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ORIGINAL RESEARCH ARTICLE

From 5G to 6G: Requirements, challenges, and technical specification

Hafida Amgoune*, **Tomader Mazri**

Advanced Systems Engineering, Ibn Tofail University, Kenitra 14000, Morocco

*** Corresponding author:** Hafida Amgoune, hafida.amgoune@gmail.com

ABSTRACT

5G is being rolled out in different parts of the world. The latter has a high-level infrastructure enabling various technologies, including eHealth remote monitoring, robotics, automation, Smart City, Smart Home, Smart Campus, etc. However, as these new technologies evolve rapidly, networks become increasingly complex and challenging to maintain. To this end, several research groups worldwide have already begun researching the sixth generation. This article presents the features and requirements of 6G, the current technical challenges facing 5G, the 6G network architecture, and the spectrum for the future 6G.

Keywords: 5G; 6G; 6G Services; 6G architecture; 6G spectrum; 6G security

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1. Introduction

Telecommunications have undergone significant recent shifts, moving from conventional wire line based services to data-based services and from non-intelligence devices to intelligent handheld computers and laptops. The advent of 5G has brought numerous benefits to mobile networks, such as increased mobility, high bandwidth, and other essential elements fostering mobile engagement. The development of next-generation technologies has introduced advancements like millimeter wave, small cells, massive MIMO, beamforming, and full duplex to enhance communication among multiple devices. However, it has become imperative for companies to transition beyond 5G and design a new architecture that integrates the technological needs of individuals and the society.

Presently, the focus is on a new generation, 6G, which has emerged and is a prime area of research interest. This new generation must establish a fresh consensus to achieve ultra-reliable-low-latency communication (URLLC). However, spectral resources are scarce to meet the throughput demands, leading to intolerable latency. Additionally, collisions in the shared spectrum render channels unreliable. Therefore, there is an urgent need to develop practical spectrum-sharing algorithms to support URLLC in both 5G and 6G[1]. Spectrum management plays a critical role deploying new wireless technologies. In the 5G era, regulators introduced various pectrum management options enabling cellular network deployment, including traditional national-only licenses, local-level licenses, and unlicensed approaches that involving different levels of spectrum sharing[2]. In order to improve mobile communication that is based on the sixth generation, many aspects need to be improved: latency (less than 1 ms), data rate (up to Tbps), quality of service (QoS), and system capacity. Nevertheless, numerous challenges need addressing for the implementation of such networks[3].

The remainder of this paper is structured as follows: Section 2 introduces the evolution of the mobile network. section 3 presents the current technical challenges facing 5G, the 6G architecture, and the requirements of 6G. Following that, section 4 focuses on the spectrum for the future 6G. Section 5 presents 6G and AI. Section 6 introduces security challenges of AI in the context of 6G Finally, we conclude in Section 7.

2. Overview

A mobile telephone network facilitates the use of millions of mobile, stationary, and cellular phones simultaneously, enabling high-speed and long-distance communication[4]. This network employs a 'cellular' structure that efficiently reuses frequencies and allows users in motion to switch cells (handover) without disrupting ongoing communications. over recent years, the mobile network has seen extensive development[5], progressing from the introduction of 1G, followed by 2G, then 3G and 4G, and more recently, 5G, with the anticipated future emergence of 6G[6]. **Figure 1** illustrates the evolution of mobile communication.

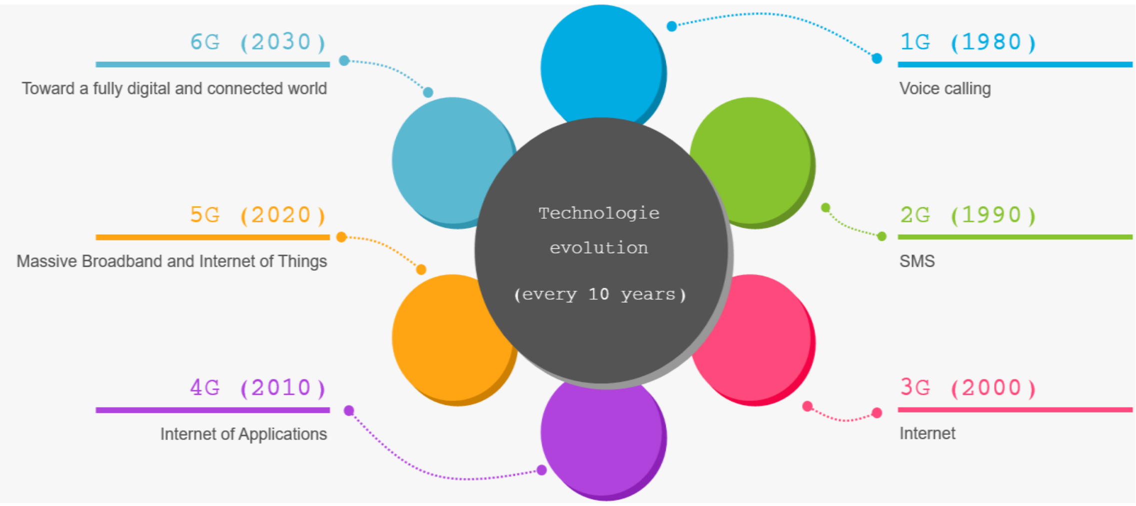

Figure 1. Communication development mobile.

The first network generation, 1G, marked a significant telephony revolution with its analog operation and usage of large devices[7]. Subsequently, the fully digital 2G rendered 1G networks obsolete, launching in 1990. Its cell system based on numerical technology for link and signal transmission[8], employing standards such as GSM (Global System for Mobile communications) and CDMA (multiple access division codes) that utilized varying frequency bands in Europe and the United States[9,10].

The transition from 1G to 2G had allowed for low-volume digital data communication, including SMS and multimedia messages such as MMS. Further enhancements led to GPRS (General Packet Radio System), a precursor to 3G, offering theoretical speeds up to 40 kbit/s, termed "2.5G"[11]. Continuing the 2G history, EDGE (Enhanced Data Rates for Global Evolution) emerged, boosting the velocity to a theoretical 384kbit/s, labeled "2.75G"[12].

The aim of 3G was to achieve speeds surpassing 144 kbit/s[13], that enabled multimedia applications, such as video transmission, videoconferencing, and high-speed Internet access. utilizing frequency bands different from previous networks. The primary 3G norm in Europe is UMTS (Universal Telecommunications system) and the 5MHz frequency band for voice and data transfer with speeds ranging from 384 kbps to 2 Mbps[14].

The advent of 4G revolutionized data exchange by separating internet data and phone conversations,providing speeds go from 100 Mb/s to 1 GB/s[15].

5G is standed as a pivotal technology offering mobile telecommunication speeds in the gigabits per second range, a significant leap compared to networks in 2010 and about 1000 times faster than 4G[16,17]. This generation adopts the 5G-NextGen Core (5GC), which refers to the new 5G network architecture released by 3GPP. This 5G architecture provides excellent flexibility in managing heterogeneous devices and applications[18].

Looking forward, The sixth generation (6G) between 2020 and 2030 aims to introduce benefits such as the transition from radio spectrum to sub-teraherz and optical, utilization of artificial intelligence and machine learning autonomous networks development, network integration, and innovative applications[19]. **Figure 2** below illustrates the evolution of mobile telecommunication:

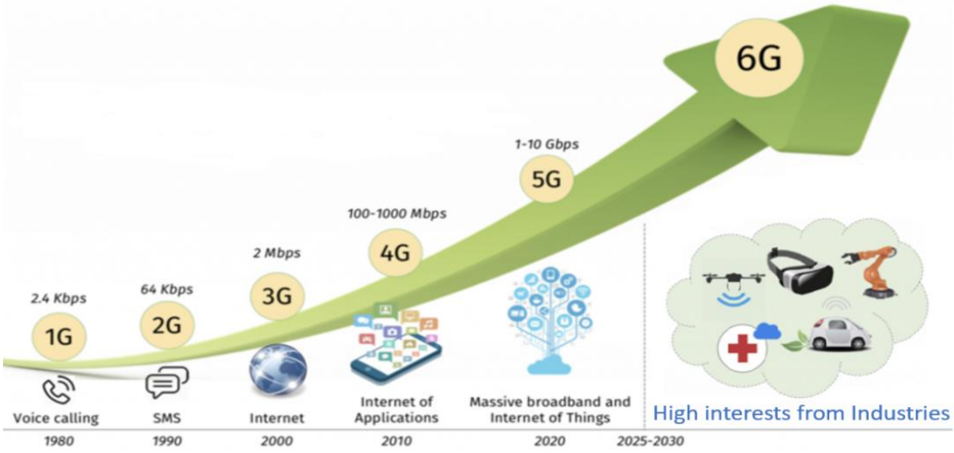

Figure 2. Evolution of technologies and services in mobile communications[19].

3. Evolution path from 5G to 6G

By 2024, the expection that the worldwide count of 5G users will hit 2.3 billion, coinciding with a surge in urban populations, transforming many cities into bustling hubs. Projections indicate that by 2050, approximately 68% of the global population will reside in urban areas[20].

Consider a scenario where 5G reaches its limitations, necessitating the exploration of alternative technologies. Luckily, scientific research into B5G (Beyond 5G) and 6G has already commenced, focusing on a complex yet fascinating realm of virtual reality. However, the evolution of 6G won’t happen overnight. The progration will progress much like maturation of the 5G network. In essence, 6G builds upon and advances the foundation established by the 5G ecosystem[21].

While 5G networks prioritize high capacity, extensive coverage, seamless connectivity, high accessibility, and low latency, 6G aims to push these technological benchmarks further, initially achieving data rates surpassing 100 Gbps and potentially reaching up to 1 Tbps per user[22]. This advancement will require exploring new spectrum bands beyond mmWave and into the highest THz frequencies. To facilite this, the FCC has already opened up the spectrum from 95 GHz to 3 THz for wireless communication devices in the United States.

Moreover, the 6G network strives to support incredibly low latency (less than 1 ms) universally, not just for specific services like presented in 5G. Additionally, it seeks to extend coverage effectively by harnessing maritime, celestial, and satellite communications, aiming to connect up to 10 million devices per square kilometer.

Maintaining reliability across all network facets will rely on a superior quality of service. Artificial intelligence will have a crucial role in optimizing the network's architecture, enhancing its efficiency, flexibility, and overall performance[23].

Telecom industries are targeting the initial deployment of 6G networks by 2030, coinciding with the maturity of 5G. 6G, beyond being a mere upgrade in communication generations, aspires to contribute to achieving the United Nations Sustainable Development Goals (SDGs) by 2030.

In addition, 6G aims to extensively leverage smart digital technology, virtual reality applications, and fully controlled humanoid robots to execute diverse tasks[24]. The Evolution path from 5G to 6G, as outlined by 3GPP, is depicted in **Table 1** below[25].

Table 1. Evolution path from 5G to 6G.

Rel-15 (2018) 5G Phase 1	Rel-15 includes work on: - Machine-type communications (MTC) and Internet of Things (IoT). - Vehicle-to-Everything Communications (V2X) Improvements - Mission Critical (MC) improvements - WLAN and unlicensed spectrum - System enhancements (control plane-user plane separation; QoE: Quality of Experience; virtual reality, codec, and multimedia-related improvements; AAS: active antenna system)
Rel-16 (2020) 5G Phase 2	Rel-16 includes work on: - Enhancement of Ultra-Reliable (UR) Low Latency Communications (URLLC) - Support of LAN-type services - IoT - User identities, authentification, multi-device - Advanced V2X support - Mission-critical, public warning - Network slicing
Rel-17 (2021)	- NTN: Non-Terrestrial Network - Frequency bands - NR light
Rel-18 (2022)	- System Architecture and Services - Security and Privacy - Multimedia Codecs, Systems, and Services - Management, Orchestration, and Charging - Application Enablement & Critical Communication Applications - Radio Layer 1(RedCap Evolution) - Radio Layer 2 & Layer 3 Radio Resource Control - UTRAN/E- UTRAN/NG-RAN architecture & related network interfaces - Radio Performance and Protocol Aspects
6G (2030)	- High-fidelity holograms - Multisensoriy communications - Pervasive AI - THz Communication - VLC - 1Tbps

3.1. Current technical challenges facing 5G

As the number of users and data generation for mobile phones and devices, the latest generation (5G) encountered limitations due to the frequency spectrum constraints. The sixth generation was introduced, to address this issue. 5G, designed to support high-frequency bands such as the mmWave band exceeding 10 GHz, offers fast wireless data communication at several gigabits per second using extensive bandwidth.

However, enhancing mmWave technology specifically for mobile communications is imperative, particularly in terms of coverage improvement and uplink performance in areas with poor connectivity. These improvements are crucial for specialized industrial applications that demand high performance[3].

Future advancements in 5G technology must cater to diverse industrial needs more flexibly, requiring improved data rates, particularly for scenarios involving large data downloads[26]. The fifth generation faced varios technical challenges[26,27]:

- Accommodating over 35 billion connected devices By 2035, necessitating scalable connectivity solutions;
- integration of 3D networks, drones, and satellites into mobile networks;
- Explore higher frequencies such as visible light and terahertz;
- Advancing Internet of Things (IoT) technologies for Ultra-Reliable and low-latency Communications (URLLC) in Industrial Internet of Things (IIoT) and smart cities' infrastructure;
- Developing Wireless Intelligence;
- Progress towards Autonomous Cars for safer and more efficient driving;
- Address societal challenges;
- Facilitate communication between humans and devices;
- Expand the communication environment;
- Enhance cyber-physical fusion;
- Implementing Blockchain and DLT services with low latency, scalability, and reliable connections, crucial for establishing robust 6G wireless networks;

The shift from the fifth-generation to the sixth-generation (5G to 6G) mobile networks brings plenty of benefits. These include enhanced mobility, high bandwidth, and critical features for mobile engagement. These features encompass advanced addressing, providing users with exceptional addressing capabilities, precise positioning for location-based services, and the integration of virtual reality. Refer to **Figure 3** for an overview of the technical challenges encountered in 5G.

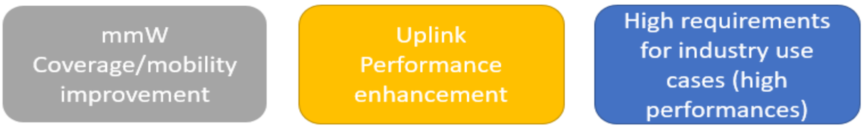

Figure 3. 5G technical challenges.

3.2. 6G network architecture

Compared to 5G, future 6G technologies are anticipated to offer even higher data rates, lower latency, increased component density, and massive integration of artificial intelligence into all network segments.

However, as we advance toward 6G, many problems need addressing. The future 6G wireless network will comprise small mobile radio cells aiming to deliver vast amounts of information rapidly and efficiently, without energy wastage. Therefore, connections to these cells will need radio links capable of transmitting at speeds of 100 Gbps on a single channel, making Terahertz band frequencies an ideal solution. Furthermore, seamless integration of wireless transmission links with fiber networks becomes crucial and to amalgamate the strengths of both technologies, focusing on capacity, reliability, mobility, and flexibility.

For global coverage, the 6G mobile system will integrate a 5G mobile wireless system and a satellite network. Satellites act as radio repeaters in space, collecting Earth-generated signals, amplifying them, and returns them to Earth, either at the same point of signal origin or at a variant position. Refer to **Figure 4** for an illustration of a 6G architecture. This technology aims to utilize millimeter wave, THz, and visible light bands for extensive coverage, employing cellular mobile communications for medium and full coverage. Satellite integration will be pivotal for achieving global coverage[28].

Further innovations in the 6G architecture might encompass virtualization of supplementary devices, efficient power harvesting, green power strategies for low-power nodes, cell-free architectures, and multi-connectivity.

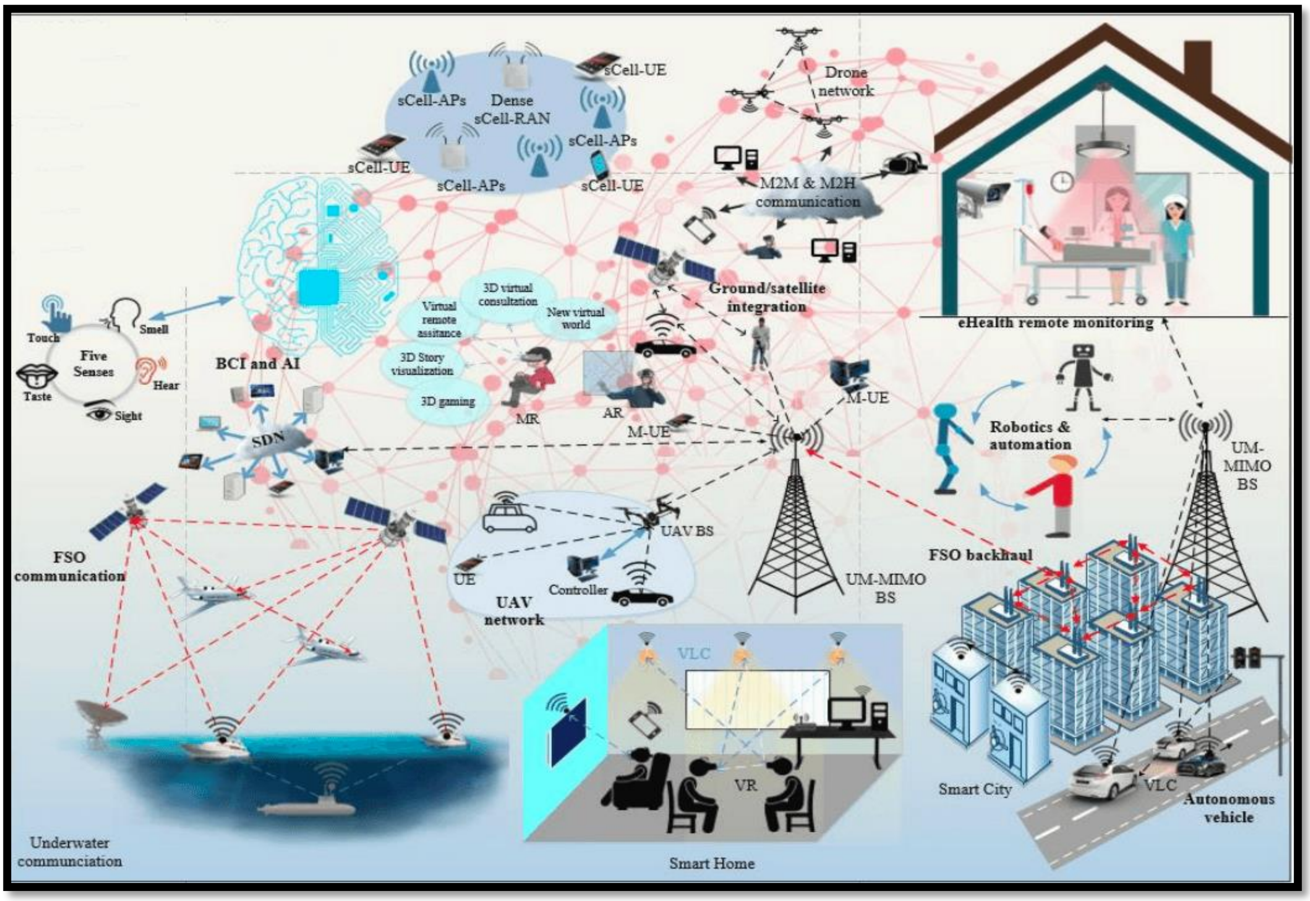

Figure 4. 6G architecture[29].

3.3. Requirements of 6G

Humans and machines will be the primary users of the 6G. The 6G will be defined by providing advanced services such as immersive extended reality (XR), high-fidelity mobile holograms, and digital replicas[30], The **Figure 5** shows these services.

Immersive extended reality (XR): XR is a term used to broadly designate a suite of immersive technologies, including AR (augmented reality), VR (virtual reality), and MR (mixed reality). These technologies will be one of the core services of 6G and will open up a great future for many domains such as healthcare, education, science, and industry[31,32].

Figure 5. 6G services.

High-fidelity mobile hologram: Holographic technology requires multiple-view cameras and high data rates to function correctly. This technology will be used in applications such as communication and telemedicine[33].

Digital replicas: In 6G, Digital replicas will reach an important level by using sophisticated sensors, AI, and matching innovations to reproduce certifiable elements into an advanced circle.

The requirements for 5G focus primarily on performance aspects; Samsung identifies three requirements that must be met to deliver 6G services: performance, architecture, and reliability. Some examples of 6G performance demands are a maximum data rate of 1000 Gbps and an air latency of fewer than 100 μs[34]. Refer to **Figure 6** fors a comparison of the main performance requirements between 6G and 5G.

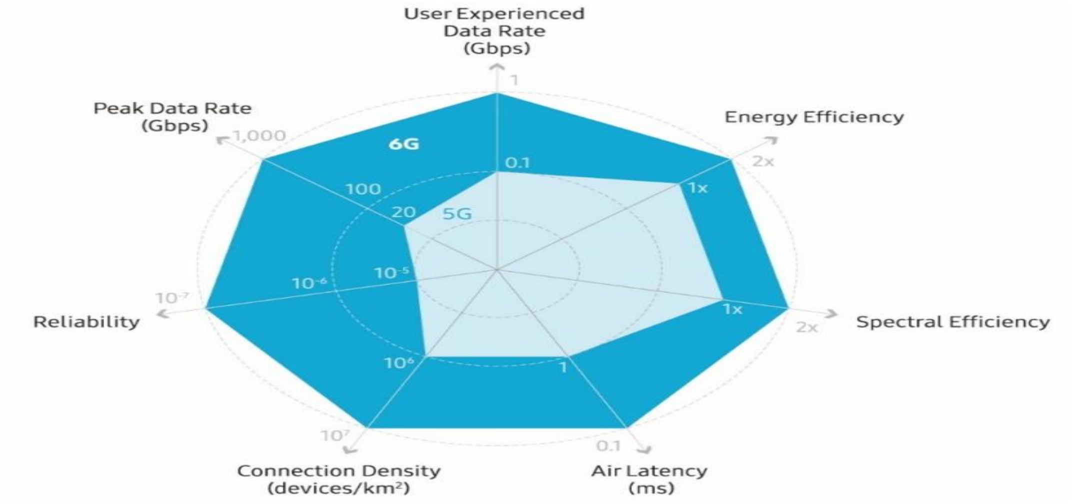

Figure 6. Comparison of the main performance requirements between 6G and 5G.

Higher bit rates and lower latency will pave the way for the introduction of innovative services, including ubiquitous edge intelligence, ultra-massive machine-type communications, highly reliable communications, and high-precision communications. These services aim to address more stringent demands, particularly in the following areas: energy efficiency, spectral efficiency, security, and privacy. Artificial intelligence approaches and techniques, such as machine learning and reasoning, are the fundamental catalysts for optimizing networks, enhancing the overall end-user experience, and facilitating the development of innovative service applications. In particular, the massive Internet of Things, industrial IoT, fully automated robotic platforms, vehicles, and extended reality are examples of new data-intensive applications that will enforce new performance goals and motivate the design and deployment of 6G[35].

4. Spectrum for the future 6G

The requirement for higher speeds and capabilities has pushed mobile communication systems to use larger frequency bands[36]. New frequency bands between 3 GHz and 6 GHz and between 24 GHz and 50 GHz have been assigned for 5G in different areas. The progression of 5G will indeed involve new bands between 52.6 GHz and 114 GHz[37].

Signal propagation in these higher bands is also tricky, as they are easy to block due to their short wavelength. The diffraction of the objects is limited, and the absorption of the signal by water is critical[38].

In addition to exploiting the sub-terahertz frequency bands, massive, low-cost MIMO techniques will allow better spectrum utilization in the mmWave and cmWave bands. Initial mmWave systems were based on analog beams and limited the number of users served[39].

As network density grows and massive MIMO technologies are reduced, multi-user MIMO techniques will be largely usable in the mmWave bands to exploit the available spectrum with massive, multi-user MIMO techniques. Today's high bands will be transformed into medium bands in the 6G era. In the lower frequency bands for 6G, the lower cmWave band, the applicability of Massive MIMO is progressively more limited by the larger dimension of the antenna elements[40].

The available spectrum is rare, and investigation on enhancing spectrum usage for lower frequency bands is critical. Spectrum allocation will shift from static allocation among operators and services to more dynamic access based on artificial intelligence across time, frequency, and space. Visible light communication will probably be used in restricted situations. However, it is not very likely to become a common 6G technology, as radio communications will be expensive to realize with identical data rates[41].

In the last few years, there has been a massive growth in wireless data traffic, driven by many wireless communication technologies. This explosive increase has been matched by increased data rates and improved connectivity. New wireless research and development trends include terahertz (0.1 to 10 THz). The THz band can offer Tbps links for enhanced ultrafast mass data transfer between nearby equipment in terabit personal and local wireless networks to high-definition video conferencing between mobile devices in small cells.

The terahertz frequency band relates to electromagnetic waves. It is intermediate between microwave and infrared frequencies, the **Figure 7** depicts this frequency band.

The THz bands allow for significant transceivers, and antenna development is advancing, as THz connections become a viable alternative for indoor communication networks. More recently, significant progress has been made in the development of a wireless network-on-chip (WNoC) employing the THz bands[42].

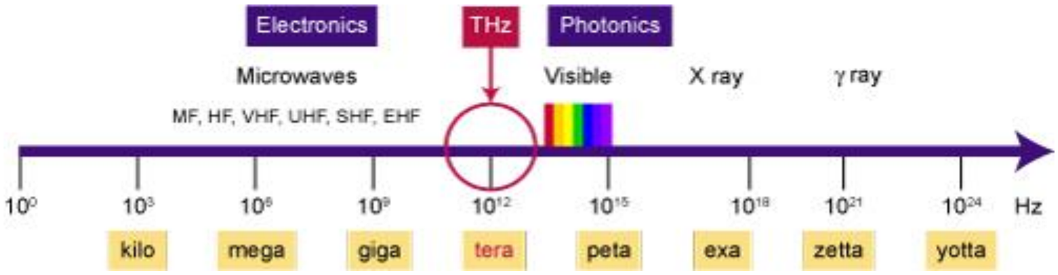

Figure 7. The THz band offers hundreds of GHz usable spectrum resources for wireless communication links in long, medium, short, indoor, and near-field ranges.

THz wireless communications have several unconventional uses and application cases. Due to the distinct electromagnetic and photonic characteristics of this highly high-frequency band, the THz band can be operated for the following scenarios[43]:

- Local Area Networks: Several spectral windows are now available for short-range links under 10 meters, specifically 625–725 GHz and 780–910 GHz[41]. THz-band communications should form the THz-optical link to allow a seamless transition between fiber and THz-band links without any latency;
- Personal Area Networks: THz-band communications can deliver a wireless “fiber-optic” data rate between multiple devices within a few meters. These types of communication scenarios are found in indoor offices and multimedia kiosks;
- Data Center Networks: Conventional data centers manage and maintain cable connectivity in wired networks, which results in high installation and reconfiguration costs. In contrast, THz links offer promising prospects for seamless ultra-high-speed connectivity in fixed networks and flexibility for equipment reconfiguration;
- Nano-networks: With its wavelength in the nanometer range (109 m), the THz band can perform better than any other frequency in nano-networks. In this context, a nano-network is a set of interconnected nanodevices or nanomachines to exchange, store, and compute information.

Samsung also suggests using radio waves to carry 6G communications. The 6G should therefore be deployed in the Terahertz band, that is to say, from a few hundred Gigahertz (GHz) to 3000 GHz (or 3 THz)[34].

In addition, the Federal Communications Commission in the US, In March 2019, opened the spectrum between 95 GHz and 3000 GHz for practical use and non-licensed applications to support the growth of novel wireless communication technologies[44].

5. 6G and Artificial Intelligence

AI will play an essential role in optimizing 6G networks by ensuring network management, connectivity, and security.

- Network Management: AI will be used to monitor and dynamically manage 6G network traffic. It will be able to anticipate user needs, optimize the use of network resources, and respond in real-time to fluctuations in demand. AI will also enable automatic network configuration based on specific requirements, making 6G networks more flexible and adaptable.
- Connectivity: AI will facilitate more efficient and reliable connectivity in 6G networks. It will be capable of optimizing antenna and channel selection, reducing interference, and improving service quality. Additionally, AI will enable multimodal communications, where devices can seamlessly switch between different communication technologies (such as 6G, Wi-Fi, and others) to ensure uninterrupted connectivity.
- Security: AI will play a major role in the security of 6G networks. It will be able to proactively detect and respond to threats by monitoring network traffic to identify suspicious activities. Furthermore, AI will be essential for implementing advanced security mechanisms, such as biometric authentication, encryption key management, and intrusion detection.

6. Security challenges of AI in the context of 6G

Since 6G is still an evolving technology, it is difficult to specify the specific attacks for this network generation, as they will largely depend on how the technology is deployed and utilized. It should also be noted that this generation of wireless communications promises unprecedented levels of connectivity but also presents significant security challenges, particularly with the integration of artificial intelligence (AI) into the network infrastructure.

However, some security concerns that could arise in 6G include:

- Data Privacy Attacks: With higher speeds and processing capabilities, attackers could more effectively target users’ personal data[45].
- Internet of Things (IoT) Network Attacks: 6G will enable even broader connectivity of IoT devices. Vulnerabilities in these devices could be exploited to disrupt networks[46].
- Enhanced DDoS Attacks: Like with 5G, DDoS attacks could leverage 6G's high bandwidth to overwhelm networks and services[47].
- Man-in-the-Middle (MitM) Attacks: The ultra-fast communications of 6G could be intercepted and manipulated by attackers.
- Autonomous Vehicle Security Attacks: 6G will play a crucial role in communications between autonomous vehicles. Security flaws could endanger road safety[48].
- Advanced Adversarial Attacks: AI models used in 6G networks are vulnerable to adversarial attacks. Attackers can deliberately manipulate input data to induce errors in AI predictions, which can be particularly concerning for critical applications like network management[49].
- AI Model Integrity: The security of AI models is critical, as attacks aimed at altering or compromising models could have serious consequences. Guarantees of model integrity, traceability, and access control must be established.
- Training Data Protection: Data used to train AI models must be protected, including data privacy and

prevention of sensitive information leaks that could be maliciously exploited.

- Autonomous System Security: 6G networks are likely to integrate AI-powered autonomous systems. These systems must be protected against attacks and manipulation, as they can significantly impact network management and security[50].
- Anomaly and Threat Detection: AI-based anomaly detection mechanisms must be resistant to attacks and capable of identifying malicious activities while minimizing false positives.
- Transparency and Explainability: AI models used in 6G networks can be extremely complex, making it difficult to understand their decisions. Model transparency and explainability are essential for security vulnerability detection.
- Data Fusion and Privacy: Data fusion from multiple sources can create privacy vulnerabilities. 6G networks will need mechanisms to protect the privacy of merged data[51].
- Operational Security: Operations and management of 6G networks, assisted by AI, must be resilient to attacks and failures to maintain connectivity and services in case of security incidents.
- Security Scalability: With the growth of 6G networks, security must be scalable to adapt to an increasing number of devices, services, and demands.

Refer to **Table 2** for an overview of security threats and potential solutions.

Table 2. Study of security threats and potential solutions.

Security issue	**Implications**	**Suggested solution**
Data Privacy Attacks	Loss of sensitive data User privacy violation Theft of personal information Compromise of confidential data	Access management Application security Security awareness Proactively monitor network traffic and activities Multi-factor authentication
Internet of Things (IoT) Network Attacks	Deniel f Service (DoS) Energy consumption Privacy violation Closing reassembly buffer	Anomaly detection through IDS Verification via the hash chain function Split buffer approach Digital Signature and mutual Authentication
Enhanced DDoS Attacks	Network resource overload Performance slowdowns Disruption of business operations Financial losses	Traffic filtering Load balancing Employee awareness Ongoing monitoring Enhancement of firewalls and intrusion prevention systems Business continuity plan
Man-in-the-Middle (MitM) Attacks	Sensitive data interception Data tampering Espionage Breaches of confidentiality	Data encryption Strong authentication Use of digital certificates Continuous network monitoring
Autonomous Vehicle Security Attacks	Risk to road safety Risk to data privacy Poor communication between autonomous vehicles	Cryptography Intrusion detection
Advanced Adversarial Attacks	AI prediction errors Security flaws in critical applications Disruption of critical services Privacy breaches	Implement regular and corrective updates Establish a certificate management system
AI Model Integrity	Poor AI decisions Privacy loss Damaged reputation Potential for cascading attacks	Anomaly detection through IDS Verification via the hash chain function

7. Conclusion

6G aims to connect a vast array of devices to the Internet, expanding beyond the capabilities of current 5G technologies.

The fundamental difference between 5G and 6G lies in the integration of artificial intelligence (AI) technologies. These advancements will enable 6G operators to create seamless experiences across diverse networks, including licensed and unlicensed spectrum bands, as well as satellite-based systems. AI will play a crucial role in managing communications across varios spectrum bands low, medium, millimeter (mmWave), and terahertz.

In summary, 6G technology is poised to significantly enhance network performance, integrate different technologies, improve the quality of service, and ultimately contribute to the creation of an ultra-smart society with virtually everything.

Author contributions

Conceptualization, HA; methodology, HA; writing—original draft preparation, HA; writing—review and editing, HA; visualization, TM; supervision, TM. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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