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Architecture, Requirements, Key Technologies & Emerging Applications of 6G Cellular Network

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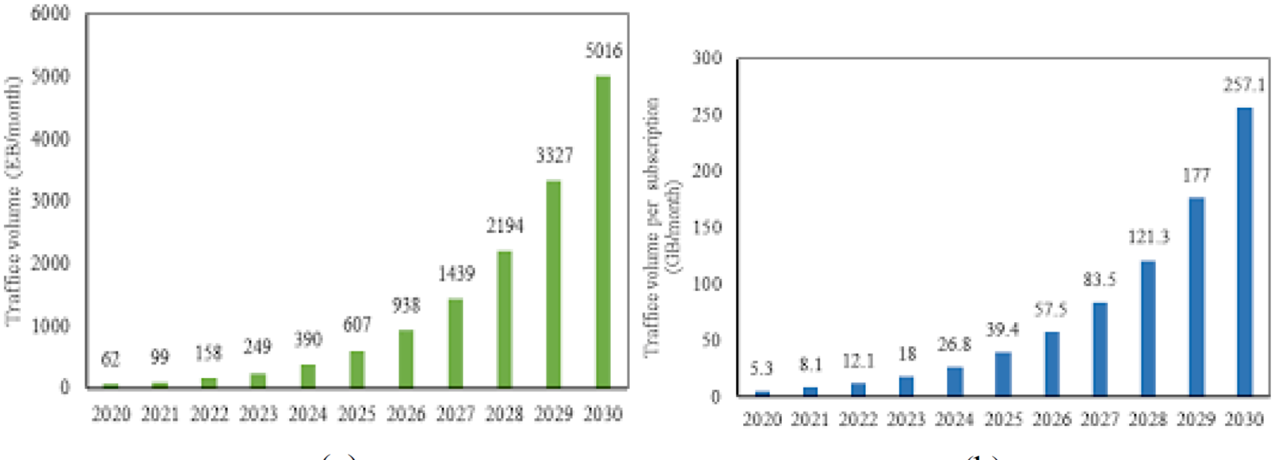
Abstract: The need for wireless communication has increased dramatically during the last two decades. Many smart applications are being integrated with 5G wireless communications technologies. In the years 2027 to 2030, a new wireless communication paradigm, sixth generation (6G) technology, with full AI capability, is scheduled to be adopted. More system capacity, reduced latency, greater security, high data rate, and enhanced quality of service (QoS) in comparison to 5G system are some of the basic issues that require resolution beyond 5G. To address these demanding requirements, research is concentrating on 6G wireless communications, which enables a variety of applications and new technologies. This paper introduces the 6G emerging technologies, key performance indicators, applications and its possible network architecture.
Keywords: 5G, 6G, Artificial Intelligence, Virtual Reality, Data Rates, Applications, Requirements, Terahertz.

Introduction

A new communication system is developed almost every 10 years, enhancing QoS, adding new functionality, and introducing new technology. The fast development of new applications like machine learning (ML), media in three dimensions (3D), virtual reality (VR), and internet of everything (IoE) has resulted in tremendous increase in traffic [1]. In 2010, worldwide monthly mobile traffic was 7.462 EB, and by 2030, expected monthly traffic will be 5016 EB [2]. This figure demonstrates how critical it is to improve communication networks. We are rapidly approaching a civilization dominated by totally automated remote management systems. Figure 1 depicts the mobile connection industry's exponential expansion. By 2030, mobile traffic is expected to have increased 670 times globally compared to mobile traffic in 2010 [2]. The International Telecommunications Union (ITU) forecasts that by the year 2030, monthly mobile data usage would reach 5 ZB. Compared to 5.32 billion in 2010, there will be 17.1 billion mobile subscribers.



(a) (b)

Fig 1. The projected increase in worldwide mobile connection between 2020 and 2030 volume of all traffic worldwide (b) volume of traffic per subscription [3]

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GROWTH IN WIRELESS TECHNOLOGY

Table 1: A Comprehensive Comparison between 1G to 6G Communications

Attributes	1 G	2 G	3 G	4 G	5 G	6G
Timeline	1980-1990	1990-2000	2000-2010	2010-2020	2020-2030	2030-2040
Peak Frequency	894 MHz	1900 MHz	2100 MHz	6 GHz	90 GHz	10 THz
Highest rate	2.4 Kb/s	144 Kb/s	2 Mb/s	1 Gb/s	35.46 Gb/s	100 Gb/s
Services Offered	Voice	Text	Picture	Video	3D AR/VR	Tactile
Standards	MTS, AMPS, IMTS, PTT	GSM, IS-95, CDMA, EDGE	UMTS, WCDMA, IMT2000, CDMA2000, TD-SCDMA	WiMAX, LTE, LTE-A	5GNR, WWWW	-
Multiplexing	FDMA	FDMA, TDMA	CDMA	OFDMA	OFDMA, Filter –Bank Multicarrier, Non-Orthogonal, Multiple Access (NOMA)	Smart OFDMA plus IM
Core Network	PSTN	PSTN	Packet Network	Internet	Internet / Internet of things (IOT)	Internet of Everything (IOE)
Architecture	SISO	SISO	SISO	MIMO	Massive MIMO	Intelligent Surface
Highlights	Mobility	Digitization	Internet	Real-time streaming	Extremely high data rate	Security, Privacy, Secrecy

Scenario for the 6G Communication Architecture

The 6G telecommunications networks will fully integrate AI. AI will be used to encompass all signal processing at physical layer and network administration, instrumentation, service-oriented communications, resource management, and other functions [4]. Industrial manufacturing is being digitally transformed, known as Industry 4.0, will be aided by it [5]. The 6G communication network's design has to be created in a way that it can address the problems caused by the constrained computing power of mobile devices. 6G should be developed to enable computing and real convergence of communication. The "Native AI" design style enables all system components to gather and assess a vast quantity of real-time data. The 6G network should be built to accommodate both terrestrial (such as fixed Base Stations (BSs) or moving BSs) and non-terrestrial components (such as aero planes, urban air mobility (UAM) systems, low earth orbit (LEO) and geo-stationary orbit satellites, and high-altitude platform stations (HAPS). Fig. 2 depicts a communication architecture scenario for the purpose of imagining 6G networks for communication.

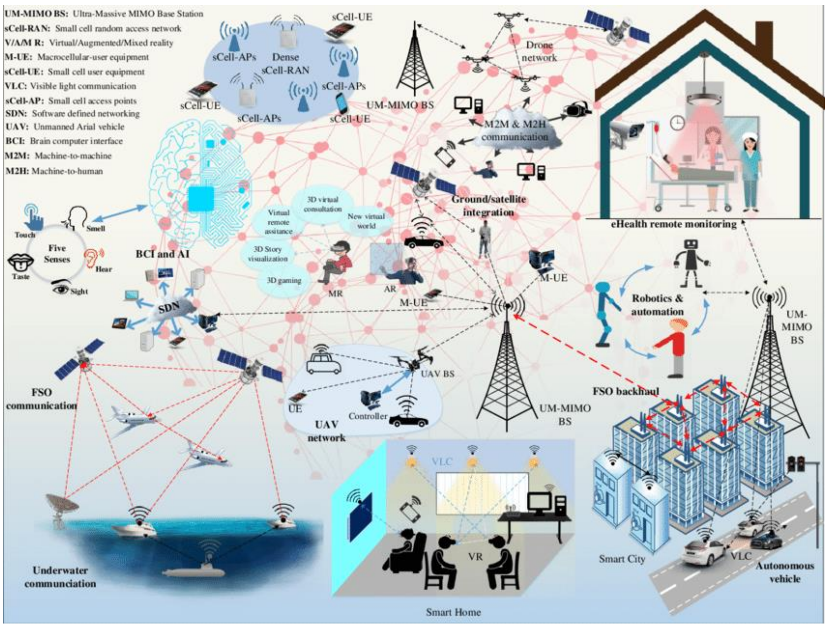

Fig 2. Scenario for a probable 6G communication infrastructure [6]

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SPECIFICATIONS AND REQUIREMENTS

The 6G system's primary goals are:

➢ Tremendous amount of real-time data processing.
➢ Very high data rates for each device.
➢ Huge number of linked devices.
➢ Reduced latency and high throughput.
➢ Global connectivity.
➢ Using battery-free IOT devices to reduce battery usage.
➢ Secured network / Connection with ultra-high reliability.
➢ Intelligent Connected Environment with Machine Learning (ML) Capacity.
➢ Network Hardness
➢ Ubiquitous network coverage

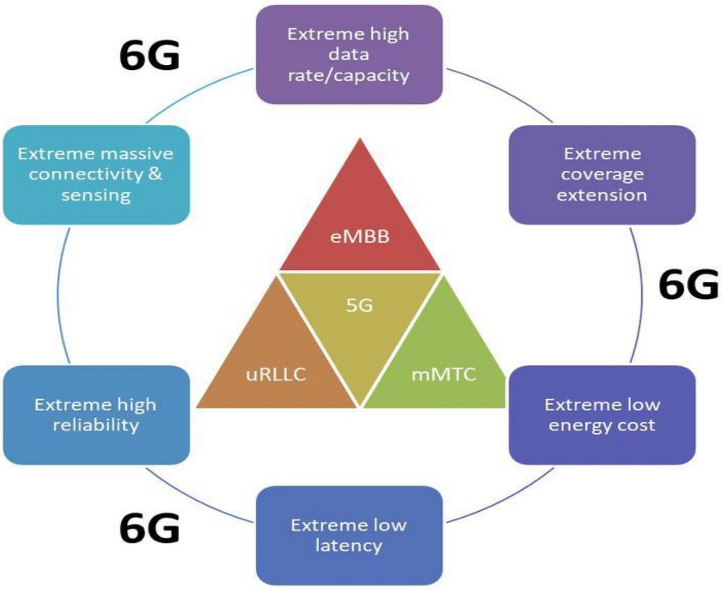

Fig. 3. Features of 6G compared to 5G [7]

Key Performance Indicator (KPI) required for 6G:

- Maximum data rate: ≥ 1 Tb/s
- Customer-experienced data rate: 1 Gb/s
- Air Latency < 100 μs
- End to End (E2E) Latency < 1 ms
- Battery life time of 20 years
- Connection Density: 107 Devices/km2
- Area Traffic Capacity: 1 Gb/s/m2
- Network Energy efficiency: 10–100× that of 5G
- Spectral efficiency: 5–10× that of 5G
- Extremely low latency jitter in order of μs
- Compared to 5G, tends to enhance reliability by 100 times.
- Mobility: ≥1,000 km/h
- Maximum one-in-a-million outage
- Precision of placement is 10 cm indoors and 1 m outdoors.

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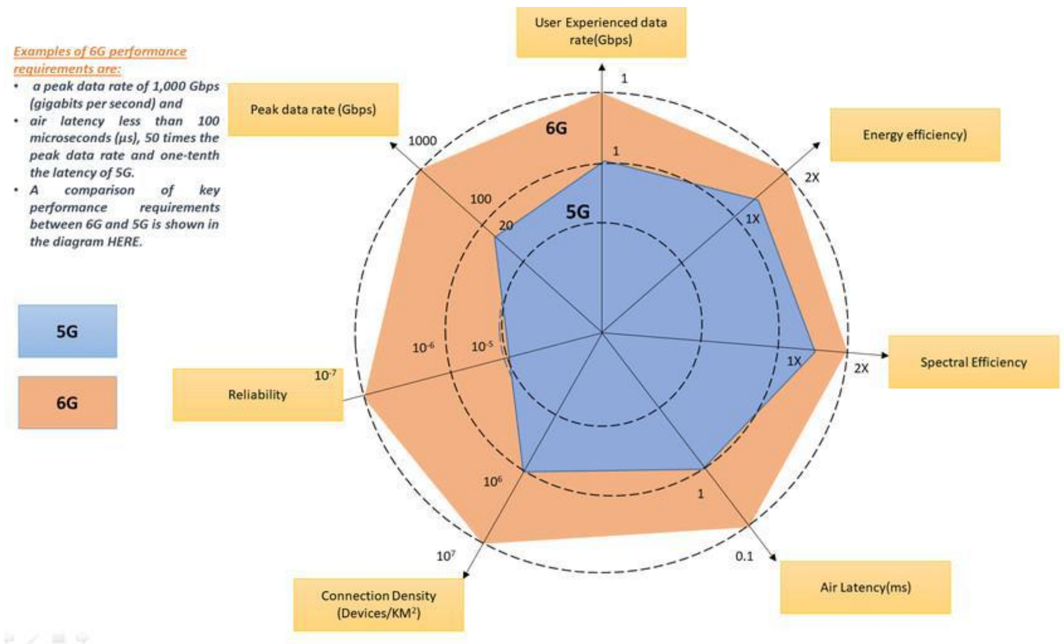

Fig 4. Comparison between 5G and 6G's Key Performance requirements [8]

PROMISING TECHNOLIGIES FOR WIRELESS 6G NETWORKS: -

Here, we discussed nine novel techniques immerging as basis of sixth generation.

1. THz Communication: **-**RF spectrum is nearly filled and cannot accommodate the rising demand for wireless communications technologies. In order to provide 6G with increased bandwidth, ultra-high data rates, capacity, and secure transmission, Terahertz (THz) band, which ranges from 0.1 THz to 10 THz, will be a key component [9]. The benefits of THz communications are as follows:

• To meet 6G's enormous bandwidth requirements and accomplish data transfer at several Tb/s, vast bandwidth resources up to hundreds of gigahertz are required, which are significantly greater than 24.25 to 52.6 GHz mm-wave range for 5G.

• Due to its much shorter wavelength than the mm-wave band, THz frequency range may be advantageous for integrating multiple antennas to produce many beams. In order to reduce beam width and combat propagation loss that can increase data transfer and simultaneously serve more users, it is anticipated that more than 10,000 antenna elements will be able to be incorporated into THz BSs.

• THz communications have extremely directed transmission, which can greatly minimize intercell interference, drastically lower the likelihood that messages can be overheard, and improve security.

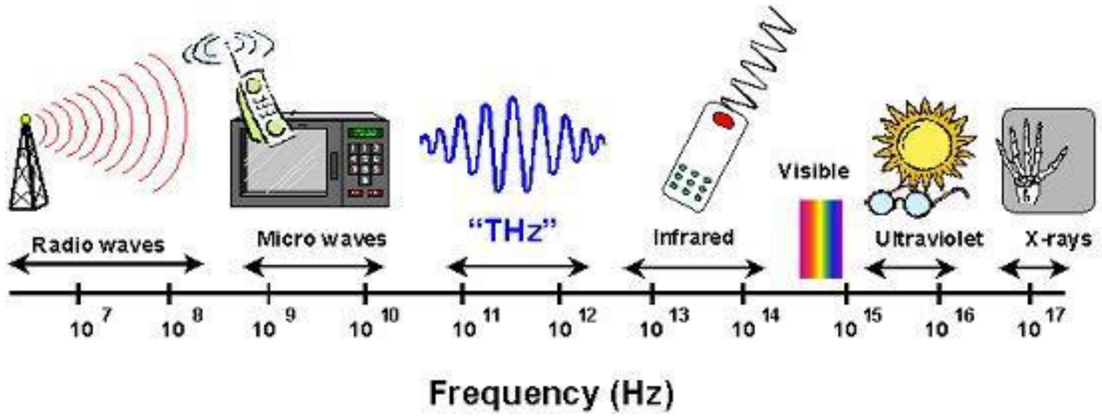

Fig. 5. Electromagnetic Spectrum

2. Supermassive-MIMO (SM-MIMO): - In wireless communications, the multiantenna approach [10] has been crucial because it has the potential to greatly boost capacity of system through spatial-multiplexing, ensure trustworthy transmission via diversity, and mitigate propagation loss through beamforming. The following advantages will be offered by SM-MIMO for 6G, which is anticipated to be implemented with more than 10,000 antenna elements.

• By use of spatial-multiplexing, which transmits hundreds of concurrent data streams over the same frequency channel, extremely efficient spectrum may be attained. Additionally, SM-MIMO can drastically lower latency and increase energy economy.

• Massive-user MIMO, as opposed to multiuser MIMO, can be used to provide hundreds of beams, serving more users concurrently. This greatly increases network throughput.

• In order to mitigate the combined co-channel intercell interference and the significant loss in mm-wave and THz bands propagation, super narrow beams must be formed.

3. Large Intelligent Surface (IRS): - Regarding the 6G communications network, Large Intelligent Surfaces (LIS), often referred to as Intelligent Reflecting Surfaces (IRS), is recognized as a significant energy efficient technology. that can provide unheard-of Massive MIMO output improvements. The IRS differs in that it includes inexpensive passive reflecting components [11], which are inexpensive and use less energy and may change the environment for controlled propagation. The resultant IRS is easily incorporated into architectural facades, walls, and ceilings. It has the ability to drastically lower energy usage.

Fig. 4 illustrates communications utilising Intelligent Reflecting Surfaces (IRS) when base station is obstructed from user equipment (UEs) by a tree.

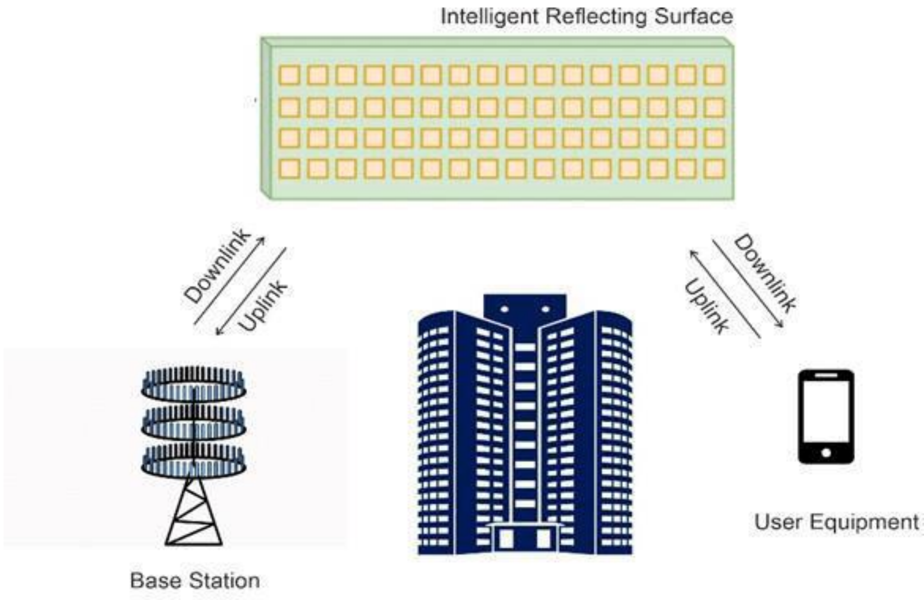

Fig. 6. Communication system with IRS

4. Holographic Beamforming (HBF): - By focusing the energy in a constrained angular space, beamforming uses an antenna array to steer a focused beam with high gain for transmission and reception. It provides greater signal-to-interference and noise ratios (SINR), improved coverage and throughput, and the ability to track users. In comparison to traditional beamforming using discrete phased antenna arrays, HBF creates the appropriate beams by holographic recording and reconstruction, resulting in superior spatial resolution.

Fig. 7. Holographic Beamforming [12]

5. Orbital Angular Momentum (OAM) Multiplexing: - Utilizing a series of electromagnetic waves that are orthogonal to multiplex several data streams on the similar frequency channel while adding angular momentum as a new degree of freedom allows the OAM multiplexing approach [13] to achieve improved spectral efficiency. Unlike spatial multiplexing, which uses several distinct broadcast and receiving antennas, this is different. One can identify the electromagnetic wave's OAM as ejs[13], where ϕ is azimuthal angle and s, is OAM state, which is an unlimited integer. Therefore, any two states of OAM are orthogonal, and there exists an endless number of OAM states. It is theoretically possible to multiplex any number of data streams into a single frequency channel.

6. Laser and Visible Light Communications (VLC): - To offer better coverage, 6G will combine terrestrial networks with networks in the air, the ocean, and space. In contrast to the terrestrial environment, the propagation conditions for air, space and underwater are different, therefore typically used electromagnetic-wave-based wireless communications cannot enable high speed data transfer for these circumstances. Laser communications are appropriate for situations like free space and the ocean because they have an extreme bandwidth and can accomplish data transmission at very high speed. However, VLC [14] is a potential 6G technology that operates in the 400-800 THz range and transmits data using visible light produced by LEDs that resemble illuminants. VLC is suited for situations like an indoor hotspot since it uses extreme bandwidth to provide data transfer at very high speed and is readily available.

7. Blockchain-Based Spectrum Sharing: - The distributed blocks that make up the data in the blockchain technology are linked together and cryptographically protected. Blockchain will be utilized to manage and organize vast data as well as 6G's massive connection. It will also be utilized for sharing of spectrum, enabling users to access the similar spectrum to address the issue of 6G's enormous spectrum demand and provide safe, affordable, intelligent, and efficient spectrum use. The QoS will be improved by using deep learning reinforcement and blockchain integration with AI [15], enabling sharing of efficient resources, developing an enhanced caching system, and enhancing network flexibility.

8. Quantum Communications and Computing: - Communication will undergo a revolution when quantum networks and the quantum internet are completely deployed on a large scale. People will not only experience quicker speeds but also more secured communication in comparison to existing system. Security and a fast data rate are two characteristics that will be crucial in the application of quantum communication for 6G technology [16]. AI algorithms that need a lot of data and extensive training can be considerably accelerated and improved using quantum computing. A stronger and more effective set of AI algorithms can be created to fulfill needs of 6G by merging AI, or quantum AI with quantum theory.

9. Artificial Intelligence: - In 4G or any earlier generations, artificial intelligence (AI) was not used. It is partially assisted by 5G, which is changing the communications landscape and paving the way for cutting-edge, ground-breaking applications like [17]– [20]. The 6G network, however, will fully enable AI for automation. It will take part in network selection, handover, and resource allocation, all of which will improve performance, particularly for applications that are delay-sensitive. The two key technologies in 6G are artificial intelligence and machine learning [21].

EMERGING APPLICATIONS OF 6G

- ➢ Communication between vehicles (V2V) and between vehicles and infrastructure (V2I)
- ➢ Smart Healthcare and Biomedical Communication
- ➢ Ocean-Ground-Air-Space Network Integration
- ➢ Automation and Manufacturing
- ➢ Five Senses Information Transfer
- ➢ Multi-sensory Extended Reality (XR) applications
- ➢ Optical Wireless Communication
- ➢ AI-Cloud Integration
- ➢ Smart Home and Super Smart Society
- ➢ Connected Robotics and Autonomous System
- ➢ Internet of Nano-Things
- ➢ Wireless Brain-Computer Interactions
- ➢ Accurate Indoor Positioning
- ➢ Holographic Communication
- ➢ Tactile / Haptic Communication
- ➢ Fully Automated Driving
- ➢ Industrial Internet
- ➢ UHD / EHD Videos
- ➢ Intelligent Internet for Medical things (IIoMT)

Conclusion

Every new generation of wireless communication technology introduces novel and interesting features. The rapidly expanding expectations in 2030 will not be satisfied by 5G telecommunication technologies. Therefore, 6G research should be carried out in order to achieve its objectives by 2030. This paper considers potential outcomes and strategies for achieving the 6G communication aim. Possible architecture along with technical requirements and emerging applications of 6G cellular network are discussed. Numerous promising technologies such as THz Communications, HBF and LIS, SM-MIMO, Laser Communication and VLC, OAM Multiplexing, quantum computing and communications and Artificial Intelligence (AI) that to be used in 6G communication are discussed in details. It is concluded that 6G will enable a highly intelligent civilization where everything is networked, enhance network efficiency, combine various technologies, and raise quality of service (QoS).

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