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Bridging the Gap to 6G: Leveraging the Synergy of Standardization and Adaptability

Anjanabhargavi Kulkarni[1], R.H. Goudar[1], Joshi Vinayak B.[2], Harish H.T.[3,*]

[1]Department of Computer Science and Engineering, Visvesvaraya Technological University, Belagavi, India.
[2]Department of Computer Science and Engineering, Garden City University, Bangalore, India.
[3]Department of Library and Information Science, Manipal Academy of Higher Education, Manipal, Karnataka, India, 576104.

Abstract

The field of wireless network and communication technology is evolving from generation to generation from 1G to 6G to date with the expectation to be deployed and used by 2030. 5G is expected to succeed and bring significant improvements in terms of connectivity, speed, and size in next-generation communication technology. 6G in turn aims to deal with the rising need for more rapid information speed, low latency, and wider network coverage. This intelligent communication is proposed to meet these demands and enable new services and applications. This review paper highlights the key enablers and challenges involved in implementing intelligent communication beyond 5G, identifying the research gaps for incorporating beyond 5G communication networks and outlining possible 6G key objectives from a flexibility standpoint. It reviews infrastructure deployment, network densification, spectrum capacity and network energy efficiency in predecessors to 6G. This paper emphasizes the need for standardization and adaptation of research areas to revolutionize 6G wireless communication, focusing on areas such as ultra massive MIMO, Terahertz Communications, Cell-Free Communications, Intelligent Reflecting Surface, Visible Light Communication, Internet of Things, Big Data management, Artificial Intelligence, and network connectivity techniques.

Keywords: 6G, Cell-Free Communications, Internet of Things, Intelligent Reflecting Surface, massive MIMO, Terahertz Communications, Visible Light Communication.

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Abbreviations

G	Generation	mMTC	massive Machine-Type Communications
B5G	Beyond 5th Generation	OFDM	Orthogonal Frequency Division Multiplexing
3GPP	Third Generation Partnership Project	OTFS	Orthogonal Time Frequency Space
AMPS	Advanced Mobile Phone Service	QoS	Quality of Service
BPSK	Binary Phase Shift Keying	QAM	Quadrature Amplitude Modulation
CDMA	Code Division Multiple Access	QPSK	Quadrature Phase Shift Keying
GSM	Global System for Mobile Communications	RAN	Radio Access Network
GPRS	General Packet Radio Service	RAT	Radio Access Technology
IRS	Intelligent Reflecting Surfaces	SISO	Single input Single Output

[*]Corresponding author. Email: harish.ht@manipal.edu

IoT	Internet of Things	SDN	Software-Defined Networking
IoE	Internet of Everything	SMS	Short Message Service
ITU-R	International Telecommunication Union - Radio communication	UAV	Unmanned Aerial Vehicle
ITU-T	International Telecommunication Union Telecommunication	VLC	Visible Light Communication
LTE	Long Term Evolution	uMBB	Ubiquitous Mobile Broadband
mBBC	mobile Broadband Communication	UMTS	Universal Mobile Telecommunication System
MIMO	Multi-Input Multi-Output	URLLC	Ultra-Reliable Low-Latency Communications

1. Introduction

Wireless cellular communication technology has been evolving extensively over the years. Starting from the analog voice calling of 1G to the digital voice calling and text messaging of 2G, the mobile technology capabilities expanded to include cellular phone internet access, video calls, and multimedia processing with 3G. Next-generation network 4G brings first-class video streaming and virtual gaming, while 5G improves data speed, reduces latency, and enables the connectivity of a large number of devices concurrently [1]. The field of wireless technology has shown noteworthy expansion and plays a major role in carrying digital data globally. As the world enters the innovation age, there is a tremendous need for higher data rates, negligible noise and latency and extreme connectivity as well. To meet these possibilities it is necessary for wireless technology to be revolutionized to 6G; this is initiated to bring a new wave of technologies and advancements. One of the major key enablers where 6G has evolved to make significant improvements is in bandwidth utilization. 6G also attempts to solve latency issues. Ultra-low latency communication (uRLLC) is made possible by the advent of technologies such as network slicing, edge computing, and sophisticated signaling mechanisms, which ensure real-time services in daily life. With higher frequencies and advanced antenna technologies, 6G networks can achieve greater spectral efficiency, enabling faster data rates and accommodating data-intensive applications [2].

Effective protection against cyber-attacks may be ensured with 6G augmented with AI-powered security solutions. Moreover, confidentiality-conserving approaches will be integrated to safeguard consumer data and assure harmless transmission [3]. The ITU supported 6G, rendering to a newfound probe from 2023. The framework is built on the tenets of affordability, sustainability, and ubiquitousness. 6G connections have the force to effect groundbreaking transformations and cover the avenue of an untouched-new age of rapid, larger transmission services [4]. With progresses in bandwidth, compact downtime, data delivery, and security, 6G is expected to convert global context expectations and support a host of modern tools and services [5]. The evolution of cellular technology from 4G to 5G and the anticipated forthcoming expansion of 6G highlights the need to identify the limitations and constraints of mobile internet processes.
These advancements promise lower network latency, higher reliability, and faster data transfer speeds. As the internet continues to evolve, it has the potential to bridge the gaps between different geographical locations, cultures, and languages. It enables us to connect and collaborate, fostering global communication and understanding. The internet has revolutionized industries such as e-commerce, education, healthcare, entertainment, and more, providing new opportunities and improving access to services and information. The present highly connected world, where physical objects and network entities are integrated with the internet is identified as the Internet of Things [6]. Figure 1 shows the concept of 6G Communication Network Technology with broader areas.

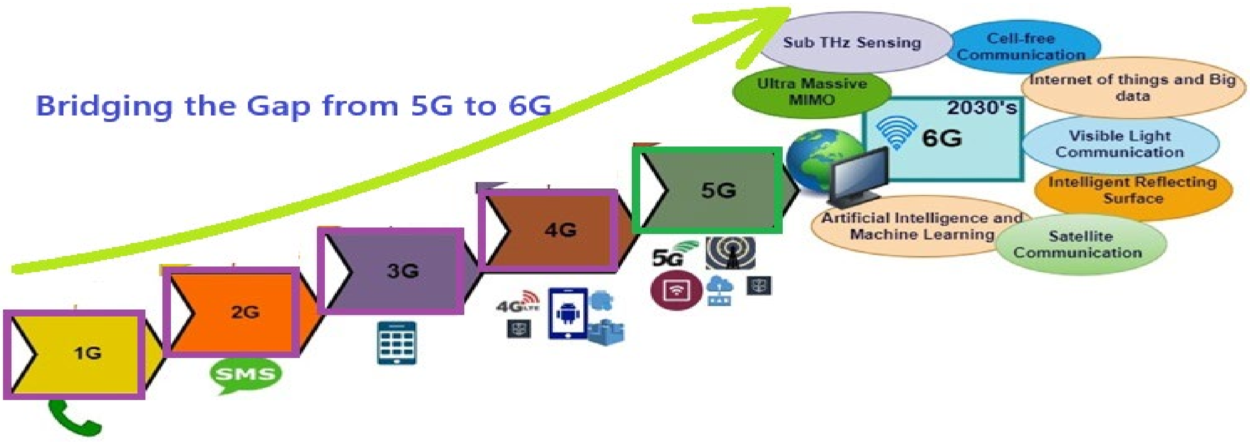


Figure 1. The concept of 6G.

1.1. Trend of 5G and Beyond

The 5th generation of digital cellular networks' wireless technology offers several technological improvements, such as faster data transfers, reduced latency, and more network capacity. Among the most important technical elements of 5G are:

1. eMBB: This is made possible by 5G's much faster data rates, HD video, virtual reality apps, and access to other bandwidth-intensive services.
2. URLLC: 5G makes it suitable for real-time responsive applications like industrial automation, virtual surgery, and self-drive cars.
3. Massive Machine-Type Communication (mMTC): 5G is provided for Internet of Things (IoT) applications and smart city infrastructure.
4. Millimeter Wave Technology: To provide quicker speed, 5G makes use of advanced frequency bands, such as millimeter wave spectrum [7].

1.2. Why 6G: Research Motivation

The 5G communication technologies currently being rolled out globally cannot cater to the capacity generated by IoT devices. 3GPP is embracing three main use cases for 5G and is currently working on the standard of 5G. These three use cases include eMBB, URLLC, and mMTC. However, 6G itself is still in the early part of research growth, where researchers and scholars from all over the world explore and study possible technologies, necessities and use cases of the 6G networks. Some of the most critical issues have been investigated in a recent survey, related to the newsletter of ITU Journal 2023, "Sights set on 6G," which, undoubtedly, are:

1) AI-powered Security in 5G and beyond

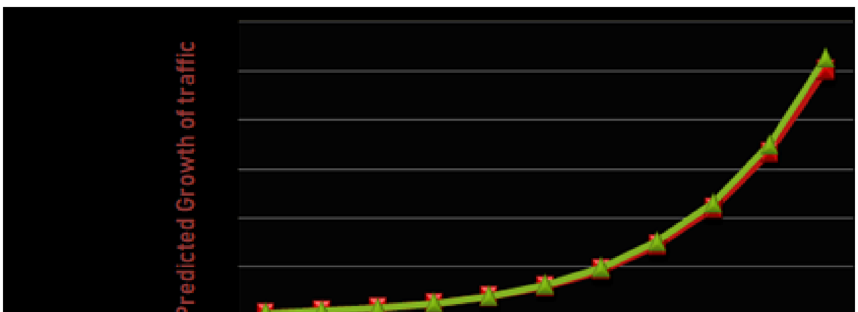
2) Fog, edge, orchestration, slicing, and network virtualization platforms for 5G and 6G wireless

3) Meta verse: Information processing, networking and, communication

4) AI and machine learning solutions for future networks, including 5G.

5) Intelligent technologies for Future Distributed Systems and networking [8].

The motivation is to outline a vision for 6G systems and their potential applications, trends, and disruptive technologies. The aim is to provide a roadmap and recommendations for transitioning from current 5G systems to future 6G systems. By identifying the advancements and emerging technologies, the article intends to offer insights into the direction of 6G development and the potential services it could enable [9]. This research motivates us to address these challenges globally. The concept envisions a future where everyday objects, such as appliances, vehicles, and even cities, are connected and can communicate with each other. This connectivity can bring greater convenience, efficiency, and automation to various aspects of human life. Even though 6G is still a concept, the actual implementation and features may vary as the technology evolves. Ongoing research, standardization efforts, and industry collaborations will shape the development of 6G in the coming years [10]. As per ITU's recent report the worldwide data statistics, global data generation, storage, replication, and usage is predicted to mount quickly, with a projected total of 64.2 zettabytes in 2020. It is anticipated that the quantity of data created globally will surpass 180 zettabytes in 2025, after five more years of growth. The quantity of data produced and duplicated struck a significant proof point in 2020 [11], and the average monthly data use per smartphone globally in 2022 was 15 gigabytes (GB). According to the source, this will rise by nearly four times, hitting at least 46 GB per smart phone each month on a global scale by 2030 [12].



	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Traffic Volume Per subscription(GB/month)	5.3	8.1	12.1	18	26.8	39.4	57.5	83.5	121.3	177	257.1
Traffic Volume(EB/Month)	62	99	158	249	390	607	938	1439	2194	3327	5016

Figure 2. The statistical analysis of data traffic from the decade 2020-2030.

Information Source: ITU-R Report M.2370-0 [79].

This review paper's contribution is to clarify the question, "Is 6G really necessary?" If so, how may mobile communications can be revolutionized? Of course, the answer to these questions is precise given the exponential increase in mobile traffic and subscriptions. In addition, the development of next-generation systems is being fueled by new disruptive services and apps. This motivates a fundamental need of mobile communication society to constantly improve network efficiencies, particularly those related to energy, cost, spectrum, and operations. Thus, this paper outlines and summarizes the surveyed papers, identifies future gaps, and determines their primary contributions.

Figure 2 shows analysis of data traffic from the decade 2020-2030. Due to this gradual increment in the data traffic usage, it's quite difficult to meet this data rate demand for researchers and industry professionals to move towards B5G or 6G. Along with this, another crucial evaluation is to convey the demands of good network with quality of service (QoS). As the number of users are increasing subscriptions to access data in number and their need for rising data rates increases the necessity for the exploration of new spectrum or higher frequency bands to evade congestion and traffic [13].

The paper emphasizes 6G will have to align with the specific performance requirements of IoE applications, which means the system should be capable of handling the massive data generated by billions of connected devices, support real-time communication with ultra-low latency, and provide reliable connectivity in challenging environments [14].

1.3 Limitations of 5G

The substantial worldwide implementation of 5G networks in 2019 has made services and apps possible. But as 5G networks and apps advance, they will encounter additional issues and difficulties. While some of these issues could be resolved by 5G networks, others might be more challenging to resolve in order to comprehend the network's limitations [15]. These issues and difficulties will serve as a major source of inspiration and innovation for the 6G design, including, network coverage, infrastructure deployment, spectrum availability, interference, signal blockage, energy consumption. 5G networks require a thick network of cells and base stations to deliver quick connectivity, which requires significant investments and coordination with local authorities. Table 1 illustrates the evolution of 1st Generation to expected 6th Generation with key enablers and performance metrics to evaluate the efficiency of network generation. Spectrum Availability of 5G networks require a large amount of spectrum to provide high data rates and capacity, but the availability of suitable frequency bands varies across different regions and countries. Interference and signal blockage due to 5G bands have smaller wavelengths and are more susceptible to interference and signal blockage. Energy Consumption in 5G is predictable to manage significantly advanced data volumes compared to previous generations, leading to higher energy consumption by the network infrastructure [15].

The arrangement of this article begins with section I describing the introduction to 6G and its importance and how it is needed for the present era and the limitations of 5G. Section II's literature review shows the wide survey of related works and research studies, Section III defines findings and discussions, including 6G requirements to deploy at the market level. It also defines the vision of 6G, applications and security measures and the challenges of 6G. Section IV elaborates different research milestones and possible technologies to overcome the raising demands of 6G and ensure implementation in future years. Finally, section V summarizes the conclusion and contributions of the paper, which are highlighted with the possible potentials of 6G as shown in Figure 3.

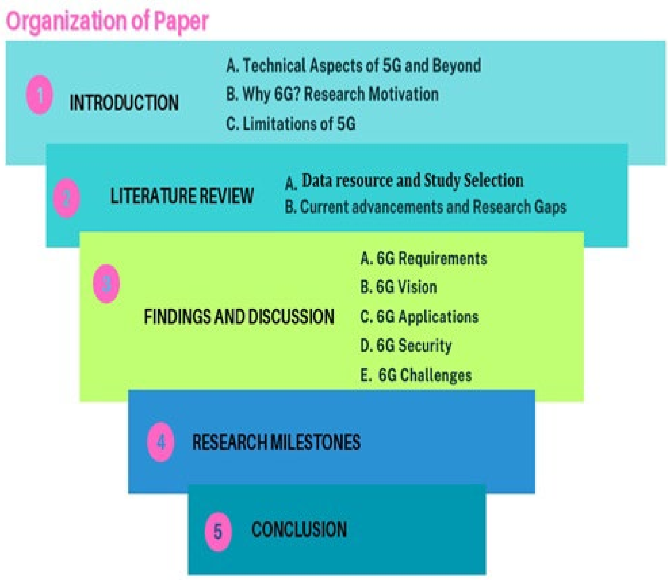


Figure 3. The paper's organization.

Table 1: Evolution of Mobile Technology 1G to 6G Communication with key enablers and metrics

Enabling Key Features and Metrics	Generations					
	1G (since 1980)	2G (Since 1990)	3G (Since 2000)	4G (Since 2010)	5G (Since 2020)	6G (2030)
Architecture	SISO	SISO	SISO	MIMO	MIMO Advanced	Massive MIMO
Transmitter Flexibility	Noisy, inflexible	Average, Less	Standard	Defined	Defined very high Flexibility	Ultra flexible transmitter, Tunable
Receiver Flexibility	Noisy, inflexible	Less	Medium	Standard	Controlled	Ultra flexible Receiver, Tunable
Modulation Scheme	FM	GSM,GPRS	CDMA,16QAM	BPSK,QPSK, 64QAM	BPSK, QPSK, 256 QAM	OFDM, RAN, Index Modulation
Data Rate	Up to 24-50 Kbps	64 Kbps	2 Mbps	100-1000 Mbps	1-20 Gbps	>=1 Tbps
Spectrum Capacity	AMPS Uplink 824-845 MHz Downlink 869-894 MHz	GSM Uplink 880-915 MHz Downlink 925-960 MHz	UMTS Uplink 1920-1980 MHz Downlink 2110-2170 MHz	LTE 4G Uplink 2500-2570 MHz Downlink 2620-2690 MHz	3-300 GHz	Up to 1 THz
Bandwidth	30 KHz	200 KHz	5 MHz	1.25 – 20 MHz	0.25-1GHz	More than 10 GHz
Switching Technique	Circuit Switching	Circuit Switching and Packet Switching	Packet Switching	Packet Switching, IPv4	Packet Switching with all IP	SDN, Seamless Broadband and Global Broadcasting
Latency	Up to 500 ms	Up to 300 ms	100 ms	10 ms	1 µs	10-100 µs
Network Energy Efficiency	Less than 0.01x	0.01x	0.1x	1x	>=10x	>=100x
Cellular Technology	Analog Communication	Digital Communication	Broadband CDMA	Unified IP LAN/WAN	Collaboration of unified IP and Broadband	SDN, Seamless Broadband Connectivity
Applications	Voice calling	SMS	Internet and multimedia	Internet of things, Multimedia,	Massive broadband and IoT applications	Massive Broadband, AI and ML, Terrestrial networks, unmanned vehicles, self-driving cars, health care systems

2. Literature Review

This manuscript has reviewed different articles on 5G to outline the recent advancements in 5G to bridge 6G demands.

2.1 Data Resource and Study Selection

To accomplish this review, an extensive study was made, collecting very recent papers, articles, white papers, and reports from ITU, which were published from 2013-2024 (10 years) from digital repositories, which include white papers and magazines such as 5G IA, 6G-ANA, vivo 6G,5G & 6G Evolution, Samsung Newsroom.
The literature study in this article was conducted and analyzed a total of 139 papers. By applying selection criteria, some articles were exempted and finally 82 relevant articles were selected. Figure 4 shows the exploratory research on data collection of 6G related articles and a year-long survey from 2013 to 2024. Efficient power management strategies and energy-saving techniques have to be implemented related to the environmental impact and operational costs of 5G networks [16]. Security and privacy must be ensured to account for expanded attack surface, increased complexity, and potential new vulnerabilities. Regulatory and policy issues are required to address the policies of 5G. Cost and return on investment must be assessed to justify the investments made in building and operating 5G networks.

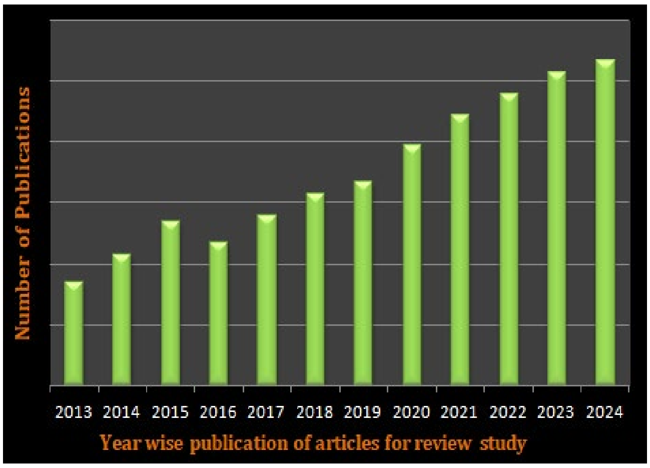


Figure 4. Exploratory Research on Data collection for the review study.

These challenges will be essential for the booming deployment and evolution of 5G networks and afford valuable insights and lessons for the propose and development of future generations of wireless networks [17]. Figure 5 Shows qualitative literature study of 139 articles by selection criteria 82 papers are selected.

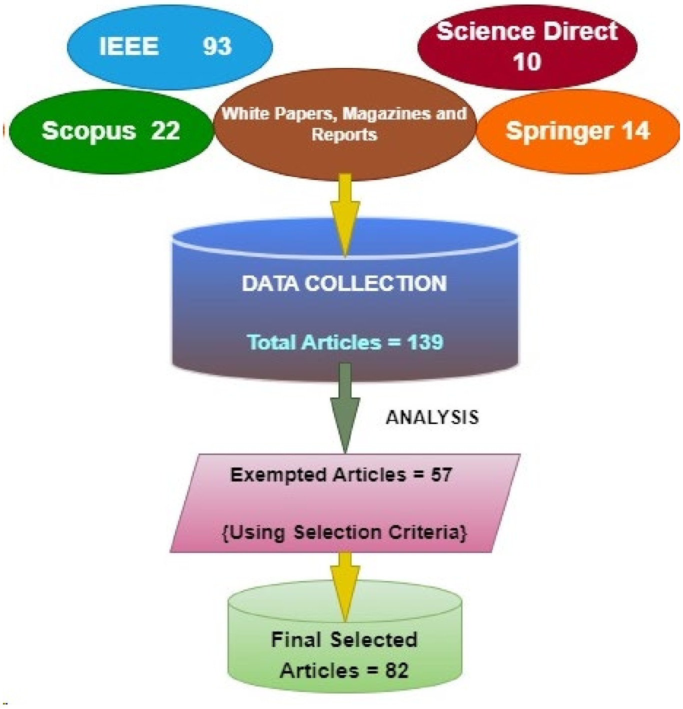


Figure 5. Data Resource and Study Selection.

2.1 Current Advancements and Research Gap

Around every decade, cellular communication systems undergo an incremental process of development. The field of 6G research is performing an investigation, yet some national and international standards bodies have made their ambitions known. During 2018, Finnish leadership initiated the world's first extensive 6G study agenda based on multi-access technology, services, and antennas. The Next generation Alliance is a trade association that specializes in telecommunications and was founded in the year 2020 over the direction as per association for Telecommunications Industry Solutions (ATIS).

To advance 6G technology development, the IMT-2030 promotion group was founded and China's Department of Science and Technology formally initiated 6G research in November 2019. The 6G schedule was unveiled in South Korea in the year 2020, with a marketable launch anticipated for 2028. Given the speed at which the mobile communications sector is growing, it is imperative that the limits of 5G be resolved and that 6G research continue. This paper provides a thorough analysis and synopsis of 6G, drawing from several current forward-looking 6G works. This research attempts to extensively examine the latest advancements in 6G technology and to provide a definition of 6G that encompasses the current general understanding of 6G [18] [79].

3. Findings and Discussions

The goal of this review paper is based on a variety of current publications, ITU reports, and white papers chosen based on the achievements of 6G wireless technology. Analysis and summary are presented in tabular form, and research gaps and future work are indicated. Table 2 shows recent advancements in 6G and research gaps in the summary of 30 articles. Then the outcome of this review study and discussion will focus on the following points:

3.1 6G Requirements

The research and advance of 6G expertise is in its early phases, with little information currently accessible. However, this paper can give some broad predictions and prospective developments for 6G networks based on market developments and discussions:

Faster data rates: 6G is anticipated to provide data rates substantially faster than those of its predecessors, possibly approaching terabits per second (Tbps) speeds. This would make it possible for ultra-high-definition material to stream more smoothly, download more quickly, and improve real-time applications.

Ultra-low latency: With aspirations of attaining sub-millisecond latency, 6G promises to significantly reduce latency. Applications such as driverless cars, remote surgery, and augmented/virtual reality experiences will all require this very immediate response time.

Significantly more device connectivity: 6G is predicted to enable significant increases in device connectivity. As high-tech cities and Metro areas IoT devices proliferate, 6G networks will need to support billions of concurrently linked devices [19].

Incorporation of AI-ML: AI is to be quite important in 6G networks. Smart networks, resource distribution, and network optimization are examples of AI-empowered technologies that potentially improve network performance and efficiency.

Increased energy efficiency: 6G networks are anticipated to use minimum energy compared to their predecessors, addressing the rising environmental issues linked to increased data use. It is necessary to use energy-saving strategies like intelligent power management and dynamic spectrum sharing.

New spectrum bands: To meet the demand of faster data speeds, 6G is anticipated to employ higher occurrence bands, as well as the terahertz (THz) frequency range. Faster data transmission is made possible by the wider bandwidths that are accessible in these frequency bands [20].

3.2 6G Vision

While 5G networks are still being deployed and optimized, researchers have previously investigated the next level of wireless technology, commonly referred to as 6G. Although there is no standardized definition or specification for 6G yet, several visions and potential areas of focus have been proposed. Global Coverage of 6G aims to offer seamless and ubiquitous connectivity, even in remote and underserved areas. It envisions extending network coverage to reach every corner of the globe, ensuring connectivity for both urban and rural areas [21].While 6G is still being deployed and widely adopted, discussions and research on 6G are already underway. According to the vision of 6G which supplies the best uses and applications are envisioned, including global coverage, satellite communication, various spectra utilization, and specific industry applications [22].Satellite Communication using 6G is most required to incorporate satellite communication into its infrastructure, enabling reliable communication between ground-based networks and satellites. This integration can enhance global connectivity and support applications such as autonomous vehicles, and emergency communication [23].
6G applications in Unmanned Aerial Vehicles using 6G can support advanced applications in UAVs or drones, enabling real-time high-definition video streaming, precise control, and enhanced communication between multiple drones. This can facilitate the widespread use of drones in various industries, including delivery services, surveillance, and disaster response. The terrestrial applications using 6G are needed for a wide range of terrestrial applications and smart cities, unmanned vehicles, virtual and augmented reality, and advanced healthcare. With its high-speed and low-latency connectivity, 6G can enable seamless and immersive experiences in these domains Utilization of all Spectra where 6G aims to leverage the frequencies and spectra for communication, including traditional cellular frequencies and bands like millimeter-wave and terahertz. By utilizing various spectra, 6G can provide higher bandwidth, faster data rates, and support for more connected devices [24].
Full-Spectrum Communication of 6G envisions utilizing the entire electromagnetic spectrum for communication with mm Wave frequencies, typically ranging from 30 to 300 gigahertz (GHz), offer superior data rates and increased capacity. In 6G, mm Wave is capable of be utilize for ultra-fast wireless systems, providing multi-gigabit per second data rates which supports the high-definition applications and video streaming, massive IoT deployments with numerous connected devices [25].Figure 6 depicts 6G vision and the applied aspects in which a wireless communication technology is expected to bring several advancements and capabilities compared to its predecessors.

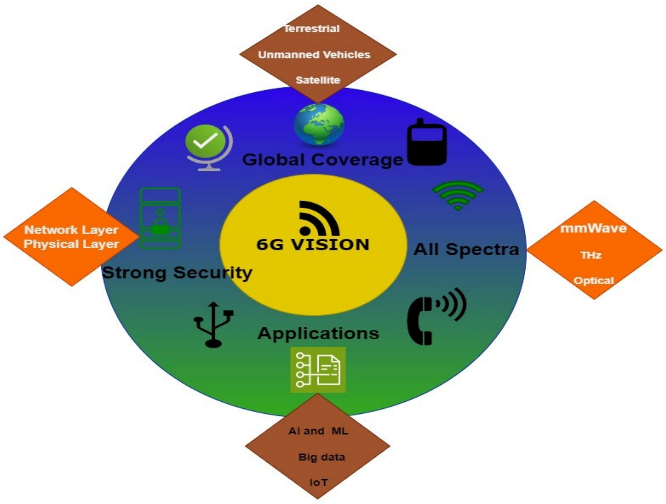


Figure 6. Vision of 6G Communication Networks.

The THz Communication frequencies, ranging from 0.1 to 10 terahertz (THz), have the latency to meet higher data speed and wider bandwidths compared to mm Wave. THz frequencies can be involved with fast communication and support bandwidth-intensive techniques as holographic imaging, immersive virtual reality, and real-time high-resolution video streaming [26].
6G uses Optical Communication and Optical frequencies, which fall within the visible light spectrum, are already used extensively in fiber optic communication systems. 6G vision, optical communication can be expanded to include wireless optical links for high-capacity and very low latency communication. Optical wireless communication can be employed for short-range, high-bandwidth links, such as indoor wireless networks, data center interconnects, and device-to-device communication [27].

3.3 6G Applications

AI-Driven Network Optimization: 6G can influence AI and ML algorithms to optimize performance, resource allocation, and energy efficiency. AI can enable self-organizing networks, intelligent network slicing, and dynamic network management, ensuring efficient utilization of network resources and improving overall network capability [28].

AI-Enabled IoT system: 6G aims to provide enhanced support for IoT deployments, enabling a massive number of interconnected network devices. AI can play a noteworthy role in organization and analyzing the huge amounts of data produced, facilitating real-time decision-making, predictive analytics, and intelligent automation [29]. AI-driven technologies can range from smart cities and industrial automation to healthcare monitoring and agriculture.

Application of Big Data Analytics: 6G can enable the transmission of huge volumes of unprocessed data from different sources, then it will be filtered and analyzed using data processing tools and techniques. By incorporating big data with 6G ecosystem which is enabling data-driven decision-making, personalized services, and improved user experiences. In the stage of 6G, network security and physical layer security will continue to be crucial areas of focus on confidentiality, integrity, and availability of wireless communication [30].

3.4 6G Security

Network Security in 6G networks can implement robust authentication mechanisms, such as multi-factor authentication and biometrics, to make sure that deliberate devices and users can access the network [31].
The encryption techniques and advanced encryption algorithms can be employed in 6G to maintain the privacy of data transmitted over 6G networks. This includes encryption of user data, control plane signaling, and management communications [35]. 6G networks offer intrusion detection and prevention systems that can utilize intelligent fraud detection systems to identify the threats or attacks in real-time. 6G systems can leverage advanced beam-forming techniques to focus the transmission of signals towards intended receivers while reducing the signal leakage, thereby enhancing physical layer security.
Secure channel estimation techniques in 6G can be employed to prevent eavesdropping or interception attempts by unauthorized entities. These techniques focus on making channel estimation difficult for potential attackers [36].
Artificial Noise Generation technique can be intentionally introduced into the transmission to confuse eavesdroppers and improve wireless communication security. Quantum Communication using 6G technologies, such as quantum key distribution (QKD), can be explored in 6G for highly secure communication. QKD utilizes the principles of quantum procedure to establish secure cryptographic keys between communicating parties [38].

3.5 6G Challenges

Challenges associated with AI and ML:
Scalability, dynamic online learning, competent dataset generation, A few of the challenges that artificial intelligence (AI) in wireless networks face is computation operating cost, feasibility authentication, consistency, learning competence, lack of explain ability. As classical theories cannot be adapted into real-time and to limitations, AI is the most dominating enabling technology to furnish to the unlock concerns of 6G. Algorithms for Deep Learning and Reinforcement Learning are more appropriate for this issue.

Challenges with Satellite communication:
The use of satellite communication as a design in 6G networks introduces challenges such as deployment scalability, effective verification, standardization, learning training issues, lack of explainability, and the need for enabling technologies that can

adapt traditional theories to the practical applications of reality and optimize reinforcement learning. Miniaturized or tiny satellites and learning algorithms are presently being developed [39].

Challenges associated with Cell free MIMO:

Using Cell Free MIMO particular difficulties arise with massive MIMO with optical wireless transmission (OWT). Short propagation lengths, signal detection and sensitivity, signal degradation, compatibility with hardware, packaging and cell-free connecting approaches, transceiver design, standardization and measurements, and system integration are some of these issues. Massive MIMO (multiple-input multiple-output) presents a unique combination of difficulties, including estimating Channel State Information (CSI) and practical deployment [40].

Challenges with Quantum Communication:

Due to limitations like quantum measurement, entanglement, non-cloning, and teleportation, quantum communication is difficult. Due to these limitations, building communications for quantum communication using quantum switches and routers is challenging [41].

Challenges with Network security and privacy:

Security approaches used in 5G are not adequate to meet the security requirements of 6G networks. As 6G aims to connect a broad diversity of devices and enable various applications, as well as automation, AI, XR, smart cities, and satellites, it introduces new security challenges. Innovative cryptographic methods and advanced security techniques will be crucial to ensure the confidentiality, reliability, and accessibility of data.

Challenges with IoT:

With the largest employment of IoT in 6G networks, the safety of all these devices becomes crucial. Implementing robust security mechanisms, such as device authentication, secure firmware updates, and secure communication protocols, will be essential to protect against unauthorized access and control of IoT devices [43].

Table 2. Recent Advancements on 6G And Research Gaps of Summary of 30 Articles.

Paper Ref.	Technology Focused	Key Insights and Contributions	Future work and Research Gap
[29]	Sub Terahertz sensing and communication, Ultra MIMO	Mobile technology anticipates the 6G standard's fundamental communication, wireless sensor technology and processing speed will be improved by December 2020. Authors while presenting a vision for 6G, the document may overlook the importance of global collaboration and standardization efforts.	Research gaps might exist if it does not emphasize the need for international cooperation, alignment with global standards, and harmonization of regulatory frameworks to facilitate the development and deployment of 6G networks worldwide.
[32]	Sub Terahertz sensing and communication, Ultra MIMO, VLC	The Next Generation Mobile Networks provides insights into the solution drivers and vision for the development of 6G. Authors outline the fundamental factors motivating the evolution towards 6G technology and presents a vision for the future of mobile communications.	The document may provide a high-level vision for 6G networks without exploring a diverse range of future scenarios and potential use cases. Research gaps could emerge if it does not adequately analyse the implications of 6G technology for various industries, applications, and user experience.
[33]	AI and ML, Virtual Reality, augmented Reality	In a white paper, emphasized the significance of AI and hoped that 6G will be able to connect macro and micro, virtual and real worlds, digital and physical worlds, history and outlook, and match technologies and requirements.5G Infrastructure Association provides insights into the European point of view on the expansion and deployment of 6G.	The white paper may primarily represent the viewpoints of industry stakeholders, policymakers, or academic experts involved in the European telecommunications sector. Research gaps could arise if the perspectives of other relevant stakeholders, such as end-users, regulatory bodies, or environmental groups, are not adequately considered.
[34]	Massive MIMO, VLC	The white paper outlines key objectives, challenges, and opportunities for 6G technology in the European context. It likely discusses various aspects of 6G networks, including technological advancements, policy considerations, research priorities, and potential use cases.	The research gaps identified in this paper would require a comprehensive and inclusive approach to analysing the idea for the 6G network system, incorporating diverse stakeholder perspectives, interdisciplinary considerations, and future scenarios into the discussion.

[37]	Sub Terahertz sensing and communication, Ultra MIMO, VLC	The paper examined the possibilities behind 6G and provided the overall visualization of 6G in conditions of 6G features and important design issues. This defines promising techniques mentioned, such as THz communications, MIMO and Visible light, block chain.	Research gaps exist in the expansion of energy-efficient 6G networks, considering the high-power requirements of some advanced techniques such as THz communications and quantum computing.
[42]	IoT, AI and ML, Virtual reality	The paper discusses Internet of Things (IoT) aspects, mobile ultra-broadband, and AI possibilities were proposed as three 6G features. Consistent data connectivity is crucial for the gradually more intelligent, automated, and ubiquitous digital world. Fifth generation (5G) wireless networks are being deployed but may not fully meet future connectivity demands and enable potential 6G use cases.	Research gaps identified in this paper is 5G wireless networks are being deployed but may not fully meet future connectivity demands. This article reveals the technologies for evolving wireless networks toward a sixth generation (6G) and enabling potential 6G use cases.
[44]	VLC, MIMO, Spectrum efficiency	The paper outlines the idea of society's progress towards 2030 and identifies new appliance scenarios for mobile communication, which are essential for shaping the future of mobile networks. Additionally, the proposed logical architecture of the mobile network and the features of the 6G provide important insights for the implementation of advanced mobile communication systems including Full spectrum, wide-coverage, large dimension and convergence.	The research gap here is related to the specific technological and architectural difficulties that need to be addressed in the development of 6G mobile networks. Identifying and solving these gaps will be crucial for advancing the research and development of 6G.
[46]	Virtual MIMO, Cell-free Communication and Full duplex	The paper describes the offshore 5G paradigm and presents a promising solution to address these challenges. By leveraging 5G technology and virtual MIMO, maritime vessels can benefit from improved data rates, increased reliability, and enhanced coverage.	The research gap of this paper is the regulatory and policy implications of deploying 5G virtual MIMO systems in maritime environments is a crucial area for further research.
[47]	Sub Terahertz sensing and communication, Ultra MIMO, VLC	Author proposes a comprehensive 6G visualization in conditions of applications, trends, and technologies emphasized the technological convergence.	The paper may provide insights into the gaps in current knowledge and the need for additional research in this area.
[48]	Satellite Communication and Terrestrial networks	It describes the project's idea, goals, obstacles, and research pillars as well as specific use cases and scenarios for satellite communications location in the context of 5G usage—an upgraded mobile broadband scenario. This suggests that the project's main goals are to integrate terrestrial and satellite networks for 5G and investigate how they may be utilized for improved mobile broadband.	Research gaps may involve identifying areas within the integration of satellite and terrestrial networks for 5G where there is limited existing research or where further exploration is needed.
[49]	IoT, AI and ML, Virtual reality	According to the paper, 6G will offer superior information, communication, and convergent computing capabilities, serving as the foundation for a linked and converging physical and digital world.	Research is needed to develop and implement effective privacy-preserving mechanisms that can safeguard user information in the context of 6G networks.
[50]	Satellite Communication and Terrestrial networks	These papers discuss that 6G will integrate satellite communications, terrestrial ultra-dense communication networks and undersea communications.	This includes exploring original data security mechanisms such as spread ledgers and privacy, as well as addressing the challenges of managing the accessible user information explosion is not a easy task for researchers.

[51]	Undersea Communication	This article focusses on underground communications, UAV communications to expand and provide ubiquitous global coverage.	Undersea wireless communication is a major milestone in 6G aspects. Physical and environmental parameters of implementation is challenging thing in undersea communication.
[53]	Quantum communication, Block Chain Security	The importance of addressing security and privacy issues of 6G networks is paramount for several reasons.	First and foremost, ensuring the security of these networks is crucial for protecting user data and privacy. As 6G networks are predictable to hold up a large variety of application and services including their critical infrastructure and sensitive information, it's essential to safeguard against potential threats and vulnerabilities.
[66]	IRS, Physical layer security	The research paper discusses the role of Reconfigurable surfaces in enhancing the security of wireless networks. It covers various aspects of Physical Layer Security including performance metrics, in the 6G scenario. The paper analyses the performance of RIS systems and discusses challenges and potential applications of RIS in improving the secrecy performance, energy effectiveness, and reliability of wireless communication systems. It emphasizes the significance of RIS in improving the security of wireless networks and proposes future research directions for further exploration of RIS with the physical security layer.	The research gap here lies in the need for further exploration of reconfigurable intelligent surfaces (RIS) in wireless communication systems. This includes addressing technical challenges, developing cost and energy, convenient protocols for RIS deployment, and investigating potential applications of RIS in security of 6G wireless networks. Additionally, there is a need for more research on the exact attainment of Channel State Information (CSI) for RIS and the exploration of future research directions must be made in the same case.
[67]	Satellite Communication THz Communication Cell-free Communication	It focuses on research in THz frequency bands, which are part of the radio spectrum. These frequency bands have the potential for wideband channels and future applications such as 5G wireless communications, cell phones, autonomous vehicles, and smart devices. The lab aims to address challenges in designing and measuring devices and systems at these frequencies by providing a state-of-the-art measurement platform. It also highlights ongoing efforts by various countries to explore applications and use cases at these frequencies. The document describes the various components of the measurement facility and emphasizes collaboration with other universities and experts in the field to enhance research capabilities in metrology, signal processing, and related areas.	This gap has limited the use of the spectrum between ~100 GHz and ~10 THz. The document highlights that although current hardware have been closing the THz gap, present are still important challenge pertaining to physical limitations, properties of materials, integrated code sign of system components for beam steering or signal processing.
[68]	Orthogonal Time frequency Space, and cell-free Communication	Authors discuss the challenges faced by conventional OFDM systems in supporting high mobility in 6G mobile communication systems and propose the use of multi-cell OTFS(Orthogonal Time frequency Space) systems as a solution. It highlights inter cell interference as a major challenge, particularly for cell-edge users and presents interfering coordination and supportive communications-based solutions for multi-cell systems. The paper evaluates the performance of these solutions through simulations and identifies the potential of OTFS as a technology for 6G networks supporting high mobility and various scenarios.	The research gap in this paper is the need for further study and clarification of the impact of diverse kinds of interference on multi cell OTFS systems. Additionally, there is a need to address the challenges and open research issues in multi cell OTFS systems before deploying them.
[69]	Physical layer security	This article discusses the challenges on the physical (PHY) layer of the sixth generation (6G) wireless networks. It highlights the shortcomings of the 5G multi-n numerology	The research gap identified in this article revolves around the need for a new physical layer (PHY) design for 6G wireless networks. The authors emphasize the necessity for a pragmatic approach that is both backward-

		orthogonal frequency division multiplexing (OFDM) and proposes a backward-compatible, forward-looking, and extendable PHY layer framework for 6G. The article also explores the OFDM compatibility for beyond 5G applications and addresses critical research problems in this area.	compatible and forward-looking, while also addressing the industry's potential resistance to a complete redesign due to associated costs.
[70]	Digital twin technology and Blockchain	This article discusses the importance of quality-evaluation for digital twins in 6G. The authors propose a Quality evaluation catalogue for human digital twins 6G networks and introduce the evaluation metric that has both features service with quality and content-quality. They conduct subjective experiments to do individual quality ratings for 400 sequences and compare their model with existing evaluation models. The investigational results confirm that their prototype works for other models, making considerable contributions to the field of 6G.	The article identifies the need for further research in addressing practical problems related to quality-of-experience for users in human digital twin applications, especially in 6G networks. It also highlights the challenges of managing factors like buffering time and stalls in real-time interactions. The authors emphasize the importance of finding user-friendly trade-offs and enhancing the applications under 6G networks.
[71]	Full- duplex, Cell-free Communication	This article presents a study on the use of all together Transmitting and Reflecting Intelligent Surface technology in a multi-STAR-RIS assisted and full-duplex (FD) cellular wireless system to provide less delay communication services. The authors propose a meta-learning approach called Meta (deep deterministic policy gradient) DDPG approach to optimize the beam forming and combining vectors and broadcast power of the STAR-RISs.	To address the research gap and upcoming work in this document computational complexity and optimality challenges, the paper proposes a Meta DDPG is a combination of DDPG and meta-learning. This approach aims to leverage the advantages of meta-learning, ubiquitous convergence, better performance, and robustness to green changes, in addressing the dynamic nature of 6G networks but percentage of performance accuracy not mentioned.
[72]	XL-MIMO	A thorough overview of the literature on very large-scale multiple-input multiple-output (XL-MIMO) wireless systems is given in this article. XL-MIMO systems are thought to be a key enabling technology for the next sixth generation (6G) of wireless mobile networks. Four XL-MIMO hardware designs are shown, along with their features and connections, in this article. It also draws attention to the advantages and disadvantages of XL-MIMO technology as it relates to improved mobile broadband.	The article identifies some research gaps, including the need for a more comprehensive study focusing on extra larger MIMO technology, elaboration on critical issues for practical implementation, and exploration of less complex signal processing techniques. Based on the article, some prospective future research directions for XL-MIMO technology include AI-aided resource allotment schemes, Energy effectiveness and green and Semantic communications where Test beds and experimental evaluation can be better implemented.
[73]	Massive MIMO	In this article, the authors propose a synthesis of wireless and sensor data to improve analytical beam forming in UAV-assisted massive MIMO communications. They developed a framework that combines channel and sensor data using an extended Kalman filter (EKF) technique to improve beam alignment and position/orientation estimation accuracy. The model results reveal that the projected scheme can significantly recover motion tracking and enhance spectral competence.	The future scope of this research could involve further exploration of real-world implementation and testing to validate the proposed method's effectiveness in practical UAV-assisted communication scenarios. Additionally, investigating the impact of environmental factors, such as weather conditions, on the proposed fusion method's performance could be a valuable area for future research. Research gaps may include exploring the robustness of the proposed fusion method in dynamic and challenging environments, as well as extending the study to address potential limitations related to hardware constraints and real-time processing requirements.

[74]	IRS, MISO communication	This article presents a study on joint beam forming and aerial intelligent reflecting surface (AIRS) positioning design for multiple input transmitters and single receiver output (MISO) several access points (APs). The authors propose algorithms for beam forming vector design and AP-user pairing, as well as a heuristic pairing algorithm. They also solve the combined AIRS positioning and beam former design problem using a proposed method. Model results demonstrate the efficiency of the algorithms, and an investigation of communication operating cost incurred.	The research gap in this paper appears to be the need for further optimization of communication efficiency for physical networks particularly in the context of joint aerial IRS (AIRS) and beam former plans.
[75]	AI and ML, Network slicing,	This script reports an exploration of source provision practices for the co-presence of eMBB and URLLC provisions in 6G radio systems including network slicing, merged learning, machine learning (ML) advanced practices.	This conclusion directs a chief study gap, an massive examination on the coexistence of eMBB and URLLC services in 6G networks is needed, with an importance on resource allocation techniques and the implementation issues that go along with them.
[76]	MM wave, THz communication	The perception of magnitude traceability and the role in establishing and sustaining traceability are described in the article. The assignment's fundamental areas, which involved determining traceability for electric dimensions at THz and mm-wave rates, are drawn in this section.	Measurement capabilities for mm-wave and THz material parameter characterization were lacking. The text suggests that methods or instruments to precisely describe materials at these frequencies were lacking prior to the study.
[77]	AI and ML, Cloud network,	The cloud-based intelligent Radio Access Network (RAN) architecture for 6G is covered in this article. It draws attention to how important artificial intelligence (AI) and cloud computing are to the advancement of programmable networks toward more automation and intelligence. The paper also offers a use case for indoor location and presents an open-source platform architecture for realistic intelligent RAN.	The research gaps in the paper include the need for further exploration and development of the proposed cloud based intelligent RAN architecture. Specifically, there is a requirement for more in-depth research on the overall architecture implementation, including addressing open challenges and refining the platform framework to enhance the integration between cloud and networks. The paper suggests continuous optimization of the platform to promote the in-detail integration connecting cloud and networks, indicating a need for ongoing refinement and improvement in this area.
[78]	Block Chain	This paper proposes a 6G architecture and authentication scheme using block chain-like technology and Verifiable Credentials. The architecture aims to enhance security for future 6G technology, particularly in transitioning between trusted zones. The proposal emphasizes the requirement for a decentralized, distributed identity authentication of request examination.	The research gap in this paper is, while block chain-like technology and Verifiable Credentials hold promise, scalability remains a significant challenge. Research is needed to explore how these solutions can scale to meet up the demands of 6G networks, which are likely to handle huge volumes of transactions and authentication requests.
[79]	Use cases and Key performance Indicators.	A brief overview of the developments in 6G technology is given in this article. It goes through the use cases, KPIs, new developments in network support technologies, and possible spectrum possibilities. The review is grounded in original literature, which includes the pertinent ITU paper on usage scenarios for IMT 2030.	The research gaps in the paper on the progress of 6G technology include the need for more in-depth exploration of the practical implementation challenges, such as the incorporation of 6G with existing 5G infrastructure, the growth of novel spectrum bands, and the exploration of non-terrestrial network requirements. Additionally, further investigation into the potential societal and economic impacts of 6G technology, as well as the identification of open research problems and opportunities, would contribute to a comprehensive understanding of the subject.

4. Future Research Milestones

There are several potential methods to face these challenges, and numerous research areas to be explored in the development of 6G. Figure 7 shows different research milestones for 6G communication systems, both for current and future research.

Sub Terahertz sensing and communication

The variety of electromagnetic waves between 100 GHz and 1 THz is referred to as sub-THz frequencies. High-resolution imaging is possible with sub-THz waves, which can also penetrate certain materials including textiles and plastics. They can therefore be used for non-destructive testing, medical imaging, and security screening. By interacting with molecular vibrations and rotational states, sub-THz waves analyze different materials using spectroscopy. This has applications in the study of chemistry, the production of drugs, and environmental monitoring.

Sub-THz waves are helpful for sensor applications that detects through opaque materials since they can surpass some obstructions, such as clothing or atmospheric conditions. Sub terahertz and terahertz frequency support as one key aspect of a 6G communication is that wider bandwidth available at these higher frequencies and therefore data rates in the one terabit per second appear as possible. In the beginning other application areas might be an even more pragmatic use case for terahertz frequencies these areas include accurate positioning sensing location awareness and gesture recognition allowing resolutions down to sub-centimeter and millimeter level and therefore enabling these types of applications [45].

New waveforms and Multiple Access

6G uses different techniques like Orthogonal Time Frequency Space (OTFS) is a waveform that can increase performance in environments with high levels of mobility, such as vehicular communication or networks for unmanned aerial vehicles (UAVs). To lessen the impacts of time-varying channels, improve spectral efficiency, and be more resilient to multipath fading, it makes use of the delay-Doppler domain. Filtered-OFDM(F-OFDM)is an adaptation of orthogonal frequency-division multiplexing (OFDM) that boosts spectral effectiveness by reducing out-of-band emissions. It manages interference while striking a balance between spectral efficiency. Universal Filtered Multi-Carrier (UFMC) waveform also tries to increase spectral efficiency via the use of sophisticated filtering methods. It supports non-contiguous spectrum allocation and offers flexibility in subcarrier spacing. Dynamic Time Division Multiple Access (DTDMA) is a dynamic multiple access method that assigns users time slots based on the channel conditions and traffic demands. It supports the effective use of network resources and allows for flexible resource allocation [52].

As a discussion of waveform encoding schemes to enable the targeted high data rates as sub-terahertz and terahertz waves travel realistically 100 to 150 meters using a multi-carrier transmission scheme58. at these frequencies becomes at least debatable one reason is that the advantage of flexible scheduling of hundreds of users in time and frequency domain might be negligible given the achievable coverage based on the technology's current state a sub-terahertz hotspot may only have to serve a few users at the point of time and with the wide bandwidth available faster data speed per user seem to most reasonable second a single carrier transmission technique offers a lower ratio allowing the amplifier to operate at a higher compression point enabling higher overall output power and contributing to an improvement of the link budget it will be interesting to see what the industry's standardization bodies will agree on the communication aspects need to be considered when defining waveforms for many one 6G use case will be location awareness of environment providing the user [54]

Ultra-massive MIMO

Ultra-massive MIMO is a technology that embeds the utilize of a very great number of antennas at the base station to serve many users simultaneously. This technology has the potential to extensively boost the ability and spectral competence of wireless communication systems. For 6G wireless communication systems, is an active field of research and development. Massive Array topologies efficiently accommodate a very high number of antennas, researchers are investigating novel array topologies and designs. Investigating cutting-edge antenna arrangements such as distributed antenna arrays, hybrid analog-digital arrays, and sophisticated antenna selection methods are part of this. Accurate and effective channel estimation becomes difficult with a large number of antennas [55],[56]. New channel estimating methods are being developed by researchers to estimate channel parameters more efficiently and simply [57]. Furthermore, effective feedback mechanisms are available for channel status information (CSI) transmission from consumers to the base station [58],[66].

Cell-Free Communication

Indeed, 6G will make sure of this technology, enabling cell-free connectivity. The user's calls need to step forward to the new cell when the user equipment (UE) changes from one cell coverage to another. Then the user's call may be disconnected and the system's QoS may be decreased, if this handover is unsuccessful in specific cases. Since the UE is attached to the entire network rather than just a single cell in 6G, the issue of cellular coverage will be solved. By combining many technologies through unmanned vehicles (UAV), the user experience (UE) will be chosen as the one with the best coverage [59],[60].

Full Duplex

In a full duplex system, data can be passed and received at an identical time without the need for switching back and forth between sending and receiving modes. This allows for efficient and seamless communication between devices. The following research area is full duplex; this is not necessarily new: in fact, full duplex has been proposed when a new 6G is around the corner in a full duplex system. The transmitter and receiver will simultaneously operate on a single carrier, which in theory doubles the communication system's spectral efficiency. The challenge lies in the induced self-interference from transmitter to receiver, which could only be resolved with innovative but costly analog circuitry concepts and cancellation techniques. With advancements of ML principles and wireless communication, a full duplex system may become a reality in a 6G wireless communication standard [61],[62].

Visible Light Communication

This light technology employs visible light between 400 and 800 THz (780–375 nm). It's an appearance of optical communications technology that uses light-emitting diodes (LEDs) for data broadcast. VLC has the prospective to be a part of 6G technology, offering high-speed data transmission, low latency, and secure communication. It can be well used in local environments, such as offices and hospitals, to provide high-speed wireless connectivity [63],[64]. VLC has the advantage of being immune to electromagnetic interference and can coexist with existing RF (Radio Frequency)-based wireless technologies. In 6G, VLC might be used to complement traditional wireless communication technologies and expand the capacity of wireless networks. This concept is an initial phase of wireless technologies using visible light corresponding to 384 terahertz to 789 terabytes. However, it is an industry procedure or practice to use the wavelength to describe this part of the electromagnetic spectrum - about 380 nanometers to 780 nanometers. In its simplest form the transmitter is an LED. It can rapidly adjust to varying light intensities for data modulation and transmission, allowing the photodiode to detect these fluctuations and subsequently decode and demodulate the data. [65],[80] .

Machine Learning

This dominant research area plays a vital integral role in 6G wireless communication which use standard machine learning algorithms, pattern identification and inference. In 6G, it is anticipated to advance to the air interface and become the basis for signal detection, synchronization, channel estimation, equalization, modulation, and coding. Machine learning aims to optimize nearly every block of the signal processing chain that has previously been individually optimized and required explicit expert knowledge for programming a specialized and complex software algorithm. [81].

Intelligent Reflecting Surfaces (IRS)

This is an expertise technique that has gained interest as a potential component of 6G wireless communication systems. IRS consists of passive reflecting elements that can be deployed in the environment to enhance wireless communication. These elements can adjust the phase and amplitude of the impinging electromagnetic waves to optimize the signal quality at the receiver. In 6G, IRS can be used to progress coverage, increase spectral efficiency, and mitigate interference in wireless networks. By intelligently controlling the reflection properties of the surfaces, IRS can improve the on the whole performance of the wireless communication system [82].

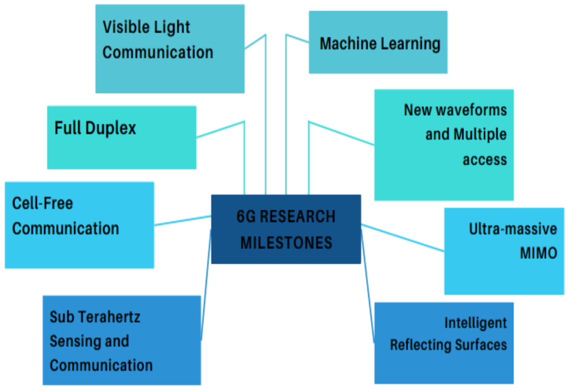


Figure 7. Research areas of 6G communication system.

5. Conclusion

In this paper, the aim is to design and explore the sixth generation of wireless communication systems (6G), industry and academia have joined forces during the widespread rollout of 5G networks. This paper aimed to prepare for the challenges and recent advancements on 6G and beyond 5G including the research gaps and identified research milestones of 6G.As the 6G new horizon, the global scope is to focus mainly on the 6G drivers, 1.Proliferation of Intelligence by AI support. 2. End to End Data Security and trustworthiness. 3. Extreme Connectivity and Sustainability with 6G. 4. Smart vision and social responsibility.
Researchers across the world are looking forward to bringing the considerable changes to implement 6G. This research started by outlining a vision and the essential components to classify and support future 6G in the subsequent areas such as energy competence, spectrum efficiency, security this paper to contribute to resolve the problems with 6G technology as well as proposed fixes to enable 6G in the future. International research initiatives are used to wrap up this work and are intended to develop a vision for 6G and encompass overall development in 6G technology to meet the evolving demands and expectations beyond the capabilities of 5G. As world move towards 2030, 6G is expected to bring new features, applications, and technologies that will enrich network efficiency also integrate various technologies and highly connected and intelligent society to outline the expectations of 6G and reshape the intelligent networks by 2030.

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