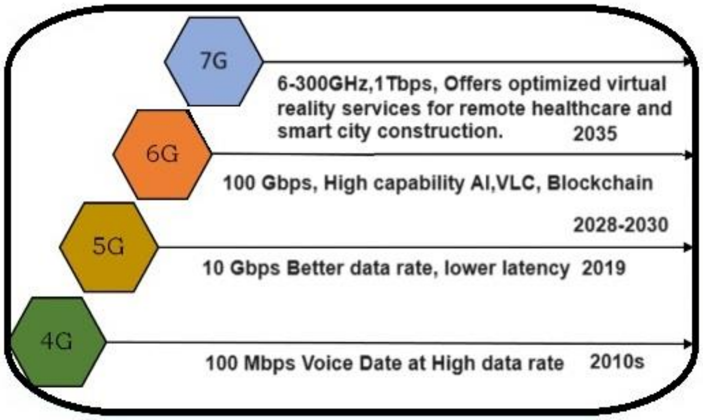

Figure 1: The Evolution of Technical Features from 4G to the Proposed 7G

The rest of this paper is organized as follows: Section 2 discusses spectrum allocation and utilization; Section 3 covers the network architecture and infrastructure; Section 4 explores the advanced applications, and finally, Section 5 presents the conclusion and future work.

Table 1: Key Characteristics of Mobile Communication Systems

Aspect	**4G (LTE/WiMAX)**	**5G (NR)**	**6G (Hypothetical)**	**7G (Purely Hypothetical)**
Launching	2010s	2020	2028-2030	2035
Technology	LTE and WiMAX.	Next-gen cellular (NR).	Hypothetical, under R&D	Purely speculative, beyond R&D
Applications	Mobile internet, Mobile TV, Mobile pay, HD videos, and voice comm.	VR/AR/360O Videos, UHD videos, wearable devices, V2X, Smart cities, Telemedicine, and IoT.	Space tourism, Tecile internet, Robotic surgery, and IoBNT	Quantum comm, Holographic medication, and Fully automated life Deep-sea slight
Data Rates	100 Mbps (LTE Advanced).	20 Gbps	1 Tbps	Speculated to be beyond Tbps
Features	Carrier aggregation, Turbo code, MIMO, OFDM, D2D comm, ICIC, and Hetnet.	Cloud/Fog/Edge computing, LDPC and Polar codes, millimeter-wave communication, Massive MIMO, NOMA, RSMA, flexible frame structure, and SDN/NFC.	QAM Mux, SM-MIMO, THz comm, Machine learning, AI, Blockchain RIS.	QAM Mux, SM-MIMO, Quantum comm, optimized VR service, ~~and~~ remote health care, and constructed smart cities.
Security	Enhanced security protocols	Enhanced security with encryption and authentication.	Expected to have advanced security measures.	Speculated to have highly advanced security measures.
Frequency Bands	2500 - 2700 MHz.	37GHz - 40 GHz.	6 GHz to 100 GHz.	6 GHz to 300 GHz.
Infrastructure	All-IP, packet switching, and ultra-bandwidth.	Packet switching, cloud computing, virtualization, slicing, and wireless www.	Intelligence, Edge computing, slicing, and full virtualization.	Speculated to have highly advanced infrastructure.
Key Focus	Greater data speeds and capacity, supporting complex and data-consuming services.	Significantly faster speeds and ultra-low latency.	Utilization of subterahertz and terahertz frequency ranges, achieving the fastest data transmissions ever.	Significant performance improvements, introducing new applications and use cases.
Latency	Improved latency compared to previous generations.	Ultra-low latency of 1 millisecond.	Low latency due to utilization of higher frequency ranges.	Satisfies latency requirement for critical communication.
Coverage	Globally deployed, replacing previous generation networks.	Offers extensive coverage.	Expected to provide extensive coverage by utilizing wider frequency bands.	Aimed to provide extensive coverage with energy-efficient technologies.
Economic Impact	Significant economic benefits from deployment and usage.	Expected to bring economic benefits in the short and long terms.	Anticipated to provide economic benefits from deployment and usage.	Economic benefits are expected from deployment and energy-efficient operations.
Mobility	350km/h.	500km/h.	1000 km/h.	> 1000km/h.
$\boldsymbol{Mbps/m^2}$	0.1	10	1000	> 1000
Overall Impact	Enabled the ushering in of futuristic technological advancements.	Revolutionizes industries and daily life with ultra-fast connectivity.	Expected to introduce capabilities and applications previously unfeasible.	Envisions advanced features and technology with substantial improvements over previous generations.

2 Spectrum Allocation and Utilization

In a wireless communication system implementation, the radio frequency (RF) spectrum should be considered a primary resource for transmitting information. Different generations of wireless communication systems are characterized by distinct frequency bands that are used for data transmission. Table 2 summarizes the spectrum used and the main challenges. Each generation presents unique challenges related to spectrum allocation, utilization, and efficiency. Overcoming these challenges is crucial for realizing the full potential of wireless communication systems and ensuring seamless connectivity in future networks, (Bangerter et al., 2014; Kumbhar, 2018; Breuer et al., 2020; Vaigandla et al., 2021).

Table 2: Frequency Ranges, Primary Uses, and Considerations

Frequency Range	Primary Use	Challenges and Considerations
2500 - 2700 MHz	4G systems	Enhanced broadband access, supports high-speed data transmission.
3.2- 3.5 GHz		Improved coverage and penetration in rural areas, challenges in urban environments.
27.5 - 28.35 GHz	5G: massive broadband uses in urban areas	High absorption rates due to atmospheric factors, challenges in maintaining signal integrity.
37 - 40 GHz	5G: massive broadband uses in Sub-urban areas	High absorption rates due to atmospheric factors, challenges in maintaining signal integrity.
6 to 100 GHz	6G Systems	Overcoming technological limitations in terahertz electronics for reliable communication. Addressing high propagation path loss and large bandwidth variations due to blocking effects of obstacles. Developing compatible hardware and infrastructure for terahertz communication. Ensuring regulatory compliance and standards development for terahertz spectrum usage. Integration with existing wireless systems and networks.
57 - 64 GHz	7G: worldwide applications	Challenges in atmospheric penetration and the potential for high data rates with innovative antenna technologies.
6 - 100 GHz	7G: urban and outdoor macro scenarios	Ensuring seamless coverage and capacity, and managing interference in densely populated areas.
Above 100 GHz	Indoor scenarios, potential for 7G systems and beyond	Strict spectrum management, efficient resource utilization, and the development of new spectrum sharing and management techniques.
6 - 300 GHz	7G: fulfilling coverage and capacity	Meeting high-level requirements including peak data rate, low latency, massive IoT connectivity, and efficient spectrum usage.

3 Network Architecture and Infrastructure

Analysis delineates the progression of wireless communication technologies from the established 4G to the envisioned 7G systems, elucidating improvements in network architecture, pivotal features, dependability, latency, and spectrum utilization. Each successive generation brings forth refinements aimed at addressing the escalating requirements of users and accommodating the emergence of novel technologies and applications. As depicted in Figure 2, the security and privacy dimensions of the 6G network are illustrated, underscoring the significance of these aspects (Vaigandla et al., 2021).

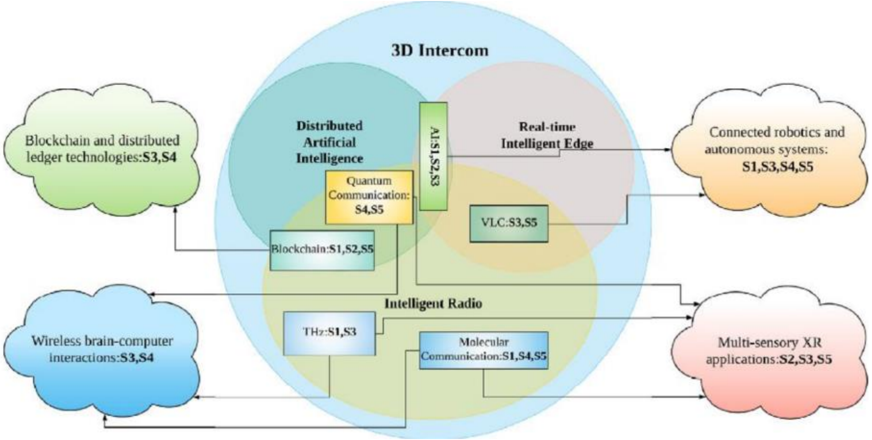

Figure 2: 6G Network for Security and Privacy Subjects Where S1: Authentication, S2: Access Control, S3: Malicious Behaviors, S4: Encryption, S5: Communication

Additionally, Table 3 presents a comparative overview of the network architectures and principal characteristics across the evolutionary advancements in wireless communication technology (Siva et al., 2017; Sun et al., 2019; Klein, 2020; Gyanchandani & Gyanchandani, 2024).

Table 3: The Network Architecture Aspects for 4G to 7G

Element	**4G Network Architecture**	**5G Network Infrastructure**	**6G Network Architecture**	**7G Network Infrastructure**
Communication Process	• Downlink: eNB broadcasts system information, UE acquires and decodes Master Information Block (MIB), and receives Reference Signal. • Uplink: UE performs uplink synchronization, transmits the Physical Random-Access Channel (PRACH), and sends the uplink synchronization signal to eNB.	• Quality and efficiency focused. • Cloud technologies maximize connectivity, communication, and data accessibility.	• Expected to increase network capacity, reliability, and edge performance. • Advanced antenna technologies enhance network capacity, reliability, and performance at the edge.	• Introduces low Earth orbit satellites to reduce latency. • Massive Multiple-In Multiple-Out (MIMO) technology for cellular networks. • Sophisticated frequency reuse patterns. • Digitized fiber optic backhaul.
Key Features	• Agile and effective data transfer. • Channel identification and synchronization. • Responsive data signaling • Error correction and integrity validation measures.	• Peak data rate of at least 20 Gbps downlink and 10 Gbps uplink. • Support for mobile devices with a minimum data rate of 100 Mbps. - 1,000 times more devices per meter than 4G. • End-to-end latency as low as 4 ms.	• Anticipated to increase network capacity, reliability, and performance. • Advanced antenna technologies like massive MIMO and active antennas enhance throughput and spectral efficiency. • Accurate beamforming and improved edge performance.	• Utilizes low Earth orbit satellites. • Massive Multiple-In Multiple-Out (MIMO) technology. • Sophisticated frequency reuse patterns. • Digitized fiber optic backhaul.
Network Capacity	• Increase in radio interface capacity promised, supporting higher data rates and improving user experience.	• Higher capacity to support data-hungry applications.	• Expected increase in network capacity to support new technologies. • Advanced antenna technologies improve throughput and spectral efficiency.	• Aims to significantly increase network capacity by utilizing low Earth orbit satellites and advanced cellular network technologies.
Reliability	• Enhanced reliability through improved data transmission and error correction measures.	• Enhanced reliability through advanced transmission technology and reduced latency.	• Improved reliability with advanced antenna technologies providing better throughput and signal quality.	• Expected to provide increased reliability through advanced satellite and cellular network technologies.
Network Management Automation	• Self-Organizing Networks (SON) • Dynamic Resource Allocation. • Policy-Based Management • Centralized Network Management.	• Emphasizes network flexibility. • Software-defined networking. • Network functions virtualization.	• Likely to employ network automation techniques to manage the complex network. • meet diverse service requirements.	

1) Data Rates and Throughput

The evolution of wireless communication from 4G to the anticipated 7G systems marks a remarkable journey characterized by exponential advancements in data rates and throughput. Every successful generation has pushed the limits of data rates and network capacity since 4G, which laid the foundation for mobile internet and high-speed multimedia services 4G connectivity revolutionized mobile connectivity, for seamless streaming, faster downloads and user experience improved. As the demand for faster and higher reliable wireless connectivity grows, 5G technology has ushered in a new era of superfast connectivity This technology promises to deliver unprecedented performance, and to enable advanced coding for a wide range of future applications such as augmented reality, autonomous vehicles and massive IoT deployments and modulation techniques, Benefit use of large MIMO systems, and the wide bandwidth that 5G networks are making new designs for throughput and network capacity Look ahead beyond 6G and researchers and industry experts are looking for more ambitious targets. Every successful generation has pushed the limits of data rates and network capacity since 4G, which laid the foundation for mobile internet and high-speed multimedia services 4G connectivity revolutionized mobile connectivity, for seamless streaming, faster downloads and user experience improved. As the demand for faster and higher reliable wireless connectivity grows, 5G technology has ushered in a new era of superfast connectivity This technology promises to deliver unprecedented performance, and to enable advanced coding for a wide range of future applications such as augmented reality, autonomous vehicles and massive IoT deployments and modulation techniques, Benefit use of large MIMO systems, and the wide bandwidth that 5G networks are making new designs for throughput and network capacity Look ahead beyond 6G and researchers and industry experts are looking for more ambitious targets. They envision terabit-per-second data rates and ultra-low latency connectivity that will redefine the boundaries of what is possible in wireless communication. Table 4 provides summaries of data rates and throughput (Rao et al., 2023; Ray et al., 2023; Kim & Yoo, 2018; Amit Kumar, 2023; Suyama et al., 2021; Xu, 2020).

Table 4: Data Rates and Throughput of Targeted Generations

Generation	Data Rates	Throughput	Challenges and Considerations
4G	Up to 1 Gbps (downlink)	Up to 500 Mbps	Achieved using LTE Advanced, WiMax, or HSPA+ technologies.
5G	Up to 20 Gbps (downlink)	Up to 10 Gbps	Utilizes sophisticated coding and modulation techniques, such as 256-QAM and MIMO.
6G	Anticipated close to 1 Tbps	Up to 500 Gbps	Challenges include spectrum scarcity, expanding frequency spectrum, and efficient modulation/coding schemes.
7G	Potentially 100x faster than 5G	Up to 1 Tbps	Challenges include massive MIMO development, machine learning integration, and achieving low latency.

The throughput for 6G is anticipated but not yet precisely defined. Likewise, the data rates for 7G are speculative, based on the potential improvements and advancements over 5G technology. Figure 3 illustrates the evolution of sub-generations within targeted wireless systems.

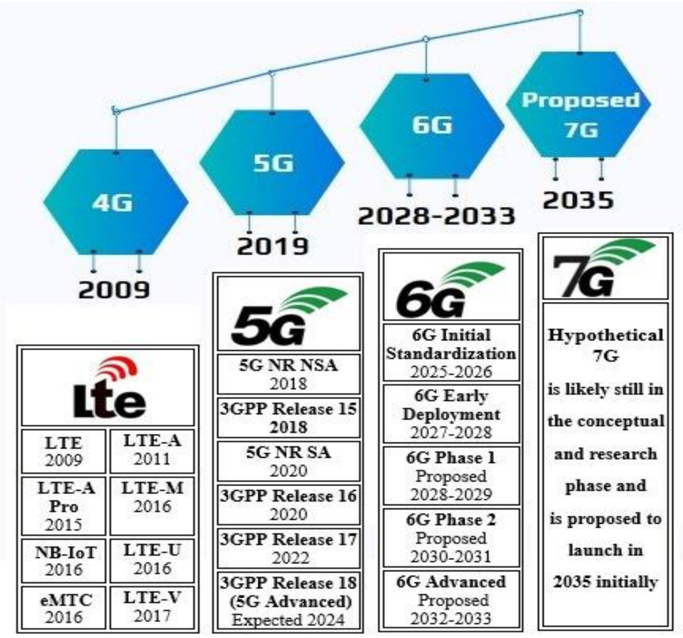

Figure 3: The Sub-Generations and the Estimated Launch Dates

2) Latency and Reliability

Substantial advancements in both latency and reliability have been exhibited by wireless communication technologies, which are critical attributes that determine the efficacy and utility of contemporary networks. Within the realm of 5G, a significant milestone has been marked by the introduction of ultra-reliable low latency communication (URLLC) services, providing genuine real-time control over wireless connections (Kumar et al., 2023). A wide range of applications, from enabling autonomous vehicles to facilitating time-sensitive industrial process control, is supported by this progress. A transformative evolution of reliability, defined as the consistency of performance despite external interferences and network fluctuations, is undergone with the advent of 5G and beyond. While moderate reliability suitable for conventional applications such as file downloads and streaming is offered by 4G networks, reliability classes tailored to various requirements, including massive machine-type communications and mission-critical scenarios, are introduced by 5G. This targeted approach ensures diverse reliability levels as guests guarantee that more resilient and flexible wireless environments are fostered (Mihret & Haile, 2021).

The wireless communication system's most crucial aspect is latency, a duration which signals endure while passing from their sources to the receiver. Reducing latency as a major aim of transitioning from 4G to 5G ensures exceptional real-time performance and many real-time applications. By envisioning accurate latency thresholds tailored for mission-critical applications, this pursuit of ultra-low latency has reached unprecedented levels through the advent of 6G. Thus, these advancements call for a complete reworking of protocol stacks which will fine tune communication procedures in order to lower down the network delay with no compromise on overall robustness. The future possibilities for wireless communication showcase increasing optimism as regards what might happen with 7G. These entail merging between communication and computation, deploying large-scale antenna systems or integrating artificial intelligence (AI) and machine learning (ML), all aimed at redefining the benchmark values for low-latency and reliability. This convergence is anticipated to usher in a new era of connectivity and innovation. The specific latency and reliability characteristics of the evolution of cellular technology are presented in Table 5 (Vaigandla et al., 2021; Zontou, 2023). The technical specifications for latency, jitter, and data rates from 4G to the hypothetical 7G are summarized in Figure 4 (Vaigandla et al., 2021; Shoewu & Ayangbekun Oluwafemi, 2020; Zontou, 2023; Takehiro, 2009).

Table 5: Latency and Reliability Comparison from 4G to 7G

Parameter	**4G**	**5G**	**6G**	**7G**
Latency (ms)	30	< 20	< 0.1	< 0.01
Reliability	Moderate	High	Targeted	Ultra-reliable
Description	Suitable for reliable file downloads and audio/video streaming applications.	Support for ultra-reliable low latency communication (URLLC) services. Offers very high-reliability classes for mission-critical communication.	Targeted latency levels can be as low as 100 microseconds for critical communications and 1 millisecond for general URLLC applications.	Promises a new era of ultra-low latency and ultra-reliable communication through the convergence of communication and computation, large-scale antenna systems, and AI/ML.

	4G	5G	6G	7G
1-Jitter	< 10 msec	< 3 msec	1 µsec	0.1 µsec
2-Latency	30 msec	< 20 msec	0.1 msec	0.01 msec
3-Energy/bit	NS	NS	1pJ/bit	1pJ/bit
4-Traffic Capacity	10 Mbps/m2	10 Mbps/m2	10 Gbps/m3	20 Gbps/m3
5-Localization Precision	8 cm on 2D	10 cm on 2D	1 cm on 3D	1 cm on 3D
6-User Experience	20 Mbps 2D	50 Mbps 2D	10 Gbps 3D	100 Gbps 3D
7-DL Peak Rate	100 Mbps	20 Gbps	100 Gbps	1 Tbsp.
8-UL Peak Rate	50 Mbps	10 Gbps	~1Tbps	~2Tbps
9-Reliability	FER 10^{-5}	FER 10^{-5}	FER 10^{-9}	FER 10^{-10}

Figure 4: The Technical Specifications for Latency, Jitter, and Data Rates from 4G to a Hypothetical 7G (Vaigandla et al., 2021; Zontou, 2023; Takehiro, 2009 & "What is Jitter, Wander and Latency," 2023)

3) Connectivity and Coverage

The transition from 4G to the anticipated 7G mobile network connectivity is a substantial advancement in coverage and connectivity, essential for ensuring universal access to high-speed data services. Within the framework of 4G Long-Term Evolution (LTE), the mobile user experience has been significantly shaped by critical factors such as efficiency, throughput, latency, and spectrum utilization (Akhtar et al., 2020). Technologies like MIMO have enhanced spectral efficiency and throughput, enabling peak data rates of up to 300 Mbps by 4G networks. Despite these achievements, coverage limitations are still faced by 4G networks due to constraints like frequency band restrictions and high penetration loss, particularly in suburban and rural areas. The area covered by 5G is expected to expand wider and have much higher data rates, which can only be obtained in some specific areas. The development of 5G networks is predicted to address the gap that exists between urban and rural areas with the help of advanced technologies such as Network Function Virtualization (NFV) and Software Defined Networking (SDN), thereby creating new prospects for economic development and innovation (Rajawat et al., 2021; Shi et al., 2020; Ahamed & Faruque, 2021). Hence, smart networking and satellite-connected systems must ensure continuous coverage across diverse geographical areas. Researchers and industry stakeholders are always on the verge of mobile network technology limits, leading to unmatched connectivity and transformative possibilities, as seen from the rise of 7G systems. This table 6 compares the changes from 4G LTE's coverage to expected 7G systems which manifest progressions in spectral efficiency, MIMO schemes, cell size, frequency bands as well as coverage enhancement strategies (Zhou et al., 2024; Wang et al., 2023; Akhtar et al., 2020; Rajawat et al., 2021; Shi et al., 2020; Ahamed & Faruque, 2021).

Table 6: Advancements in Spectral Efficiency, MIMO Schemes, Cell Size, Frequency Bands, and Coverage Enhancement Strategies

Aspect	4G LTE	5G Technology	6G Systems	7G Systems
Peak Spectral Efficiency.	15 bits/s/Hz downlink; 3.231×10^-3 bits/s/Hz/cell throughput.	30 bps/Hz	45 bps/Hz	Proposed to be 60 bits/s/Hz. Higher data rates and more users supported.
MIMO Scheme.	Utilizes 4x4 spatial multiplexing MIMO.	Implements advanced MIMO technology.	Supports multiple transmitters and receivers.	Enhanced coverage with better connectivity.
Cell Size.	Macrocells predominant in suburban and rural areas.	Utilizes macrocells, microcells, and picocells.	Coverage expanded to densely populated urban areas.	Continuous coverage from cities to the countryside.
Coverage Enhancement.	Limited extension due to high penetration loss and spectrum limitations.	Widened through extended sub-1GHz bands and high-frequency bands.	Expanded to densely populated urban areas and crowded buildings.	Satellite-connected system for continuous coverage.
Coverage connectivity.	Up to 100,000 devices/km².	Up to 1million devices/km².	Up to 5million devices/km².	Up to 10million devices/km².

4) Energy Efficiency and Sustainability

Because of the environmentally sustainable communication landscape, the development of 6G technologies and ongoing investigations into 7G signals signify the beginning of a transformative shift (Zhang et al., 2020). The proposed strategies for these next-generation networks aiming to enhance energy efficiency, necessitating interdisciplinary collaboration within the research community. Emerging 6G technologies and the frameworks of 7G is seeking to surpass the efficiencies achieved in 5G by exploring infrastructure-based energy-saving initiatives then integrating renewable energy sources. The transition from 4G to 5G has already demonstrated significant improvements in energy efficiency through strategies such as intelligent power management mechanisms and base station optimization. These advancements not only reduce operational expenses but also lay the base for environmental sustainable communication networks (Miao et al., 2021). As research progresses into the realms of 6G and the potential of 7G is considered, the emphasis on energy efficiency remains paramount that offering a vision of a future where communication networks operate sustainably and eco-consciously (Giordani et al., 2020). Table 7 below encapsulates the advancements in energy efficiency and sustainability across different generations of wireless communication networks (Miao et al., 2021; Giordani et al., 2020; Rappaport et al., 2013; Wang et al., 2021; Zhang et al., 2020).

Table 7: The Integration of Energy Efficiency with Economic and Social Sustainability

Aspect	4G LTE	5G Technology	6G Systems	7G Systems
Energy consumption	Over-provisioned infrastructure; research on intelligent power management mechanisms.	Focus on hardware efficiency, flexible infrastructure management, 'sleep mode' for energy optimization.	Expected to be nearly 100 times faster than 5G; higher energy efficiency and sustainability are anticipated.	Nanotechnology, energy harvesting, and intelligent device coordination for maximum energy efficiency.
Environmental Sustainability	Integration of renewable energy sources such as solar and wind power.	Ambitious targets for zero-carbon network deployment; EU initiatives.	Focus on reducing carbon footprint and end-of-life disposal impact.	Pervasive energy sustainability with renewable energy integration and efficient device coordination.
Economic Sustainability	Research on cost-effective solutions for renewable energy integration.	Economical studies predict reduced costs with renewable energy.	Economic constraints on deployment addressed by technological advances.	Economic viability supported by renewable energy and advanced technologies.
Social Sustainability	Preservation of existing systems; benefits for diverse user classes.	Continuity of services with manageable maintenance costs.	Ensuring accessibility and benefits for diverse user groups.	Achieving sustainable services for all user segments through efficient network management.

5) Security Challenges

The movement from 4G to the expected 7G cellular networks has witnessed significant strides in security showing the consistent efforts in preserving data and enhancing the network operational integrity. In 4G, protections are mostly centered on effective connection establishment by verifying if User Equipment (UE) is authorized to communicate with the network or not, using authenticated processes for deriving encryption keys which can apply to establish secure communication channels. When moving towards 5G, a different approach focuses on improvements in privacy safeguards that related to emerging services like machine-type communications (MTC) and Internet of Things (IoT). Additionally, this new technology bring about a flexible access control framework which allows for easy adjustments, so it supporting the management of resources and controlling who gets what and when (Odilov et al., 2024). Discussions about the next generation of wireless technologies, such as 6G, revolves around ensuring network security through migration patterns that will be leading to more advanced data encryption methods. This will be merged with artificial intelligence for better predictability and preventive actions. AI-powered security monitoring for the future 6G networks will be predicting and counteract real-time security threats to enhance network resilience and reliability. 7G is about to commence, and attention is now shifting towards quantum-secured encryption mechanisms that will change the security paradigm by protecting quantum vulnerabilities. Additionally, decentralizing communication architectures will introduce in 7G systems where communication nodes are scattered across a network, thereby removing any single point of failure and improving network resilience. Hence, these developments underscore an emphasis of prioritizing privacy, trustworthiness, and sustainability during the digital era. Table 8 highlights on privacy protection features of 4G through 7G mobile networks according to following papers (Yang et al., 2021; Bertino, 2023; Choudhury, 2022; Xu et al., 2022; Ounza, 2023; Sonwalkar, 2022).

Table 8: Aspects of Privacy Protection, New Services, Access Control Models, and Security Monitoring

Aspect	4G Systems	5G Technology	6G Systems	7G Systems
Privacy Protection	Mutual authentication between UE and network; encryption keys derived from authentication processes.	Reduced information transmission in initial network access; enhanced privacy support for new services.	Evolving encryption keys; proactive security monitoring with AI.	Quantum-secure encryption; decentralized communications for resilience against future threats.
Support for New Services	Limited support for MTC and IoT.	Facilitates the deployment of MTC and IoT; security for slices.	Enhanced encryption and access control; proactive security measures.	Decentralized communications; diverse applications for societal benefit.
Access Control Model	static access control hierarchy; authentication required before network access.	Dynamic access permissions based on real-time network status; proactive threat mitigation.	Evolving encryption keys; AI-driven security monitoring.	Quantum-secure encryption; proactive security measures for resilience against quantum computing threats; decentralized communications.
Security Monitoring	Standard security protocols.	Continuous security monitoring; dynamic adjustments based on the network status.	Utilization of AI for security monitoring; proactive measures to counter emerging threats.	Quantum-secure encryption; decentralized communications for resilience against future threats.

4 Advancement Applications

The realm of wireless communication networks has undergone significant evolution, with each generation introducing transformative applications and use cases. It starts with 4G networks; and emphasize network expansion and allow mobile broadband for growth, delivering applications such as mobile TV and mission-critical voice service 5G technology promises to transform industries, such as mobile broadband Energy, transportation, public safety, and so on. and health care. Notably, 5G is expected to revolutionize intelligent transportation design in the automotive industry. Looking ahead to the 6G strategy, anticipated applications include augmented reality, ubiquitous artificial intelligence and secure communications. These developments aim to facilitate sustainable development in the areas. But the future prospects for 7G systems, which are still in their infancy, hold enormous potential for even more impressive applications. Expected features such as very large connectivity, extremely low latency, easy coverage are expected to transform domains such as healthcare innovation, industrial automation, smart cities and intelligent transport system Notably namely, real-time remote health monitoring, intelligent diagnostics and seamless communication in healthcare sector mobility is starting to drive 7G smart in industrial automation and usher in the next wave of flexible manufacturing will be coming. In smart cities, these bright lights will greatly enhance traditional systems such as waste management. Furthermore, the intelligent transportation system can significantly improve traffic and fuel consumption through very large 7G networks and low latency factors to support 7G Specifications for mobile technologies across generations, including special functions, expected features. The implications of mobile technology across different generations that including key applications, anticipated features, and potential impacts, are outlined in Table 9. (Park & Kwon, 2011; Rappaport et al., 2013; Zhao et al., 2021; Islam & Hossain, 2020; Hossain et al., 2017; Al-Fuqaha et al., 2015 & Goumiri et al., 2023).

Table 9: Main Applications, Impact Areas, and Impacts of 4G to 7G Systems

Aspect	4G Systems	5G Technology	6G Systems	7G Systems
Key Applications	Mobile broadband, mobile TV, mission-critical voice and data services, and machine-to-machine communication for cyber-physical systems.	Mobile broadband, energy, transport, public safety, healthcare, intelligent transport systems, and diverse IoT applications.	Extended reality, ubiquitous artificial intelligence, digital replica, secured connectivity, and sustainable development initiatives.	Smart healthcare, industrial automation, smart cities, and intelligent transportation systems.
Impact Areas	Healthcare, public safety, industrial automation, and mobile communication.	Healthcare, automotive, energy, transportation, public safety, industry automation, and IoT.	Healthcare, smart cities, industrial automation, environmental monitoring, and intelligent transportation systems.	Healthcare, smart manufacturing, smart cities, and intelligent transportation systems.
Anticipated Features	Network capacity expansion, broadband access, and mission-critical communication.	Ultra-fast data rates, low latency, massive connectivity, network slicing, IoT support, and enhanced mobile broadband.	Ultra-high speed, low latency, ubiquitous connectivity, advanced security, AI integration, and sustainability initiatives.	Ultra-massive connectivity, ultra-low latency, seamless coverage, enhanced reliability, advanced security, and smart capabilities.
Potential Impacts	Improved patient care, remote diagnostics, and IoT advancements in industries.	Enhanced mobile internet, IoT proliferation, intelligent transport systems, smart cities, and improved industrial automation.	Enhanced user experiences, sustainable development, improved industrial efficiency, and transformative smart city solutions.	Revolutionized healthcare, advanced industrial automation, smart cities, and intelligent transportation systems.

5 Conclusion

This paper provides a thorough analysis of the advancements in wireless communication technology from 4G to 7G, highlighting significant improvements in network architecture, spectrum allocation, data rates, throughput, security, and coverage. A shift toward more efficient, high-speed, and high-capacity systems that cater to diverse user requirements across various sectors is marked by the evolution from 4G to 7G. Reliable and secure communication amidst evolving challenges is ensured by enhancing security and expanding coverage. Key statistical features of this paper is included as follows:

1. Data rates are increased from up to 1 Gbps in 4G to nearly 1 Tbps in proposed 7G.
2. Latency is reduced from 30 milliseconds in 4G to sub-millisecond levels in 7G.
3. Spectrum efficiency is improved from 15 bps/Hz in 4G to 60 bps/Hz anticipated in 7G.
4. The number of devices per square kilometer is expected to increase from 100,000 in 4G to over 10 million in 7G.
5. Mobility is increased threefold from 4G to 7G.
6. A 90% reduction in energy consumption per bit is achieved from 4G to 5G, with near-zero consumption anticipated in 7G.
7. Security enhancements progress from basic encryption in 4G to quantum-resistant encryption and AI-driven protocols in 7G.

The transition to 7G technology promises to meet society's evolving demands, enabling new applications and enhancing wireless communication quality. Continued research and innovation are crucial to fully realize the potential of 7G systems, benefiting individuals, businesses, and industries. Future trends and considerations for 7G systems include:

- Increasing reliance on 7G applications for security and job creation.
- Efforts towards higher efficiency and lower power consumption in 7G systems.
- Ongoing research into spectrum optimization and technological advancements.
- A focus on achieving high levels of security and minimizing latency in high-capacity systems.

Continued research and innovation are essential for the full realization of 7G systems and their impact on various industries and aspects of daily life.

References

[1] Ahamed, M. M., & Faruque, S. (2021). 5G network coverage planning and analysis of the deployment challenges. *Sensors*, *21*(19), 6608. https://doi.org/10.3390/s21196608

[2] Akhtar, M. W., Hassan, S. A., Ghaffar, R., Jung, H., Garg, S., & Hossain, M. S. (2020). The shift to 6G communications: Vision and requirements. *Human-centric Computing and Information Sciences, 10,* 53. https://hcis-journal.springeropen.com/articles/10.1186/s13673-020-00258-2

[3] Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, *17*(4), 2347-2376.

[4] Al-Obaidi, M. A. M., Ali, B. J., & Alkindy, B. (2022). A comparative study of the evolution different mobile generations for wireless communication. *Journal of the College of Basic Education, 26*(109), 488–497. https://doi.org/10.35950/cbej.v26i109.5352

[5] Amit Kumar, G. (2023). FSO-5G networks with enhanced throughput, reliability and low latency. *Petroleum and Chemical Industry International*, *6*(4), 290-295. https://doi.org/10.33140/pcii.06.04.08

[6] Bangerter, B., Talwar, S., Arefi, R., & Stewart, K. (2014). Networks and devices for the 5G era. *IEEE Communications Magazine*, *52*(2), 90-96. https://doi.org/10.1109/MCOM.2014.6736741

[7] Bertino, E. (2023). Privacy in the era of 5G, IoT, big data, and machine learning. *IEEE Security & Privacy*, *21*(1), 91–92. https://doi.org/10.1109/msec.2022.3221171

[8] Breuer, D., Mirahsan, F., & Kasparick, M. (2020). Fundamental technologies of 6G: Key drivers, enabling technologies, and challenges. *IEEE Communications Magazine*, *58*(3), 33-39. https://doi.org/10.1109/MCOM.001.1900497

[9] Bykovsky, A. Y., & Kompanets, I. N. (2018). Quantum cryptography and combined schemes of quantum cryptography communication networks. *Quantum Electronics*, *48*(9), 777. https://doi.org/10.1070/QEL16732

[10] Choudhury, H. (2022). Enhancing the Elliptic Curve Integrated Encryption Scheme in 5G mobile network for home network identity privacy. *Security and Privacy*, *5*(4), e222. https://doi.org/10.1002/spy2.222

[11] Debbarma, K., & Praveen, K. (2019). LIS Education in India with the Emerging Trends in Libraries: Opportunities and Challenges. *Indian Journal of Information Sources and Services*, *9*(S1), 41–43.

[12] Di Domenico, A., Perna, G., Trevisan, M., Vassio, L., & Giordano, D. (2021). A network analysis on cloud gaming: Stadia, geforce now and psnow. *Network*, *1*(3), 247-260.

[13] Eswaran, S. (2022). Opportunities and Trends of Wireless Communications. *IRO Journal on Sustainable Wireless Systems*, *4*(2), 102-109.

[14] Giordani, M., Polese, M., Mezzavilla, M., Rangan, S., & Zorzi, M. (2020). Toward 6G networks: Use cases and technologies. *IEEE Communications Magazine*, *58*(3), 55-61.

[15] Goumiri, S., Yahiaoui, S., & Djahel, S. (2023). Smart mobility in smart cities: Emerging challenges, recent advances and future directions. *Journal of Intelligent Transportation Systems*, 1–37. https://doi.org/10.1080/15472450.2023.2245750

[16] Gyanchandani, V., & Gyanchandani, V. (2024). 7G network: The next generation of connectivity - TTC. TT Consultants. https://ttconsultants.com/7g-network-a-game-changer-for-mobile-and-internet-connectivity

[17] Hossain, M. S., Islam, S. H., Ahammad, T., & Rahman, A. (2017). Internet of things (IoT) applications: A systematic review. *Future Generation Computer Systems*, *87*, 661-675.

[18] Islam, S. H., & Hossain, M. S. (2020). Applications of 5G technology in healthcare: A survey. *Journal of Network and Computer Applications*, *150*, 102501.

[19] Jameel, A., & Shafiei, M. M. (2017). QoS performance evaluation of voice over LTE network. *Journal of Electrical and Electronic Systems*, *6*(1), 1-10.

[20] Karthikeyan, G., Manoharan, A., & Swaminathan, S. (2019). A Scientometric Study on Neuro Science with Special Reference to Growth of Literature. *Indian Journal of Information Sources and Services*, *9*(S1), 77–79.

[21] Khan, M. S., & Salah, K. (2019). Smart cities and 5G: Complementary technologies for sustainable urban development. *Sustainable Cities and Society*, *45*, 577–586.

[22] Kim, H. (2020). 5G core network security issues and attack classification from network protocol perspective. *Journal of Internet Services and Information Security*, *10*(2), 1-15.

[23] Kim, J. H., Kim, M., Park, M., & Yoo, J. (2023). Immersive interactive technologies and virtual shopping experiences: Differences in consumer perceptions between augmented reality (AR) and virtual reality (VR). *Telematics and Informatics*, *77*, 101936. https://doi.org/10.1016/j.tele.2022.101936

[24] Kim, S., & Yoo, Y. (2018). Contention-aware adaptive data rate for throughput optimization in LoRaWAN. *Sensors*, *18*(6), 1716. https://doi.org/10.3390/s18061716

[25] Klein, A. E. (2020). 6G research challenges. *IEEE Journal on Selected Areas in Communications*, *38*(4), 680-688. https://doi.org/10.1109/JSAC.2020.2984769

[26] Koi-Akrofi, G. Y., Kuuboore, M., Odai, D. A., & Kotey, A. N. (2023). Telecommunications wireless generations: Overview, technological differences, evolutional triggers, and the future. *International Journal of Electronics and Telecommunications*, *69*(1), 105–114. https://doi.org/10.24425/ijet.2023.144338

[27] Kumar, N., Ch, S., & NCRTCA. (2023). Advancements and analysis of cellular networks: A comprehensive research study. *International Journal of Engineering Research & Technology (IJERT)*, *11*(06).

[28] Kumar, S. (2022). *Wireless Communication-the Fundamental and Advanced Concepts*. River Publishers.

[29] Kumbhar, A. (2018). 5G NR (New Radio) speed, bands, specifications, overview. RF Wireless World. https://www.rfwireless-world.com/Terminology/5G-NR-speed-bands-specifications-overview.html

[30] Li, Q., & Wu, Z. (2020). 5G-enabled healthcare: Opportunities, challenges, and applications. *Journal of Medical Internet Research*, *22*(8), e19577.

[31] Liu, P., & Springer, A. (2014). Space shift keying for LOS communication at mmWave frequencies. *IEEE Wireless Communications Letters*, *4*(2), 121–124. https://doi.org/10.1109/lwc.2014.2381671

[32] Liu, Z., & Chen, S. (2024). Design principles and challenges of 7G wireless communication systems: A review. *IEEE Journal on Selected Areas in Communications*, *42*(5), 1124–1138.

[33] Miao, G., Zhang, Y., Li, D., & Cui, Q. (2021). Green and energy-efficient design for 5G and beyond wireless networks: Techniques, challenges, and prospects. *IEEE Transactions on Green Communications and Networking*, *5*(1), 2-19.

[34] Mihret, E., & Haile, G. (2021). 4G, 5G, 6G, 7G and Future Mobile Technologies. *American Journal of Computer Science and Information Technology, 9*(2), 75.
[35] Mishra, A., Mao, Y., Sanguinetti, L., & Clerckx, B. (2022). Rate-splitting assisted massive machine-type communications in cell-free massive MIMO. *IEEE Communications Letters, 26*(6), 1358-1362.
[36] Nowaczewski, S., & Mazurczyk, W. (2020). Securing Future Internet and 5G using Customer Edge Switching using DNSCrypt and DNSSEC. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, *11*(3), 87-106.
[37] Nur, G., Barış, B. N., Levent, B., Sazaklıoğlu, B. S., & Ak, E. (2023). BUSER Transcutaneous Electric Nerve Stimulator Device Design. *Natural and Engineering Sciences*, *8*(1), 18-30.
[38] Odilov, B. A., Madraimov, A., Yusupov, O. Y., Karimov, N. R., Alimova, R., Yakhshieva, Z. Z., & Akhunov, S. A. (2024). Utilizing Deep Learning and the Internet of Things to Monitor the Health of Aquatic Ecosystems to Conserve Biodiversity. *Natural and Engineering Sciences*, *9*(1), 72-83.
[39] Olga, F., Larisa A., Heriberto, S.S., Shiguay, G.G.A., Angélica, S.C., Fernando, W.M.G., & David, A.P. (2023). Advancements in Flexible Antenna Design: Enabling Tri-Band Connectivity for WLAN, WiMAX, and 5G Applications. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications*, *14*(3), 156-168.
[40] Ounza, J. E. (2023). A taxonomical survey of 5G and 6G security and privacy issues. *Global Journal of Engineering and Technology Advances*, *14*(3), 42-60.
[41] Park, J., & Kwon, T. (2011). The success factors of 4G mobile communication service: Case of LTE. *Journal of The Korean Institute of Communication Sciences*, *29*(4), 69-78.
[42] Park, K., Lee, J., & Kim, S. (2023). Towards 6G wireless communication systems: Requirements, challenges, and opportunities. *IEEE Communications Magazine*, *61*(2), 98–105.
[43] Rajawat, A. S., Bedi, P., Goyal, S. B., Shukla, P. K., Jamal, S. S., Alharbi, A. R., & Aljaedi, A. (2021). Securing 5G-IoT Device Connectivity and Coverage Using Boltzmann Machine Keys Generation. *Mathematical Problems in Engineering*, *2021*(1), 2330049. https://doi.org/10.1155/2021/2330049.
[44] Rao, A. S., Mole, S. S. S., & Raju, D. V. R. (2023). Beyond 5G and 6G: A Comprehensive Overview of 7G Wireless Communication Technologies. *European Chemical Bulletin*, *12*(4), 9725-9739.
[45] Rappaport, T. S., Sun, S., Mayzus, R., Zhao, H., Azar, Y., Wang, K., & Gutierrez, F. (2013). Millimeter wave mobile communications for 5G cellular: It will work!. *IEEE Access*, *1*, 335-349.
[46] Ray, J. K., Bera, R., Sil, S., Alfred, Q. M., Mondal, S. A., & Pit, M. (2023). Estimation of Reliability, BER, BLER and Throughput During the Coexistence of 4G LTE and 5G NR. *In International Conference on Advanced Communication and Intelligent Systems*, 179-195.
[47] Seraji, N., Ahmed, T., & Al Muntasir, F. (2023). Performance analysis of the physical layer of long-term evolution (LTE). Australian *Journal of Engineering and Innovative Technology*, 72–93. https://doi.org/10.34104/ajeit.023.072093.
[48] Sharma, A., & Singh, B. (2023). Interdisciplinary collaborations in wireless communication research: Trends and perspectives. *IEEE Transactions on Emerging Topics in Computing*, *11*(1), 1124-1138.
[49] Shi, L., Xu, S., Liu, H., & Zhan, Z. (2020). QoS-Aware UAV Coverage path planning in 5G mmWave network. *Computer Networks*, *175,* 107207. https://doi.org/10.1016/j.comnet.2020.107207
[50] Shoewu, O. O., & Ayangbekun Oluwafemi, J. (2020). Insights into the development trends in 7G mobile wireless networks. *Journal of Advancement in Engineering and Technology*, *8*(1), 202.

[51] Siva, R., Gajendran, P., & Asha, M. (2017). A study on 4G technology. *In IEEE International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT)*, 301-304. https://doi.org/10.1109/ICICICT1.2017.7975321

[52] Solyman, A. A. A., & Yahya, K. (2022). Evolution of wireless communication networks: from 1G to 6G and future perspective. *International Journal of Electrical and Computer Engineering*, *12*(4), 3943-3950.

[53] Sonwalkar, V. (2022). 7G communications. Medium. https://vsonwalkar3.medium.com/7g-communications-b0a8c6bb6b00

[54] Sun, S., Li, X., Zhang, S., Wang, W., & Wang, X. (2019). Key technologies for 5G wireless communications: Machine learning, IoT, MAC layer, and RANs. *IEEE Wireless Communications*, *26*(2), 153-159. https://doi.org/10.1109/MWC.2019.1800103

[55] Suyama, S., Okuyama, T., Kishiyama, Y., Nagata, S., & Asai, T. (2021). A study on extreme wideband 6G radio access technologies for achieving 100Gbps data rate in higher frequency bands. *IEICE Transactions on Communications*, *104*(9), 992-999.

[56] Takehiro, N. (2009). 3GPP TSG-RAN Chairman, ITU-R WP 5D 3rd Workshop on IMT Advanced. https://www.3gpp.org/img/pdf/2009_10_3gpp_imt.pdf

[57] Talić, Z., & Mešić, M. (2022). Landslide Remediation on Location of Transmission Line Pole SM 134 on DV 110 kV TS TUZLA C. – TS Dubrave. *Archives for Technical Sciences*, *1*(26), 33–42.

[58] Vaigandla, K. K., Azmi, N., Podila, R., & Karne, R. K. (2021). A survey on wireless communications: 6g and 7g. *International Journal of Science, Technology & Management*, *2*(6), 2018-2025.

[59] Vaigandla, K. K., Bolla, S., & Karne, R. (2021). A survey on future generation wireless communications-6G: requirements, technologies, challenges and applications. *International Journal of Advanced Trends in Computer Science and Engineering*, *10*(5), 3067-3076. https://doi.org/10.30534/ijatcse/2021/211052021

[60] Wang, C., Zhang, P., Kumar, N., Liu, L., & Yang, T. (2022). GCWCN: 6G-based global coverage wireless communication network architecture. *IEEE Network, 37*(3), 218-223.

[61] Wang, H., & Li, Y. (2022). Challenges and opportunities in 6G wireless networks: A systematic review. *IEEE Wireless Communications Letters*, *11*(3), 1124–1131.

[62] Wang, Q., Zhu, H., Zhu, X., & Zhu, X. (2021). Green communication for future 7G: A green relay-based multi-scale dynamic network architecture. *IEEE Network*, *35*(1), 140-146.

[63] What is jitter, wander and latency in LTE / 5G / 6G system? (2023). Telecom Hall Forum. Retrieved from https://www.telecomhall.net/t/what-is-jitter-wander-and-latency-in-lte-5g-6g-system/25615.

[64] Xu, G. (2020). Research on 6G characteristic attenuation rate. *In Journal of Physics: Conference Series*, *1693*(1), 012091. https://doi.org/10.1088/1742-6596/1693/1/012091

[65] Xu, Q., Su, Z., & Li, R. (2022). Security and privacy in artificial intelligence-enabled 6G. *IEEE Network*, *36*(5), 188-196.

[66] Yang, C., Wu, S., & Wang, L. (2021). Security and privacy in 5G and beyond: A comprehensive survey. *IEEE Internet of Things Journa*l, *8*(16), 12354-12385.

[67] Zahra, M. M. A., & Abdul-Rahaim, L. A. (2022). Performance of RoF-MMW-WDM Backhaul System based on Hybrid Optical OFDM Transportation Enabling 128-QAM Format for B5G Communication Networks. *Journal of Internet Services and Information Security*, *12*(4), 164-176.

[68] Zhang, H., Chen, X., & Wang, Y. (2022). Technical specifications and performance metrics of 5G networks: A comprehensive review. *IEEE Transactions on Wireless Communications, 21*(3), 1124–1138.

[69] Zhang, L., & Wang, J. (2021). 5G-enabled industrial internet of things: State-of-the-art, challenges, and opportunities. *IEEE Transactions on Industrial Informatics, 17*(6), 4512–4522.

[70] Zhang, W., Wang, H., Zhang, Y., & Cui, Y. (2020). Energy-efficient resource allocation for NOMA-based ultra-dense networks: A deep reinforcement learning approach. *IEEE Transactions on Vehicular Technology*, *69*(12), 14708-14718.

[71] Zhang, Y., Li, D., Zhao, J., & Zhang, Y. (2020). Energy-efficient communications in beyond 5G networks: A comprehensive survey. *IEEE Communications Surveys & Tutorials*, *22*(4), 2623-2653.

[72] Zhao, W., Pang, Y., & Zhang, P. (2021). Toward 7G: Trends, key technologies, and challenges of future mobile communication systems. *IEEE Access*, 9, 57065-57081.

[73] Zhou, D., Sheng, M., Bao, C., Hao, Q., Ji, S., & Li, J. (2024). 6G Non-terrestrial networks-enhanced IoT service coverage: Injecting new vitality into ecological surveillance. *IEEE Network*. https://doi.org/10.1109/MNET.2024.3382246

[74] Zontou, E. (2023). Unveiling the Evolution of Mobile Networks: From 1G to 7G. *arXiv preprint arXiv:2310.19195*.

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