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TRANSITIONING TO 6G WIRELESS: INVESTIGATING CORE TECHNOLOGIES, CHALLENGES, DEMANDS, APPLICATIONS AND RESEARCH AVENUES

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Abstract

Amidst the expanding reach of 5G networks, researchers are increasingly uncovering limitations inherent in this technology, thereby sparking a surge of interest in the exploration and development of 6G, the forthcoming generation of cellular communication. Despite the specifics of 6G remaining nebulous, certain experts predict a transformative impact on mobile data usage and smartphone functionality. This review aims to consolidate ongoing research efforts and elucidate technological uncertainties surrounding the evolution of 6G. Expected to debut between 2027 and 2030, 6G is poised to introduce a new framework leveraging artificial intelligence. The integration of higher frequencies is anticipated to yield significantly accelerated data rates, expanded system capacity, reduced latency, enhanced security, and superior quality of service, with the overarching goal of providing high-speed gigabit Ethernet access to both businesses and consumers via their devices. This review examines various proposed technologies for enabling 6G communication, along with key performance indicators (KPIs) for the network, potential challenges, and directions for future research.

Keywords: 6G, Artificial Intelligence, Quality of Service, Key Performance Indicator

I. Introduction

The wireless communication industry, known for its constant innovation, is already looking beyond 5G towards the next generation: 6G. Though 5G networks are still being deployed globally, research for 6G has begun. This new technology aims to revolutionize wireless evolution, shifting from simply connecting things to enabling "connected intelligence" with more rigorous standards. Robotics, AI, XR, automation, and other emerging technologies will all play a role in 6G's development [1] [2].

Key design considerations include network programmability, flexible and affordable deployment, enhanced security and reliability, and automation. 6G promises a staggering 1000 times more concurrent connections compared to 5G, alongside ultra-low latency communication below 1 millisecond. This ultra-reliable, high-capacity network is crucial for the growing use of autonomous systems in various industries, from healthcare and transportation to manufacturing. It will enable the creation of a "smart life" by seamlessly integrating thousands of sensors in homes, factories, vehicles, and other products. To cater to diverse user needs, 6G envisions a unique wireless and access architecture that combines communication and sensing capabilities, AI-powered wide-area networks, co-designed data centers, and dynamic orchestration of personalized services [3].

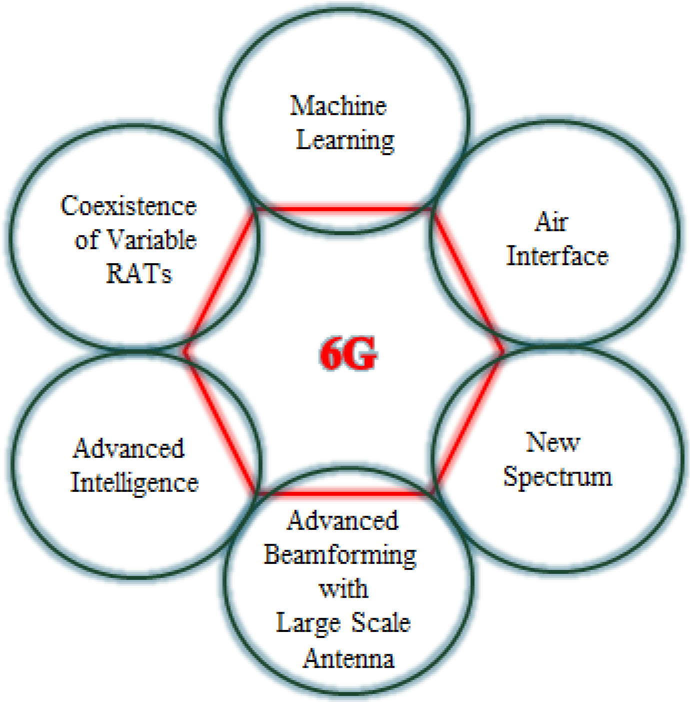

Figure 1: Emerging Technology Opportunities

II. Shifting Technological Paradigms in Mobile Communications

In contrast to the incremental improvements observed in prior advancements of mobile technology, the endeavors surrounding B5G (Beyond 5G) and 6G are characterized by their aspiration for a significant leap in performance. These initiatives are ambitiously targeting a notable surge ranging from 10 to 100-fold in capabilities [4]. This ambitious pursuit of advancement is primarily catalyzed by the exponential surge in mobile data traffic observed over the course of the last decade. This surge has been fueled by the pervasive integration of smart devices into everyday life and the continuous expansion of Machine-to-Machine (M2M) communication networks.

The trajectory of mobile data demand is anticipated to experience a significant upward trajectory in the forthcoming years. As per projections from the International Telecommunication Union (ITU), the global mobile data traffic is forecasted to witness a remarkable surge, reaching an astounding 5 Zettabytes (ZB) per month by the year 2030. This represents an impressive 670-fold increase from the levels observed in 2010. Furthermore, there is an expectation of an unprecedented surge in the number of mobile connections, estimated to climb to a staggering 17.1 billion by 2030. This stands in stark contrast to the 5.32 billion connections documented in

2010. These projections serve to highlight the imminent challenges posed by capacity constraints in 5G networks, which are predicted to reach their limits by the year 2030 [5].

In response to this exponential growth in demand and the need to accommodate advanced services, the spotlight is now on the development of 6G networks. Equipped with intelligent network adaptation and management capabilities, 6G technology is poised to revolutionize the landscape of mobile connectivity and data utilization, offering unprecedented performance and unlocking a new era of seamless communication and connectivity [6].

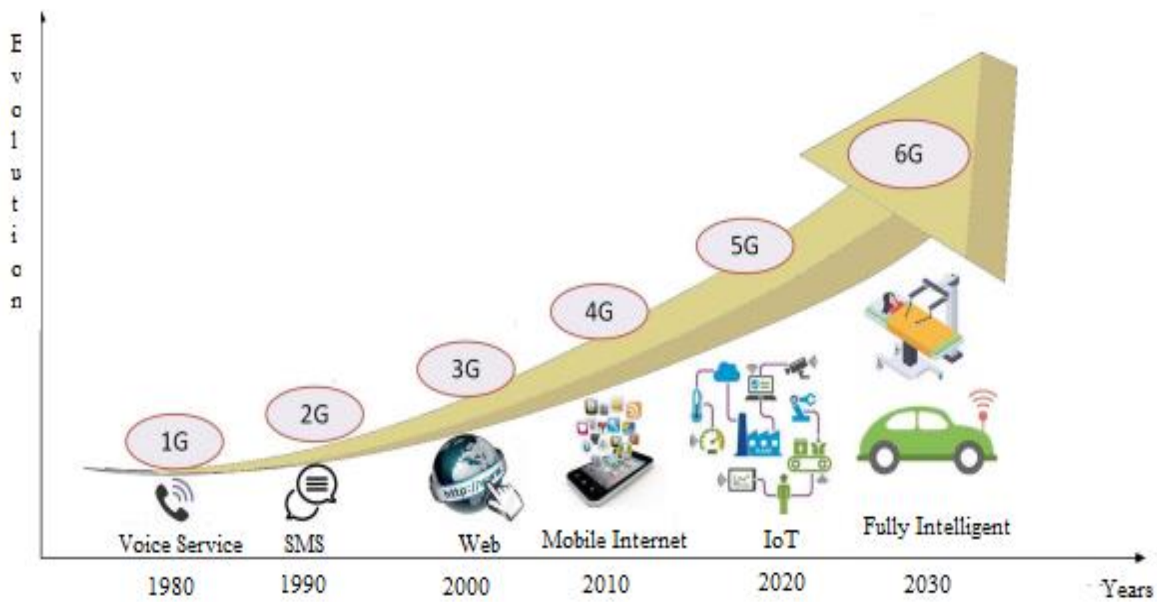

Figure 2: Advancements in Wireless Mobile Communications

III. Precise Requirements and Standards of Quality

As the capabilities of 5G networks approach their limits, the emergence of 6G technology signifies a pivotal transition bridging the chasm between current capacities and the burgeoning demands of the future. This next-generation evolution places paramount emphasis on facilitating exponential data transfer speeds for individual devices while simultaneously enabling widespread global connectivity with unparalleled reliability. Recognizing the imperative of ultra-low latency and energy efficiency, particularly in the ever-expanding landscape of Internet of Things (IoT) devices, 6G endeavors to address these critical requirements with innovative solutions.

Furthermore, the impending advent of 6G technology is positioned to instigate a paradigm shift in network intelligence through the incorporation of advanced machine learning capabilities [7]. This integration is set to empower networks with the ability to foresee future demands and dynamically adapt to them. The promise of this adaptive intelligence heralds a new era characterized by enhanced responsiveness and efficiency, adept at meeting the evolving requirements of users and applications alike.

While it is anticipated that 6G networks may draw upon certain existing Key Performance Indicators (KPIs) inherited from their predecessor, 5G, the emergence of this next-generation technology is expected to introduce entirely novel drivers for network performance. Consequently, it becomes imperative to reassess the current set of 5G KPIs and introduce fresh metrics tailored specifically to the unique demands of 6G. Although some of these nascent drivers may currently lack precise definition, ongoing research initiatives are poised to elucidate and solidify them in the years ahead. This concerted effort will pave the way for the seamless integration and optimization of 6G networks [8].

Table 1: Contrast Between KPI Drivers in 5G and 6G Communication Systems

KPI	**5G**	**6G**
Peak data flow rate/device	20 Gb/s	1 Tb/s
Experienced data rate	0.1 Gb/s	1 Gb/s
End-to-End (E2E) Latency	10 ms	1 ms
Max. Spectral Efficiency	30 b/s/Hz	100 b/s/Hz
Experienced Spectral Efficiency	0.3 b/s/Hz	3 b/s/Hz
Energy Efficiency	Not Specified	1 Tb/J
Satellite Integration	Not Applicable	Entirely
Haptic Communication	Limited	Wholly
Autonomous(Self-directed) Vehicle	Limited	Wholly
Artificial Intelligence	Limited	Totally
THz Communication	Very limited	Widely
Services	Virtual Reality, Augmented Reality	Tactile
Architecture	Massive MIMO	Astute Surface
Max. Frequency	90 GHz	10 THz
Max. Bandwidth	1 GHz	100 GHz
Jitter	Not Specified	1 µs
Reliability	$1\text{-}10^{-5}$	$1\text{-}10^{-9}$

Mobility	500 km/h	1000 km/h
Area traffic capacity	$10Mb/s/m^2$	$1\ Gb/s/m^2$
Density of connections	10^6 devices per km^2	10^7 devices per km^2

6G systems prioritize a tiered approach to KPI-related services. The most crucial service is ubiquitous Mobile Ultra-Broadband (uMUB), ensuring widespread access to high-speed internet for all devices [9]. Following this is ultra-High-Speed with Low-Latency Communications (uHSLLC), catering to applications requiring near-instantaneous data transfer. The network then supports massive Machine-Type Communication (mMTC), enabling the vast number of devices in the Internet of Things (IoT) to connect efficiently. Finally, ultra-High Data Density (uHDD) ensures the network can handle situations with an extreme concentration of data traffic.

IV. Services and Requirements for 6G Networks

The four categories of services outlined here find numerous applications in both individual and specialized settings, such as smart manufacturing, smart transportation, intelligent energy management, and healthcare innovation [10].

- Traditional services encompass Mobile Internet services, IoT services, and the integration of broadcasting and communication services.
- AI services include Assistant services relying on human-machine interface (HMI) and unmanned services leveraging machine-machine (M2M) interface.
- Immersive Services, which involve holographic communication or Extended Reality (XR), offer multi-sensory virtual experiences (MSVE) and control functionalities.
- Digital services entail simulation and control services that leverage the interactive mapping of physical and virtual spaces.

In terms of network architecture:

- For enabling swift network functionality reconfiguration and upgrades, along with dynamic scheduling of service resources and functionalities to meet evolving demands, the 6G network must incorporate an End-to-End (E2E) microservice architecture and Software-Defined Network (SDN) framework.
- To support ubiquitous AI computational resource allocation and ensure widespread availability of AI applications and services, the 6G network should adopt a distributed AI architecture.
- For facilitating global deployment and operation of services, the 6G network should feature an integrated space-ground architecture.
- To promote a sustainable global equilibrium of traffic and processing capacity, as well as ensuring End-to-End (E2E) service quality and information computing capabilities, the 6G network should implement a cloud-network-edge-terminal integrated scheduling model.

In terms of network capability (function):

- The 6G network should enhance communication and coverage, boost data rates, reduce latency, improve reliability, and ensure global and microspace coverage.
- It should possess inherent sensing capabilities for global perception of service, network, client, terminal, and environmental attributes.
- Native computing capacities must be integrated, allowing for network-wide computational power visualization, encapsulation, and scheduling.
- Native AI is essential for realizing both "network for AI" and "AI for/in network" paradigms within the 6G infrastructure.
- The network should consistently support deterministic data processing, enabling timely sensing, transmission, and computation.
- Capacity exposure features should facilitate the utilization of foundational sensing, communication, and computational resources, enabling capability-as-a-service models.
- Native security features are crucial for zero trust, active defense, and self-immunity, with potential integration of blockchain for resource sharing and collaborative ventures.

V. Opportunities and Potential Applications

Exploring the Potential of 6G: Diverse Applications

Education: 6G systems, fully integrated with AI, offer groundbreaking opportunities in education. Utilizing holographs and Extended Reality (XR), students can engage in immersive learning experiences. For instance, XR facilitates surgeon training by providing a realistic platform for skill development. Moreover, 6G enables remote access to surgical procedures, allowing teaching hospital consultants to mentor students virtually in real-time. Additionally, Unmanned Aerial Vehicles (UAVs) enhance emergency communication by connecting mobile ambulances to the network, ensuring swift assistance. The integration of multi-sensory XR and holographic communication further enriches educational experiences [11].

Haptic Communication: Leveraging the sense of touch, haptic communication becomes a powerful tool for Non-Verbal Communication (NVC) in diverse applications. With 6G connectivity, real-time interactive systems enable users worldwide to experience tactile sensations. From robotics sensors to individuals with disabilities learning through touch, medical haptic techniques in surgery, and immersive entertainment, haptic communication finds extensive utility in various domains [12].

Internet of Everything (IoE): The limitations of the current 5G mobile system in supporting IoE applications are driving global research efforts towards the development of 6G technology. Anticipated to offer robust IoE support across various domains, 6G integrates data, people, processes, and physical devices within a unified framework, leveraging Internet Infrastructure akin to IoT [7] [12].

Smarter Healthcare and Biomedical Communication: 6G networks revolutionize healthcare by offering dependable remote monitoring and enabling remote surgeries. With significantly higher data speeds and minimal failures, 6G ensures rapid and reliable transmission of vast volumes of medical data, enhancing access to quality healthcare. Biomedical communication, facilitated by 6G technology, involves transmitting data from sensors embedded in the body to healthcare providers, ensuring consistent and long-term monitoring [12] [13].

Entertainment and Media: 6G introduces innovative applications in entertainment and media, including cloud gaming, Tactile Internet, Over-the-Top Television, Augmented Reality (AR), and Virtual Reality (VR). However, seamless experiences in AR and VR require ultra-low latency, which 6G networks provide, ensuring minimal delays and enhancing user immersion in virtual environments .

Amazing-Smart Society: 6G's innovative architectures are poised to accelerate the realization of Amazing-Smart Societies, characterized by life-changing innovations, environmental monitoring, and AI-driven M2M communication and energy harvesting. Through the deployment of smart mobile devices, AI-based driverless vehicles, and other cutting-edge technologies, 6G wireless connectivity facilitates unprecedented levels of societal intelligence. Smart homes become achievable as remote control of devices from disparate locations becomes seamless via smart devices [13].

Automation and Manufacturing: Revolutionizing automation systems, 6G technologies redefine manufacturing processes by offering high-data-rate, low-latency connectivity for ultra-reliable, flexible, and secure connections, enhancing efficiency and productivity across industries.

Brain-Computer Interactions (BCI): Facilitating direct communication between the brain and external technologies, BCI technology receives and interprets signals from the brain, enabling various applications including non-visual BCI for the visually impaired, demanding swift responses. 6G advancements simplify the integration of BCI networks into everyday life, unlocking possibilities for smarter living [14].

Five Senses Information Transfer: 6G systems facilitate the transfer of data from all five human senses to remote locations, leveraging Brain-Computer Interface (BCI) technology [14]. This application harnesses sensory integration and neurological processes to interpret sensations from the body and surroundings, effectively integrating the human body within its environment.

Extended Reality (XR): Critical components of 6G networks, XR services such as AR, VR, and MR deliver immersive experiences with unparalleled quality. Leveraging advanced design integration and superior connectivity, 6G elevates AR, MR, and VR experiences, seamlessly blending real and virtual worlds to create interactive environments in real-time [14] [15].

Connected Robotics and Autonomous Systems (CRAS): Emerging technologies like self-driving vehicles and drone-based delivery systems are gaining momentum, revolutionizing industrial and manufacturing processes. CRAS relies on 6G networks to deliver ultra-high data rates, minimal latency, and exceptional reliability, enabling the deployment of networked robotics and autonomous systems. With 6G, autonomous transportation systems have the potential to reshape daily life significantly, necessitating interfaces that inform passengers or supervisors of potential risks for proactive accident mitigation measures [15].

VI. Core Technologies Enabling 6G Advancements

Below are a handful of the most important 6G technologies to expect:

Artificial Intelligence (AI): For automation, AI will fully support 6G. The entire potential of radio transmissions will be realized with AI-powered 6G, allowing the transition to intelligent radio from cognitive radio (CR). Machine Learning (ML) advancements provide much more intelligent [7] and smart networks for real-time data transmissions in 6G. AI improves data transmission efficiency while reducing communication processing time. AI can speed up time-consuming operations like handover and network selection. Machine-to-Human (M2H) and human-to-machine (H2M) connections will all benefit from AI. The combination of ML and big data to discover the optimum route for data transmission to end-users by giving predictive study and analysis would drastically minimize latency [16] [17].

Holographic Beamforming (HBF): HBF is a novel beamforming technique so as to differ from MIMO systems in that it employs software-defined antennas. In 6G, HBF is a great solution for effective and feasible signal transmission and reception using multi-antenna communication systems [11].

Massive MIMO and Intelligent Reflecting Surfaces (IRS): Massive MIMO technology will be important in facilitating uHSLLC, mMTC, and uHDD services in the 6G system. IRS is a relatively new hardware technology with a lot of promise in terms of energy-efficient green communication. IRS with wireless environment management capability has been identified as a viable technology for 6G networks, according to new research. IRS can use enormous configurable elements to intelligently regulate the wave front and is very effective in improving the user rates in massive MIMO systems [18] and results in fine-grained 3-D passive beamforming.

FSO Fronthaul/Backhaul Network: Free Space Optics (FSO) is a great way to provide fronthaul and backhaul connectivity is used in 6G. It is feasible and flexible to have communications that cover long-range using FSO, even over 10,000 km away places, including the sea, ocean, outer space, undersea, and islands that are also isolated.

Terahertz (THz) Communications: To satisfy increased demand, 6G seeks to push the frequency band's boundaries to THz. THz also known as sub-millimeter radiation, will be used in 6G. Sub-millimeter radiation is electromagnetic waves with wavelengths ranging from 1 mm to 0.1 mm. THz offers a number of benefits that make it ideal for 6G, including high bandwidth, extremely high data rate (up to several Gbps), high capacity, and extremely high throughput. THz signal efficiency can be improved by reusing and sharing spectrum. Spectrum reuse solutions such as CR are already in use [1] [11].

Cell-Free Communications: The widespread cell-free massive MIMO is a combination of Time Division Duplex (TDD), massive MIMO operation, massively dispersed network, and user-centric network. The term "cell-free Massive MIMO" refers to a combination of the distributed MIMO and Massive MIMO principles in which the network has no boundaries or cells [18]. Huge data speed, ultra-low latency, ultra-high dependability, excellent energy efficiency, and ubiquitous and uniform coverage are among the projected benefits. This lets users to effortlessly migrate from one network to the next.

Block chain: With better security, anonymity, interoperability, dependability, and scalability, the blockchain is essentially an ideal complement to the massive IoT. It is decentralized and the data on a block chain is collected then organized into blocks. This solution protects remote resources and offloads computations while also establishing credibility between edge servers and consumer devices. It does away with intermediaries and provides the best inference management possible [19].

Big Data Analytics: Data comes from a many sources, including social media, videos, sensors, and photographs. It is a fabrication that this technology can handle massive amounts of data in 6G systems. 6G networks are expected to advance through automation using computerization and self-optimization as a result of the potential to leverage massive amounts of data, big data analytics, machine learning and deep learning techniques.

Integration of Wireless Information and Energy Transfer: When it comes to upcoming viable ways of energizing the increasing number of connected devices, energy harvesting has been a highly pursued topic of research. Wireless Energy Transfer (WET) is used to transfer energy from a source to a destination in man-made energy harvesting. WIET will be one of the most revolutionary technologies in 6G connectivity. During communication, wireless power transfer is used to charge sensors and cellphones. WIET is a potential solution for extending the battery life of wireless charging systems. As a result, devices without batteries will be able to connect to 6G networks [20].

Unmanned Aerial Vehicles (UAVs): UAVs, sometimes known as drone BSs, are expected to play an important role in the forthcoming 6G network. UAV technology will be used to achieve efficient wireless communication in various applications exceptional data rate. The BS entities are used to offer cellular communication in UAVs. In the times of emergency, such as a natural calamity, implementing a traditional terrestrial infrastructure-based network will be difficult, if not impossible, to supply any service in such a dangerous environment. These situations are easy for UAVs to handle [19] [21] [22].

Optical Wireless Technology: Visible Light Communication (VLC), Light Fidelity (LiFi), Optical Camera Communication (OCC), and Free Space Optics (FSO) are the four key OWC technologies that are seen to be promising in addressing the demands of 6G.These technologies will be employed in a variety of applications, including V2X communication, interior movable robot positioning, Virtual Reality, and under water Optical Wireless Technology. LiDAR has high-resolution 3D mapping technology that can be used in 6G communications, as it is likewise based on the optical band [23].

Mobile Edge Computing: Mobility-Enhanced Edge computing (MEEC) is becoming a critical aspect of 6G technologies as a result of dispersed massive cloud - based services. The adoption of AI-based MEEC will enable bigdata analytics and permits the system to control the edge.

Integration of Sensing and Communication: The ability to continuously monitor frequent and random fluctuations in environments, as well as information exchange among various device units, is a significant step toward autonomous systems. The main challenges in achieving the integration includes many sensing devices, sophisticated resources required for communication, multiple computer and multilevel caching resources.

Dynamic Network Slicing (DNS):DNS enables network operators to dedicate virtual networks to the efficient delivery of services to various industries, equipment, vehicles, and people. The main enabling techniques for DNS implementation are software-defined networking and network function virtualization. The cloud computing perspective in network administration is influenced by these factors.

3D Networking: Users will be able to interact in vertical extensions because to 6G's planned integration of several networks. The 3D Base Stations will also be realized via Low Orbit Satellites (LOS) and UAVs. 3D coverage will be provided by the 6G heterogeneous networks. Extra dimensions can be added with altitude will significantly alter 3D connection in comparison to present 2D networks.

Proactive Caching: One of the most challenging issues for 6G is the massive deployment of tiny cell networks, which will considerably improve network capacity, transmission range and node mobility management. The BSs will experience massive downlink traffic overload as a result of this. Proactive caching has become a must-have option for reducing access delays and traffic offloading while improving user satisfaction levels.

Quantum Communications: Quantum communication is expected to be critical in the implementation of secure 6G communications. Unsupervised back propagation is an efficient way to reach the main goals of 6G. Combining reinforcement and unsupervised learnings can evolve to network operation that is really autonomous. 6G will use enhanced quantum computing and communication technologies that affords strong protection against all types of cyber-attacks [24].

VII. Current Technological Issues and Future Research Pathways

In order to establish 6G communication systems effectively, several technological challenges must be addressed. Here are some key considerations:

Transitioning from Possibility to Reliability: Historically, mobile internet services have grappled with uncertainty and instability due to the unique characteristics of Internet Protocol (IP). However, with the expansion of 5G and eventual integration of 6G networks across all industries, including IoT applications [12], ensuring low latency and high reliability becomes paramount. The reliability of network services is expected to improve significantly in the 6G era, enabling seamless adaptation to diverse industry requirements.

Dynamic Allocation of Radio Resources: The dynamic nature of Quality of Service (QoS) requirements necessitates the provision of variable radio resources to users. Bandwidth and power requirements may fluctuate, posing challenges such as signal attenuation and penetrating loss at higher frequencies. To address these challenges, stable, rapid, and precise algorithms are needed to proactively distribute variable resources and meet the stringent QoS requirements of consumers in the 6G network [20].

Precision of Service Timing: Various market segments rely on time-bound operations for operational and mechanical independence. Industrial automation, for example, depends heavily on precise timing to reduce waste, improve quality, and lower costs. Ensuring millisecond precision for sensors, controllers, electronic physical models, and robots is essential [25].

Maximizing Spectrum Efficiency: In the 6G era, research will focus on flexible spectrum sharing technologies to intelligently and flexibly regulate spectrum allocation. Utilizing AI, blockchain [19], and other associated technologies, the wireless industry aims to distribute spectrum more efficiently. Pioneer spectrum blocks for 6G may include mid-bands for urban outdoor cells and sub-THz frequencies for peak data rates higher than 100 Gbps [25].

Strategic Scheduling for Extensive Networking: Allocating radio resources strategically to connected devices is a fundamental task for network nodes in wireless technology. However, meeting the stringent latency and packet loss requirements set by 6G standards poses challenges in determining priority levels for all connected devices. Developing efficient algorithms for pre-emptive communication on the 6G network is an active area of research to address this complexity [25] [26].

Device Capability: Ensuring that devices can accommodate new functionalities is crucial, especially as communication infrastructure transitions from 5G to 6G. The compatibility of 5G devices with 6G networks is a critical issue, as it allows end-users to benefit from new functionalities while also saving costs [26].

Harmonization of Networks: In order to support emerging use cases, fulfill evolving network requirements, ensure extensive transmission range, and enable flexible network resource deployment, 6G networks must leverage both Stand-Alone (SA) and Non-Stand-Alone (NSA) deployments utilizing existing and future network resources. This necessitates seamless integration of technology and resources spanning from IoT devices to core-network and cloud infrastructure. Future research in 6G should focus on harmonization efforts, particularly in nodes utilizing spectrum above 100 GHz (including optical), Nano networks, autonomous Device-to-Device (D2D) communication, and cell-free Multiple-Input Multiple-Output (MIMO) systems [27]. Advancements in radio access virtualization approaches will play a crucial role in facilitating harmonization, promoting abstraction and programmability essential for the development of harmonized 6G networks [28].

Seamless Coexistence of Multiple RATs: 6G's support for numerous Radio Access Technologies (RATs) through multiple interfaces ensures collaboration with various technologies including Wi-Fi, Bluetooth, Adhoc sensor networks, and IoT [12] devices. Dynamic adjustment of the air interface to accommodate changes in the user's radio environment is crucial. Developing scalable strategies for interoperability while meeting 6G Key Performance Indicator (KPI) standards remains a significant challenge [28].

Increased Hardware Complexity and Chip Size: Next-generation mobile phones will integrate various communication devices, from sensors to high-definition video transmission equipment, as well as connectivity with high-speed trains and airplanes. The transmission requirements of such devices will vary, necessitating adaptable packet sizes. In next-generation communication systems, multiple RF and signal processing chains will cover the entire spectrum, leading to increased chip size and hardware complexity. While this may increase processing time, it also poses challenges in minimizing mobile size, which is undesirable in next-generation wireless communication [28].

Integration of Artificial Intelligence: Both link and system-level solutions in 6G networks will heavily rely on Artificial Intelligence (AI) [11] and Machine Learning (ML) [7]. With the proliferation of massive machine-type communications, novel access mechanisms will be essential. Additionally, exploring new modulation and duplexing systems beyond conventional techniques like QAM and OFDM, including analogue modulation at Terahertz (THz) frequencies, becomes imperative [1] [29].

Network Security & Privacy: With the advent of 6G facilitating large-scale cyber operations such as IoT services, the risk of large-scale DDoS attacks becomes more prominent. The proliferation of IoT devices connecting to the internet [12] amplifies the potential for widespread

DDoS attacks, raising concerns about information security, privacy, and trust in 6G networks. Addressing these concerns is paramount in 6G network research [29].

Low-Power High-Performance Circuitry: To address latency-sensitive scenarios like automated vehicles and healthcare applications, communication must occur within tight time constraints. Achieving very low latency of a few milliseconds poses significant challenges. Designing robust, low-power high-performance processors is crucial for achieving low latencies with ultra-high reliability [20] [29].

Holographic and Multi-Sensory Media: The substantial data transfer rate required for holographic media streaming poses challenges beyond bandwidth issues, particularly regarding the network's ability to maintain jitter-free connections critical for interactive applications [11].

Sustainable Networks: Achieving energy-efficient networks, zero-energy network resource management, and green computing while upholding acceptable service quality is essential to meet global sustainability objectives. AI analysis of network data trends and patterns can aid in assessing network activity and identifying demand requirements in conjunction with 6G technology. Utilizing AI-based systems to dynamically reroute energy resources in real-time reduces power consumption and enhances efficiency. Optimization approaches, including AI and 6G technology, can also optimize the sleep and wake schedule of base stations, reducing the number of transmissions and energy demand. Hybrid energy-powered cellular networks with scheduled base station wake-up procedures improve resource management and energy efficiency [26] [29].

Terahertz (THz) Communication: The THz frequency band, ranging from 100GHz to 10THz, will be utilized in the 6G era due to its large bandwidth. However, THz communication may encounter challenges similar to mm wave technology, including limited coverage, high network deployment costs, and an immature terminal ecosystem. These challenges must be addressed by the telecom sector to harness the potential of THz communication in 6G networks [1] [11].

Green Transformation: Achieving low-carbon (Green) transformation is a global imperative and a key trend in the ICT industry. To minimize operational expenses and fulfill social responsibility, operators must deploy low-carbon and energy-saving networks, especially in the face of increasing network throughput and resource consumption.

Economic Planning: Economic considerations are paramount for the introduction of 6G connectivity, as it involves substantial investment in network infrastructure. Thorough analysis of infrastructure frameworks, data distribution, spectrum regulation, and commercial strategies is essential to establish cost-effective 6G systems and facilitate the transition from 5G to 6G [26] [28] [29] .

VIII. Conclusion

With each evolution of communication technology comes fresh features and capabilities. While the current 5G system showcases impressive performance, experts predict that by 2030, the escalating need for wireless communication will outstrip its capabilities. To tackle this challenge, a new network architecture is envisioned to accommodate the evolving applications demanded by the highly interconnected world of 2030. These applications will necessitate ultra-high data rates, extremely low latency, unmatched reliability and availability, extensive scalability, exceptional power efficiency, and unparalleled mobility. Research into 6G technology is still in its nascent stages, with ongoing exploration and study. 6G networks are projected to leverage new frequency bands and integrate advancements in circuit and antenna design, network architecture, protocols, and artificial intelligence (AI) throughout the network infrastructure.

This study seeks to offer a comprehensive overview of the current advancements in 6G technology. It delves into the various applications and technologies anticipated for use in 6G systems. Furthermore, it identifies potential challenges, difficulties, and research avenues aimed at realizing the objectives of 6G communication.

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