# Towards 6G: Understanding Network Requirements and Key Performance Indicators

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**Abstract:**

Although the fifth-generation (5G) is not yet officially launched, researchers worldwide have turned to the sixth-generation (6G) communications system. The 3G has opened the gap to fourth-generation (4G). It will be the same for 5G, which will facilitate the path to 6G. The technology 5G provides a high-level infrastructure enabling various technologies such as autonomous cars, artificial intelligence, drone networking, mobile broadband communication, and, most importantly, the Internet of Things (IoT) and the concept of smart cities. We are, therefore, in the middle of the fourth industrial revolution (Industry 4.0). However, as new technologies gain traction, networks become increasingly complex and difficult to pin down to keep networks operating at the level prescribed by evolving services. The ultimate goal of 6G is to move from the concept of the internet of intelligent things to the new idea of the intelligent internet of intelligent things. This article shows the features and tools of 6G technology that will help meet these traffic needs. Besides, we highlight the main feature of the 6G, in terms of architecture and services, scheduled as recommended by the International Telecommunications Union (ITU) in its current technical specifications and discussions on the latest research in this area.
**Keywords:** Internet; 5G; 6G; Wireless Communication; Artificial Intelligence (AI); Drone Networking; Internet of Things (IoT); Network 2030.

## 1 Introduction

Mobile communications have been fundamental in the production of our contemporary connected societies. From older analog mobile systems to more sophisticated long-term evolution (LTE) networks, advances in wireless systems have radically changed the way humans access and exchange information.

Currently, wireless communications are at a crossroads. Indeed, the ever-increasing demand for capacity and the proliferation of smart devices, with applications requiring high speeds, need new generations of more efficient networks to enable a substantial increase in performance. Fifth-generation (5G) mobile communications systems are emerging at high speed to meet a wide range of challenges brought by our current and future societies' thirst for wireless communications. 5G must tackle, in addition to increasing traffic volume, the challenge of connecting billions of devices with heterogeneous service needs.

With the beginning of global commercialization of the fifth-generation mobile network (5G), the sixth generation (6G) research initiatives have gained significant attention in academia and industry, focusing on identifying the main drivers and performance requirements, and technological innovations related to the future generation 6G. By targeting 6G, the International Telecommunication Union (ITU) has created a "Focus Group on Technologies for Network 2030" (FG-NET2030) for the future network so-called "Network 2030" [1]-[3].

Several initiatives have been made, in fact, in the United States; the Federal Communications Commission (FCC) has decided to open the Terahertz spectrum for 6G [4] and has also suggested using blockchain technology to allow sharing of spectrum in a flexible and also dynamic way [5]. Meanwhile, to enable 6G to ensure wide-ranging and global communication, satellite communication is also considered the primary feature of the future generation 6G, to form integrated "space-air-ground" networks and thus provide complete coverage worldwide [6]. Like the United States, South Korea is actively researching Terahertz and "space-air-ground" communication networks.

As shown in Figure 1, we can see that the use of smart devices is increasing every year and that the use of data traffic will increase exponentially, which will surely put several constraints on the 5G network. As a result, wireless data rates have almost doubled every 18 months [7]. As soon as 5G technologies' commercialization begins, universities and industry are already launching research activities to shape the next-generation 6G communication properly. It is very reasonable to expect 6G to meet the demands and demands new and unprecedented expectations that 5G cannot achieve so far. Figure 1 shows that mobile traffic, without machine-to-machine (M2M) traffic, is estimated to grow at an annual rate of around 54%. Mobile traffic, including M2M traffic, is expected to grow at a yearly rate of approximately 55% in 2020-2030. The 5G technology that is starting to be deployed will not be sufficient to satisfy such traffic and users. Therefore, a significant improvement is necessary to absorb such traffic and above all the traffic, which requires high throughput, high availability and reliability, and very low latency.

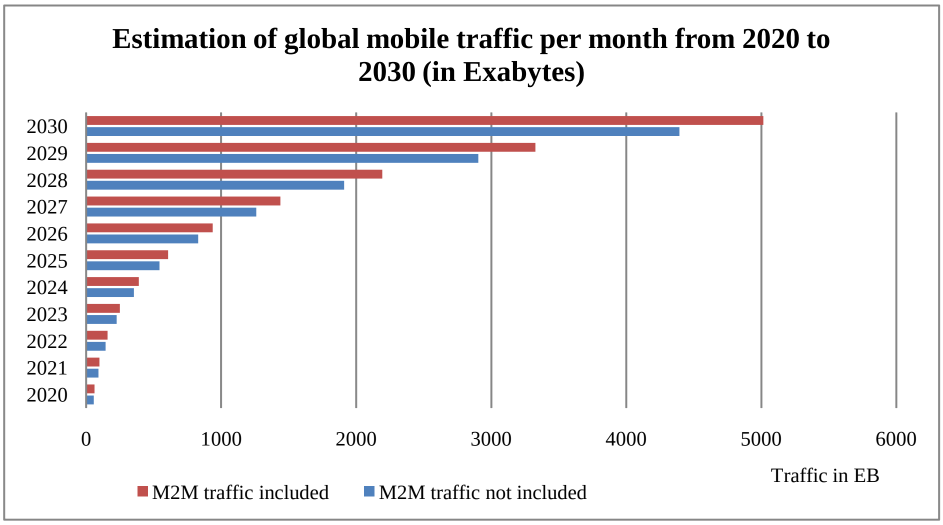


**Fig.1.** Estimation of global mobile traffic from 2020 to 2030.

As depicted in Figure 2, the passage from one generation to the next is dictated by a significant change in technology and new service requirements. Thus, the transition from the first-generation (1G) to the second-generation (2G) has been transitioning from analog technologies to digital technologies and the spread of mobile phones through the possibility of owning mobile equipment for all mobile customer's telecommunications operators.

The switch from 2G to 3G is the transition from low-speed voice and data services to high-speed multimedia services. The switch from 3G to 4G aimed to enable a significant increase in throughput based on a considerable improvement in architecture and development in Voice over IP (VoIP) and Smartphones. The 5G has introduced three categories of services. The first one is called enhanced mobile broadband (eMBB). eMMB allows a very high speed. The second so-called massive machine type communication (mMTC) allows connecting and communicating many objects. Third so-called ultra-reliable and low latency communications (uRLLC) allow having very low latency and very high reliability.

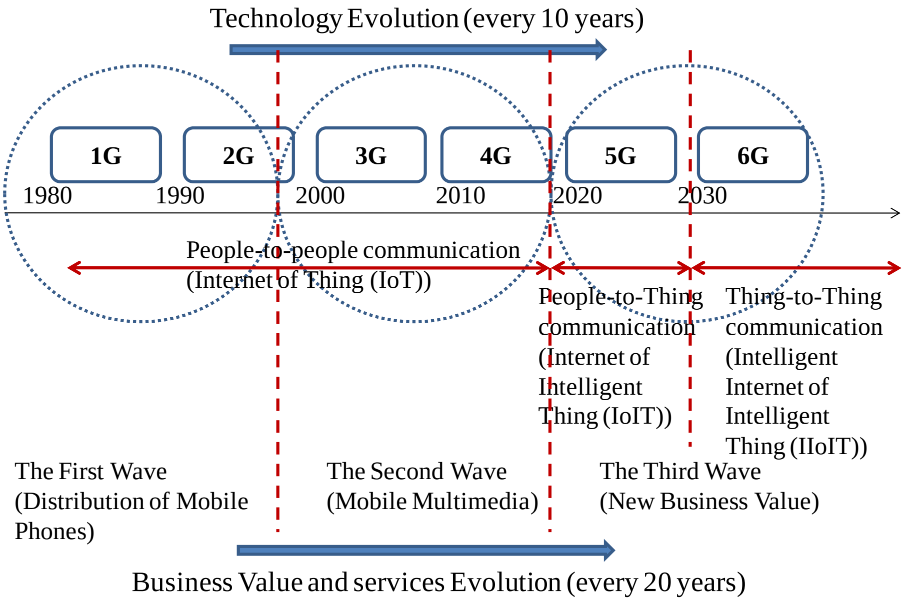


**Fig.2.** Evolution of technologies and services from 1G to 6G [9].

Therefore, the fifth-generation 5G is considered to communicate a considerable number of objects with a human user. And finally, the transition from 5G to 6G expects to allow communications of objects between them with or without human intervention and the introduction of new services and integration of satellite in the network for permitting global coverage. These new services will be highlighted in the rest of this paper.

The rest of the paper is structured as follows: Section 2 presents the evolution of mobile networks' different generations. Section 3 presents the key performance indicators of the 6G networks. Section 4 describes the 6G architecture. Section 5 discusses a variety of spectrum bands available for deployment of 6G. Section 6 focuses on managing the 6G frequency spectrum. Section 7 deals with Channel Models: Requirements and Deployment Scenarios. Finally, the conclusion is given in Section 8.

## 2 Evolution from 5G to 6G

The new 5G network infrastructures will use virtualized technologies. The physical nodes will be replaced by a modern architecture where the network protocols are established and executed through software programs (network functions virtualization or NFV) on available servers (networks defined by software or SDN). This new paradigm offers excellent flexibility, scalability, and specialization capacity to provide innovative and specialized services with agility and improvements in efficiency in operating costs (OPEX) and investment (CAPEX) concerning current technologies. It also makes it easier to update and patches the software. In return, it increases network functions' exposure to cyber-attacks if the software developers do not integrate security from the initial design. Virtualization allows segmenting network services (network slicing) tailored to end devices or the needs of different verticals (e.g., internet access, industry 4.0, corporate networks, etc.), but at the cost of increasing the surface of risk exposure. The decentralization of the mobile network architecture (mobile edge computing) reduces latency and provides intelligence to a highly capitalized 5G access network. The 5G offers coverage and processing capacity to thousands of connected devices (IoT) to decentralize and lower the demands of the security controls characteristic of the core of today's network.

New 5G technologies increase the exposure surface of current networks, the sensitivity, and vulnerability of components to new threats (actors) and risks (integrity, availability, and confidentiality) [10]-[15].

These building blocks will thus allow 5G technology to offer even more targeted 5G devices. It should also be noted that while version 15 provides a robust framework for improved network performance and an even more attractive mass service offering, 3GPP is actively working on further improvement of the framework, as highlighted in Figure 3.

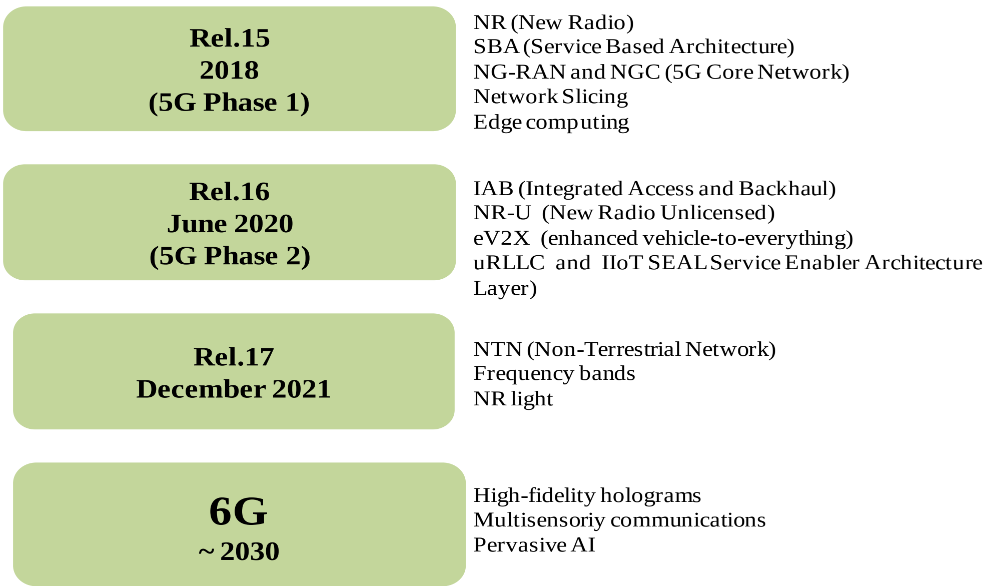


Fig.3. Evolution path from 5G to 6G.

The 5G of mobile communications drives network services in different industries, such as transport, retail, medicine, and security; therefore, it accelerates the digital transformation of vertical services.

5G will provide more advanced and enhanced capabilities compared to 4G LTE (IMT-Advanced). Table 1 summarises some of the key terms and technologies of the 5G.

Implementable standards for 5G are being incorporated in 3GPP Release 15 onwards. As noted, 3GPP Release15 defines new radio (NR) and Packet Core evolution (PCE) to facilitate interoperable deployment of the technology. 3GPP Release 16 aims at full compliance to IMT-2020 (e.g., supporting 1 GHz channels) and other spectrum capabilities. Release 16 is expected to add standards for connected cars and smart factories. In Rel-17, NR for Unlicensed Spectrum (NR-U) enhancements are expected to expand NR-U use cases beyond eMBB services (Fig. 3). For example, improvements to communication latency and reliability may be introduced to better facilitate industrial use cases. Rel-17, including 5G New Radio (NR)-Light, aims to enable lightweight communications for industrial sensors and similar applications, IIoT, MIMO enhancements, sidelink enhancements for both Vehicle-to-X communication and public safety, support for Non-Terrestrial Networks (NTNs) [16]-[20].

**Table 1.** 5G Terms and Acronyms.

| Acronyms | Definition |
|---|---|
| NOMA (Non Orthogonal Multiple Access) | NOMA is a multiple access technique, like CDMA and OFDMA, introduced in release 16 for the 5G cellular network. This multiple access technique will significantly improve mobile networks' spectral efficiency and broad connectivity and thus meet the requirements of 5G mobile technology. This technique consists of serving several user equipment using a single 5G base station (gNodeB) and serving several user equipments on the same frequency resources [21]. |
| C-RAN: Cloud (sometimes known as Centralized)-Radio Access Network | The C-RAN is an innovative architecture, running in a cloud network, that tries to meet such needs by centralizing the base stations and providing a cooperative solution between multiple operators [22]. |
| Machine Learning (ML) | Machine learning (ML) is a subset of AI that allows software applications to become more precise in the prediction of outcomes without being programmed explicitly. ML is one of the most exciting technologies that one would have ever come across. As it is evident from the name, it gives the computer that makes it more similar to humans: the ability to learn [23]. |
| Machine-to-Machine (M2M) | M2M as This acronym concerns communications from one machine to another without human intervention [24]. |
| enhanced Mobile Broadband (eMBB) | eMBB, as enhanced Mobile Broadband, is a category of service that enables high-speed connection with a suitable quality of service even at the edge of the cell [25]. |
| massive Machine Type Communication (mMTC) | mMTC is a service category that enables communications between many users (like connected objects in IoT) with multiple service quality [26]. |
| Ultra-Reliable and Low Latency Communications (uRLLC) | uRLLC is a service category that enablers communications were demanding very low latency and reliability [27]. |
| Ultra-Dense Networks (UDN) | UDN consists of networks that connect many users and more or less short links and have an enriched topology, comprising different technologies and operating in various spectral bands [28]. |
| Network Function Virtualization (NFV) | NFV consists of separating network functions from the hardware (physical part) on which these functions run using virtual hardware abstraction [29]. |
| Software-Defined Network (SDN) | SDN refers to a network architecture designed primarily to minimize hardware constraints by disregarding low-level functions [30]. |

The 5G technology should first support eMBB services and also and above all, coexists with LTE, and Advanced-LTE of 4G technology, for broad coverage needs, relying on the core network Evolved Packet Core (EPC) for control plane and user plane functionalities, with the new radio (NR) allowing only one additional radio carrier. Therefore, investment costs are relatively minimized, while mobile network operators can still offer advanced broadband capabilities.

To this aim, the introduction of artificial intelligence (AI) at all network segments, namely the radio part of the network and core network, can provide distributed learning in the system and indeed leads to optimized heterogeneous wireless networks and applications.

Beyond 5G, the technology is expected to improve the new radio and millimeter wave (mmWave) by exploiting a wider frequency range, namely from less than 6 GHz to 300 GHz. Beyond 5G will lead to the concept of user-centric cell-free coverage [31].

The vertical industries that are starting to emerge today, beyond 5G applications and the new services of the next-generation 6G, will always require an enormous volume of data.

Besides, applications beyond 5G can be supported by many improvements that need to be made to the transport network, exploiting deterministic network (DetNet), time-sensitive networking (TSN) techniques as well as segment routing [32]. Deterministic networking (as defined in IETF RFC 8655) allows minimal latency, delay variation, and low packet loss for selected services. It thus introduces guaranteed quality of service (1) managing the latency and the packet loss by allocating more resources, (2) protecting the service to tolerate packet loss, which can be due to random errors or failure of specific equipment's and finally (3) by avoiding temporary disruptions that may be caused by routing or bridging protocols, and that may interfere with the sequencing and replication/elimination process by implementing explicit routes and pining.

## 3 Key Performance Indicators

Fifth-generation mobile wireless communications technology is still in an early phase of deployment. Currently, the "most extended" version of 5G is Non-Stand Alone (NSA), where existing 4G infrastructures support the 5G network, which is the one built on the 5G infrastructure, and for 5G to arrive, there is still a long way to go.

However, the world of telecommunications does not stop, so while waiting for 5G to expand worldwide, some research has already set its sights on the 6G, the next generation. So much so that they hope that the standard will be defined in 2028 and that the commercialization will begin in 2030.

The 6G will provide advanced services such as immersive mixed reality, high-fidelity mobile holograms, and digital replication.

All these services require a network speed and stability that 5G cannot offer. The company gives an example: digitally duplicating an area of 1x1 square meters requires a throughput of 0.8 Tbps, assuming a latency of 100 ms and a compression ratio of 1/300.

Three parameters are required to meet the demand for these services: performance, architecture, and reliability. In terms of performance, 6G will offer peak speeds of 1.000 Gbps (5G stays at 20 GB maximum), latencies of 0.1 milliseconds, and twice the energy and spectral efficiency. And they believe that 6G will allow us to connect ten million devices per square kilometer.

To achieve all this, you will have to opt for the terahertz frequency bands. 4G reaches 6 GHz, 5G reaches 110 GHz, and 6G Samsung believes that the spectrum will have to be expanded to 3.000 GHz. This poses clear technical challenges because new antennas that improve coverage would have to be designed and advanced duplex technologies investigated.

The envisaged KPI for 6G are as follows:

• *Extreme data rates:* Maximum data rates of up to 1 Tbps are envisioned for indoor and outdoor connectivity. User-experienced data rate guaranteed at 95% of user locations is expected to reach 1 Gbps;

• *Enhanced spectral efficiency and coverage:* The maximum spectral efficiency can be increased by using improved Multiple Input and Multiple Output (MIMO) technology and different modulation schemes, which can go up to 60 bps/Hz. What is expected as significant improvement is instead to have a uniform spectral efficiency and the same for the entire coverage area. The spectral efficiency experienced by the user is expected to be approaching 3 bps/Hz. Also, it is necessary to develop new techniques at the physical layer level to allow broadband connectivity, especially in the case of high mobility and even more comprehensive in cases where the old generations of wireless networks cannot meet these special needs;
• *Very wide bandwidths:* To meet the needs of supporting very high data rates, increasing the bandwidth to a very high level is required. It should be noted that in the millimeter bands (mmWave) we can support bandwidths up to 10 GHz and also the Terahertz (THz) bands, as well as those of visible light (VLC), can support bandwidths up to 100 GHz;
• *Enhanced energy efficiency:* 6G technologies should focus more and place great importance on enabling better energy efficiency than the generations that preceded it. The energy efficiency effort must be achieved at the level of user equipment (for interpersonal communications or between machines or objects) and at the level of transmission efficiency. The future 6G technology is expected to yield an output that should reach Terabits' order per second per Joule. Therefore, it is important to emphasize here that developing a communication strategy that is very energy efficient is one of the essential components of future 6G technology.
• *Ultra-low latency:* A latency that may be less than 0.1 ms can be enabled using bandwidth greater than 10 GHz. The future 6G generation must also ensure variations in latency (jitter), which should be less than 1 μs;
• *Extremely high reliability:* New use cases in 6G technology must require too high reliability to enable mission and safety-critical applications.

6G technology is a very significant improvement over 5G. 6G technology makes it possible to integrate even more advanced functionalities into existing 5G technology. This will likely achieve even higher performance objectives by introducing intelligence in all network segments, namely in the core network, access network, and all devices such as user equipment or connected IoT objects. 6G technology services include holographic communications, artificial intelligence, high precision manufacturing, new technologies using visible light communications (VLC).

Comparing the two technologies is shown in Table 2, where we can observe a better improvement compared to 5G. For example, holographic communication requires a very high speed and a very low latency, which is not possible with 5G. Also, 6G technology has integrated the satellite segment to allow global coverage and terrestrial, as in 5G. The introduction of a new frequency spectrum in the Terahertz band (not harmful to humans) is not used by cellular telecommunication networks and will allow a large network capacity. A comparison of 5G and 6G is shown in Table 2 as follows [33]-[34]:

**Table 2.** A comparison of 5G and 6G KPIs

| Characteristic | 5G | 6G |
|---|---|---|
| Operating frequency (GHz) | 3-300 | Up to 1000 |
| Frequency bands | Sub-6 GHz<br>mmWave for fixed access | Sub-6 GHz<br>mmWave for mobile access<br>exploration of high frequency and THz bands (above 300 GHz)<br>Non-RF (e.g. optical, VLC) |
| Uplink Peak data rate (Gbps) | 10 | 1000 |

| | | |
|---|---|---|
| Downlink Peak data rate (Gbps) | 20 | 1000 |
| Experienced data rate (Gbps) | 0.1 | 1 |
| Peak spectral efficiency (bps/Hz/$m^2$) | 10 | 1000 |
| Peak spectral efficiency (b/s/Hz) | 30 | 60 |
| Experienced spectral efficiency (b/s/Hz) | 0.3 | 3 |
| Maximum bandwidth (GHz) | 1 | 100 |
| Area traffic capacity (Mb/s/$m^2$) | 10 | 1000-10000 |
| Connection density (million devices/$km^2$) | 1 | 10 |
| Energy Efficiency (Tb/J) | Note specified | 1 |
| U-plane latency (ms) | 0.5 | 0.1 |
| C-plane latency (ms) | 10 | 1 |
| End-to-end delay requirement (ms) | 5 | <1 |
| Radio-only delay requirement (ns) | 100 | 10 |
| Processing delay (ns) | 100 | 10 |
| Reliability (%) | 99.999 | 99.9999999 |
| Jitter (μs) | Note specified | 1 |
| Maximum Mobility (km/h) | 500 | 1000 |
| Localization precision (cm) | 10 on 2D | 1 on 3D |
| Uniform user experience (Mbps) | 50 on 2D | 10000 on 3D |
| Time buffer | Non real time | Real time |
| Coverage (%) | About 70 | >99 |
| Receiver Sensitivity (dBm) | About -120 | <-130 |
| Center of gravity | User-centric | Service-centric |
| Ultra-sensitive applications | Not feasible | Feasible |
| Smart city components | Separate | Integrated |
| Satellite integration | No | Fully |
| Visible Light Communication (VLC) | No | Yes |
| Artificial Intelligence integration | Partially | Fully |
| Extended Reality integration | Partially | Fully |
| Haptic communication integration | Partially | Fully |
| Automation integration | Partially | Fully |
| Application types | eMBB, uRLLC, mMTC | MBRLLC, muRLLC, Human Centric Service (HCS), Multimedia Priority Service (MPS) |
| Device types | Smartphones, Sensors, Drones | Sensors and DLT devices, CRAS, XR and BCI equipment, Smart implants |
| Security | Not specified | Support |

## 4 6G Network Architecture

Compared with 5G technology, the future 6G technology is expected to allow even higher throughputs, even shorter latency times, greater component density, and the mass integration of artificial intelligence in all segments constituting the network. As we move towards the next-generation 6G mobile radio, many challenges will need to be fully mastered concerning the individual components and their interactions. For example, the future 6G wireless network will consist of a large number of small mobile radio cells within which large amounts of data can be transmitted quickly and in an energy-efficient manner.

Therefore, these cells' connections will require radio links that can transmit tens or even hundreds of gigabits per second on a single channel. Until then, the frequencies in the new Terahertz band not yet explored for telecommunications are ideal for this purpose. Another task is to transparently connect the wireless transmission links to fiber-optic networks to combine both technologies' advantages, particularly in terms of capacity, reliability, mobility, and flexibility.

Future 6G technology will integrate the space segment to ensure global coverage. It will also integrate maritime space. The 6G mobile system for global coverage will incorporate a 5G wireless mobile system and satellite network.

A satellite can be defined as a radioelectric repeater located in space, which receives signals generated on the earth, amplifies them, and sends them back to earth, either to the same point where the signal originated or to a different position. Figure 4 shows an example of 6G architecture.

Figure 5 shows that 6G technology allows several coverage types, ranging from in-depth coverage to global coverage. 6G technology uses millimeter waves (mmWave), Terahertz, and visible light bands to permit deep coverage. For medium and extensive coverage, 6G uses cellular mobile communications, and for global coverage, 6G uses satellite communications.

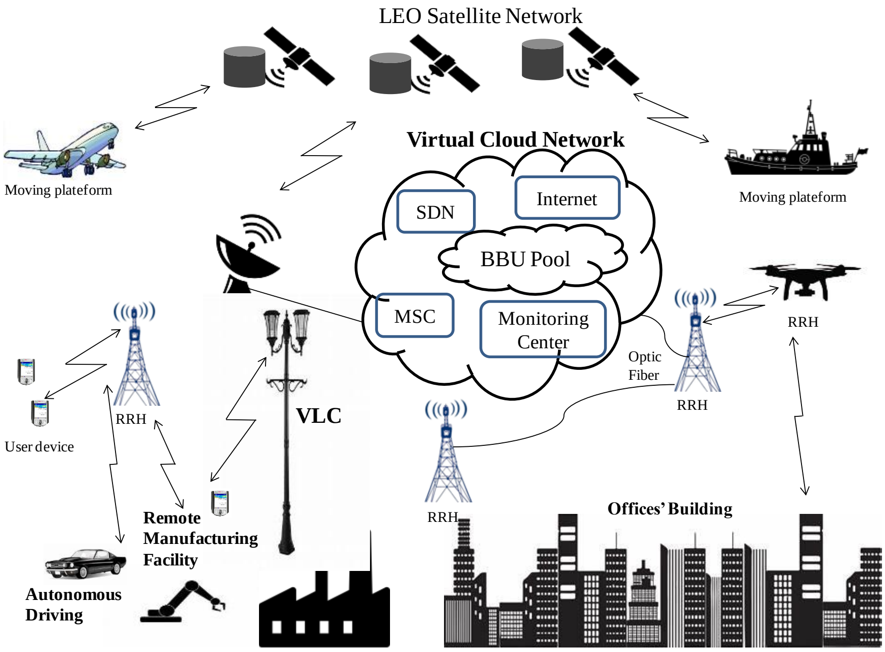


**Fig.4.** 6G Architecture.

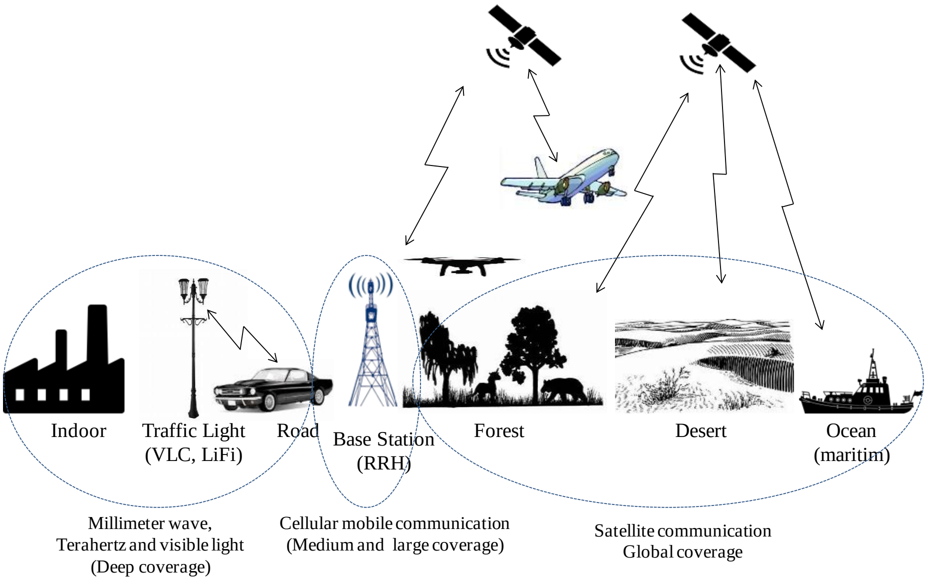


**Fig.5.** Different types of radio coverage for 6G technology.

Drones and 5G is a successful pairing. No one is missing the rapid development of drones in today's world, with more and more appearances in the media: lifeguard drones, firefighters, precision agriculture drones, as delivery men, and even drones that issue traffic fines.

On the other hand, when it comes to mobile communications, expectations are growing about the new 5G networks. Can mobile networks contribute to the development of drones? And in particular, 5G will have any impact on the explosion of this sector?

Airspace's occupation by so many drones and their coexistence with other ships is a great challenge, especially for security, both for the different government agencies and private companies and society in general.

The management of unmanned aircraft air traffics and its integration into the current panorama is a tremendous technological challenge that many countries are trying to solve.

Additionally, digitization, video, artificial intelligence, the Internet of Things (IoT), and other technological developments make drones mostly dependent on their communications. That is where Telecommunications operators play a relevant role; there is a wide field of action in drones and 5G.

Such is the interest of the operators, the global consortium of mobile.

In addition to the network's location mechanisms and secure communications, it seems that they have the basic ingredients for its management and control in the airspace. Aspects such as integration with current air traffic management (ATM) systems and regulations are currently under study, but the opportunity will be a reality in the coming years.

This is also should be complemented by other services such as the legal interception of unauthorized drones, the authorization of flights, the establishment of virtual perimeters and beacons, and the control beyond the ships' visual range. However, all of the above scenarios can be achieved with current mobile technologies such as 4G, so what can be the differential contribution of 5G networks?

- The 5G network and beyond provides higher transmission speed by multiplying by a hundred up to 10Gbps, which will allow the emission of 4K video in real-time. In addition to other telemetry functions, bringing artificial intelligence (AI) to the nodes of the network.
- The higher density of devices: Ten times the current one, up to one million of them per km2, something fundamental for the management of drones, especially in urban environments or near airports.

- Reduced latency, which reduces ten times up to 1 ms. This lower delay is essential to pilot drones from kilometers away without the pilot having to see the device or automatic responses of the drone-based on the information provided by the network, for example, to avoid restricted areas or collisions.
- The higher speed of the devices, which can remain connected when traveling at speeds of up to 500 km/h.
- Finally, the low energy cost, which reduces the energy per Kilo bit of the transferred data packet by a hundred times, makes it possible to connect at high speed more efficiently in these battery-powered devices.

The future of drones and 5G and beyond is promising, and we are at a turning point that will give way, in the coming years, to a sky full of connected devices.

## 5 Spectrum for the Future 6G

The use of very high-frequency bands, which are still unregulated today, further alleviates the scarcity of the frequency spectrum and also the limitations of the capacity of wireless communications that currently exist. Future 6G technology is expected to operate at even higher frequencies to achieve even greater bandwidth. The candidate bands to be used are the millimeter-wave band (mmWave), the Terahertz band, and the wireless optical band and visible light (VLC).

• *mmWave band: To* achieve 100 times the peak data rate than 5G, it is necessary to look for other frequency bands. It can be noted that 5G will aim to provide 20 times the peak data rate (speed), ten times lower latency, and three times more spectral efficiency than 4G LTE.
This increase in throughput is made possible in particular thanks to millimeter waves (mmWave). These high frequencies waves between 6 GHz and 300 GHz have a much wider spectrum width than 4G. Future 6G technology will still use this frequency band.

• *Terahertz band*: as shown in Figure 6, the Terahertz (THz) [35], or so-called sub-millimeter band, covers the frequency range between 100 GHz and 10 THz, with corresponding wavelengths between 3 mm and 30 µm [36]. It should be noted that, unlike X-rays, the radiation of frequencies in the Terahertz band is non-ionizing, which constitutes a significant advantage in the field of telecommunications because it can be used near the human body without worry. There are also other important advantages of Terahertz radiation, which relate to the penetration of many opaque materials and the high selectivity because many molecules have resonant frequencies that lie within the Terahertz band, and which allow their detection in the event of their presence [37]. It should also be noted that until today, Terahertz waves are not yet used for wireless communications due to the lack of devices to generate them and also to detect them [38]. Several potential applications can be achieved, such as indoor wireless mobile networks supporting holographic video conferencing and virtual reality. Nanoscale communication networks can be used in health surveillance using nano-machines and in space communication networks such as inter-satellite communication. Future 6G can introduce those uses cases.

• *Visible light (VLC) band*: It should be noted that VLC can achieve transmission of the order of a few gigabits per second with commercial LEDs and this through a downlink. We can cite several applications in the field of VLC communications, such as high-speed indoor data links for personal networks. Outdoor vehicle-vehicle and vehicle-infrastructure communication, and environments that are not compatible with radio frequencies such as mines and submarine networks [39]. Although VLC has a significant number of inherent advantages such as ultra-wide frequency band, very high power efficiency, very low cost, and much better security. The VLC is found still facing technical challenges in terms of bandwidth and limited modulation, slow modulation response, non-linearity of LEDs, and more complexity with MIMO systems.

Finally, it should be noted that, according to [39]. However, the sub-millimeter bands are essential for future 6G. The corresponding Terahertz communications and visible light communications remain the two promising technologies for future 6G and beyond.

## 6 Spectrum Management for 6G

The frequencies that have been proposed for 5G are between ranges from 600-700 MHz to 3-4 GHz. They can reach ranges of 26-28 and 38-42 GHz or even 86 GHz, which would imply a spectacular increase in transmission capacity concerning current technologies.

For 5G telephony to use the 700 MHz band, this implementation will require a new retuning that will probably have to receive compensation for part of governments.

The millimeter-wave thing has to do with the following. Frequency and wavelength are related by the equation: speed of light = frequency * wavelength. The speed is constant, so the higher the frequency (or energy), the shorter the wavelength or, the lower the energy (or frequency), the longer the wavelength. As 5G increases the frequency, these radiations' wavelength will be less than those used until now. As the speed of light is 300,000,000 meters / second, and the rates we are talking about here are of the order of 10,000,000,000 Hertz (tens of GHz), dividing one by the other, we will calculate the wavelength that will be of about 30 millimeters. Hence we are dealing with millimeter waves, millimetric waves, mmWaves or mmW (not confused with watts).

Increasing the frequency above 30 GHz implies that coverage and communication with the antennas will not be as before. Although we always talk about electromagnetic radiation, we already know that visible light and FM radio waves are mostly the same. Still, their different characteristics (of energy, wavelength, and frequency) make them have other properties.

At the frequencies predicted for 5G, the radiation beam does not open like an umbrella but is directed as if it were a pipe, almost as if it were a cable connection, concentrating the energy in a small portion of space, enhancing the quality, the connection and reducing the radiation that we receive from the antennas, because that umbrella of "traditional" coverage that should always be there, will not be necessary nor will it be like that with, or rather, 5G.

Over the years and for deploying all new and even old wireless communications technologies, radio spectrum management still plays a key role [40]. The management decisions (allocation and control of good management) of the spectrum taken by national regulators have the ultimate goal of ensuring efficient use of spectral resources by natural scarce natural resources. Simultaneously, it provides equity between the various stakeholders who are usually existing mobile telecommunications network operators or service providers, while respecting international bodies' recommendations such as the International Telecommunication Union (ITU). According to regulations ( license, authorization, etc.) in force adopted in each country wishing to use the radioelectric spectrum necessary to provide their services.

Today, discussions on the spectrum that will be reserved for future 6G networks are currently in their infancy, and decisions will be taken following the work of WRC-2023, which is held every four years.

Research in the next-generation 6G has identified the Terahertz spectrum as a significant area for mobile communication networks. Also, the frequency spectrum bands currently used for previous generations from 2G to 5G in many countries continue to be available for future 6G networks. Therefore, the resulting range of frequency bands for 6G will be extensive, leading to the adoption of a wide variety of radio spectrum management approaches to deal with the differences between the medium, high, and even very high bands.

6G technology will need to be very flexible to operate in multiple frequency bands and with different spectrum management approaches. Local networks' role is also significant in the future 6G generation and will involve adopting several spectrum, management models.

According to [41], the frequency band 275-3000 GHz is until today not allocated as shown in Table 3, and to operate applications of mobile, fixed, and terrestrial in the frequency bands included in the range 275-450 GHz, we have the following distribution:

- The 275-296 GHz, 306-313 GHz, 318-333 GHz, and 356-450 GHz frequency bands are identified to be used for the implementation of applications of both fixed and land mobile services, and this when none particular condition is necessary for the protection of Earth exploration-satellite service (passive) applications.

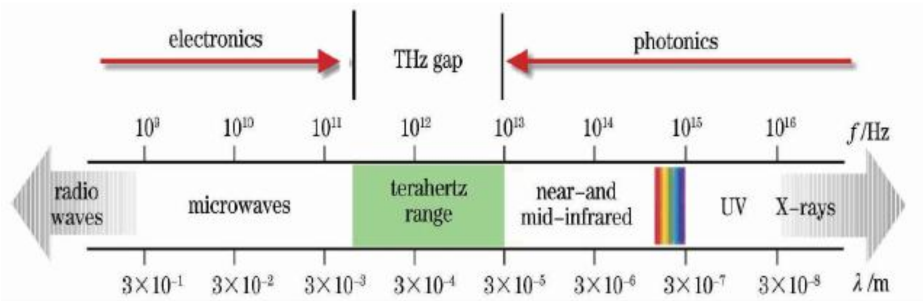


**Fig.6.** Spectrum for future 6G [41].

- The frequency bands 296-306 GHz, 313-318 GHz, and 333-356 GHz may be used only by applications of the service as fixed as land mobile if specific conditions are intended to ensure the protection of the applications of the service. Earth exploration-satellite (passive) is well defined following Resolution 731 (Rev.WRC-19).
- For the 275-450 GHz frequency band in which radio astronomy applications are used. Special conditions, such as those regarding minimum separation distances and avoidance angles, may be necessary to adequately protect radio astronomy sites from land mobile and fixed service applications on a case-by-case basis, accordingly with Resolution 731 (Rev.WRC-19).
- The use of the frequency bands, which are indicated above by applications of both fixed and land mobile services, will not exclude the use of the 275-450 GHz frequency band by other radiocommunication services applications, nor establish priorities from these applications in this same frequency band.

**Table 3.** 275–3000 GHz frequency range (Terahertz) [42].

| Allocation to services | | |
|---|---|---|
| Region 1 | Region 2 | Region 3 |
| 275-3000 GHz | (Not Allocated) | |

Blockchain technology data is represented in several blocks distributed and well connected and very secure by the use of cryptographic techniques. The blockchain, by its notoriety, is highly recommended to be used in the sharing of specifications. This will allow all network users to share the same spectrum and solve the problems related to the substantial spectrum requirements in 6G and to guarantee the spectrum's use, which must be safe, intelligent, efficient, and at a lower cost.

## 7 6G Channel Models: Requirements and Deployment Scenarios

### 7.1 Controllable Wireless Propagation Through Intelligent Reflective Surfaces

Intelligent Reflective Surfaces (IRS) is about fine-tuning wireless environments to increase performance and also energy efficiency. Figure 7 shows IRS assisted communications between a base station (BS) and a terminal such as a user equipment, unmanned vehicle, and intelligent vehicle [43] where an obstacle blocks the line of sight (LOS).

An IRS is a thin surface composed of N elements. Each is a reconfigurable scatterer: a small antenna that receives and re-radiates without amplification, but with a configurable time delay. Each component is controlled by software. These elements induce specific phase shifts for the incident electromagnetic signal wave and reflect the signals with very low power consumption. The IRS could intelligently configure the wireless environment to facilitate transmission between transmitter and receiver.

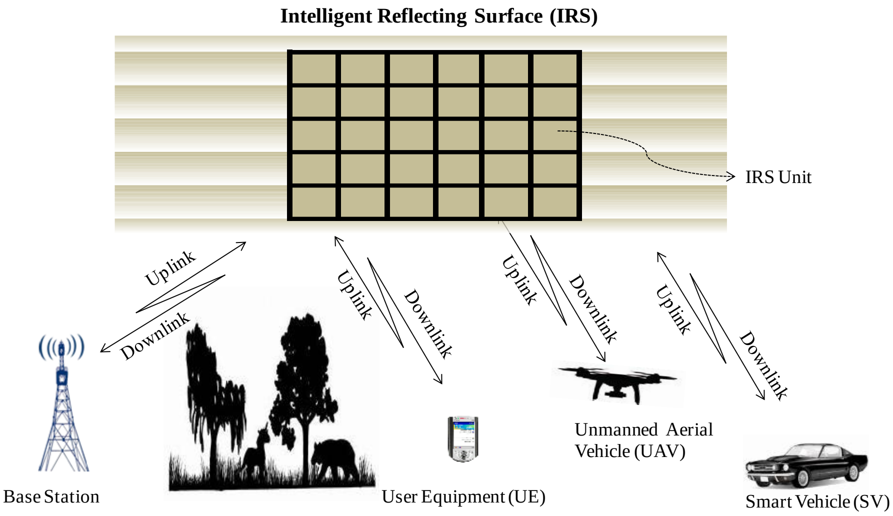


**Fig.7.** Communication between a BS and mobile equipment (UE, UAV, SV) via IRS.

### 7.2 Path Loss Model For Terahertz Wireless Communication Systems

The physical mechanisms that control a wireless transmission in the Terahertz frequency band are very different from those affecting the patterns that operate in the lower frequency bands. The propagation is mainly impacted by the phenomenon caused by the loss of spreading. For this purpose, already existing channel models cannot be reused for Terahertz communications. Absorption at the molecule level is strongly caused by the transmitted electromagnetic wave, which moves molecules from the medium to even higher energy states. Energy, being equal to the difference between the higher energy state and the lower one of a given molecule, determines the absorption energy drawn from the electromagnetic wave [44].

The main features of Terahertz radiation are, on the one hand, a very high molecular absorption and, on the other hand, a loss of spreading, which results in a very substantial path loss and which represents very high-frequency selectivity for the links line of sight (LOS). Besides, for propagation without a line of sight (NLOS), the terahertz wave's propagation is strongly impacted by a very high reflection loss. This depends on the shape, material, and roughness of the reflecting surface.

The loss of the signal path or intensity can have happened due to several disturbing effects. One of them is the loss of the free space path or the loss of signal spreading, absorption losses mainly due to interactions signal with atmospheric molecular resonances due to oxygen and water vapor present in atmospheric layers [45].

The molecules which are confined in the atmospheric medium are excited by the radiation coming from the electromagnetic waves in the Terahertz band; a molecular noise is generated during the discharge of energy towards the medium by the molecules [46].
Terahertz signal total path loss $PL_T(f,d)$ can be defined as the spreading loss function $PL_{spr}(f,d)$, absorption loss function $PL_{ab}(f,d)$, scattering loss function $PL_{sc}(f,d)$and noise function $PL_n(f,d)$ as:

$$PL_T(f,d) = PL_{sp}(f,d) + PL_{ab}(f,d) + PL_{sc}(f,d) + PL_n(f,d) \quad (1)$$

In what follows, we give the expressions of each of the terms involved in the calculation of the total pathloss.

$$PL_{sp}(f,d) = 20 \log_{10}\left(\frac{4\pi\ f\ d}{c}\right) \quad (2)$$

Where f is the signal frequency, d the distance between transmitter and receiver and $c$ is the light celerity. We suppose here the case of a medium composition in free space wireless communication.The absorption path loss $PL_{ab}(f,d)$for terahertz signal molecular absorption loss is given by :

$$PL_{ab}(f,d) = 10.\beta_m(f).d.\log_{10}(e) \quad (3)$$

Where $\beta_m(f)$ is the molecular absorption coefficient. We can find an example of a detailed calculation of the absorption coefficient in [46] and [47].
The propagation signal pathloss due to molecular and particle scattering in LOS propagation medium can be calculated by using scattering coefficient $\alpha_s(f)$ as inverse Beer-Lambert law as the following:

$$PL_{sc}(f,d) = 10.\alpha_s(f).d.\log_{10}(e) \quad (4)$$

And finally, the molecular noise generating $PL_n(f,d)$due to molecular discharge energy can be given by:

$$PL_n(f,d) = 10.\log_{10}(K_B.W.\theta_n(f,d)) \quad (5)$$

Where $W$ is the channel bandwidth, $K_B$ is the Boltzmann constant (1.380649x10$^{-23}$ J/K) and $\theta_n$ is the temperature of noise [48]- [51].

## 8 Conclusion

The technology in the wireless industry has been evolving rapidly over the past few years. Much research in academia and industry has already begun to focus on developing the next generation 6G, while 5G networks' deployment is still in its infancy. Thanks to 5G technology, many attractive services have already emerged, and communication with objects and between objects has started to experience significant growth. However, 5G technology is starting to have these limits to offer some very demanding services, particularly speed, latency, reliability, and security. 5G will serve as a springboard towards 6G, exceeding the limits reached by 5G by 2030.

6G will explore other frequency bands that have never been used for telecommunications needs until now and provide everyone segments of the network with even more intelligence and widen the coverage as much as possible by integrating the space segment into the architecture. In this article, we have presented the architecture of this next generation, the new features, and the possible applications and technologies that will be deployed. The main challenges of 6G technologies and the different use cases are presented and discussed. 6G technology will improve network performance, integrate different technologies, increase service quality, and provide an ultra-smart society with everything connected to it.

## Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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