



Review On: “5G Horizons: Technologies Shaping the Future of Wireless Communication”

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Abstract

The evolution from 4G to 5G addresses growing demands for higher data rates, reduced latency, and improved Quality of Service (QoS). 5G introduces a user-centric architecture that integrates diverse wireless technologies and supports seamless switching via policy routers. Key features include ultra-dense radio access networks (UDRAN), mobile traffic offloading, cognitive radio (CR), software-defined radio (SDR), and software-defined networking (SDN). These innovations enable faster data speeds, massive call volume capacity, and enhanced connectivity. Foundational technologies for 5G include IEEE 802.11 WLAN, 802.16 WMAN, WPAN, and digital wireless networks. Unlike 4G, which unified standards post-deployment, 5G integrates IEEE 802.xx networks from inception. Projects led by researchers, telecom industries, and academia are shaping 5G's architecture and performance. Future networks aim for speeds up to 1 Gbps using smart antennas and adaptive modulation. 5G also supports hybrid infrastructure and emphasizes consumer experience. Emerging paradigms like the World-Wide Wireless Web (WWWW), Dynamic Adhoc Wireless Networks (DAWN), and Real Wireless Communication further define its scope. With ultra-high bandwidth and advanced capabilities, 5G is set to revolutionize mobile communication and become the dominant global technology.

Keywords: Faster Speeds, Lower Latency, Wider Bandwidths, Massive Connections, Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), Massive Machine-Type Communications (mMTC), mmWave, MIMO, and Network Slicing.

1. Introduction

5G, the fifth generation of wireless communication technology, is expected to bring a revolutionary impact across multiple sectors of society. As mobile traffic continues to rise due to cloud gaming, high-resolution video streaming, and virtual reality, the limitations of 4G have become increasingly clear. Future applications such as autonomous vehicles, unmanned aerial vehicles (UAVs), and immersive VR demand ultra-fast, highly reliable networks that only 5G can provide. Researchers from both academia and industry are working together to make 5G a reality, using advanced technologies such as Network Function Virtualization (NFV) and Software-Defined Networking (SDN). With data

transmission rates of up to 10 Gbps, nearly 100 times faster than 4G, and latency as low as one millisecond, 5G offers near-instant responses. It goes beyond speed to integrate with IoT, AI, cloud computing, big data, and blockchain, enabling innovative services and interconnected smart ecosystems. The ability of 5G to support billions of devices with near-complete coverage makes it a foundation for healthcare, energy, and smart city applications. In healthcare, it will allow real-time communication between advanced medical devices, while in energy, it can enable intelligent virtual power plants for efficient resource use. Countries like South Korea have already begun applying 5G to real-time energy



trading, demand management, and distributed resource control. Through AI and big data, 5G can analyze and predict energy consumption patterns, while digital twin technology supports real-time simulations to balance production and usage. Blockchain adds a further layer of security by enabling transparent and secure transactions. Global technology companies including Intel, Qualcomm, Nokia, Samsung, and Ericsson are leading investments, recognizing 5G as a critical driver of future growth. The network will also evolve into 5G-as-a-Platform (5GaaS), providing a base for hyper-connected services. For industry, 5G enables Industrial IoT (IIoT), where high reliability, low latency, and strong security are essential. Features such as enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), and Massive Machine-Type Communications (mMTC) make industrial applications feasible. With support for mobile edge computing, AI-driven optimization, and private campus networks, 5G addresses challenges in flexibility, scalability, and security. Ultimately, 5G is not just a faster mobile network but a transformative platform that will drive future innovation, connect billions of devices, and reshape the way societies and industries operate.

1.1. From Analog to Ultra-Fast: The Road to 5G

The Era of 1G Mobile Networks: The first generation (1G) of mobile networks was launched in 1979 in Tokyo, Japan, by Nippon Telephone and Telegraph (NTT), and by the early 1980s it had expanded to the United States, the United Kingdom, Finland, and other parts of Europe. Based on analog signals, 1G offered limited capabilities but marked the beginning of mobile communication. Popular systems of this generation included the Advanced Mobile Phone System (AMPS) in the USA, the Nordic Mobile Telephone System (NMTS) in Nordic countries, the Total Access Communication System (TACS) in the UK, and the European Total Access Communication System (ETACS) in Europe. The technology operated at frequencies of 800–900 MHz with a bandwidth of 10 MHz, supporting 666 duplex channels of 30 KHz each, and used analog switching with frequency modulation (FM). It provided only

voice services and employed Frequency Division Multiple Access (FDMA) as the access technique. However, 1G suffered from several drawbacks such as poor voice quality due to interference, short battery life, bulky and inconvenient handsets, low security that allowed calls to be intercepted, limited coverage and user capacity, and the absence of roaming between networks [1].

The Era of 2G Mobile Networks: The second generation (2G) mobile communication system was introduced in the early 1990s and marked the transition from analog to digital technology. It primarily used Global System for Mobile Communications (GSM) along with other standards such as IS-95 (CDMA) and IS-136 (D-AMPS). Operating in the 900 MHz and 1800 MHz frequency bands, 2G provided digital voice transmission with improved call quality, greater security, and the introduction of text messaging (SMS) and multimedia messaging (MMS). Data services were very limited, with speeds up to 64 kbps in GSM and slightly higher in CDMA systems. Despite these improvements, 2G was still constrained by low data rates and could not support high-speed internet or advanced applications [2].

The Era of 3G Mobile Networks: The third generation (3G) mobile networks emerged in the early 2000s and were designed to provide better data services alongside voice communication. Built on technologies such as Universal Mobile Telecommunications System (UMTS) and Code Division Multiple Access 2000 (CDMA2000), 3G operated mainly in the 2.1 GHz frequency band. It offered higher data speeds ranging from 384 kbps to a few Mbps, enabling mobile internet access, video calling, and basic multimedia streaming. This generation represented a significant shift from voice-centric communication to data-oriented services, laying the foundation for mobile applications and internet-enabled devices. However, the infrastructure cost was high, and network coverage was not always consistent, which limited its adoption in some regions [3].

The Era of 4G Mobile Networks: The fourth generation (4G) of mobile communication, launched around 2009, was a major advancement that

introduced all-IP (Internet Protocol) based networks. Using Long Term Evolution (LTE) and LTE-Advanced technologies, 4G provided much higher data rates, with download speeds ranging from 100 Mbps to 1 Gbps under ideal conditions. Operating in frequency bands such as 700 MHz, 1800 MHz, and 2600 MHz, 4G enabled high-definition video streaming, online gaming, faster browsing, and seamless use of applications requiring real-time data transfer. It also offered improved spectral efficiency, enhanced security, and better support for global roaming compared to earlier generations. However, 4G deployment required significant investment in infrastructure, and performance often varied depending on location and network congestion.

The Era of 5G Mobile Networks: The fifth generation (5G) mobile communication system, introduced in the late 2010s, represents a revolutionary step forward in wireless technology. Operating in frequency ranges from sub-6 GHz to millimeter waves (up to 100 GHz), 5G offers extremely high data rates exceeding 10 Gbps, ultra-low latency as low as 1 ms, and massive connectivity to support billions of devices. Based on technologies such as Massive MIMO, beamforming, and network slicing, 5G enables advanced applications including autonomous vehicles, smart cities, industrial automation, augmented and virtual reality, and the Internet of Things (IoT). Its high reliability and scalability make it suitable for mission-critical services and next-generation innovations. Despite its transformative potential, 5G deployment faces challenges such as high infrastructure costs, limited initial coverage, and concerns about spectrum availability [4-6].

1.2. Figures



Figure 1 5G Services

1.3. 5G Services

The 5G system (5GS) introduces advanced capabilities to support a wide range of services and markets. One of its core features are,

Enhanced Mobile Broadband (eMBB): Which enables significantly higher data rates. Outdoor downlink speeds can reach up to 50 Mbps and indoor speeds up to 1 Gbps (5GLAN), with uplink speeds being half of these values. A notable application is in aviation, where eMBB has delivered data rates of up to 1.2 Gbps to airborne flights.

Critical Communications (CC) and Ultra-Reliable Low Latency Communications (URLLC): Designed for scenarios requiring extremely high reliability, such as remote control of process automation, URLLC delivers a reliability of 99.9999%, user-experienced data rates up to 100 Mbps, and end-to-end latency as low as 50 ms. These capabilities are enabled through Edge Computing, ensuring minimal delays and highly reliable performance.

Massive Internet of Things (mIoT): This is also a vital component, supporting very high traffic densities across a wide variety of IoT devices and services. This ensures the scalability and flexibility required for the expected explosion of connected devices in the 5G era. Complementing this, 5GS provides flexible network operations: Including network slicing, scalability, security, efficient content delivery, interworking with other systems, and diverse mobility management. These features enable 5G to support new market sectors, often referred to as "verticals", which include automotive, rail and maritime communications, transport and logistics, automation, energy distribution, public safety, healthcare, smart cities, and entertainment. Importantly, the 5G system maintains support for most 4G LTE services, while also enabling seamless mobility between the 5G core network and the existing 4G EPC with minimal impact on user experience.

1.4. Social Impact of 5G in Rural Areas

Fifth-generation (5G) networks can significantly improve mobile broadband access in rural regions. Traditionally, high deployment costs and low average revenue per user (ARPU) have hindered network

expansion in these areas. However, 5G implementation can become more cost-effective through technologies like TV White Space and traffic offloading. Additionally, favorable signal propagation in high-frequency bands allows for the use of smaller base stations, making rural deployment more viable and affordable, shown in Figure 1.

1.5. Alternative Offloading Techniques for Mobile Networks

WiMAX (World-wide Interoperability for Microwave Access) can serve as an offloading option, mainly for backhauling large-scale Wi-Fi systems. However, integration with 3GPP-based mobile networks remains limited, requiring additional standardization. Device-to-device (D2D) communication, operating in licensed bands, offers offloading potential similar to mobile ad-hoc networks (MANETs) that use unlicensed spectrum. Future mobile systems could enhance offloading capabilities by combining these technologies. Cognitive radio (CR) can extend this further through intelligent traffic management. For example, a mesh of White-Fi hotspots and Wi-Fi backhauled via WiMAX or wired broadband, integrated with D2D links and femtocells, presents a viable offloading solution, shown in Table 1.

2. Tables

2.1. “Numerology Framework in NR “

Table 1 Numerology Framework in NR

Numerology (μ)	Δf ($2^\mu \cdot 15$ [kHz])	Cyclic prefix	Number of OFDM symbols per slot	T_{slot} [ms]
0	15	Normal	14	1
1	30	Normal	14	0.5
2	60	Normal/Extended	14/12	0.25
3	120	Normal	14	0.125
4	240	Normal	14	0.0625

2.2. Over All Architecture of 5G Wireless Technology

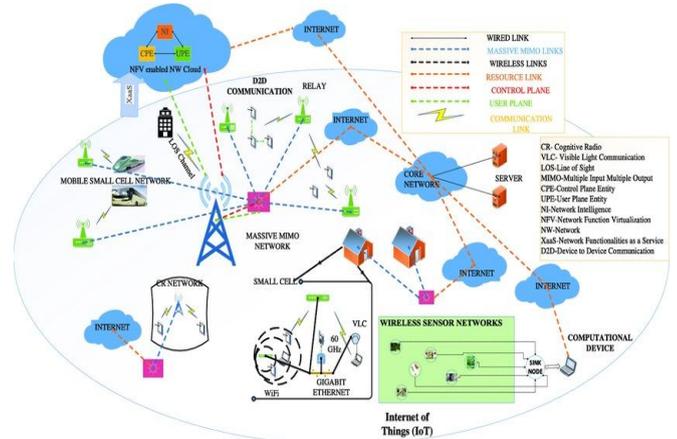


Figure 2 5G Wireless Technology

2.3. Global 5G Services Shares and Trends

The 5G services market is expected to grow from USD 205.52 billion in 2023 to USD 497.24 billion by 2028, with a CAGR of 19.3%. Key drivers include the integration of 5G in environmental monitoring and sustainability. Its high-speed, low-latency networks enable real-time data collection and efficient resource management. In smart agriculture, 5G allows precision farming by providing instant feedback on soil, weather, and crop health, optimizing irrigation, fertilization, and pesticide use while reducing waste. Additionally, 5G supports smart grid systems to enhance energy distribution efficiency. By enabling swift data transmission from environmental sensors, 5G promotes sustainable, responsive solutions and environmentally conscious practices, shown in Figure 2 & 3.

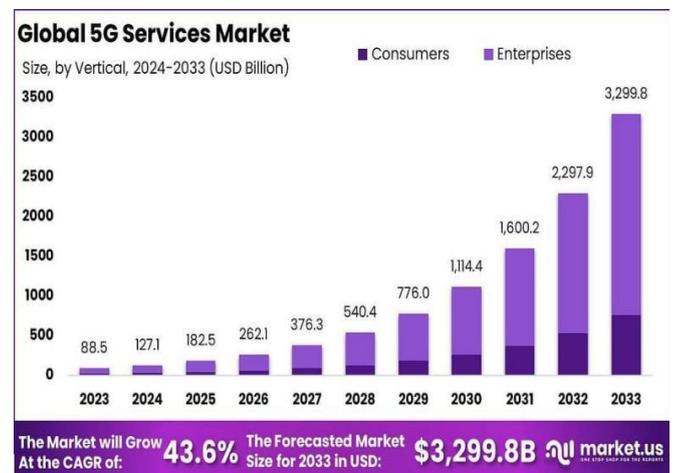


Figure 3 Global 5G Services Shares and Trends



2.4. Applications of 5G Wireless Technology

2.4.1. Smart City

A smart city integrates technology, human capital, and governance to improve sustainability, efficiency, and social inclusion. It uses digital technologies to collect and share data across sectors like transportation, healthcare, energy, and community services. As of 2022, major investments were in visual surveillance, public transit, and outdoor lighting.

2.4.2. 5G Drones

5G drone technology leverages high speed, ultra-low latency, and massive connectivity for real-time data transmission, autonomous control, and swarm coordination. It transforms sectors like agriculture, security, and logistics through remote operation, immediate analysis, and automation over long distances.

2.4.3. Industrial Automation

5G enables ultra-low latency, high reliability, and seamless IoT connectivity in smart factories. It supports applications like AGVs, predictive maintenance, and remote human-robot interaction, leading to improved efficiency, quality control, lower costs, and enhanced security in industrial manufacturing.

3. Results and Discussion

3.1. Results

The 5G network architecture features key components enabling multi-Gigabit speeds, massive IoT capacity, and ultra-low latency. Its flexible, software-defined, cloud-native design supports diverse services via network slicing and an intelligent core for efficient resource and user management. Key highlights include the shift from hardware to software functions, adoption of technologies like OFDM and MIMO, and integration of AI/ML for automation and improved service quality.

3.2. Discussions

5G evolves previous mobile tech using OFDM for efficient data transmission. Its cloud-native core boosts scalability, agility, and cost-effective management. The architecture supports diverse services—from enhanced broadband to massive IoT and ultra-reliable low latency. Future research targets better network resilience, resource allocation, and

performance using methods like reinforcement learning.

Conclusion

5G adopts a cloud-native, service-based architecture (SBA) with SDN and NFV, enabling high speed, low latency, scalability, and flexibility. It supports applications like autonomous vehicles, smart cities, and IoT, while offering end-to-end network slicing and API exposure through NEF. Despite challenges in deployment, cost, and security, it provides a strong foundation for future innovation and economic growth.

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