Unleashing the Potential: The Joint of 5G and 6G Technologies in Enabling Advanced IoT Communication and Sensing Systems: A Comprehensive Review and Future Prospects

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***Abstract*—The rising demand for fast and reliable wireless communication has spurred extensive research in 6G network development. This study evaluates the limitations of current 5G networks, emphasizing the need for progress in 6G technology. Combining 5G and 6G technologies in collaborative communication and sensing systems has the potential to transform IoT applications significantly. The paper examines the synergies achievable by integrating 5G and 6G within the IoT landscape, highlighting the enhanced functionalities of each generation and their role in meeting growing IoT demands. It explores the connectivity and minimal latency features of 5G, illustrating their effectiveness in managing IoT implementations through practical scenarios. In contrast, 6G introduces groundbreaking advancements such as high data speeds, terahertz communications, AI, machine learning, and quantum communication, paving the way for more sophisticated IoT systems. The study delves into the intricacies of establishing collaborative communication and sensing systems within this framework, emphasizing real-time data optimization through components like data fusion and edge computing. Furthermore, it discusses the potential impact of integrating 5G and 6G across sectors like autonomous systems, smart cities, and industrial IoT, while addressing challenges like security and privacy concerns. Ultimately, the paper underscores the importance of this dynamic environment and sets the stage for future advancements in the field.**

***Keywords*—wireless communication, 6G networks, advanced algorithms and protocols, communication and sensing integration**

I. Introduction

The exponential expansion of the Internet of Things (IoT) has fundamentally revolutionized our interactions with technology, data, and the physical environment. The applications of the IoT encompass a wide range of fields, including but not limited to smart cities, autonomous vehicles [1], industrial automation [2], and environmental monitoring. The increasing proliferation of IoT devices has resulted in a corresponding rise in the need for wireless communication systems that offer uninterrupted, high-speed, and dependable connectivity [3].

The advent of the fifth generation of wireless technology, commonly referred to as 5G, has marked the onset of a novel age in connection, characterized by its notable attributes such as high-speed data transfer capabilities, minimal latency, and the ability to accommodate a substantial volume of devices [4]. The aforementioned characteristics have rendered 5G a transformable force in the realm of IoT, facilitating a wider array of applications and utilization scenarios. Nevertheless, the expansion and diversification of IoT deployments have given rise to emerging difficulties [5]. The issues encompass the necessity for increased velocities, heightened dependability of connections, and improved functionalities, specifically in situations that demand instantaneous data processing and communication with high data transfer rates [6]. The emergence of 6G as a crucial domain of research and development marks the advent of the forthcoming frontier in wireless technology.

The acknowledged limitations and vulnerabilities that have been spotted within the scope of the currently active 5G standard are the driving force behind the requirement for the deployment of 6G networks [7]. Despite the significant leaps forward in wireless communication that have been made possible by 5G technology, there are still

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challenges to be overcome in the areas of providing ultra-high data rates, ultra-low latency, and accommodating the extensive proliferation of IoT devices. Accomplishing these goals is necessary in order to fulfill the requirements of upcoming applications. The fundamental objective of 5G technology has been to improve mobile broadband capabilities; however, it is not yet capable of achieving the special requirements of Ultra-Reliable Low-Latency Communication (URLLC) and massive Machine-Type Communication (mMTC) [8, 9], both of which are essential for IoT.

The advent of 6G technology holds the potential to effectively mitigate these constraints and susceptibilities. The advent of 5G technology has established a fundamental framework, upon which 6G technology is anticipated to expand, including enhanced data transmission rates, terahertz communication, sophisticated Artificial Intelligence (AI) and machine learning capabilities [10], as well as quantum communication. These aspects are anticipated to revolutionize the landscape of IoT applications, enabling enhanced video streaming with greater resolution, more accurate location capabilities, and the efficient management of progressively intricate and self-governing systems. Within the realm of the IoT, the incorporation of 5G and 6G technologies signifies a crucial advancement in unlocking the complete capabilities of interconnected devices. The integration of these technologies enables collaborative communication and sensing systems to function with unparalleled efficiency and adaptability [11]. Technology enables IoT devices to engage in collaborative sensing and communication, thereby establishing dynamic networks that can promptly adapt to environmental changes as shown in Fig. 1.

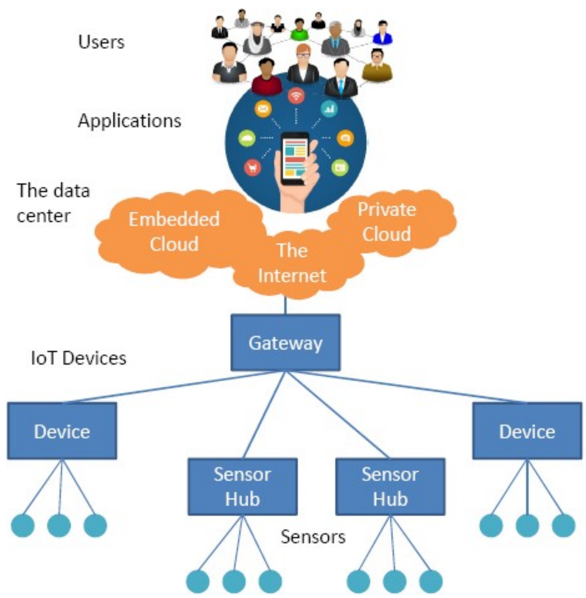

Fig. 1. Reference IoT model.

The integration of this technology holds the potential to enhance the efficiency of data gathering and processing, hence enhancing the reliability, intelligence, and responsiveness of IoT applications as in Fig. 2. The research was conducted to address the escalating demand for reliable and rapid wireless communication, which has driven extensive exploration in 6G network development. This study specifically focuses on understanding the limitations and vulnerabilities of existing 5G networks, emphasizing the imperative for advancements in the 6G domain. By integrating both 5G and 6G technologies into collaborative communication and sensing systems, there is a potential to transform IoT applications significantly. The prerequisites and context of the issues at hand revolve around the need to enhance IoT capabilities through the integration of advanced wireless communication technologies. The study explores the potential synergies achievable by combining 5G and 6G technologies within the IoT landscape. It investigates the enhanced functionalities and unique benefits contributed by each generation, underscoring the pivotal role of an integrated system in meeting the evolving requirements of IoT applications. Furthermore, the study delves into the comprehensive connectivity and minimal latency characteristics of 5G technology, demonstrating how these attributes enable the efficient management of extensive IoT implementations. Real-life applications and practical scenarios are examined to illustrate the feasibility and practicality of these features. In contrast, the revolutionary advancements offered by 6G technology, such as high data speeds, terahertz communications, AI, machine learning, and quantum communication, are explored for their potential to further enhance IoT systems. The study also delves into the intricacies of establishing and operating collaborative communication and sensing systems within this integrated framework. It emphasizes the optimization of data gathering, processing, and decision-making in real-time IoT scenarios through critical components like data fusion, edge computing, and collaborative sensing mechanisms.

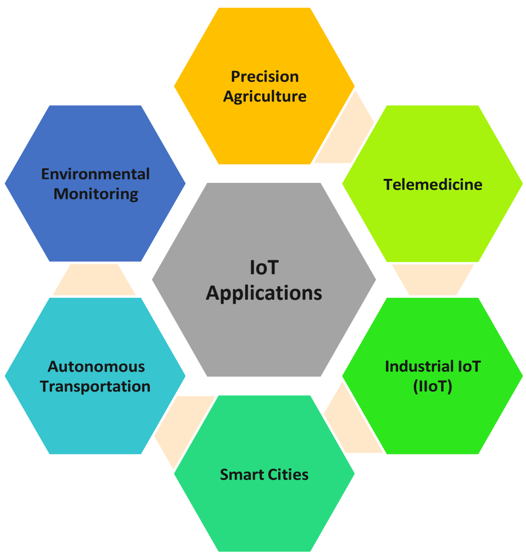

Fig. 2. 5G and 6G technologies in IoT systems.

Finally, the research paper investigates various obstacles, including security and privacy concerns, while contemplating the innovative opportunities that arise from the convergence of 5G and 6G technologies. Overall, the study highlights the importance of the dynamic environment and lays the groundwork for future exploration and advancement in this captivating field of research. This research paper also explores the potential collaboration between 5G and 6G technologies in the context of cooperative communication and sensing systems, with a particular emphasis on their application in IoT. This study investigates the sophisticated functionalities and benefits that each subsequent generation offers, while also considering the changing requirements of the IoT in many sectors. This study examines the potential revolution in the IoT environment through the integration of technologies such as extensive connection and low latency in 5G, as well as extreme data speeds and quantum communication in 6G. Moreover, this study explores practical applications in autonomous systems, smart cities, and industrial IoT, emphasizing the transformable capabilities of integrated 5G and 6G systems. This study further explores the difficulties and factors to be taken into account while creating such systems, encompassing issues related to security and privacy. Ultimately, this lays the foundation for subsequent investigation and advancement in this dynamic and swiftly progressing field.

The rest of the paper is organized as follows: Section II discusses the architecture of IoT, 5G, and 6G networks. Section III highlights the constraints and the need for 6G in IoT. Section IV examines the technological components of 6G and their impact on IoT. Section V explores the integration of 5G and 6G in IoT. Section VI outlines the enhanced functionalities and benefits of 5G and 6G for IoT. Section VII presents practical IoT scenarios and applications. Section VIII describes the sensing-enabled 6G infrastructure framework. Section IX examines sensing and data fusion algorithms for IoT using 5G and 6G. Section X discusses advancements in 5G and 6G from an IoT perspective. Section XI addresses challenges, unresolved matters, and future prospects for 5G and 6G in IoT.

II. Architecture of IoT, 5G, and 6G

The explosion of the IoT hinges on robust communication infrastructure. This section dives into the architectural blueprints of the technologies powering this revolution: 5G networks and the soon-to-be-realized 6G. By examining their structures, we can understand how they work in concert to unlock the true potential of IoT applications.

A. IoT Architecture

- Sensing Layer: This layer forms the foundation, consisting of the real-world devices and sensors that gather data from the environment. These can be anything from simple temperature sensors in thermostats to complex industrial machinery embedded with monitoring systems. Imagine these devices as the eyes and ears of the IoT system, constantly capturing information about their surroundings.
- Network Layer: Once data is collected by the physical layer devices, it needs to be transmitted. The network layer handles this responsibility. It utilizes various communication protocols like Bluetooth, Wi-Fi, and cellular networks to ensure seamless data transfer between devices and the network infrastructure. Think of this layer as the communication channel, carrying the data from the sensors to the processing centers.
- Data Management Layer: The raw data received from the network layer is not always usable in its original form. The data management layer steps in to process this information. Tasks in this layer involve data filtering, preprocessing (cleaning and organizing), and transformation (converting the data into a usable format) to prepare it for further analysis or storage. Additionally, this layer might house applications for real-time data visualization or data storage in cloud platforms. Imagine this layer as a refinery, transforming the raw data into something valuable and actionable.
- Application Layer: This layer interacts with the processed data from the data management layer. It delivers services and user interfaces tailored to specific applications. This is where the data becomes truly meaningful. Building management systems that utilize sensor data to optimize energy consumption or remote health monitoring applications that display vital signs collected from wearable devices are just a few examples. The application layer takes the processed information and puts it to work, providing valuable insights and functionalities.

While the layered approach provides a foundational understanding, additional aspects are crucial for robust IoT architecture:

- Security and Management: With an ever-expanding network of connected devices, robust security measures have become paramount. These measures protect against cyber-attacks and ensure data privacy. Device management plays an equally important role, guaranteeing proper configuration, firmware updates, and optimal device functionality throughout their lifecycle.
- Regulatory and Business Layer: As the IoT landscape matures, regulations are being established to address data privacy concerns and ensure responsible data collection practices. The business layer focuses on the economic aspects of IoT, exploring revenue models and creating value propositions for different stakeholders involved in the ecosystem.

Understanding the various components of IoT architecture is fundamental for researchers, developers, and anyone working within the domain of interconnected devices [12]. This architecture establishes a framework for designing, developing, and deploying solutions that harness the power of IoT to create a smarter and more efficient world. By leveraging advancements in communication technologies like 5G and the promise of 6G, IoT architecture will continue to evolve, enabling groundbreaking applications that shape the future.

B. 5G Network Architecture

The 5th generation (5G) mobile network architecture represents a significant advancement compared to its predecessors. Designed to handle the exponential growth of data traffic and cater to a wider range of functionalities, 5G boasts a more complex and sophisticated architecture. This section delves into the core network elements that form the backbone of 5G networks, enabling them to support a diverse array of applications, particularly within the burgeoning realm of the IoT as in Fig. 3.

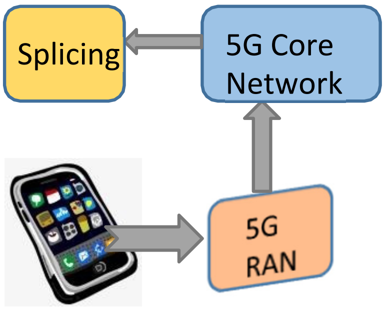

Fig. 3. 5G architecture.

Radio Access Network (RAN): The RAN acts as the crucial intermediary between User Equipment (UE) and the core network. It comprises two key components:

- Base Stations: These function as cellular towers, strategically deployed to provide network coverage. Base stations are responsible for transmitting and receiving data signals to and from devices like smartphones, tablets, and various IoT sensors within their designated coverage area.
- User Equipment (UE): This encompasses all devices that connect to the 5G network, including smartphones, tablets, and a vast array of IoT devices. These devices utilize radio signals to communicate with base stations, enabling data exchange within the network.

Core Network (CN): The CN serves as the central hub of the 5G network, handling critical tasks that ensure proper network operation and functionality. These tasks include:

- User Authentication: This process verifies the identity of devices attempting to connect to the network, ensuring only authorized devices gain access.
- Data Routing: The CN is responsible for efficiently directing data packets to their intended destinations within the network. This ensures that data reaches the appropriate device or application.
- Mobility Management: As users move around within the network coverage area, the CN facilitates seamless connection handover between base stations. This ensures uninterrupted communication even while users are in motion.

To delve deeper into the core network functionality, it's essential to consider two key functional elements:

- Service Gateway (SGW): This element acts as the entry point for user data traffic into the core network. It performs critical tasks like packet inspection, ensuring data integrity and security. Additionally, SGW plays a role in user identification, verifying the legitimacy of devices attempting to access the network.
- Packet Data Network Gateway (PDN GW): This element serves as the bridge between the core network and external networks like the internet. The PDN GW allows devices to access various data services offered through the internet, enabling functionalities like web browsing, data download, and online application usage.

Network Slicing: Network slicing is a groundbreaking concept introduced by 5G that revolutionizes network resource allocation. It allows for the creation of virtual networks on top of the physical network infrastructure. These virtual slices can be customized with specific configurations to cater to diverse application needs. Imagine a single physical network as a large, multi-lane highway. Network slicing allows for the creation of dedicated lanes with specific speed limits, traffic rules, and functionalities. Here are some examples:

- High-Bandwidth, Low-Latency Slice: This slice can be optimized for applications requiring real-time data trans- fer and minimal delays. Examples include autonomous vehicles, which rely on ultra-fast communication and minimal latency for safe and efficient operation.
- Energy-Efficient Slice: This slice can be configured to prioritize energy conservation for battery-powered IoT devices. This is crucial for applications where frequent battery replacements are not feasible, such as remote environmental sensors or wearables.

By combining these core elements–the RAN, the CN with its functional components, and the innovative concept of network slicing–5G networks provide a flexible and adaptable foundation for the ever-evolving needs of IoT applications. This architecture lays the groundwork for diverse functionalities, enabling the efficient and reliable communication required for the continued growth and success of the IoT ecosystem. While the concept of soft transactions within the context of 6G architecture is still under exploration, the envisioned features like network programmability and intelligent resource allocation hold immense potential for optimizing these transactions. Soft transactions, which prioritize successful completion over guaranteed success within a specific timeframe, could benefit from the ability to dynamically adjust network resources based on real-time conditions. This could lead to more efficient data exchange and improved overall performance for IoT applications that rely on these transactions.

C. 6G Architecture

While still under development, 6G network architecture promises to be a game-changer, building upon the foundation laid by 5G and introducing groundbreaking features [13]. Here, we explore the envisioned architecture of 6G as shown in Fig. 4, focusing on its potential for seamless integration with existing infrastructure and its exciting new capabilities.

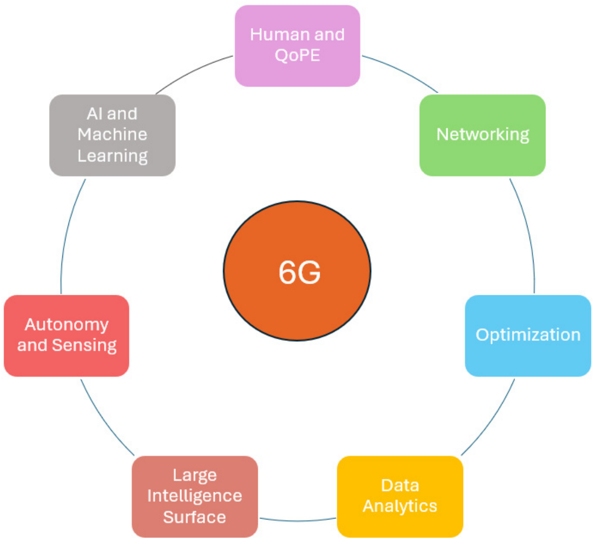

Fig. 4. Potential application of 6G.

1) Integration with existing infrastructure

A key feature of 6G is its design compatibility with existing 5G infrastructure. This ensures a smoother transition and avoids the need for a complete overhaul of network equipment. Here's how this might be achieved:

- Software-Defined Networking (SDN): Leveraging the principles of SDN allows for greater control and flexibility in managing network resources. Existing 5G infrastructure can be integrated with SDN controllers within the 6G architecture, enabling dynamic configuration and optimization of network resources across both generations.
- Network Slicing Enhancements: 6G aims to build upon the network slicing concept introduced by 5G. By incorporating advanced software and hardware, 6G networks can offer even more granular control over virtual network slices. This allows for the creation of highly specialized slices tailored to the specific needs of diverse IoT applications.

2) Unveiling new features

Beyond integration, 6G architecture introduces exciting capabilities that push the boundaries of network performance:

- Network Programmability: 6G envisions a more software-driven approach to network management. By leveraging advancements in SDN and AI, the network itself becomes programmable. This allows for on-demand configuration adjustments, enabling real-time optimization based on traffic patterns and user demands. Imagine a network that can automatically adjust bandwidth allocation or prioritize data streams based on real-time needs, ensuring optimal performance for all users and applications.
- Intelligent Resource Allocation: AI plays a crucial role in 6G's envisioned architecture. AI algorithms can analyze network traffic patterns, user demands, and application requirements to dynamically allocate resources like bandwidth and processing power. This ensures efficient network operation, prioritizing resources for critical applications and avoiding bottlenecks. Imagine a network that can anticipate surges in data traffic and automatically allocate resources to handle them seamlessly, preventing service disruptions.
- Support for Extreme Bandwidths and Lower Latency: 6G promises a significant leap in data transfer speeds and latency reduction compared to 5G. This will empower real-time applications with minimal delays, critical for advancements in areas like remote surgery, tactile internet experiences, and ultra-reliable communication for autonomous vehicles. Imagine performing complex medical procedures remotely with virtually no lag or experiencing a truly immersive virtual reality environment with near-instantaneous response times.

The envisioned architecture of 6G paves the way for a future of ubiquitous connectivity, characterized by seamless integration, intelligent resource management, and ultra-fast, low-latency communication. This paves the way for the continued growth and success of the IoT ecosystem, enabling applications that were previously unimaginable.

III. Constraints and Susceptibilities in 5G Networks and the Imperative for 6G in IoT Prospects

The present condition of 5G networks exhibits inherent limitations and vulnerabilities, underscoring the pressing necessity for advancements in the domain of 6G, particularly within the framework of the Internet of Things. The significance of advancing in the field of 6G becomes particularly evident when taking into account the Internet of Things. This section explores the limitations imposed by 5G networks and emphasizes the significance of transitioning to 6G networks to fully harness the capabilities of Internet of Things applications.

A. Limitations of 5G Networks

One significant constraint of 5G networks lies in their limited bandwidth [14], which can lead to congestion and reduced performance. The sheer volume of data generated by the multitude of IoT devices can overwhelm the available bandwidth, resulting in network congestion that obstructs the seamless integration and deployment of numerous IoT devices. Additionally, it should be noted that 5G networks are prone to latency concerns [15], hence impeding the seamless transmission of real-time communication and data transfer, which are of utmost importance for the successful functioning of Internet of Things applications. In domains such as remote surgery [16], autonomous vehicles, and industrial automation, where the ability to make rapid decisions is of utmost importance, the inherent latency associated with 5G networks can have adverse effects. Furthermore, it should be noted that 5G networks possess inherent security flaws [17] that have the potential to compromise the integrity of IoT devices, hence making them susceptible to cyber threats and unauthorized intrusion. The expansion of the Internet of Things ecosystem leads to a wider range of potential targets for hackers. Consequently, there is a growing need for improved network security protocols to safeguard valuable information and maintain the reliability of IoT systems.

B. The Imperative of 6G in the Internet of Things Prospects

The anticipated progress in 6G networks is poised to effectively tackle these constraints and offer critical resolutions crucial for the progression of IoT. With the expectation of data speeds above 100 Gbps [18], it is projected that 6G networks will hold the capability to effectively handle the significant data flows created by a vast number of IoT devices. The implementation of real-time data analytics will facilitate optimal performance and responsiveness of IoT applications. In addition, it is anticipated that 6G networks will have advanced security capabilities in order to protect against any cyber threats. The aforementioned features will encompass sophisticated encryption, authentication, and anomaly detection functionalities in order to protect Internet of Things ecosystems [19]. In summary, the adoption of 6G networks is needed in order to fully harness the capabilities of the Internet of Things, rather than being merely a matter of convenience as the 6G technology is positioned to overcome the limitations of wireless communication by offering unparalleled speed, capacity, and dependability as it is shown in Table I, hence outperforming the capabilities of 5G. The daring aim includes achieving data rates of 1 terabit per second, latency of 100 microseconds, and a connection density that can accommodate 10 million devices per square kilometer [20]. This transition relies on the investigation of the extensive terahertz spectrum, which is an unexplored domain that offers the potential for significant growth of bandwidth. The reign of 6G will provide a period of widespread and immediate communication, where uninterrupted connectivity infiltrates every aspect of our life. It will create a world where networks and artificial intelligence work together seamlessly to make intelligent decisions, allowing the Internet of Things to reach its full potential and driving significant progress in various industries. The advent of 6G networks is expected to lay the groundwork for a more interconnected, adaptable, and secure IoT environment. This development will facilitate the emergence of innovative IoT applications in several sectors, leading to significant advancements and improvements.

TABLE I. COMPARISON OF 5G AND 6G SPECIFICATIONS

Aspect	5G	6G
Year	2020	2030
Peak data rate (per device)	10 Gbps	1 Tbps
Maximum frequency	300 GHz	10 THz
Downlink data rate	20 Gbps	1 Tbps
Uplink data rate	10 Gbps	1 Tbps
Latency	1 ms	100 µs
Jitter	not specified	1 µs
Mobility	500 km/h	1000 km/h
Maximum bandwidth	1 GHz	100 GHz
Density of devices	10^6 devices/km^2	10^7 devices/km^2
Area traffic capacity	10 Mb/s/m^2	1 Gb/s/m^2
Peak spectral efficiency	30 b/s/Hz	100 b/s/Hz
Reliability	⩾ 99.999%	⩾ 99.9999%

In the following section, we will conduct a more comprehensive examination of the technological components of 6G networks, investigating their potential influence on the IoT domain, as well as the obstacles and prospects they offer.

IV. A COMPREHENSIVE EXAMINATION OF THE TECHNOLOGICAL COMPONENTS OF 6G NETWORKS AND THEIR IMPACT ON THE INTERNET OF THINGS LANDSCAPE

The emergence of 6G networks represents a momentous advancement in the field of wireless communication, transcending the capabilities of its predecessor, 5G. Unlike mere incremental progress, 6G signifies a paradigmatic shift in the conceptualization of connectivity. Acknowledging the relentless surge in data demand and the expanding array of applications that demand not only faster but more intelligent communication networks, the 6G vision is built upon the foundation of integrating real-time sensing capabilities within the network infrastructure [21].

A. Integration of Sensing and Connectivity

At the heart of the 6G vision lies the innovative concept of merging the boundaries between communication and sensing [22]. This novel approach creates a network fabric that is holistic in nature, capable of not only connecting devices but also comprehending and actively interacting with the physical world. The integration of real-time sensing fundamentally transforms the network from a passive data transport system to an active participant in our daily lives. 6G networks, with their ability to sense the environment, understand context, and anticipate user needs, hold significant promise for the enhancement of the IoT ecosystem.

B. Influence on IoT Domain

The potential influence of 6G networks on the IoT domain is profound. With real-time sensing integrated seamlessly into the network, IoT devices cease to operate in isolation. Instead, they become integral components of a dynamic, responsive, and interconnected system. This vision could have profound implications across various sectors such as smart cities, health- care, agriculture, and industrial automation. For example, in smart agriculture, 6G's real-time sensing capabilities could optimize crop management by continuously monitoring soil conditions and adjusting irrigation strategies accordingly [23]. In healthcare, 6G networks could facilitate remote patient monitoring with unparalleled precision, offering real-time data for timely medical interventions. This represents a monumental leap from the current state of IoT, where many devices rely on intermittent data transmission.

C. Obstacles and Prospects

However, the realization of the 6G vision is not without its challenges. Overcoming technical hurdles, ensuring data privacy, and addressing security concerns will be paramount. The seamless integration of sensing functions raises questions regarding data ownership and the ethical utilization of collected information, Narges Arastouei [24]. Furthermore, the deployment of 6G networks will necessitate significant infrastructure development, posing economic and logistical challenges.

Despite these obstacles, the prospects offered by 6G networks are nothing short of awe-inspiring. They hold the potential to elevate user experiences to unprecedented levels, revolutionize industries, and enable innovations that are at the cusp of our imagination [25]. In the subsequent sections of this research paper, we will undertake a comprehensive examination of the technological components that constitute 6G networks, investigate their potential impact on the IoT domain, and address the obstacles and prospects that these advancements offer. This exploration aims to provide valuable insights into the future of connectivity and its transformable power. The 6G vision represents not just a technological milestone but a profound shift in our relationship with the digital realm, empowering us to embrace a world where communication and sensing converge to create a more dynamic, responsive, and transformable connectivity landscape.

Our examination of 6G's technological components reveals its transformable potential for IoT. This foundation sets the stage for exploring the synergies of 5G and 6G technologies in the next section, unlocking new dimensions of IoT connectivity and intelligence.

V. Synergies of 5G and 6G Technologies in IoT

The integration of 5G and 6G technologies inside the IoT ecosystem represents a significant progression in wireless communication, wherein certain technical characteristics assume crucial significance. Significantly, the primary advantage of 5G technology resides in its improved connectivity and reduced latency, rendering it the fundamental component of this integration. 5G technology operates throughout both sub-6 GHz and mm-Wave frequency bands, effectively achieving a compromise between providing extensive network coverage and delivering high data transmission rates. On the other hand, 6G technology expands the boundaries by utilizing terahertz (THz) frequencies [26], which span from 300 GHz to 3 THz. This enables the utilization of much broader bandwidths, leading to the attainment of exceptionally high data transmission rates. Nevertheless, the adoption of this shift requires the implementation of novel strategies, such as beam forming and dynamic spectrum access, in order to address the obstacles posed by environmental attenuation in THz transmissions.

The integration of 5G and 6G is enhanced by the utilization of artificial intelligence and machine learning as fundamental components of the network [27]. Artificial intelligence algorithms are designed to maximize network performance, while machine learning techniques enable IoT devices to acquire knowledge and adjust their behavior, thereby boosting their autonomy and efficiency [28]. Furthermore, within the context of 6G, quantum communication is a distinct feature that utilizes quantum key distribution and entanglement to provide encryption that cannot be deciphered, hence guaranteeing the confidentiality and integrity of data transfer in the IoT.

In addition, the integration addresses the rigorous requirements of Ultra-Reliable Low Latency Communication (URLLC), ensuring latency below 1 millisecond and a high level of dependability for IoT applications that are crucial to missions [29, 30], such as remote surgical procedures and autonomous vehicles. In contrast, Massive Machine Type Communication (mMTC) facilitates the efficient connectivity of a large number of low-power Internet of Things devices [31]. This is achieved through the utilization of technologies such as Narrow band IoT (NB-IoT) in the context of 5G, as well as the enhanced device-to-device communication mechanisms that will be available in 6G. The promotion of a collaborative sensing ecosystem is actively encouraged, which facilitates the interchange of real-time data among Internet of Things sensors. This enables the development of applications in various fields such as environmental monitoring, disaster management, and agricultural.

The convergence of network slicing and edge computing represents crucial elements in this context. The utilization of network slicing allows for the creation of customized network partitions that are specifically designed to cater to various IoT applications [32]. Additionally, the edge computing capabilities of 6G enable the processing of data in real-time at the edge, resulting in a substantial reduction in latency for IoT services. The comprehensive integration described has the potential to significantly transform the field of IoT connectivity, enabling the development of intelligent, efficient, and secure IoT applications in various areas such as healthcare, transportation, industrial, and environmental monitoring. 5G and 6G technologies collaborate to enhance IoT applications by leveraging their respective strengths and capabilities. While 5G provides comprehensive connectivity and minimal latency, enabling efficient management of IoT implementations, 6G introduces groundbreaking advancements like high data speeds, terahertz communications, AI, machine learning, and quantum communication. Together, they facilitate the development of more sophisticated IoT systems, optimizing data gathering, processing, and decision-making in real-time IoT scenarios. This collaboration aims to address the evolving requirements of IoT applications and unlock new possibilities for innovation and advancement in the field.

VI. Enhanced Functionalities and Benefits of 5G and 6G in IoT

Within the context of the Internet of Things, the integration of 5G and 6G technologies brings forth an array of enhanced functionalities and benefits. This section delves into the distinctive advantages that each generation contributes, highlighting their pivotal role in addressing the burgeoning demands of IoT. Fig. 5 shows some of the benefits of 5G and 6G in IoT.

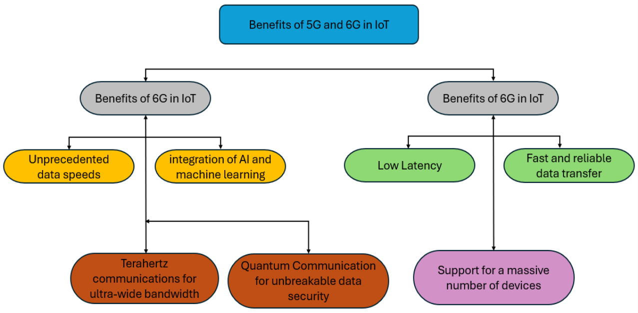

Fig. 5. Benefits of 5G and 6G in IoT.

5G, with its comprehensive connectivity and minimal latency, offers a robust foundation for real-time data transmission, making it well-suited for a wide range of IoT applications. Some of the benefits of 5G in IoT include:

- Fast and reliable data transfer, essential for applications like autonomous vehicles and telemedicine.
- Low latency, ensuring minimal delay in communication for mission-critical tasks.
- Support for a massive number of devices, enabling the simultaneous connectivity of numerous IoT sensors and devices.

Simultaneously, 6G introduces a new era of possibilities with exceptionally high data speeds [33, 34], terahertz communications, artificial intelligence, machine learning, and quantum communication. The benefits of 6G in IoT encompass:

- Unprecedented data speeds, facilitating near-instantaneous data transfer for immersive experiences.
- Terahertz communications for ultra-wide bandwidth and rapid data exchange.
- Integration of AI and machine learning, enabling IoT devices to adapt, learn, and make autonomous decisions.
- Quantum communication for unbreakable data security, crucial in preserving the privacy and integrity of IoT data.

The integrated system formed by these two generations represents a pivotal development in the evolution of wireless communication technologies. By combining 5G's strengths with the advanced features of 6G, the IoT ecosystem gains access to unparalleled capabilities [35]. This integration enables faster data transmission, improved reliability, and more intelligent communication, all of which have the potential to transform industries, enhance user experiences, and drive innovation. As we explore the enhanced functionalities and benefits of 5G and 6G in the context of IoT, we recognize the profound implications of this convergence on the future of connectivity and technology.

VII. Practical Scenarios and Real-Life Applications

This section explores real-life situations and applications across several sectors to demonstrate the feasibility of integrating 5G and 6G technology in the Internet of Things realm. The aforementioned examples demonstrate the potential for a transformable impact on several businesses and an overall improvement in the standard of living through the incorporation of these technologies. In the context of smart cities, the integration of 5G and 6G technologies brings about significant transformation in the urban environment. This integration facilitates the development of intelligent transportation systems that possess remarkable capabilities [36, 37], such as comprehensive analysis of traffic data and real- time traffic management. As a result, these advancements contribute to the reduction of travel time and fuel consumption. The integration of 5G and 6G technologies in the healthcare sector presents significant opportunities for enhanced remote patient monitoring. This advancement enables the utilization of wearable IoT devices to gather real-time data on patients' vital signs with unparalleled accuracy. In the realm of industrial IoT, the integration of various technologies plays a crucial role in enabling predictive maintenance. This, in turn, leads to a decrease in operational downtime and an enhancement in overall productivity. The process involves the utilization of sensors that feed real-time data to predictive maintenance algorithms. The agricultural sector has experienced a significant transformation in farming methodologies with the advent of 5G and 6G technologies [38]. These advanced technologies have revolutionized agricultural practices by enabling precision agriculture, which involves the utilization of remote sensors and drones to monitor soil conditions and assess crop health. Furthermore, within the realm of environmental monitoring and efforts to mitigate climate change, the utilization of 5G and 6G technologies serves to facilitate the gathering of data from distant regions, thereby bolstering climate models and enabling the timely detection of environmental shifts [39]. The aforementioned practical situations serve to underscore the profound and far- reaching effects of 5G and 6G technologies on various aspects of our daily lives, professional endeavors, and engagement with our surroundings. Through the analysis of practical implementations, valuable perspectives can be obtained on the potential of efficiency, innovation, and enhanced quality of life that can be achieved through this convergence [40]. Table II summarizes and compares the different practical scenarios and their corresponding benefits.

TABLE II. COMPARISON TABLE FOR DIFFERENT PRACTICAL SCENARIOS AND REAL-LIFE APPLICATIONS

Sector	Application	Technology/Feature	Benefit	Source
Smart Cities	Intelligent Transportation Systems	5G/6G, real-time data analysis	Optimized traffic flow, reducedtravel time, fuel consumption	[41, 42, 43]
Healthcare	Remote Patient Monitoring	Wearable IoT devices,5G/6G connectivity	Accurate real-time vital sign monitoring, improved healthcareoutcomes	[44, 45]
Industrial IoT	Predictive Maintenance	Sensors, 5G/6G data transmission, AI algorithms	Reduced downtime, increased productivity	[46, 47, 48]
Agriculture	Precision Agriculture	Remote sensors, drones, 5G/6G data gathering	Optimized resource utilization, improvedcrop yields	[49, 50]
Environmental Monitoring	Climate Change Mitigation	Sensor networks, 5G/6G data transmission, advanced models	Improved climate forecasting, Timely detection of environmental changes	[51, 52, 53]

VIII. SENSING-ENABLED 6G INFRASTRUCTURE AND ITS ARCHITECTURAL FRAMEWORK

This chapter delves deep into the essence of 6G networks, elucidating the architectural framework that underpins the harmonious integration of communication and sensing capabilities. Beyond merely offering faster connections, 6G represents a paradigm shift in wireless communication, with its core objective being the establishment of a pervasive sensory network that seamlessly extends its reach into our physical surroundings. This network, comprised of a vast array of sensors, serves as the sensory fabric that bridges the divide between the digital and physical realms, forging a dynamic and interconnected environment.

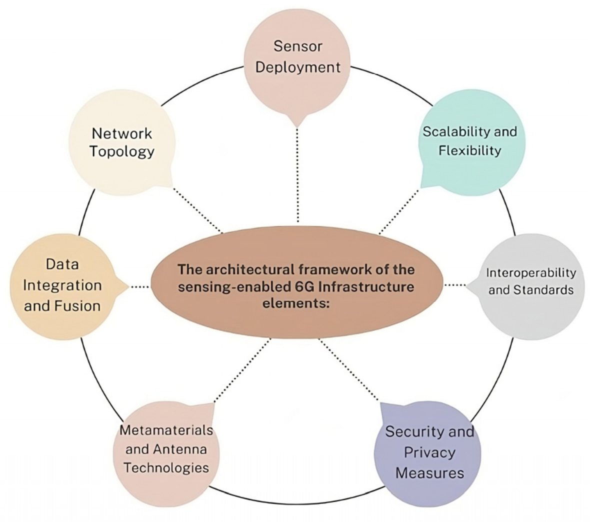

Fig. 6. The architectural framework of the sensing-enabled 6G Infrastructure elements.

The architectural framework of the sensing-enabled 6G infrastructure is designed to realize this vision. It encompasses several key elements as shown in Fig. 6.

Sensor Deployment: The framework involves the strategic placement of an extensive array of sensors throughout the environment, including environmental sensors, biometric sensors, and IoT devices. These sensors collectively form a dense sensory network, strategically positioned in urban areas, industries, healthcare facilities, and remote locations. This comprehensive network serves as the foundation for perceiving and understanding the physical world.

Network Topology: The architectural framework incorporates diverse network elements, such as terahertz base stations, edge computing nodes, and advanced antennae. Terahertz base stations provide the high-frequency backbone of the network, facilitating ultra-fast data transfer. Edge computing nodes enable real-time data processing and decision-making at the network's edge, significantly reducing latency. The network is interconnected through high-capacity optical and wireless links, ensuring seamless data flow.

Data Integration and Fusion: Real-time data processing and analytics are central to the framework. Advanced data processing algorithms, driven by artificial intelligence and machine learning, analyze data streams from various sensors. Data fusion techniques aggregate information from different sources, enhancing the overall understanding of the environment and enabling context-aware decision-making.

Metamaterials and Antenna Technologies: The architectural framework incorporates metamaterials, engineered materials with extraordinary electromagnetic properties [54]. These materials enable sensor miniaturization and enhance sensing capabilities, making sensors more compact and sensitive. Advanced antenna technologies, including phased array antennae, ensure efficient data transmission and reception.

Security and Privacy Measures: Robust security and privacy measures are integrated into the framework to safeguard sensitive IoT data. Quantum communication, a fundamental component of 6G, is utilized for secure data transmission through quantum key distribution. End-to-end encryption and authentication protocols are implemented to protect the integrity and confidentiality of data.

Interoperability and Standards: Interoperability is a key consideration in the architectural framework. Common standards and protocols are established to ensure that sensors and devices from different manufacturers can seamlessly communicate and share data within the network. This promotes a cohesive and unified IoT ecosystem.

Scalability and Flexibility: The framework is designed to be scalable and flexible, capable of accommodating the addition of new sensors and technologies as the IoT land- scape evolves. It can adapt to the unique requirements of various applications, whether in smart cities, healthcare, agriculture, or industrial IoT.

By embracing these architectural elements, the sensing-enabled 6G infrastructure creates a dynamic and interconnected network that goes beyond conventional communication. It not only communicates but also perceives, learns, and adapts, ushering in a new era where our environment becomes smarter, more responsive, and increasingly interactive. Thereby this innovative framework sets the stage for a future where the very fabric of our world is intricately interconnected, leading to transformable applications and an enhanced quality of life.

IX. Sensing and Data Fusion Algorithms for The Internet of Things Utilizing 5G and 6G Technologies

The expeditious advancement of IoT technology, in conjunction with the incorporation of 5G and 6G networks, has initiated a period characterized by unparalleled data generation and connection. Within this particular setting, the significance of sensing and data fusion techniques cannot be emphasized enough. The utilization of these algorithms plays a crucial role in the functioning of IoT applications [55], facilitating the extraction of significant insights from a diverse range of sensors and data sources. IoT ecosystems encompass a wide array of sensors, including ambient sensors, LiDAR sensors, and computer vision sensors, each offering distinct datasets. The task of integrating heterogeneous sensor data in order to achieve a holistic comprehension of the surrounding environment poses a substantial obstacle. Data fusion methods, such as the Kalman Filter, assume a pivotal role in this procedure by amalgamating data from several sensors to enhance the overall precision. The utilization of 5G and 6G networks enables the processing of data in real-time, hence facilitating prompt and well-informed decision-making across several domains such as healthcare and smart cities. In addition, the preservation of strong privacy and security is ensured by employing cryptographic methods, which effectively protect sensitive data within the IoT ecosystem. The confluence of technology offers promising prospects in several fields, ultimately transforming our interactions and comprehension of the IoT driven environment.

X. Advancements in 5G and 6G from an Internet of Things Perspective

The integration of 5G and 6G technologies within the context of the IoT ushers in a period characterized by significant revolutionary potential. This section examines three crucial aspects: the mitigation of security and vulnerability, the utilization of edge computing and fog networking, and the implementation of network slicing. These elements collectively redefine the capabilities of these technologies inside the IoT domain.

A. Security Measures and Strategies for Mitigating Vulnerabilities

Ensuring security is of utmost importance in the context of technological convergence. Encryption and authentication protocols are fundamental components of comprehensive security architecture, used to guarantee the confidentiality and integrity of data transported within a network [56]. These procedures are implemented to safeguard privacy and ensure the integrity of users. The integration of block chain technology in 6G networks enhances security by strengthening trust, ensuring data integrity, and promoting transparency. The implementation of this holistic approach enhances the network's ability to withstand and defend against cyber threats and malicious attacks, thereby fostering the necessary trust and readiness to fully embrace the digital era.

B. The Concepts of Edge Computing and Fog Networking

In the era of 6G, the fusion of communication and sensing surpasses the confines of cloud computing and expands into the domains of edge computing and fog networking. The implementation of a strategic deployment strategy involving edge servers, which are positioned in close proximity to data sources, serves to minimize latency and optimize the performance of sensory applications. The utilization of real- time processing capabilities at the edge brings about a trans- formable impact on the utilization of data, hence making responsiveness a core and integral component of the sixth generation (6G) technology. Furthermore, the energy-efficient elements of edge computing align with the worldwide effort to promote sustainability [57]. The deployment of 6G networks plays a crucial role in promoting ecological responsibility within the digital revolution, facilitating the advancement of intelligent, environmentally friendly, and interconnected communities.

C. Network Slicing

Network slicing refers to the process of dividing a physical network infrastructure into multiple virtual networks, each tailored to meet certain requirements and characteristics [58]. In the realm of 6G technology, the concept of a universal solution is no longer applicable. The notion of network slicing is a transformable strategy that enables the creation of distinct network slices tailored to the specific needs of various sectors and services within the Internet of Things ecosystem. The implementation of dedicated network slices guarantees the provision of services of high quality and ensures constant user experience. This marks the beginning of a new age where the network adjusts itself according to the requirements of the application. The concept of network slicing represents a significant transformation in which the network is customized to meet the specific needs of various industries. This approach enhances operational effectiveness and fosters unprecedented levels of innovation. This permits the unhindered growth and development of apps, leading to a paradigm shift where the network effectively transforms into a customized service that caters to individual requirements.

The integration of these fundamental components demonstrates the significant possibilities that arise from the convergence of 5G and 6G technologies within the context of the Internet of Things. This convergence has the potential to fundamentally reshape the domains of connectivity, security, efficiency, and adaptability, providing a glimpse into a future where network infrastructure and technological advancements align seamlessly with the requirements of human society.

XI. Prospective Challenges, Unresolved Matters, and Broadening Perspectives in The Context of 5G and 6G for the Internet of Things

The ongoing investigation into the synergistic capabilities of 5G and 6G technologies within the Internet of Things sector is a continuous endeavor. This section acknowledges the enduring obstacles and unresolved matters that necessitate attention as we strive to expand the frontiers of innovation.

A. Challenges and Open Issues

The integration of 5G and 6G within the IoT domain presents numerous challenges and open issues that must be addressed [59]. One significant concern is the scalability and interoperability of IoT devices operating on these advanced networks. As the number of connected devices continues to grow exponentially, ensuring that these devices can communicate seamlessly and that the network can handle the increasing load is a pressing issue. For instance, in a smart city environment, a multitude of IoT devices, including sensors for traffic management, waste management, and public safety, must collaborate in real-time. Interoperability issues can hinder the seamless operation of these systems.

Additionally, guaranteeing the privacy and security of the substantial volume of data generated and sent within these networks is of utmost importance. With cyber threats evolving rapidly, safeguarding sensitive IoT data remains an ongoing challenge [60]. For example, in healthcare IoT applications, patient health data is transmitted wirelessly. Ensuring that this data remains private and secure is essential to comply with regulatory requirements and protect patients from data breaches.

Another crucial consideration is the energy efficiency and sustainability of IoT systems that rely on 5G and 6G technology [61]. As the environmental impact of technology becomes a paramount concern, finding ways to reduce the energy consumption of IoT devices and network infrastructure is essential. This includes optimizing device power consumption, exploring renewable energy sources for network operation, and adopting sustainable practices across the IoT ecosystem. For instance, IoT devices in agriculture need to operate for extended periods on limited power sources. Optimizing energy usage in such scenarios is crucial for sustainable and efficient agricultural practices.

B. Broadening Perspectives

This study also explores the captivating possibilities for forthcoming networks, providing subtle indications of potential advancements beyond the sixth generation (6G) within the IoT framework. As technological innovation continues at an accelerated pace, there are intriguing prospects for what future networks may hold. Concepts like AI-driven IoT, quantum communication, and even more efficient and sustainable networks may shape the landscape of IoT in the years to come. Within a domain characterized by perpetual technological advancement, this particular sector highlights the crucial significance of collaboration and invention [62]. It accentuates the imperative of addressing hurdles and unresolved matters as prospects for development, rather than hindrances to forward movement. In the world of IoT and 5G/6G technology, it is essential that challenges are viewed as opportunities for innovation and growth.

As we contemplate the future developments beyond the sixth generation (6G) in the realm of IoT, our dedication to fostering innovation, promoting diversity, and ensuring sustainability remains unwavering. Ensuring the advancement of the future network, which combines the capabilities of 5G and 6G, is of utmost importance. This network should exhibit enhanced capabilities, security, and accessibility, thereby driving us towards a future where the potential of connection and IoT is boundless.

XII. Conclusion

Our research into leveraging 5G and 6G technology in IoT has revealed a world of new possibilities and promises. Our acknowledgment of future obstacles and unresolved issues highlights technical growth as we embark on this transformable journey. These include scalability, interoperability, security, and sustainability difficulties.

The scalability of IoT devices in 5G and 6G networks is crucial as the number of connected devices grows. Device communication is crucial in smart cities with varied sensor networks and healthcare applications using wearable IoT devices. However, interoperability allows IoT systems to cooperate. Interoperability issues must be overcome in smart cities to enable real-time collaboration between traffic, garbage, and public safety sensors.

In data security, safeguarding the large amount of data crossing these networks is ongoing. The rapid growth of cyber dangers requires careful IoT data protection. This means keeping wirelessly transmitted patient health data confidential and secure to meet regulatory and patient privacy obligations. Additionally, 5G and 6G IoT system energy efficiency and sustainability are becoming important. Technology's environmental effect can be reduced by optimizing IoT device and network infrastructure energy usage. IoT devices in agriculture must work efficiently on limited electricity to ensure sustainable and eco-friendly farming.

We have several prospects for innovation and advancement amid these problems and open issues. Future networks may include AI-driven IoT, quantum communication, and more sustainable and efficient technologies than 6G. We prioritize innovation, collaboration, and sustainability.

In the 5G and 6G-enabled IoT ecosystem, difficulties are opportunities. Our focus on addressing these difficulties and cultivating development potential will lead us to a future of limitless connectivity, security, and IoT possibilities. In the IoT arena, 5G and 6G are merging to push technological boundaries and unleash the IoT ecosystem's boundless potential to change the world.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Prajoona Valsalan, Najam Ul Hasan, Imran Baig, Manaf Zghaibeh, and Umer Farooq collectively contributed to the conceptualization, methodology, investigation, and original draft writing of this research. Prajoona Valsalan developed the core research idea and methodology. Sharifa Suhail Zaabanoot and Sunil Kumar Sreedharan E conducted the literature review, data collection, and data analysis. Rajkumar Singh Rathore provided overall supervision and guidance for the research, reviewed and edited the manuscript, and ensured the quality and coherence of the work. All authors have reviewed and approved the final published version of the manuscript.

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