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Research Paper

The Evolution and Impact of 6G Technology in the Present Decade

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ABSTRACT

6G technology is set to transform wireless communication by delivering unprecedented data speeds, potentially reaching terabits per second, ultra-low latency as low as one millisecond, and the ability to connect trillions of devices. These advancements will power a new era of real-time, data-heavy applications, including autonomous vehicles, remote surgery, and immersive virtual reality. By operating in the terahertz frequency range, 6G will offer significantly larger bandwidths, enabling advanced technologies like holographic communications and high-fidelity digital twins, with the potential to revolutionize industries such as healthcare and manufacturing. AI integration within 6G networks will enhance data processing, predictive maintenance, and dynamic resource management, making networks more adaptive and reliable. Emphasizing sustainability and energy efficiency, 6G will play a crucial role in global efforts to minimize the environmental impact of communication systems. Moreover, 6G seeks to provide comprehensive global coverage, including in remote and underserved areas, thereby bridging the digital divide and promoting greater inclusivity and economic development. Enhanced security protocols will be vital to protecting sensitive data in an increasingly interconnected world. Anticipated for commercial rollout by 2030, 6G is expected to overcome many of the limitations of 5G, driving forward technological innovation, economic growth, and the creation of smarter cities, more efficient industries, and a more connected and inclusive global community.

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1. INTRODUCTION

6G technology is expected to revolutionize wireless communication with unprecedented data speeds, ultra-low latency, and the ability to connect trillions of devices. These advancements will enable real-time, data-intensive applications like autonomous vehicles, remote surgery, and immersive virtual reality, while driving the development of smart cities and industries through the IoE. Integrating AI for efficient network management, 6G will enhance data processing and optimization, contributing to global sustainability efforts by reducing the carbon footprint of communication networks. The technology will also provide global coverage, bridging the digital divide, and ensuring robust security in a highly interconnected world. By supporting mission-critical applications and fostering economic growth, 6G will play a pivotal role in shaping the future of communication, technology, and the global economy. The IoE is shifting wireless networks' focus from increasing data rates to ensuring ultra-reliable, low-latency communications (URLLC). While 5G was meant to enable IoE, it has mainly supported enhanced mobile broadband (eMBB). New IoE applications, like extended reality (XR) and autonomous systems, demand high reliability, low latency, and integrated communication and computing, which 5G cannot fully provide. Thus, a specialized 6G technology in sixth-generation wireless system, incorporating AI and advanced sensing, is needed to drive future wireless communication [1]. The design of 6G systems is driven by key performance indicators (KPIs) in three main areas: System Capacity, System Latency, and System Management, emphasizing high data rates, minimal latency, and improved energy efficiency. Meeting these KPIs will necessitate progress in spectrum utilization, radio design, network architecture, automation, and extending coverage beyond terrestrial networks to encompass space connectivity [2]. The key features include exploring the taxonomy, current applications, and prospects of Metaverse technology, with an emphasis on the critical role of 5G/6G in its support. A literature review highlights the absence of comprehensive studies on Metaverse security, which this work aims to address by analyzing potential security threats, existing countermeasures, and their limitations, particularly concerning 5G/6G technology. Additionally, the discussion will examine open security challenges, offer future research insights and provide a roadmap to enhance the security and efficiency of the Metaverse [3].

Mobile data traffic is rapidly increasing, with forecasts predicting it will grow from 158 exabytes per month in 2022 to 5016 exabytes by 2030. Data consumption per user is expected to rise to 257 gigabytes by then. By 2025, 70% of the global population will utilize mobile services, driven by advancements in IoT, AI, and augmented reality. While 5G technology is currently addressing this surge, the forthcoming 6G network is anticipated to provide faster speeds, reduced latency, and enhanced connectivity to manage even greater traffic and enable advanced applications such as smart cities and autonomous vehicles. This paper presents a detailed overview of 6G networks and their potential effects [4]. The 6G Wireless Communication Network (WCN) is designed to offer advanced, intelligent, and energy-efficient connectivity that will enhance quality of life. It is projected to achieve data rates of 1 Terabytes per second, cut latency to one-tenth of 5G levels, and boost both energy and spectrum efficiency. By 2030, global mobile data traffic is expected to surpass 5 Zettabytes per month. Key attributes of 6G include improved reliability, new spectrum usage, smart networking, and eco-friendly communication. Projects like 6Genesis are focused on attaining sub-millisecond latency, high downlink spectral efficiency, and integrating satellite and terrestrial systems. 6G will facilitate high-data-rate applications, including augmented reality, virtual reality, and autonomous vehicles. This paper offers an in-depth review of 6G technologies, covering key advancements, research areas, and future developments in communication networks, which Figure 1 gives the scenario [5].

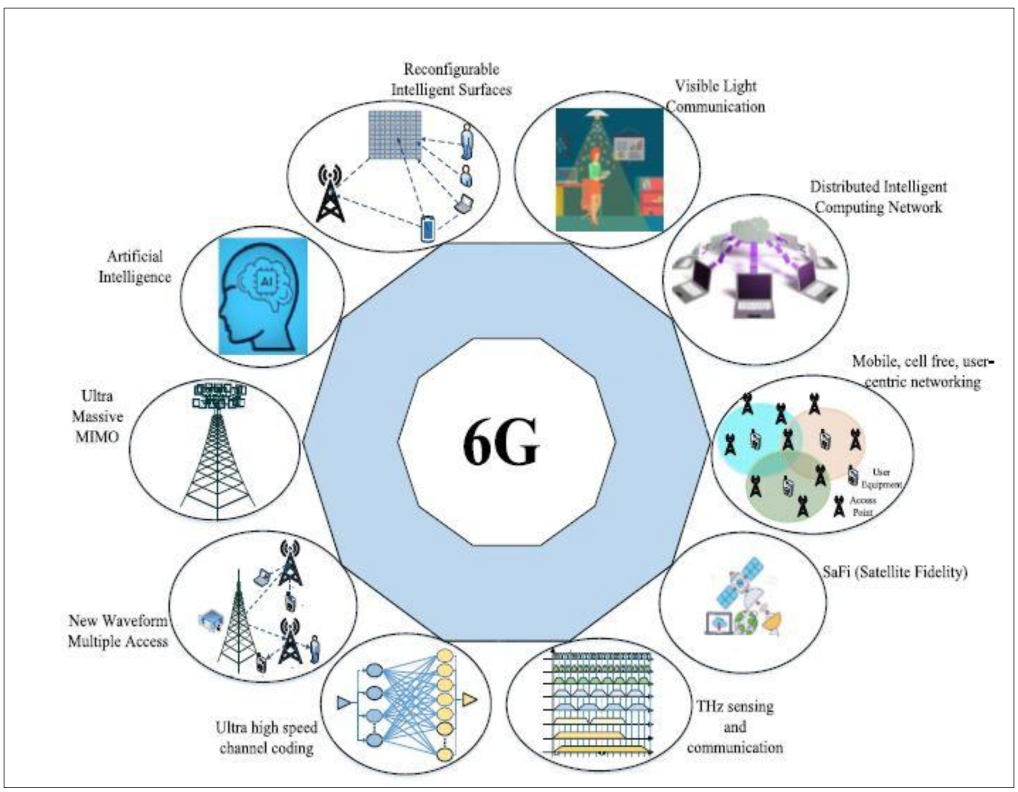

Fig 1: 6G Technologies [5]

The above figure explains that the 6G network will introduce groundbreaking advancements through several core technologies. Reconfigurable Intelligent Surfaces (RIS) will improve signal quality by manipulating electromagnetic waves, while Visible Light Communication (VLC) will enable high-speed data transmission using light. Distributed Intelligent Computing Networks will decentralize data processing for quicker, lower-latency responses, ideal for real-time applications. Mobile, cell-free, user-centric networking will focus on user-specific needs to deliver uninterrupted, high-quality connectivity. Satellite Fidelity (SaFi) will incorporate satellite communication for global reach, and Terahertz (THz) sensing and communication will offer ultra-fast data transfer and sophisticated sensing capabilities. Ultra high-speed channel coding will enhance error correction for faster, more reliable data transfer, supporting immersive technologies like AR and VR. New waveform multiple access will increase device connectivity and spectrum efficiency, while ultra massive MIMO will use vast antenna arrays to boost network capacity and data speeds. Additionally, Artificial Intelligence (AI) will be integral in managing and optimizing 6G networks, ensuring they are adaptive and efficient. These innovations promise to make 6G significantly faster, more dependable, and highly intelligent.

The 6G Technology aims to utilize cutting-edge AI-native architectures and innovative communication paradigms that emphasize semantics and objectives. It critiques the conventional method of data transmission, which frequently overlooks the relevance of information for AI algorithms—a practice termed content-blind transmission. Instead, the project argues that information holds value only if it is practically significant to the receiver. Its objective is to transmit only the most pertinent data, specifically tailored to meet the learning or inference needs in machine-oriented communications [6].

2. REVIEW OF LITERATURE

P. Jayadharshini, G. V. Kamalam, & T. Abirami. (2024) to analyze 6G technology is expected to significantly surpass 5G, offering data transfer rates up to 1 terabit per second and latency below 1 millisecond. Operating in the terahertz range, 6G will enable real-time applications like remote surgery, virtual reality, and autonomous vehicles. It will also enhance cloud applications, IoT, blockchain, and intelligent systems, revolutionizing communication and transforming everyday life.

Strinati, E. C., Di Lorenzo, *et.al.* (2024) to examine the 6G-GOALS strategy focuses on integrating communication, computation, control, and intelligence in AI-native 6G networks. It emphasizes goal-oriented and semantic communication to optimize data exchange among intelligent agents, improving bandwidth, latency, and energy efficiency. This approach relies on AI-enhanced semantic data representation, foundational AI reasoning, and sustainability. The strategy also includes proof-of-concepts to demonstrate these principles in near-future scenarios, making data communication more targeted and efficient.

Giuliano, R. (2024) explores the upcoming advancements in telecommunications are set to surpass traditional services like voice, video, mobile internet, and IoT by introducing three emerging services: immersive communications, everything connected, and high-positioning. The paper reviews developments in 3GPP Releases 17, 18, and 19 related to these services and proposes new Key Performance Indicators (KPIs) for evaluating technologies in virtual/mixed reality, smart sensors, and gesture recognition. It also explores the requirements for key applications expected to grow in the next 3–8 years and identifies promising technologies that will support these new services.

Dasika, S. R. C. M., Kakulapati, V., & Saligrama, S. (2024) examine the evolution of wireless cellular technology from 1G to 6G marks significant advancements in connectivity. 1G introduced mobile phones, 2G transitioned to digital networks, 3G enabled faster data rates, and 4G improved web access and supported advanced services. 5G, launched in 2019, brought high-speed, low-latency connectivity. Looking ahead, 6G will utilize higher frequencies for greater capacity and ultra-low latency, supporting applications like e-health and robotics. It will focus on spectrum efficiency, new IP technologies, and address challenges such as technological, regulatory issues, security, AI-based protection, and post-quantum cryptography.

Jha, A. V., *et al.* (2024). analysis of the 6G wireless technology has the potential to revolutionize Intelligent Transportation Systems (ITS) by providing ultra-high data rates, low latency, broad connectivity, and advanced network management, enabling innovations like autonomous driving and smart traffic control. However, challenges such as spectrum management, network security, and compatibility with existing infrastructure must be addressed. The overview discusses recent 6G advancements, including mm Wave communications, terahertz spectrum, visible light communication, AI, and edge computing, highlighting their relevance to ITS. It also explores the potential benefits of 6G in enhancing safety, efficiency, and sustainability in transportation, while outlining the research needed for effective deployment.

Alhammadi, A., *et al*. (2024) explores the rapid advancements in wireless technologies, highlighting the potential of cutting-edge techniques to enhance network performance, with AI playing a crucial role in managing and optimizing information delivery in future networks. The paper offers a comprehensive review of AI technologies, including recent progress in machine learning and deep learning, and their applications in wireless networks. It also addresses unresolved research challenges and emerging trends in AI-enabled wireless networks, providing insights and solutions to enhance network intelligence. The paper aims to guide researchers in understanding current AI-driven network designs and identifying key research areas for further exploration.

Lai, B., *et. al.* (2024) examines generative mobile edge networks that combine 6G technologies with generative artificial intelligence (GAI) to enhance wireless communication and connectivity. The article reviews GAI technologies and their applications in mobile edge networks, focusing on challenges in resource-limited environments. To address these, it introduces a resource-efficient framework that minimizes network overhead and optimizes resource allocation using generative diffusion models (GDMs). A case study demonstrates model partitioning for AI task offloading and a GDM-based Stackelberg model to incentivize edge devices to share computing resources. The article concludes with suggestions for future research to advance generative mobile edge networks.

Shafi, M., Jha, R. K., & Jain, S. (2024) examine the Sixth Generation (6G) Wireless Communication Network (WCN) aims to significantly enhance performance with ultra-low latency and exceptional energy efficiency. By integrating artificial intelligence, 6G WCN supports seamless communication across human, physical, and digital realms. The paper presents a detailed framework for 6G WCN, highlighting key technologies and their impact on data rate, spectrum efficiency, energy efficiency, connection density, and reliability, and discusses how these advancements could transform future wireless networks.

Kulkarni, A., Goudar, R. H., Rathod, V., & Hukkeri, G. S. (2024) analyses the evolution of wireless communication has led to seamless global data transfer, with the upcoming sixth-generation (6G) system, expected between 2027 and 2030, representing a significant advancement. 6G aims to address challenges beyond 5G by improving system capacity, data rates, security, latency, and quality of service (QoS). The paper identifies key enablers for intelligent communication in 6G, discusses necessary adaptations and standards, and explores its potential and versatility. It addresses research gaps related to spectrum efficiency, network parameters, infrastructure, and security, and highlights important areas for future research, including AI, IoT, Big Data, Massive MIMO, quantum communication, blockchain, Terahertz (THz) communications, cell-free communications, and Intelligent Reflecting Surfaces.

Adil, M., Song, H., Khan, M. K., Farouk, A., & Jin, Z. (2024) describe the Internet has significantly driven innovations in virtual interactions, leading to the development of various systems for digital transformation, such as gaming and social networks. However, these systems often struggle with maintaining consistent connectivity and communication. The concept of the "Metaverse" has emerged to address these issues, integrating technologies like 5G, 6G, virtual reality, machine learning, and AI to create a unified virtual environment. While these advancements offer promising applications, they also introduce cyber security concerns. The paper reviews the taxonomy, applications, and security challenges of Metaverse technologies, focusing on the role of 5G and 6G, and proposes research directions to tackle potential cyber security threats.

Shin, H., Park, S., Kim, L., Kim, J., Kim, T., Song, Y., & Lee, S. (2024) examine 6G technology promises significant advancements over 5G, including ultra-high data rates, enhanced bandwidth, and reduced latency, paving the way for new services. This has led to increased research into potential 6G applications across various sectors. The study aims to identify key 6G service scenarios by analyzing public data, such as research papers and corporate reports, using topic modeling to reveal four major domains and 16 application areas. The feasibility and potential of these services are evaluated through tools like the future-context canvas and business model canvas, providing insights to support technology development and business planning.

Saad, W., Bennis, M., & Chen, M. (2019) analyze the limitations of 5G, especially in supporting Internet of Everything (IoE) applications, have spurred global efforts to define 6G, which aims to integrate diverse applications like autonomous systems and extended reality. While progress has been made, many core aspects of 6G's architecture and performance remain undefined. The paper presents a comprehensive vision for 6G, emphasizing that it will involve more than just high-frequency spectrum exploration, integrating emerging technological trends and novel services. It identifies key drivers and trends, introduces new service classes with specific performance requirements, and outlines enabling technologies and a research agenda. The paper concludes with recommendations to advance 6G and encourages innovative research in the field.

Zawish, M., Dharejo, F. A., Khowaja, S. A., Raza, S., Davy, S., Dev, K., & Bellavista, P. (2024) explain the rebranding of WhatsApp and Facebook as Meta has intensified interest in the Metaverse, marking it as the next phase of the Internet. The Metaverse will integrate emerging technologies, use cases, and experiences. This survey reviews advancements in augmented reality (AR), virtual reality (VR), mixed reality (MR), spatial computing, AI, and 6G technologies. It examines AI's role in the Metaverse through deep learning, computer vision, and Edge AI, and outlines 6G requirements for its development. The paper also explores promising Beyond 5G (B5G) and 6G services for the Metaverse, how AI and 6G can enhance Metaverse applications, and the importance of sustainability. It identifies existing and potential applications, research challenges, and gaps to guide future advancements.

Chataut, R., Nankya, M., & Akl, R. (2024) examine the abstract reviews the evolution of mobile networks from 1G to 5G, highlighting key technological advancements. It introduces the upcoming 6G era, which will transform wireless communication with innovations such as terahertz communication, ultra-massive MIMO, AI, ML, quantum communication, and reconfigurable intelligent surfaces. The paper emphasizes AI's crucial role in enabling intelligent, self-optimizing 6G networks for smart cities and autonomous systems. It also addresses the challenges of deploying 6G and provides a comprehensive analysis of current research and potential future developments in this rapidly evolving field.

Akyildiz, I. F., Kak, A., & Nie, S. (2020) describes how the paper discusses how 6G and future technologies will enable a fully connected world with ubiquitous wireless access. It emphasizes the key technological advancements required for 6G, such as THz band networks, intelligent communication environments, pervasive AI, large-scale network automation, dynamic spectrum access, energy-efficient communications, the Internet of Space Things, and cell-free massive MIMO networks. The paper reviews use cases, recent advancements, and challenges in these areas, and provides a development timeline for 6G. It also explores emerging technologies beyond 6G, including the Internet of Nano Things, the Internet of Bio Nano Things, and quantum communications, which are expected to significantly impact future wireless communication.

3. RESEARCH OBJECTIVE

To analyze the technological evolution of 6G and assess its potential impact on communication systems and society in the current decade.

The Role of 6G Technology in the current era-

Expected around 2030, 6G will harness cutting-edge technologies such as terahertz communication, massive MIMO, AI-powered networks, and integrated sensing. Quantum communication, reconfigurable intelligent surfaces, and holographic beam forming will improve security, signal efficiency, and coverage. Additionally, advancements in edge computing, nanotechnology block chain, and ambient backscatter communication will transform healthcare, environmental monitoring, and IoT, together redefining the capabilities of future wireless networks. These technologies set to enable 6G networks, highlighting both evolutionary and revolutionary developments. While certain technologies were proposed for 5G, they weren't deployed due to technical limitations or market factors. 6G advancements are expected across various network layers, architectures, protocols, and intelligence. Evolutionary technologies, like MIMO, enhance existing solutions for 6G, whereas revolutionary technologies, such as THz communications, aim to radically transform network layers compared to 5G. Many of these revolutionary technologies are still under scientific investigation.

1. Non-Terrestrial Technologies-

Existing cellular networks face challenges in providing reliable coverage in rural areas and in withstanding natural and human-made disasters. To overcome these issues, 6G networks will incorporate non-terrestrial technologies, such as UAV-assisted communications and satellite connectivity, to ensure full coverage and high-capacity connectivity [7].

2. AI and 6G-

AI is set to become a crucial enabling technology for 6G networks, expanding well beyond its limited use in 5G, where it primarily supported tasks like traffic classification, prediction, and intrusion detection. In 6G, AI will be deeply integrated for intelligent reasoning, decision-making, and the design and optimization of network architecture, operations, and protocols. By harnessing vast amounts of data, AI will significantly improve the performance of wireless networks, even in the absence of complete system information. The greatest impact of AI in 6G is anticipated in air interface design and optimization, building on its successes in the upper layers of communication systems. Ultimately, AI will be foundational to the design and optimization of future wireless networks, particularly 6G [8], [9].

3. Energy Harvesting-

In 5G, energy harvesting is used to tackle energy constraints by generating power from external sources for network devices, though it faces issues like protocol compatibility and efficiency loss during signal conversion. As 6G networks expand, it will be essential to develop more efficient energy harvesting methods and communication techniques. A significant challenge for 6G IoT will be extending the lifespan of low-power, battery-less devices, which can be addressed through enhanced energy efficiency and advancements in energy harvesting and wireless power transfer (WIPT). Emerging 6G technologies, such as Terahertz communications and intelligent surfaces, provide promising avenues for achieving energy self-sufficiency, with THz frequencies being particularly effective for WIPT due to their superior directionality [10].

4. Large Intelligent Surfaces (LIS)-

Spectral efficiency is a critical KPI for 6G, with technologies like massive MIMO and the THz frequency band playing key roles in its enhancement. However, their combined deployment in 6G may bring challenges such as high-power consumption, complex signal processing, and increased hardware costs. To mitigate these issues, LIS are suggested as a solution. These smart electromagnetic materials, which can be integrated into various environments, can alter radio wave reflections, paving the way for innovations like holographic MIMO and holographic RF. Concepts such as smart radio environments, reconfigurable intelligent surfaces (RIS), and LIS each provide distinct advantages, including boosting data rates and improving MIMO channel efficiency [11].

5. Mobile edge computing (MEC)-

MEC, as defined by ETSI, entails the deployment of distributed computing, content caching, and data analytics at the network edge. In 6G networks, MEC will be crucial for enabling real-time data processing at the source, which is essential for resource-constrained applications. Key use cases for MEC include V2X communication, improving energy efficiency, offloading computing tasks for URLLC, and enhancing security and privacy [12]. By processing data locally, MEC can significantly reduce end-to-end latency for services like AR/VR and V2X, while also minimizing the need to transmit unnecessary data to cloud centers. Additionally, MEC will aid in efficient network resource management through the deployment of edge servers, facilitating semi-centralized resource allocation with lower complexity and limited channel state information [13].

6. Non-orthogonal multiple access (NOMA)-

Multiple access techniques are crucial for communication systems, and this importance will extend into 6G. NOMA is anticipated to be a central radio access technology for both 5G and 6G networks, offering notable advantages over traditional Orthogonal Multiple Access (OMA) methods. NOMA improves spectral efficiency, security, secrecy capacity, and user fairness by employing techniques such as successive interference cancellation (SIC) and user-specific decoding orders. In 6G, NOMA will be essential for enabling massive URLLC and mMTC services. Furthermore, integrating NOMA with MEC has the potential to enhance computational services in future networks [14], [15], [16].

7. Device-to-device (D2D) Communication-

Device-to-Device (D2D) communication is anticipated to be a pivotal technology in 6G, enabling emerging applications like NOMA, network slicing, and MEC. It will be essential for achieving low-latency, high-speed communication in ultra-dense heterogeneous networks (UDHN) and for addressing the range limitations of THz technology [17]. By leveraging the unused resources of user equipment (UEs), D2D can enhance edge computing and establish virtual network infrastructures for more efficient resource management. D2D will also contribute to intelligent network slicing, allowing telecom operators to centralize and optimize resources at the network edge. Furthermore, integrating NOMA with D2D communication will enable a single D2D transmitter to connect with multiple receivers, significantly enhancing performance [18].

8. Grant-free Transmission-

Grant-free transmission is becoming a crucial medium access control technology for future mobile networks, particularly in facilitating massive IoT connectivity. While grant-free techniques have been implemented in 5G for mMTC and URLLC services, their capacity remains constrained. As the number of smart devices continues to rise and these services become more prevalent, more advanced grant-free transmission methods will be needed for 6G. The integration of NOMA with grant-free transmission (GF-NOMA) offers a promising solution for 6G IoT systems, thanks to NOMA's low latency. Traditionally, NOMA techniques have relied on a centralized scheduling scheme for managing connected IoT devices [19].

6G Technology Speed and Performance-

In current era how 5G and 6G technologies will revolutionize IoT and IoE connectivity, significantly altering human-device interactions. While 5G enables machine-to-machine (M2M) communication for real-time applications, 6G will enhance this experience with advanced AI and machine learning, offering superior capacity and connectivity. Expected around 2030, 6G will focus initially on business and high-performance needs, featuring higher frequencies, greater capacity, and lower latency than 5G. It will use cell-free smart surfaces and AI for network management, and support innovations like wearable tech and 8K holograms. 6G will also extend connectivity to marine, drone, and space applications, aiming for terabit data transfer and addressing challenges like energy management, privacy, and health impacts of terahertz waves. Overcoming these challenges will be vital for 6G's successful deployment [20-27].

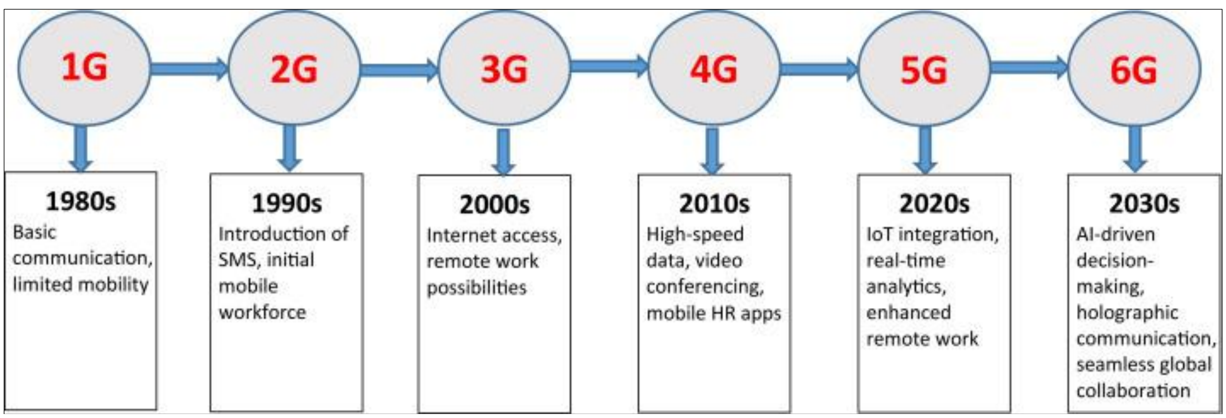

Figure 2. The mobile network evolution from 1st to the 6th generation [20-27].

The figure illustrates the evolution of mobile communication from 1G to 6G, highlighting the increasing data speeds and expanded capabilities with each generation. It starts with 1G's analog voice communication at 20 kbps, progressing through 2G's introduction of SMS, 3G's mobile internet, 4G's high-speed data for HD streaming, and 5G's ultra-fast speeds supporting IoT. Finally, 6G is anticipated to offer over 1 Tbps, enabling advanced applications like holographic communication and AI integration, marking significant technological advancements in mobile networks.

6G technology is expected to deliver unprecedented speed performance, with anticipated data transfer rates reaching up to 1 Tbps, far surpassing 5G's maximum speeds of around 10 gigabits per second (Gbps). It aims to achieve ultra-low latency of under 1 millisecond, a significant improvement over 5G's latency of 1-10 milliseconds. By utilizing higher frequency bands, including terahertz (THz) frequencies, 6G will support extremely high bandwidths for faster data transmission and more efficient spectrum use. The enhanced network efficiency will enable simultaneous connections of up to a trillion devices, compared to the billion devices supported by 5G, which is crucial for managing vast data traffic and maintaining high speeds in dense networks. This high-speed capability will facilitate advanced applications such as real-time holographic communication, immersive augmented and virtual reality experiences, and sophisticated autonomous systems that require near-instantaneous data processing and response. Overall, 6G promises to revolutionize connectivity with terabit-per-second data rates and sub-millisecond latency, leveraging advanced frequencies and network technologies.

6G Technology Working Architecture-

The 6G architecture represents a significant advancement over previous generations, featuring cell-free smart surfaces for improved coverage and reduced interference. It will utilize high-frequency bands, including sub-THz frequencies, and require new transceiver designs and signal processing. AI will manage the network through Open Radio Access Networks (O-RAN), and MEC will reduce latency. 6G will integrate ground, satellite, and marine networks for global coverage, with a strong focus on security, privacy, and scalability. Distributed machine learning will enhance data processing efficiency, while innovations in energy efficiency, such as energy harvesting and self-powered circuits, will be prioritized. Overall, 6G is designed to offer a high-performance, adaptable network for future technologies [28], [29].

The 6G network will meet the connectivity needs of robotics and autonomous drone systems, which can be managed by 5G but will perform optimally with 6G due to its low-latency capabilities. Additionally, 6G will incorporate human intelligence, enabling advanced communication with smart terminals. It will support mobile internet, IoT, holographic communications, and precision applications that demand low latency and high data throughput [30]

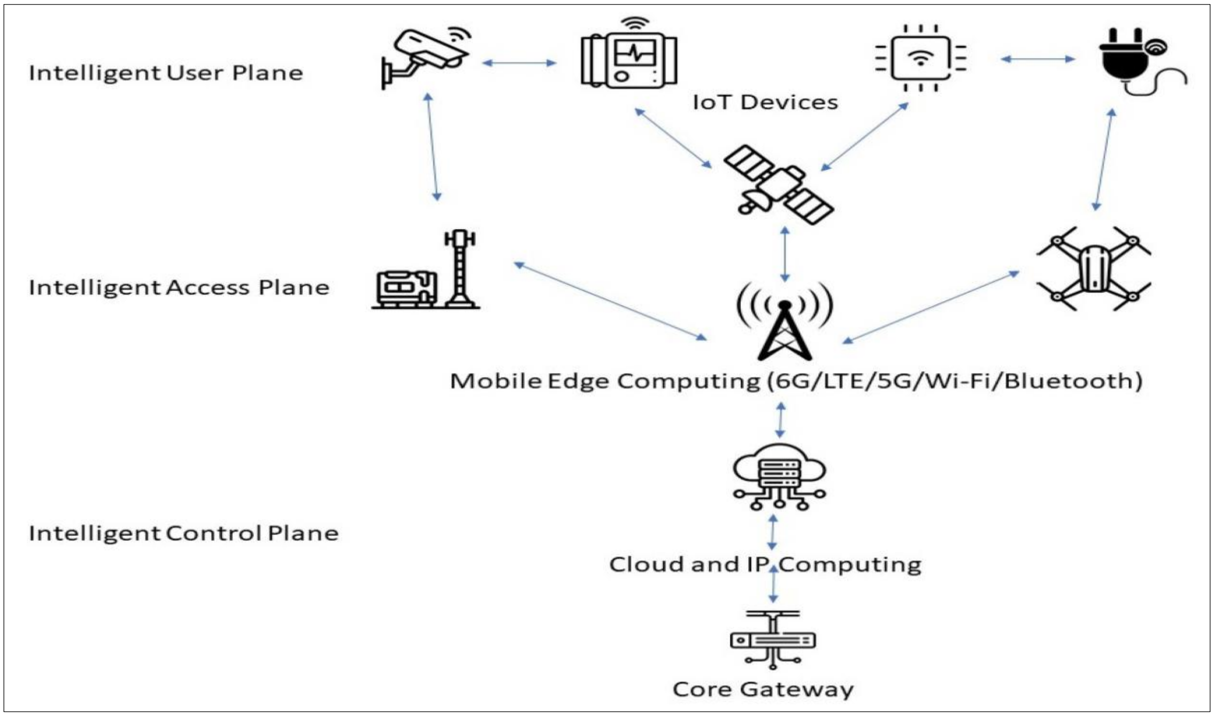

Figure 3. The 6G network architecture [28], [29]

The above figure depicts a layered architecture for an intelligent network system, detailing interactions across three planes: the Intelligent User Plane (comprising IoT devices like cameras and drones), the Intelligent Access Plane (involving Mobile Edge Computing and communication infrastructure like 5G and satellites), and the Intelligent Control Plane (including cloud computing and the core gateway). Data flows from IoT devices through edge computing for processing, then to the cloud for storage and analysis, while the control plane manages the network's overall operation and security. This architecture enables efficient and connected intelligent systems.

Impact of 6G Technology in the Current Era-

6G Technology Speed Performance Metrics-

6G technologies are poised to revolutionize wireless communication by building upon the advancements made in 5G, delivering much higher data rates and enhanced network performance. It will employ terahertz (THz) frequencies to achieve ultra-high data rates, though these frequencies present propagation challenges, requiring innovative antenna designs and advanced beam forming techniques. Massive MIMO and beam forming will be critical for optimizing data rates and maximizing spectrum efficiency. Quantum communication may also play a role in 6G, enabling ultra-secure and rapid data transmission. Additionally, artificial intelligence (AI) and machine learning (ML) will be integral in optimizing resource allocation, predicting traffic patterns, and improving overall network efficiency. The target performance for 6G includes achieving peak data rates of 1 terabit per second (Tb/s) and a spectral efficiency of 60 bits per second per hertz, though actual performance will depend on technological progress and spectrum availability. Potential applications for 6G include real-time augmented reality, holographic telepresence, self-driving vehicles, and enhanced video streaming and online gaming, with the full capabilities of 6G evolving as the technology matures [31],[32].

To calculate the theoretical speed of a 5G network, you can use the following formula:
Speed (bps)=Bandwidth (Hz)×Spectral Efficiency (bps/Hz)

1. **Bandwidth (Hz):**
The bandwidth is the range of frequencies used by the network. For 5G, this can range from a few MHz to several GHz, depending on the spectrum.

2. **Spectral Efficiency (bps/Hz):**
- Spectral efficiency is a measure of how efficiently the available spectrum is used. It is usually given in bits per second per Hertz (bps/Hz). Higher-order modulation schemes (like 64-QAM, 256-QAM) and advanced techniques (like MIMO) can increase spectral efficiency.
- For example, in ideal conditions with advanced modulation and MIMO, spectral efficiency can reach 30 bps/Hz or more.

Example Calculation:
Assume a 5G network with the following parameters:
- **Bandwidth:** 100 MHz (which is 100,000,000 Hz)
- **Spectral Efficiency:** 15 bps/Hz

Using the formula:
Speed=100,000,000×15=1,500,000,000 bps
Speed=1.5 Gbps
So, the theoretical speed in this case would be 1.5 Gbps.

Additional Considerations:
- **Carrier Aggregation:** 5G can combine multiple bands for higher speeds.
- **MIMO (Multiple Input, Multiple Output):** This involves multiple antennas to send and receive more data simultaneously, effectively increasing the spectral efficiency.
- **Modulation:** Higher-order modulation schemes can carry more bits per signal, enhancing the overall speed.

Real-world speeds will depend on various factors like network congestion, signal strength, and environmental conditions.

To calculate the speed of 6G technology, the basic formula for data rate in a communication system is used:
Data Rate (Speed) = Bandwidth × Spectral Efficiency
Where:
- **Bandwidth** is the range of frequencies used for data transmission (measured in Hz).
- **Spectral Efficiency** is the amount of data transmitted per unit of bandwidth (measured in bits per second per Hertz, bps/Hz).

Example Calculation:
Consider the following:
- **Bandwidth for 6G:** 100 GHz (which is 100×109100 \times 10^9100×109 Hz)
- **Spectral Efficiency:** 60 bps/Hz (as outlined in the summary)

Applying the formula:
Data Rate=100×10^9 Hz×60 bps/Hz
Data Rate= 6X10^{12}
Data Rate=6 Tbps (terabits per second)

Explanation: In this scenario, the 6G network could theoretically achieve a data rate of 6 Tbps under ideal conditions with the specified bandwidth and spectral efficiency. This is a significant increase compared to current 5G speeds, underscoring 6G's potential to support extremely high-speed communication. However, real-world speeds may vary due to factors like signal interference, distance from the antenna, and network congestion.

Importance of developing 6G technology-
Each new device requires specific systems and environmental conditions for communication, with higher quality devices needing more advanced conditions that only 6G can provide. Despite improvements in 4G and 5G, these technologies may still face challenges like high mobility, Doppler shift, frequent handovers, and limited coverage, making it difficult to achieve seamless, high-quality communication everywhere [33]. The 6G architecture will address current communication challenges and provide global coverage. While existing technologies may struggle with indoor communication and rural areas, 6G will be effective in both undeveloped regions and busy cities. This extensive communication network will be supported by terrestrial, airborne, and satellite communications [34-35-36]. 6G technologies will enhance reliability, reduce latency, and provide broad bandwidth, making it integral to the . It will support the integration and autonomous coordination of devices in daily life, enabling smart homes, cars, and factories. 6G will revolutionize healthcare with reliable remote monitoring and even allow for remote surgeries due to its high data rates and low latency. The defense industry will benefit from secure, high-speed wireless connections for UAVs. Additionally, 6G will enable the transfer of sensory experiences, such as taste and touch, through brain-computer interactions, and will support advanced technologies like AI, virtual reality, and haptic communication [37], [38].

Opportunities of 6G mobile technology-
6G mobile technology offers significant advantages over 5G, including high bandwidth, reliable communication links, faster data transmission, low latency, and an ideal environment for AI applications. These features open up new application areas, ranging from military use to remote personal needs, especially highlighted during the pandemic [52].
1. Industrial automation-
Industrial automation, driven by Industry 4.0, aims to fully automate manufacturing processes across various sectors to eliminate human error. For automation to replace human roles effectively, machines must be highly reliable. Low latency is critical to ensure smooth operation and prevent issues in systems with thousands of devices. 6G mobile technology is essential for providing the fast and reliable data transmission needed to support full industrial automation [39].

2. Internet of space things

The Internet of Space Things (IoST) extends the concept of IoT to space-related applications, addressing the limitations of IoT's infrastructure and coverage. IoST is particularly crucial for remote areas, like the North and South Poles, where traditional infrastructure is costly or impractical. 6G technology, with its data transmission rate of up to 100 Gbps and wide bandwidth, enables seamless communication between these remote areas and satellites. This allows for latency-free transmission of space data, advancing our capabilities and knowledge in space exploration [40].

3. Drones Utility

Drones are used in various fields, including transportation, package delivery, surveillance, and media production, requiring secure, reliable, and stable wireless communication. One of the main challenges for drone operations is maintaining seamless connectivity in the sky, where issues like radio link failure and frequent handovers can occur. 6G technology, combined with AI-based solutions like reinforcement learning, can address these challenges by optimizing handover processes and reducing connectivity disruptions, ensuring continuous and stable drone communication [41-47]. Fig.4 illustrates the RL-based schema for drone communication in the sky.

Fig. 4 The RL-based schema for drone communication in the sky [52].

The figure represents a reinforcement learning model used in a 6G base station to optimize network performance. The model involves the base station (agent) interacting with the serving cell (environment) by observing the Reference Signal Received Power (RSRP). The agent takes actions, like adjusting transmission settings, based on the observed RSRP state. The environment responds with a new RSRP state, and the agent receives a reward based on the outcome, guiding future decisions. This iterative process enables the base station to continuously learn and improve network performance.

4. Remote medical operations

The COVID-19 pandemic has highlighted the vulnerabilities of the healthcare system, particularly the shortage of medical staff and inadequate transportation for critically injured patients. A significant number of patients die in ambulances before reaching the hospital. Tele surgery, or remote medical care, offers a potential solution to these issues, but it requires real-time communication beyond the capabilities of current 5G technology. The upcoming 6G technology, with its high data rates exceeding 1 Tbps and ultra-low latency, is expected to meet these demands, enabling advancements such as holographic communication and tactile/haptic feedback, which can enhance remote medical procedures [48]. Fig. 5 represents the 6G communication model for remote medical healthcare.

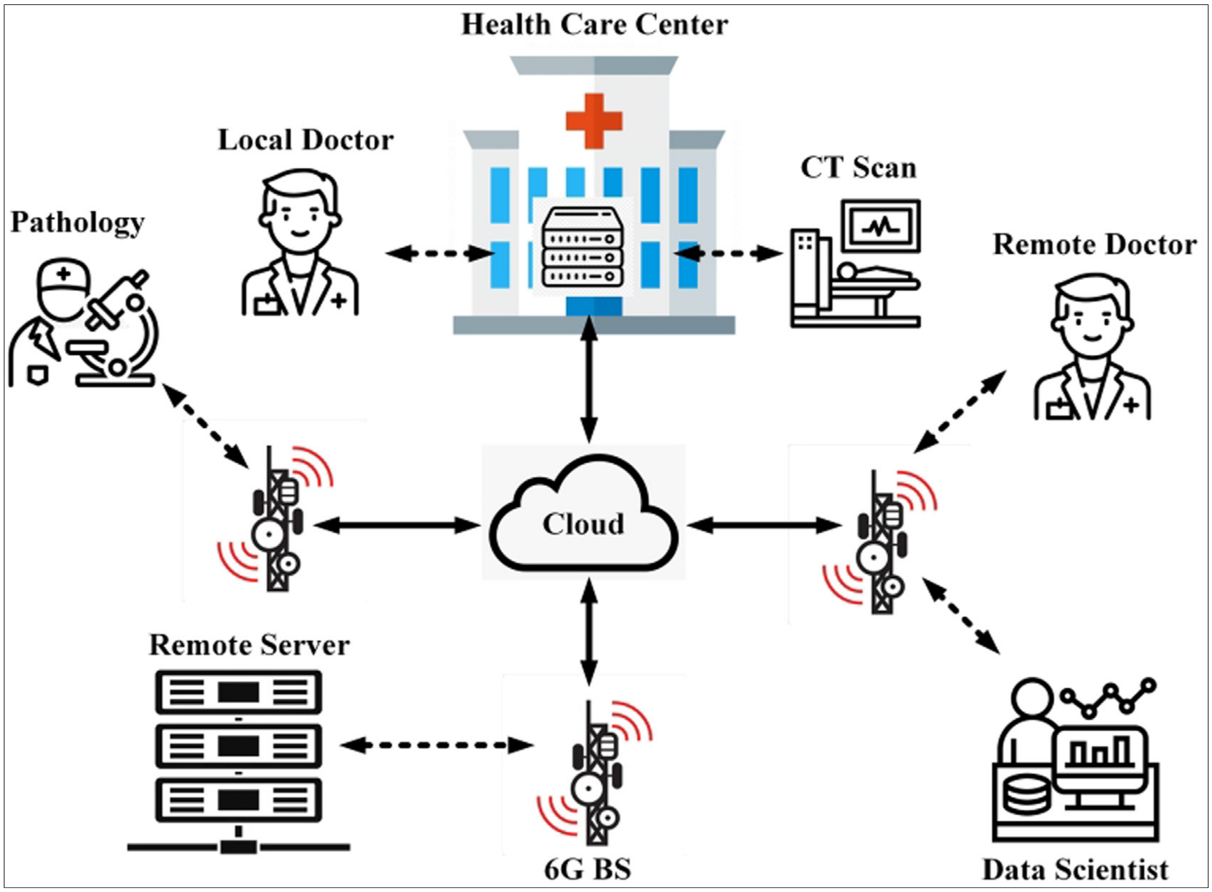

Fig. 5 represents the 6G communication model for remote medical healthcare [52].

Above figure depicts a future healthcare system leveraging 6G technology, cloud computing, and data science to enhance medical services. At the core, a healthcare center provides local medical services such as CT scans and pathology, while medical data is uploaded to the cloud via 6G networks. This data is accessed and analyzed by local and remote doctors, and data scientists for advanced diagnostics and treatment planning. Remote doctors support telemedicine, and data scientists apply advanced analytics to improve care, demonstrating how technology enables real-time, distributed medical services for better patient outcomes.

5. Autonomous vehicles and robotics

Connected Autonomous Vehicles (CAVs) will significantly benefit from 6G technology, which offers higher frequency bands like the THz band (100 GHz to 1 THz) for enhanced communication, sensing, and positioning. This will enable critical functions like remote driving, real-time sensor data processing, and mobile edge intelligence. The shorter wavelengths in the THz band allow for smaller, more precise antenna arrays, improving localization accuracy and object detection compared to traditional GPS. Overall, 6G will provide low latency, high-speed communication, and increased reliability, crucial for the full realization of autonomous driving [49]. Fig.6 presents the key features of 6G technology for autonomous vehicles.

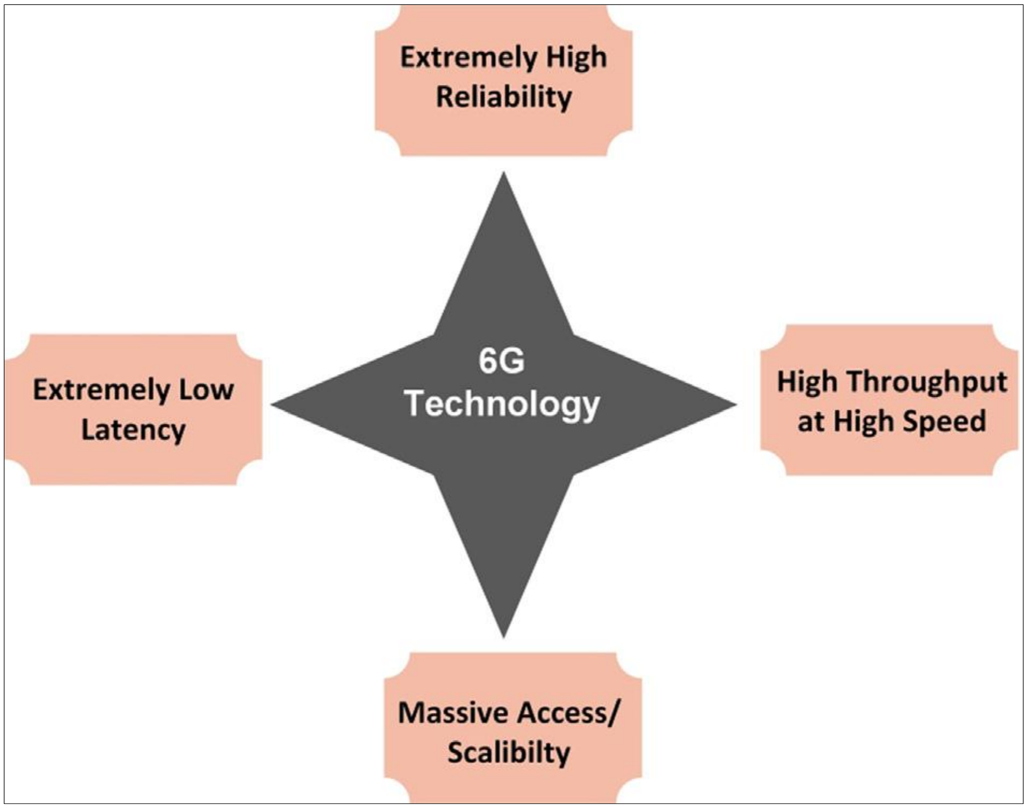

Fig.6 presents the key features of 6G technology for autonomous vehicles [52].

The figure highlights four key characteristics of 6G technology: extremely low latency, extremely high reliability, high throughput at high speed, and massive access/scalability. These features enable 6G to support real-time, mission-critical applications such as remote surgeries, autonomous vehicles, and immersive virtual experiences. Additionally, 6G's ability to handle large-scale data transmission and connect billions of devices makes it ideal for advanced applications in healthcare, industry, and smart technologies, offering unprecedented speed, reliability, and scalability.

6. Use in Smart cities

The concept of Smart Cities, originating in 1994, has become increasingly crucial due to the COVID-19 pandemic, which has pushed many activities, like education and cultural events, onto digital platforms. Smart cities aim to integrate technologies such as autonomous vehicles, traffic control systems, and cashless financial systems, all of which require fast connectivity. While 5G supports these technologies, 6G promises to enhance them further with speeds up to one thousand times faster, enabling the full potential of AI and IoT. This will lead to better access to personal and environmental data, making cities smarter, more efficient, and better suited to modern needs [50]. Fig. 7 provides an overview of the smart city concept.

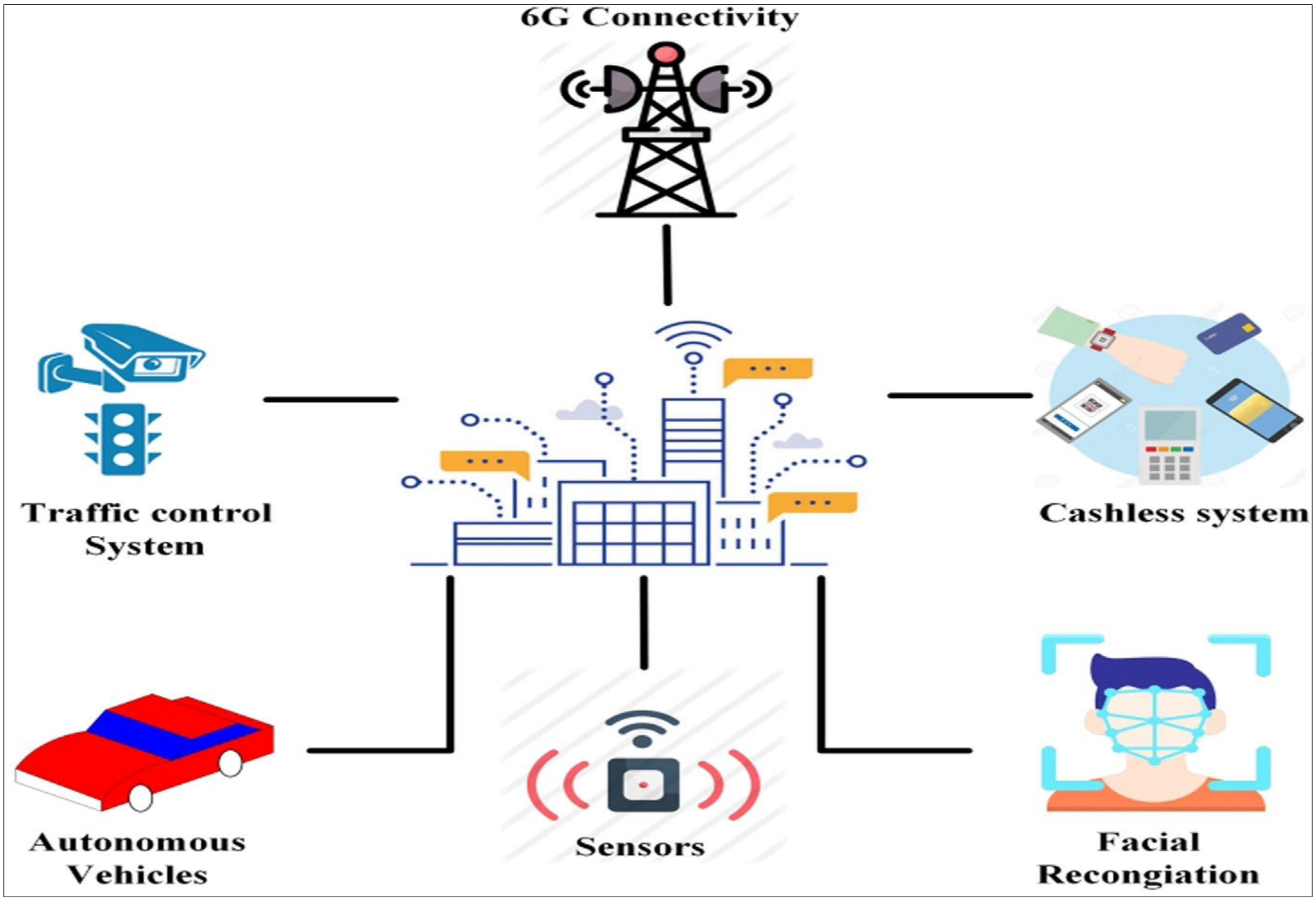

Fig. 7 provides an overview of the smart city concept [52]

The above figure presents a 6G-powered smart city ecosystem, showcasing various technologies interconnected through 6G connectivity. These include automated traffic control systems, autonomous vehicles, IoT sensors, facial recognition, and cashless transaction systems. 6G enables ultra-fast, low-latency communication between these systems, improving urban management, safety, efficiency, and convenience.

7. IoE-

The IoE encompasses the networked communication of humans, processes, files, and objects. Unlike the IoT, which focuses on communication between simple physical devices like phones and alarm systems, IoE extends to include people and processes. As IoE is expected to connect 99.4% of solid objects in the future, its demands far exceed those of IoT, requiring seamless connectivity, wider bandwidth, and high-speed, continuous data transmission. While 5G meets IoT needs, 6G technologies will be essential for the full realization of IoE, supporting applications from smart devices to smart cities and industries [51]. Fig. 8 provides an overview of the IoE technology.

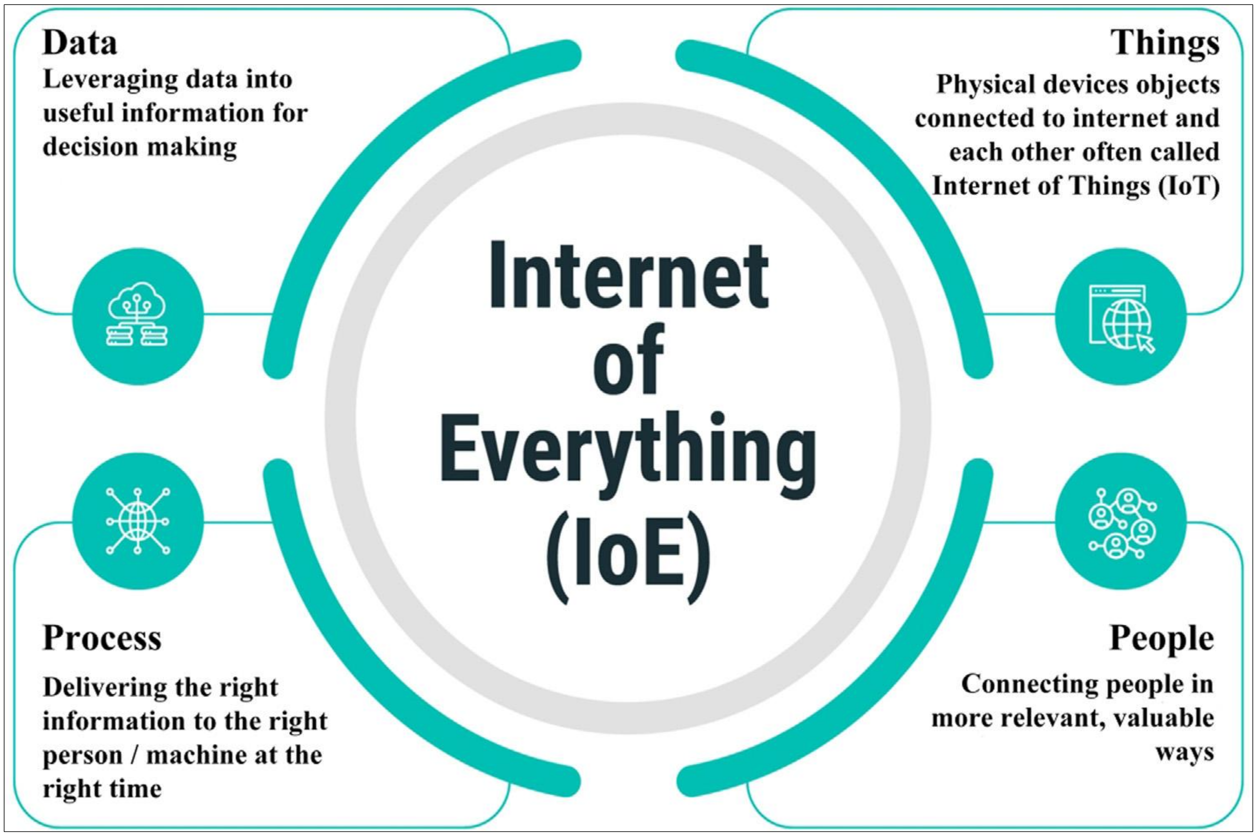

Fig.8 provides an overview of the IoE technology [52].

In the above figure explain the Internet of Everything expands on the IoT (IoT) by connecting people, data, things, and processes into a seamless, intelligent network. IoE enables decision-making through data, connects physical devices (IoT), enhances communication among people, and ensures efficient information delivery to the right stakeholders at the right time. This interconnected system improves automation, collaboration, and decision-making in various sectors.

Challenges and Research Directions

Currently this era the limitations of 4G and the need for faster, more reliable internet, leading to the development of 5G. However, it suggests that 5G is just the beginning, with 6G expected to usher in a new era of internet connectivity that could drastically transform our lives. The paragraph also briefly touches on the challenges and research directions for 6G networks.

1. Sustainability and green

The role of regulatory bodies like the United Nations and the European Union in overseeing technological advancements. As countries aim for sustainable development due to global and climate challenges, there are concerns that 6G technology might increase carbon footprints due to more antenna installations and IoT devices. However, 6G could also lead to significant energy savings, similar to 5G, and reduce carbon emissions in various sectors such as health, agriculture, and entertainment. Despite these benefits, the development of 6G will face challenges [53], [54].

2. Trustworthiness –security

Todays emphasize the growing importance of security in the face of rapid technological advancements. New devices and usage patterns introduce vulnerabilities that can be exploited maliciously. The proliferation of IoT devices, along with technologies like MEC, may significantly increase security risks. As a result, trust in new technologies, particularly 6G, starts off low, presenting a major challenge that needs to be addressed [55-56].

3. Applications and performance

Discusses here the potential expansion of 5G technology, which, if successful, will reach even the most remote areas, increasing user experience. However, growing demand will necessitate further advancements, leading to the adoption of 6G. This new technology will offer benefits like near-zero latency, long-range capability, and reduced power consumption. As 6G becomes essential for high-performance applications, it will enable advancements in critical fields such as medicine, defense, and space exploration, including remote operations like sterile brain surgery. However, these extreme applications will also introduce new challenges for the technology [57].

4. Integrating systems

Here by highlights the increasing demand for automated systems powered by machine learning (ML) and artificial intelligence (AI) due to advancing technology. However, achieving flawless systems remains a challenge, as glitches in critical real-time tasks can be costly. ML and AI technologies need to be refined using 5G and 6G infrastructures to function optimally. As all devices are now considered "smart," a significant challenge will be determining the most efficient integration of these devices with the new infrastructure [58]. As shown in Fig.9.

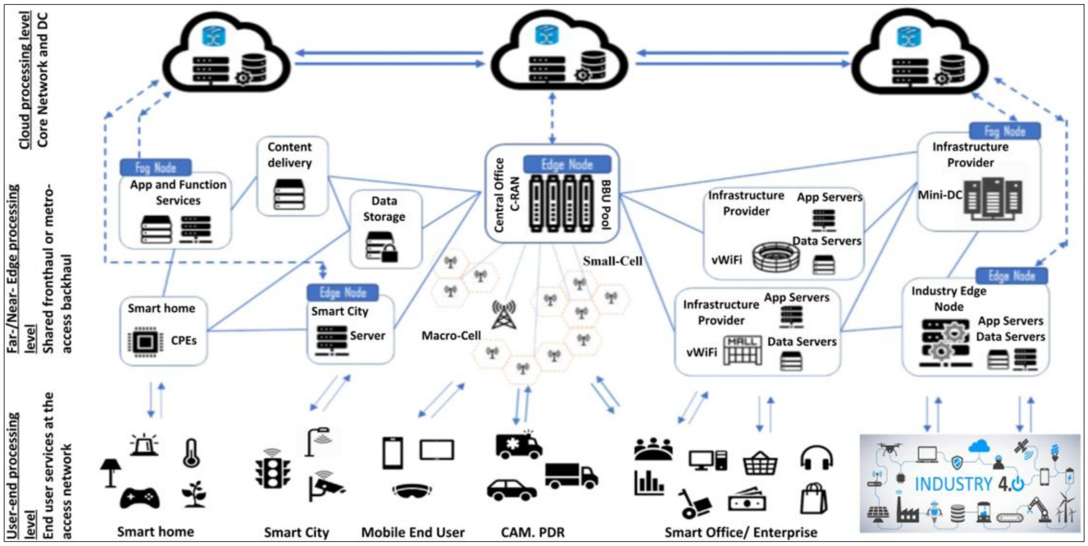

Fig.9 Entire network structure [52].

The above figure presents a 5G/6G-based smart network architecture that integrates cloud and edge computing to support various smart applications. Cloud networks handle data storage and applications, while edge nodes located near users (in homes, cities, offices, and industries) reduce latency and improve efficiency. The core network connects devices via macro and small-cells, enabling smooth communication. Infrastructure providers maintain app and data servers. The system supports use cases like smart homes, cities, autonomous vehicles, Industry 4.0, and more, enhancing automation and service delivery in smart ecosystems.

5. New core network architecture

Explains that, unlike previous generations, 6G will merge terrestrial mobile systems with satellite mobile systems, creating a unified, three-dimensional network architecture. This integration will include terrestrial wireless, medium and low orbit satellite communication, and short-distance direct communication. Additionally, 6G will incorporate new technologies such as communication, computing, navigation, and perception. Through intelligent mobility management and control strategies, 6G will enable global, ubiquitous high-speed mobile communication coverage across air, space, land, and sea [59].

6. Economic prospect

Identifies economic factors as a critical issue for the development of 6G, aside from technical challenges. A global technological revolution like 6G is expensive, and economic constraints are a major limitation. Precise financial calculations are essential to ensure the project's efficiency meets expectations. Optimizing costs is a significant challenge. According to Patwary et al., integrating 6G with existing 5G infrastructures, along with strategies like neutral hosting and location-based spectrum licensing, could reduce costs by 50% [60].

7. Device capability

Discusses the evolution of devices in response to new telecommunications technologies, particularly the shift from 5G to 6G. It highlights the importance of smart devices adapting to new technologies in a rapidly changing environment. The incompatibility between 5G and 6G devices could lead to significant economic costs, emphasizing the need for devices that can integrate and harmonize both technologies. This integration poses a major challenge in the ongoing technological advancements [61].

8. Operational Management

Here emphasizes the importance of management and operational aspects in the development of new technologies, alongside technical considerations. It highlights the challenges of legal regulation and management between various stakeholders, including countries, operators, users, and infrastructure providers. A highly skilled team is essential, with expertise in legal regulations, technical infrastructure, and data privacy.

Given the global nature of the technology, managing international relations is also a critical issue [62].

9. Enabling satellites

The role of satellites in 6G technology, which will enhance internet connectivity by providing reliable, robust, and low-latency connections. However, challenges such as the Doppler shift, caused by the relative motion between low Earth orbit satellites and geostationary satellites, can disrupt communication. The Doppler Effect is particularly significant in the Ka-band, where it can cause frequency shifts that interfere with signals. Another challenge is the large transmission delay due to the vast distances between satellites and the ground, which can hinder communication compared to conventional systems [63-64].

10. Peak data rates

Explains that 6G technology will need to use extremely high frequency (EHF) bands to increase capacity, but these frequencies suffer from significant path losses, leading to a short communication range. This limitation allows for extensive frequency reuse but requires a large number of access points, which is economically costly. The dense network of access points will result in frequent handovers for mobile users as they move between small coverage areas, posing a significant challenge for maintaining continuous connectivity [64].

11. THz wireless communication

Here discuss about the use of THz bands in 6G technology, noting that these bands are relatively narrow compared to lower frequencies, which makes directional antennas more suitable. However, determining the appropriate MIMO (Multiple Input Multiple Output) structures for 6G is challenging. Implementing a massive MIMO system with each antenna focusing on a narrow THz beam is currently almost impossible. Although THz communications offer significant advantages for 6G, several technical challenges must be resolved before they can be successfully deployed [65].

4. CONCLUSION

This research paper provides an in-depth exploration of 6G technology is poised to revolutionize wireless communication, building on the advancements of 5G while addressing future demands that current technologies may struggle to meet. Researchers and industry leaders are exploring ways to enhance not just speed and connectivity but also how networks operate and interact with the digital world. 6G aims to offer significantly higher performance, including data rates potentially reaching terabits per second, ultra-low latency in the microsecond range, and support for vast numbers of connected devices with high energy efficiency. Unlike previous generations, 6G will likely involve a convergence of various technologies, including communications, computing, control, localization, and sensing, necessitating a fundamental shift in network architecture. This convergence will enable new and emerging applications beyond the capabilities of current mobile networks, such as advanced virtual and augmented reality, holographic communication, smart cities, remote healthcare, and autonomous systems. Critical technologies like terahertz communication, AI/ML, quantum communication, and advanced MIMO are essential for realizing the 6G vision, though challenges like power consumption, cybersecurity, and hardware limitations remain. AI/ML will play a pivotal role in automating network management, enhancing user experience, and dynamically allocating resources, making 6G networks more responsive and adaptive. Ultimately, 6G represents a fundamental shift in mobile communication, offering advanced solutions to current challenges and opening up new possibilities, with a focus on smarter, more flexible, and capable networks that transform industries, economies, and everyday life.

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