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Review

AI-Enabled 6G Internet of Things: Opportunities, Key Technologies, Challenges, and Future Directions

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Abstract: The advent of sixth-generation (6G) networks promises revolutionary advancements in wireless communication, marked by unprecedented speeds, ultra-low latency, and ubiquitous connectivity. This research paper delves into the integration of Artificial Intelligence (AI) in 6G network applications, exploring the challenges and outlining future directions for this transformative synergy. The study investigates the key AI technologies for 6G: the potential of AI to optimize network performance, enhance user experience, and enable novel applications in diverse domains and AI-enabled applications. Analyzing the current landscape, the paper identifies key challenges such as scalability, security, and ethical considerations in deploying AI-enabled 6G networks. Moreover, it explores the dynamic interplay between AI and 6G technologies, shedding light on the intricate relationships that underpin their successful integration. The research contributes valuable insights to the ongoing discourse surrounding the convergence of AI and 6G networks, laying the groundwork for a robust and intelligent future communication infrastructure.

Keywords: 6G networks; artificial intelligence; Internet of Things; smart cities

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1. Introduction

The convergence of Artificial Intelligence (AI) with 6G technology marks a huge transformative frontier for the Internet of Things (IoT), promising unprecedented opportunities alongside substantial challenges. AI-enabled 6G IoT networks are poised to revolutionize connectivity, efficiency, and intelligence across diverse sectors, including smart cities, autonomous vehicles, industrial automation, and healthcare. The sixth generation (6G) of wireless systems, emerging as the next evolutionary step beyond 5G, is already attracting significant attention. With applications demanding vastly expanded spectrum resources, frequencies ranging from 100 GHz to 1 THz are becoming essential. This necessitates a broad-spectrum ecosystem, spanning from below 6 GHz to beyond 1 THz, accommodating diverse needs [1].

Sixth-generation technology aims to achieve substantial advancements in data throughput, latency, synchronization, security, and processing capabilities, underpinning transformative applications across various domains. Expected data rates could exceed terabits per second, enabling seamless virtual-reality experiences, real-time applications like remote surgery, and robust autonomous vehicle operations. Security and resilience will be paramount, ensuring robust defenses against cyber threats and uninterrupted connectivity in challenging scenarios. Distributed intelligence and edge computing will facilitate localized processing, enhancing network efficiency [1].

The envisioned applications of 6G are extensive and revolutionary, potentially transforming sectors such as transportation with real-time, secure, and ultra-low latency connections for autonomous vehicles and trains. These advancements leverage high-speed adaptive networks, particularly in the terahertz band, for critical and aggregate data transmissions [1].

The introduction of 6G technology promises unprecedented speeds, minimal latency, and transformative possibilities in wireless communication. Achieving these goals requires cutting-edge technologies, including terahertz band communication for high-frequency electromagnetic wave utilization, seamless integration of terrestrial and satellite networks for global coverage, and AI-driven network management for adaptive resource allocation and enhanced service optimization. Sustainability will be ensured through energy-efficient designs, supporting massive connectivity without compromising energy resources. New communication paradigms, such as ambient backscatter communications and quantum communication for enhanced security, will further augment 6G capabilities [2].

AI-enabled 6G networks are expected to deliver ultra-low latency, extensive connectivity, and enhanced reliability, supporting advanced applications across smart cities, autonomous vehicles, industrial automation, and healthcare. The integration of AI facilitates intelligent decision-making, real-time data processing, and network optimization, addressing current IoT limitations and paving the way for more efficient and resilient systems. However, achieving AI-enabled 6G IoT networks involves overcoming challenges such as developing advanced algorithms, enhancing data handling capabilities, ensuring robust security measures, and addressing ethical and societal concerns related to privacy and digital equity.

This paper stands out from existing review papers by providing a holistic view of the synergy between AI and 6G within the IoT ecosystem. Unlike other reviews, we offer a detailed analysis of key enabling technologies such as edge computing and intelligent reflecting surfaces, and we identify unique opportunities arising from this convergence, including ultra-reliable low-latency communications and enhanced data analytics. Our comprehensive discussion on the multifaceted challenges—technical, regulatory, and ethical—along with a forward-looking research roadmap, provides strategic guidance for future developments. Further, our interdisciplinary approach integrates insights from telecommunications, computer science, and data science, ensuring a well-rounded understanding of the subject. This comprehensive, nuanced, and forward-looking perspective sets our review apart from the more generalized or narrowly focused existing literature.

Moreover, this paper explores the opportunities presented by AI-enabled 6G IoT, analyzes the key technologies driving integration, and discusses the challenges and future directions of this burgeoning field. Through comprehensive analysis, it aims to provide insights into how AI can unlock the full potential of 6G networks, transforming the IoT landscape and shaping the future of connectivity. Standardizing 6G technology in collaboration with regulatory bodies and industry stakeholders will be crucial for establishing a cohesive and interoperable ecosystem [2].

1.1. First-Generation (1G) Technology

In the 1980s, an analog telecommunications system known as first-generation (1G) wireless telephone technology was unveiled. Speech services were transmitted analogously by first-generation mobile devices. NTT (Nippon Telegraph and Telephone) introduced the first commercial 1G cellular network in Japan in 1979, first in the Tokyo metropolis and then in Europe in 1981. Cellular networks could not be utilized to place calls across international borders, although 1G systems did offer handover and roaming capabilities. This was a blatant flaw in the initial generation of mobile networks. Features of 1G technologies were similar, only supporting analog systems, and adopting the Frequency Modulation (FM) schemes; they had a low capacity, since they employed FDMA multiplexing and 1G was limited to voice calls exclusively. However, 1G cellular networks also had several drawbacks. The analog signal transmission led to poor voice quality and frequent call drops. The lack of encryption made these networks highly insecure, making it easy for eavesdroppers to intercept calls. The devices themselves were bulky and expensive, with limited battery life. Moreover, the network coverage was sparse, often resulting in poor connectivity in less populated areas [3].

1.2. Second-Generation (2G) Technology

A commercial introduction of second-generation (2G) mobile systems based on GSM standards was made in Finland by Radiolinja in 1991, at the end of the 1980s. Both the conventional speech service and low-bit-rate data services were supported. In 1947, plans for the first cellular network were originally discussed. It was created with the intention of being utilized for military operations to provide more sophisticated communication methods to the troops. Many new types of broadcasting technology evolved between 1947 and 1979, roughly. In contrast to Europe, which was establishing its own communication systems, the United States started to build the AMPS (Advanced Mobile Phone Service) network. However, 2G cellular networks had several drawbacks. The data transfer rates were relatively low, limiting the types of services that could be offered. Further, the coverage and signal quality were inconsistent, especially in rural and less densely populated areas. Security features were also relatively basic, making these networks more vulnerable to eavesdropping and fraud. As technology advanced, the need for faster and more reliable networks led to the development of subsequent generations of mobile technology [4].

1.3. Third-Generation (3G) Technology

The third generation of mobile communications is known as 3G. With EDGE, high-volume data transfer is now possible, but because the packet transfer over the air interface behaves like a circuit's switch call, some of the packet connection efficiency in the circuit switch environment is lost. The 3G network was created in response to the requirement for a network with universally standardized performance. On 1 October 2001, NTT DoCoMo in Japan introduced the first commercial W-CDMA network, with the exception of the United States, where carriers were able to run 3G service on the same frequencies as other services, due to the fact that 3G networks utilized different radio frequencies than 2G. Three large businesses received licenses to run the 3G network on various protocols after China's 3G debut in 2009. These companies were China Mobile (Beijing, China)for TD-SCDMA, China Unicom (Beijing, China) for WCDMA, and China Telecom(Beijing, China) for CDMA2000. Some of the main features of 3G are third-generation (3G) features, including GPRS, with a maximum downlink speed of 144 kbps, EDGE, with a maximum downlink speed of 384 kbps, UMTS WCDMA, with a maximum downlink speed of 1.92 Mbps, and HSDPA, with a maximum downlink speed of 14 Mbps. Despite its advancements, 3G networks have several drawbacks. Firstly, the infrastructure costs for deploying 3G networks are high, which made the initial rollout expensive for service providers. Secondly, while 3G offers better data speeds than its predecessors, it still falls short compared to the capabilities of newer 4G and 5G technologies, leading to slower internet experiences for users. Additionally, 3G networks tend to have higher latency, affecting real-time applications such as video calls and online gaming. Lastly, the battery consumption of devices using 3G is generally higher, due to the increased data processing requirements, leading to shorter battery life for mobile devices [4].

1.4. Fourth-Generation (4G) Technology

"Connect anytime, anywhere, anyhow" is the guiding principle of 4G communication. Its primary characteristics are seamless access, personalization, Quality of Service (QoS) management, and an IP-based system (end-to-end IP transmission). The sole packet-switching technology, 4G, sometimes referred to as IMT-Advanced, was initially introduced in 2010. It integrates with one Core Network and many Radio Access Networks (RANs) to offer a comprehensive IP-based network with speeds ranging from 100 Mbps to 1 Gbps, with a frequency of 2–8 GHz [5]. Due to the high speed, the coverage area was reduced, necessitating the use of numerous smart antennas to provide long-range communication [6]. Good Quality of Service (QoS) and data speeds in 4G support services with improved clarity; such services include, but are not limited to, Mobile Television, HDTV content, Digital Video Broadcasting (DVB), Video Chat, Multimedia Newspapers, and High-Quality Live Streaming. Compared to 3G, 4G delivers incredibly reduced latency. However, there are some drawbacks to 4G cellular networks. The increased number of antennas and infrastructure required for extensive coverage leads to higher deployment and maintenance costs. Moreover, 4G networks are more susceptible to interference, especially in densely populated urban areas where signal congestion can occur. The battery consumption in 4G devices is higher, due to the continuous need for high-speed data transmission, which can reduce the overall battery life of mobile devices. Furthermore, despite the high speeds, the actual performance may vary significantly, depending on the user's location, network traffic, and the number of connected devices. Lastly, the transition from older networks to 4G requires compatible devices, which may not be affordable for all users, creating a digital divide.

1.5. Fifth-Generation (5G) Technology

With its emphasis on record-breaking data rates, extremely low latency, and widespread device connection, fifth-generation (5G) technology marks a substantial advancement in wireless communication. Fifth-generation promises data speeds up to 100 times faster than 4G by operating in higher frequency bands and leveraging cutting-edge technology like Massive MIMO and beamforming. Real-time applications like augmented reality, remote surgery, and driverless cars are improved by this technology. The network slicing capabilities of the 5G architecture make it possible to build virtual networks that are specialized for certain use cases. Although it is still being implemented, 5G opens the door for revolutionary applications that make the Internet of Things (IoT) and smart cities more practical [7].

1.6. Sixth-Generation (6G) Technology

The sixth generation (6G) of technology aims to achieve unheard-of performance levels in a network that goes beyond 5G. Instantaneous downloads and streaming of ultra-high-resolution information are made possible by 6G, which aspires to offer peak data speeds of up to terabits per second. Beyond faster data rates, 6G concentrates on seamless satellite and terrestrial network integration to provide worldwide coverage. It incorporates ideas like superior energy-efficient solutions, holographic communications, and networks with AI capabilities. By prioritizing sustainability in both construction and operation, 6G aims to address environmental concerns, marking a significant step towards eco-friendly telecommunications infrastructure. The comprehensive implementation of 6G is poised to revolutionize industries and reshape social connectedness in unprecedented ways. Despite its potential, 6G is currently in the early stages of research and exploration, laying the groundwork for the transformative advancements to come [8].

The progression from 2G to 6G highlights a series of significant advancements and persistent challenges in mobile communication technologies. Second-generation networks, primarily designed for voice communication and limited data services like SMS, faced issues with low data rates and limited internet capabilities. Transitioning to 3G brought improved data speeds and mobile internet access, but was constrained by relatively high latency and inconsistent connectivity, which hindered real-time applications. The advent of 5G introduced enhanced data rates, reduced latency, and greater connectivity, supporting a broader range of IoT devices and high-bandwidth applications. However, 5G still encounters challenges such as limited coverage in rural areas, high energy consumption, and potential security vulnerabilities. In contrast, 6G aims to overcome these issues by delivering ultra-low latency, ubiquitous connectivity, and enhanced energy efficiency through AI integration, promising smarter, more adaptive networks that can meet the demands of future digital landscapes while addressing the shortcomings of its predecessors. Further,

Table 1 expresses the features of each generation while Figure 1 shows the evolution of mobile radio networks.

Table 1. 1G to 6G network and their features.

Technology	Features
First-Generation Technology (1G)	Analog, voice-only, limited coverage, large phones, low capacity
Second-Generation Technology (2G)	Digital, text messaging (SMS), improved voice quality, better security, limited data services
Third-Generation Technology (3G)	Higher data rates, mobile internet, video calling, better coverage, multimedia messaging (MMS), location-based services
Fourth-Generation Technology (4G)	Mobile broadband, high data rates (up to 1 Gbps), seamless handovers, HD streaming, VoIP, improved spectral efficiency, reduced latency
Fifth-Generation Technology (5G)	Ultra-fast data (up to 10 Gbps), massive device connectivity (IoT), network slicing, low latency (1 ms), enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLCs), massive machine-type communications (mMTCs)
Sixth-Generation Technology (6G)	Terabit data rates, satellite integration, advanced AI for network management, ubiquitous connectivity, tactile internet, enhanced security, energy efficiency, holographic communication, integrated sensing and communication (ISAC)

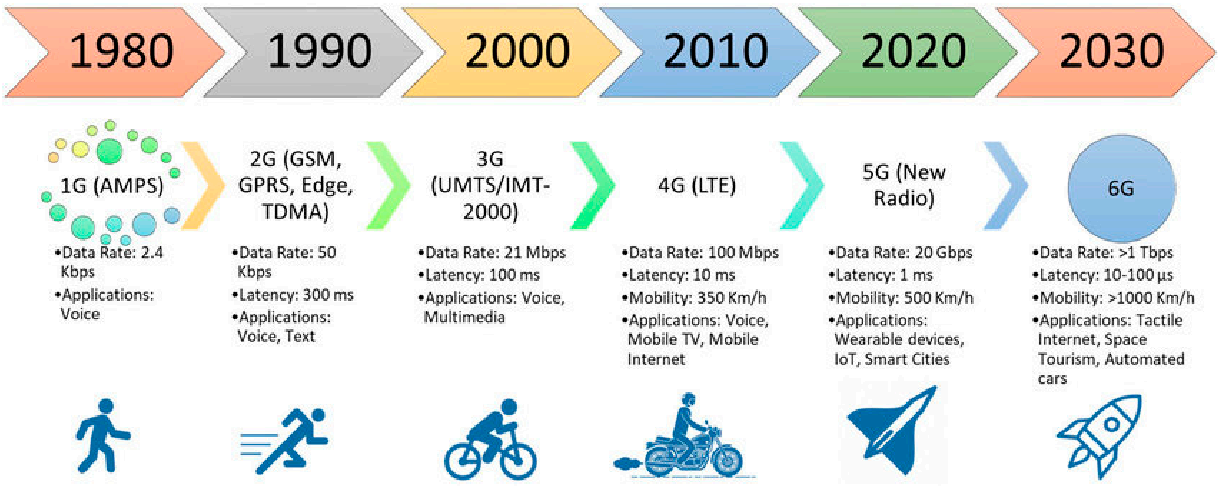

Figure 1. A road map from 1G to 6G network [4].

2. Methodology

This review paper adopts the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology to systematically collect, analyze, and synthesize the existing literature on AI-enabled 6G Internet of Things (IoT). The PRISMA methodology is widely recognized for its systematic approach to conducting comprehensive literature reviews, particularly in fields with broad topics and structured research questions, similar to the scope of this review.

The process begins with identifying relevant studies from academic databases like SCOPUS and other reputable sources, utilizing keywords such as "AI", "6G", "Internet of Things", and "AI in IoT" to gather pertinent literature. The search results include 38 papers and 5 book chapters on AI, 40 papers and 3 book chapters on 6G, 18 papers and 4 book chapters on the Internet of Things, and 14 papers and 5 book chapters on AI in IoT. Next, records are screened to remove duplicates and assess titles and abstracts, resulting in 100 papers and 15 book chapters after duplicates are removed, and 85 papers and 13 book chapters are screened. Full-text articles are then evaluated for eligibility, with 40 papers and 10 book chapters assessed, and 8 papers and 2 book chapters excluded, with the reasons documented. Finally, the studies that meet the eligibility criteria are included in the qualitative synthesis, resulting in 32 papers and 8 book chapters.

Figure 2 illustrates the selection process, and is included to provide a visual representation of the methodology. This includes the number of studies identified, screened, excluded, and included at each stage of the review process.

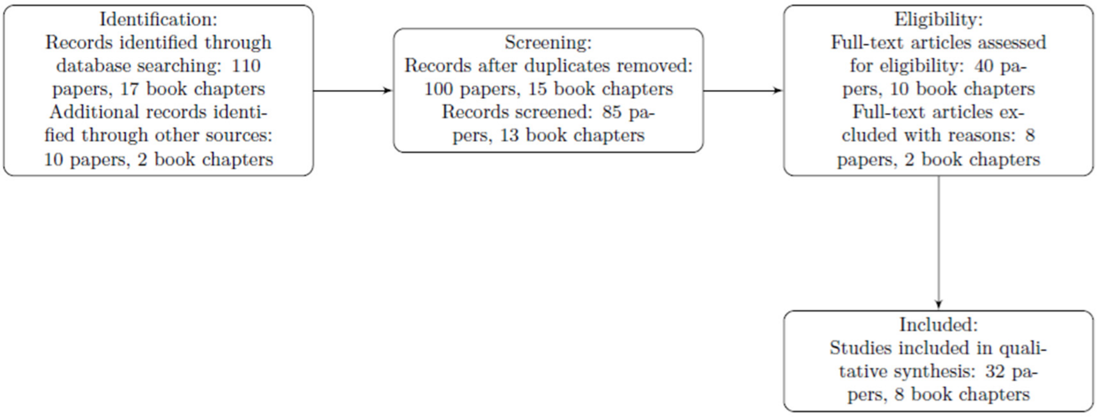

Figure 2. PRISMA Flowchart of the Selection Process.

In this phase, retrieved studies are screened based on predefined inclusion and exclusion criteria. Inclusion criteria prioritize studies that specifically address AI applications in the context of 6G IoT technologies, covering opportunities, key technologies, challenges, and future directions. Exclusion criteria filter out studies that are not directly related to the primary focus or lack relevance to the thematic scope.

Selected studies undergo a thorough eligibility assessment to ensure they meet the defined criteria and contribute substantively to the review objectives. Relevant data from eligible studies are extracted and organized to facilitate detailed analysis and synthesis.

The included studies are critically appraised to assess their methodological quality and relevance to the review's objectives. This step ensures that the selected literature provides robust insights into AI-enabled 6G IoT applications, supporting a comprehensive understanding of opportunities, technological advancements, challenges, and future research directions.

Data synthesis involves a systematic extraction and integration of findings from selected studies. Key themes, trends, and emerging perspectives related to AI applications in 6G IoT are identified and synthesized to develop a cohesive narrative that addresses the review's research questions.

The synthesized data are analyzed to uncover patterns, relationships, and gaps in the existing literature. This critical analysis informs discussions on the current state of the art, identifies technological advancements, evaluates challenges, and proposes future directions for research and development in AI-enabled 6G IoT.

Finally, the findings are reported following the PRISMA guidelines, ensuring transparency and rigor in presenting the review process, methodology, results, and conclusions. This structured approach enhances the reliability and reproducibility of the review, contributing to its academic integrity and value to the research community.

By adopting the PRISMA methodology, this review paper systematically integrates and analyzes the existing literature on AI-enabled 6G IoT, offering comprehensive insights into its opportunities, key technologies, challenges, and future directions.

3. Artificial Intelligence Techniques for 6G Networks

3.1. AI-Empowered Mobile Edge Computing

Artificial intelligence methods are included in the edge computing architecture of 6G networks as part of AI-empowered mobile Edge Computing, which is a distributed computing paradigm that brings computational resources and services closer to the end-users at the edge of the network. As a result, real-time data processing, analysis, and decision-making are made possible closer to the network edge, lowering latency and increasing network efficiency as a whole. In order to improve user experiences and effectively employ resources, processes like data offloading, resource allocation, and content caching may be optimized with the use of AI algorithms [9].

3.2. Intelligent Mobility and Handover Management

In 6G networks, AI is used to anticipate and manage user movement patterns and provide smooth handovers between base stations. AI algorithms are capable of predicting user mobility, network circumstances, and traffic patterns, in order to decide when and how to execute handovers. This leads to less disruption of service, more seamless switching between network cells, and increased network resilience [10].

3.3. Intelligent Spectrum Management

In order to dynamically assign and manage frequency spectrum resources in 6G networks, intelligent spectrum management leverages AI approaches. AI systems can improve spectrum allocation, minimizing interference and increasing network capacity, by continually monitoring spectrum utilization and user requests. This adaptive strategy allows a variety of services and applications with different bandwidth needs, while enabling effective usage of the spectrum that is already available [11].

3.4. Terahertz Band Communication

The use of very high-frequency electromagnetic waves for wireless communication in 6G networks is investigated by terahertz band communication. In comparison to conventional radio frequencies, this technology offers much better data rates and capacity. AI can help to improve signal processing, beamforming, and channel estimation for effective terahertz communication. AI-enhanced algorithms can be used to solve the problems associated with propagation and absorption at these frequencies [12].

3.5. Intelligent Communication Environment

In 6G, the idea of an Intelligent Communication Environment entails leveraging AI to build a context-aware and flexible network environment. In order to comprehend user behaviors, preferences, and contextual information, AI algorithms may evaluate data from a variety of sources, including sensors, social networks, and IoT devices. As a result, individualized and pertinent services, effective resource management, and proactive network management based on real-time insights are all made possible [13].

3.6. Pervasive Artificial Intelligence

All facets of 6G networks will be equipped with AI, thanks to pervasive artificial intelligence. Artificial intelligence-driven decision making improves network speed, security, and user experiences across devices and edge nodes, as well as core network activities. Federated learning is an AI approach that enables collaborative model training across devices, while protecting data privacy. With this strategy, networks become self-adaptive and self-learning, and continuously enhance their performance [14].

3.7. Ambient Backscatter Communications

In 6G networks, ambient backscatter communications investigate the idea of using the present ambient radio frequencies for communication. These signals can be captured and modulated by devices to communicate data, while using little power. To establish reliable communication, AI approaches can be used to enhance backscatter modulation techniques, data encoding, and signal processing. For IoT devices and sensor networks, this strategy may make ultra-low-power communication possible [15].

3.8. Internet of Space Things with Cubesats and UAVs

The Internet of Space Things (IoST) idea in 6G uses linked Cubesats (miniature satellites) and Unmanned Aerial Vehicles (UAVs) to build a flexible and adaptable communication infrastructure. Global coverage, on-demand network resource deployment, and real-time monitoring are all made possible by IoST. In order to optimize their location for smooth communication and effective data transmission, Cubesats and UAVs must move in concert and cooperate with one another. This is where AI comes into play. It may be possible to extend network coverage to remote locations and disaster-affected areas thanks to this cooperation between space-based and airborne assets [16].

3.9. Cell-Free Massive MIMO Communications

A cutting-edge strategy used in 6G networks that obfuscates the lines between conventional cells is called cell-free massive MIMO communications. It entails placing several access points (APs) around the coverage region without using specialized cells. These distributed APs work together to provide simultaneous service to many consumers, thanks to AI-driven algorithms. AI improves resource allocation, signal transmission, and interference control by utilizing sophisticated beamforming and spatial processing algorithms. This strategy boosts spectral efficiency, decreases latency, and improves user experiences, making it a potential 6G wireless communication strategy [17].

3.10. Tentative Timeline for 6G

The projected development and deployment stages of the sixth-generation wireless network are described in the 6G timeline's preliminary schedule. It is widely anticipated that research and standardization efforts will pick up over the early-to-mid-2020s; however, the timetable might vary. In order to confirm the practicality of suggested concepts and methodologies, technological experiments and prototypes may be conducted in the late 2020s. Early in the 2030s, full-scale deployment of 6G networks may begin, with the initial rollouts focusing on certain use cases and geographical areas. However, once infrastructure, devices, and ecosystem maturity are attained, significant worldwide acceptance may take several years after the initial deployments [18].

3.11. Channel Estimation

Large intelligent surfaces, ultra-massive multiple-input multiple-output (MIMO), visible-light communication, terahertz communication, and other emerging technologies will enable 6G radio access in order to meet the stringent requirements of smart city applications in terms of high data rate (Tbps), low latency (order of 0.1–1 ms), and high reliability (order of 10–9). Due to the increased complexity of radio communication channels brought about by these technologies, standard mathematical methods for efficient channel estimates will become more difficult to use. The information is transferred using a wireless communication channel that attenuates phase changes and adds noise to the data [19].

3.12. Semantic Interoperability

Semantic interoperability is a crucial aspect of AI-enabled 6G networks, ensuring that different systems and devices can effectively exchange and interpret data, with shared understanding. In the context of 6G, which involves a diverse array of applications, devices, and communication protocols, achieving semantic interoperability is vital for seamless integration and functionality. This entails the use of standardized data formats, ontologies, and metadata frameworks to enable consistent data interpretation across heterogeneous systems. AI plays a pivotal role in enhancing semantic interoperability by leveraging machine learning and natural language processing to automate the translation and alignment of disparate data sources. As 6G networks aim to support advanced applications like autonomous vehicles, smart cities, and IoT ecosystems, robust semantic interoperability ensures that data flow smoothly and meaningfully between various components, thereby enhancing efficiency, reducing errors, and enabling more intelligent and responsive network behaviors.

3.13. Modulation Recognition

Different modulation techniques are used in a communication system to achieve efficient and effective data transmission by modifying the delivered signal in light of the growing amount of data traffic in smart cities. In this situation, the goal of modulation recognition is to distinguish the signals' modulation information amid loud interference. Applications including cognitive radio, interference detection, spectrum monitoring, threat assessment, and signal recognition benefit from the assistance of modulation recognition in signal demodulation and decoding. For modulation recognition in smart city applications, the traditional statistical pattern recognition and decision theory-based approaches become computationally complex and time-consuming [19].

3.14. Intelligent Routing

Numerous routing algorithms have been developed to effectively manage network traffic and meet the quality of service (QoS) requirements of 6G applications. However, when traffic variability increases, the conventional routing protocols created using meta-heuristic techniques become more computationally expensive. ML- and DL-based techniques have therefore been put out to remedy the drawbacks of the conventional techniques [19].

4. AI-Enabled Intelligent 6G Network Applications

4.1. Smart Cities

A developing idea, the "smart city", integrates a variety of electronic gadgets with city people to improve information flow. A smart city is one that has technology that integrates waste management, transportation, resource usage, and public health, while being intelligent, economical, and cost-effective. Sixth-generation technology will be a game changer, redefining wireless development with more demanding standards such as greater capacity, lower latency, extended connectivity, enhanced security, high quality of experience, low energy consumption, and robust connections that may be employed in smart cities [20]. Figure 3 illustrates the areas of 6G-AI applications in smart cities.

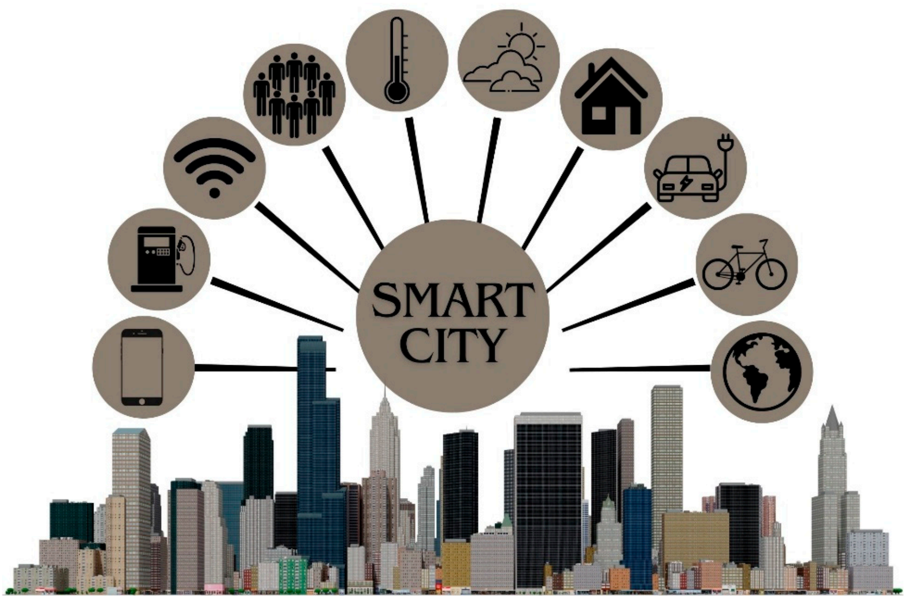

Figure 3. AI-enabled smart cities.

4.2. Autonomous-Vehicle Communications

While varying degrees of autonomy are now being tested in a number of countries across the world, mass-produced autonomous cars appear to be a long way off. Sixth-generation (6G) communications have several applications and are gaining appeal as a novel strategy to integrate current automobiles and communication technologies in autonomous vehicles (AVs). Communication between autonomous vehicles and infrastructure systems will be more precise or better in real time with 6G networks. Because of the functional efficacy of communication activities, the role of artificial intelligence in 6G networks expressly adds to real-time routing decisions, notably in autonomous-vehicle navigation [21,22].

4.3. UAV Communication

Based on their weight, UAVs are divided into four categories: micro (less than 100 g), very small (between 100 g and 2 kg), small (between 2 and 25 kg), medium (between 25 and 150 kg), and giant (greater than 150 kg). Small unmanned aerial vehicles (UAVs) carry out routine duties similar to those found in civilian applications, whereas big UAVs perform mission-critical or defense missions. Cellular networks provide the finest support for inter-drone communication, boosting the efficacy and security of drone operations. The 6G communication network improves the reliability and connection of UAV operations outside of the direct line of sight. The denser IoT deployment of 6G facilitates IoT acceptance, as well as IoT application in blind regions. UAVs require low latency, high throughput, and dependability, which a 6G connection provides. UAV networks benefit from the enormous coverage of 6G networks, since they can host roughly ten times the number of devices per square kilometer as 5G networks [23].

4.4. Smart Robotic

With new connectivity and radio-based sensing capabilities, 6G capabilities will radically alter how robotics may be developed. Despite the wide variety of robot categories, according to the definition of a robot, every robot possesses the ability to sense its surroundings, function with varying levels of autonomy, and activate actuators to enable movement and regulate moving components in order to complete certain tasks [24].

With the help of 6G mobile technologies, connected robots and autonomous systems will evolve, revolutionizing daily life. Autonomous cars are a famous example, which can sense their environment using sensors like GPS, light detection, distance measurement, sonar, radar, and odometry [25].

4.5. Smart Agriculture

The advent of 6G will revolutionize automation and precision agriculture, ushering in a new era of connectivity, data collection, and automation. According to predictions, 6G will be up to 100 times faster than 5G, opening up new possibilities for data collection and real-time analysis. By using this knowledge, farmers will be able to make better decisions and boost agricultural production. The data gathered may include information on the amount of soil moisture present, water utilization, and other environmental factors. With 6G, farmers can quickly obtain information and take action, leading to better decisions and greater yields.

This automation may save expenses, boost productivity, and lessen the chance of human mistakes. Farmers will have access to real-time connection and speedier data transfer thanks to 6G, which will allow them to manage their business from anywhere. Farmers will thus have better access to business data and control over their businesses [26].

4.6. Virtual Reality

Sixth-generation networks are anticipated to be far faster than 5G networks, with speeds of up to 1 terabit per second. With this increased speed, virtual-reality experiences could be more engaging and interactive. With the increased speed of 6G networks, better resolution and quicker frame rates in VR apps will be available, providing a far more feasible virtual experience. In addition to gaming and entertainment, this has the potential to be extremely helpful in medical and educational applications. As tracking and latency are improved by 6G networks, more responsive and lifelike VR interactions are made possible. Users may be able to interact with others without any delay and move around more freely in virtual environments, as a result [27–29]. Figure 4 shows the application of AR/VR with 6G.

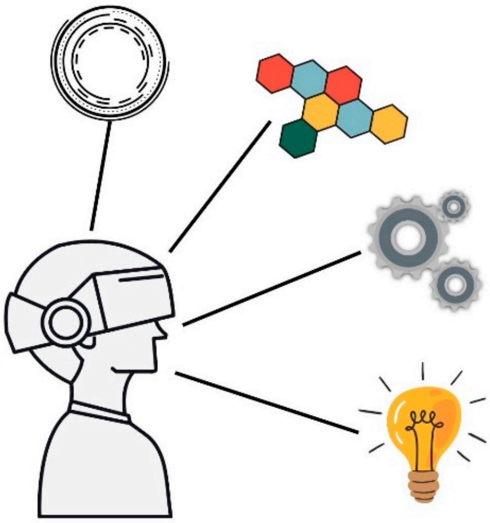

Figure 4. Virtual reality.

4.7. Online Video Games

Social interaction is a feature of both mobile and metaverse games. Modern video-game players prefer to converse with one another in person, rather than exchange text on chat windows. Because of this and a quick Wi-Fi connection, players like immediate input. This can be aided by quick cellular technologies like 5G and 6G, which promise quicker wireless internet-connection rates. Additionally, 6G enables in-game player involvement in real time. The quicker pacing and lack of interruptions mimic how individuals go through real-world activities. In other words, 6G makes it possible for gaming to once again use AR/VR technology [28].

4.8. Remote Surgery

Sixth-generation networks will enable remote surgery, allowing doctors to operate on patients while they are apart. This might be very beneficial in situations when it is not practical for the patient and medical professional to be in the same location, such as in remote or underserved areas. With the aid of 6G networks, surgeons will be able to operate robotic surgical equipment and view the surgery site in real time [29,30].

Future smart healthcare will feature freely accessible, locally independent, and unrestricted healthcare services. Dynamic personal health monitoring, tele-diagnosis and pathological inference, holographic medicine, patient recovery training, and telesurgery are just a few of the unique use cases that will be made possible by the introduction of new sensors and AI capabilities in the 6G mobile network [25,26].

5. AI-Enabled 6G Network Challenges

5.1. Channel Estimation

Channel estimation is an essential receiver function in 6G networks. Many of the primary 6G technologies under consideration pose novel channel-estimation problems that are intractable by means of the techniques already in use. For instance, due to the extreme noise, THz communication has very lengthy channel responses and low SNR.

Furthermore, even slight environmental modifications might result in large inaccuracies in channel estimates.

The emergence of beam-split phenomena in large MIMO systems operating in the THz region can result in significant reductions in array gain. As a result of this phenomenon, route components are divided into various spatial directions across distinct subcarrier frequencies. Because they cannot send, receive, or analyze pilot signals, passive Reflective Intelligent Surface (RIS) components complicate channel estimates even more. As a result, the development of channel-estimate approaches capable of dealing with this complexity becomes critical. These approaches must strike a compromise between great spectrum efficiency and computational simplicity, while maintaining estimate accuracy. The following sections will go into the current state of channel estimate in the context of 6G networks [30].

5.2. Network Traffic Prediction and Classification

This improvement in service quality and the inclusion of new features are two advantages, as we move forward in time. Mobile traffic has increased dramatically over previous generations, due to the introduction of new services such as mobile-to-mobile communications and the use of smartphones. Understanding the dynamic of traffic demands in a wireless network is a difficult task, due to the increased densification of mobile devices linked to the network [31].

5.3. Intelligent Routing

Because of the high user density expected in the 6G network, sophisticated algorithms and methods will be needed to meet user demand. Additionally, it is anticipated that the 6G network would support a wide range of complex ultra-low latency applications, including holographic imaging, haptic communication, Tele driving, Tele Robotics, and others. When a call is dropped due to a lack of resources, the network experiences an extra delay that is unsuitable for latency-sensitive applications like haptic communication. The issue could be resolved by adding a Wireless Intelligent Router (WIR) to the network. The router will keep an eye on the network in cases of congestion, and reroute users as necessary. In order to meet customer demand, the WIR is a trained router that uses reinforcement learning to connect to the closest accessible access point. It makes sure that the user receives the optimal power allocation based on the desired application [32].

5.4. Radio Resource Management

A few 6G applications that will necessitate an evolution of present RAN techniques in order to satisfy the key performance indicators (KPIs) required for 6G networks are unmanned aerial vehicles, multi-dimensional sensing services, smart factories, and cities. The majority of Dynamic Radio Resource Management (RRM) systems are dynamic and flexible. These characteristics suggest that radio resources may be distributed flexibly, depending on traffic demands, channel circumstances, and user QoS needs, enabling the optimization of network performance [33].

5.5. Network Fault Management

The latency, reliability, data criticality, and privacy challenges associated with 6G will be addressed using distributed AI in a distributed network. However, the network's dispersed structure will provide a number of challenges, most of which will be reliability-related. Because 6G networks would be widely dispersed, proper coordination of compute nodes will be a key reliability concern. To do this, successful communication protocols between those computer nodes are necessary, as well as an effective underlying network capable of handling the level of traffic generated by data storage and retrieval [33].

5.6. Mobility Management

"Mobility" is a characteristic of mobile technology. Fifth-generation (5G) mobile networks were unable to satisfy performance specifications; hence, sixth-generation (6G) mobile network technology will establish new benchmarks. This is due to the strong demand for a more intelligent network, extremely low latency, lightning-fast network connections, and support for a wide range of linked applications. When controlling mobility, neither 5G nor pre-5G networks took network node movement into consideration. The rapidly moving satellites will provide considerable challenges for 6G. The mobility options with 6G will be even more complex. The inter-satellite linkages alter when the satellites' positions vary. The network topology, handover control methods, and other elements will change as a result of the relocation [34].

5.7. Network Botnet Detection

To facilitate artificial intelligence-driven communication, future 6G networks are expected to include post-quantum encryption, increased edge computing, machine learning, and other technologies. The strings function is one of the most significant characteristics for recognizing malware. It is also expected that a data-modeling change in malware detection would be easily transferrable to other cybersecurity fields. In addition to addressing the new problems introduced by the data-centric paradigm, these newly developed continuous, explicable, and visualizable machine-learning-based approaches will provide a way to maximize their benefits for the various data modeling domains where learning transparency is required [35].

5.8. Network Energy Optimization

Energy efficiency is critical for the advancement of 6G networks. AI integration is expected to be a crucial technology for increasing network speed, user experience, and resource management. AI-based solutions have the potential to significantly cut energy usage while also improving the overall performance of 6G networks. Furthermore, the integration of wireless communication systems, communications, and the Internet of Things (IoT) will be a critical component of the architecture of 6G networks. Energy efficiency is a major focus of 6G, which also increases security and allows communications to be sent through satellites. Through the combination of cryptographic technologies, satellite communication, and simpler networking for smart cities, the 6G standard provides the groundwork for a future in which wireless communication becomes increasingly secure, sustainable, and energy-efficient [36].

The transition to AI-enabled 6G networks presents several complex challenges that necessitate innovative solutions. Channel estimation faces difficulties due to THz communication's extreme noise and environmental sensitivity, requiring new methods that balance efficiency and accuracy. The rapid growth of mobile traffic and the increased device density demand sophisticated traffic prediction and classification techniques. High user density and diverse applications necessitate advanced intelligent routing algorithms, while evolving applications require dynamic radio resource management to optimize performance. Distributed AI must address reliability concerns in the decentralized network structure, and new mobility management techniques are essential to handle moving network nodes and satellites. Enhanced cybersecurity measures, including post-quantum encryption and explainable machine-learning models, are vital for detecting botnets and other threats. Finally, AI-driven energy optimization is crucial for enhancing network performance while reducing consumption, and supporting the development of secure, sustainable 6G networks.

The development of 6G networks brings forward several research gaps that need to be addressed to fully leverage AI-enabled technologies. First, channel estimation faces significant hurdles, due to extreme noise and complex environmental changes, particularly in THz communications and large MIMO systems. There is a critical need for new methods that balance spectrum efficiency and computational simplicity while maintaining accuracy. Further, the rapid increase in mobile traffic and device density requires advanced techniques for network traffic prediction and classification. Intelligent routing poses another challenge, necessitating sophisticated algorithms to manage high user density and support ultra-low-latency applications. Radio resource management must evolve to meet the dynamic demands of 6G applications, such as unmanned aerial vehicles and smart cities. The dispersed nature of 6G networks raises reliability concerns, making effective network fault-management essential. Mobility management will also be complex, due to the movement of network nodes and satellites, requiring new strategies for seamless handovers. Furthermore, enhancing network security through advanced botnet-detection methods and AI-driven approaches is vital. Lastly, optimizing energy management using AI techniques is crucial for ensuring the sustainability and efficiency of 6G networks, particularly given the integration of IoT and satellite communications. Addressing these gaps will be pivotal in realizing the full potential of 6G technology.

6. Future Research Directions

As 6G networks continue to evolve, numerous challenges and opportunities for future research have emerged. This section explores key areas where further investigation and development are crucial for advancing 6G technology. These research directions include improving computation efficiency and accuracy, real-time video analytics, big data analytics, robustness and flexibility of learning frameworks, hardware development, and energy management. Moreover, developing AI models that are transparent and explainable will be crucial for public trust and to ensure responsible development and deployment. Ensuring that AI systems can be understood and scrutinized by users and stakeholders is essential to avoid biases, enhance security, and maintain accountability. Addressing these areas will not only enhance the performance and capabilities of 6G networks, but also ensure their scalability, reliability, and sustainability in the face of increasing demands and complexities.

6.1. Computation Efficiency and Accuracy

The collection rates of large numbers of data and intricate network topologies of the 6G networks hinder AI-enabled learning and training procedures. Additionally, it is possible that the restricted computer capacity will not be able to analyze the enormous numbers of high-dimensional data required to accomplish the training accuracy rate. Deep learning is very costly, since it typically necessitates sophisticated computing systems. Therefore, one of the most crucial research fields is how to create effective AI learning methods that will increase computing efficiency and accuracy. Recently, it has been apparent that high-performance computing abilities may be used to hasten convergence, lessen difficult computations, and boost training precision. These methods include feature matching, graphics processing, residual networks, and offline training [35,36].

6.2. Real-Time Video Analytics

Using a range of precise analytical and approximative numerical methodologies, intelligent video analytics is the automated analysis of images coming from video cameras in real-time or from archive recordings. Video analytics are implemented utilizing software (software) when dealing with video footage. The application makes use of a wide range of statistical models and techniques to enable video monitoring and data mining without the direct involvement of people. More and more, problems with video surveillance systems are being solved using video analytics. Video analyzing software could use to acquire an objective assessment of the performance of airspace monitoring, since it can perform continuous and automatic gathering and analysis of video data, independent of the human factor, and create reports at the user's request at any time [35,36].

6.3. Big Data Analytics for 6G

Future wireless communication will need higher data speeds and a significantly more dependable transmission link in order to keep up with the growth of multimedia services while maintaining a decent level of service quality. In order to increase data speeds, which are predicted to be 100–1000 times faster than 5G, 6G will likely utilize a higher frequency spectrum than prior generations. By stacking algorithms and identifying patterns in even the most complex and abstract data, deep learning in big data analysis imitates human learning processes [35].

6.4. Robustness, Scalability, and Flexibility of Learning Frameworks

Aspects of 6G networks that are highly dynamic include BSs affiliations, wireless routes, topologies of networks, and mobility dynamics. For instance, devices or terminals that enter or leave networks may have different QoS and QoE requirements. The settings of AI learning algorithms must be continuously modified, due to all of the aforementioned uncertainties in dynamic networks. High resilience, scalability, and flexibility in learning frameworks are essential for sustaining an infinite number of interacting entities and providing high-quality services in actual dynamic networks. As a result, the issue of how to develop powerful, scalable, and adaptable learning frameworks to support 6G networks is still open [34,35].

6.5. Hardware Development

In order to operate in the millimeter, wave and THz bands, hardware components must use a significant amount of energy, and are costly. Some gadgets and terminals only have a finite amount of processing and storage capacity. The learning and recognizing capabilities of AI learning algorithms have improved, but they typically require high levels of computational complexity, power consumption, and enough computer resources. In order to improve the collaboration between hardware components and AI learning algorithms, a lot of study is required. Being able to manage matrix calculations and transfer learning-enabled intelligent communications that can adjust to various limitations in the hardware by transferring one learning framework to other hardware components makes graphics processing units (GPUs) suitable for learning computation [35].

6.6. Energy Management

Various ground-based equipment can be recharged by power stations in 6G networks, while other sensors and infrastructure in the air, sea, and space cannot. Furthermore, 6G networks must be used to link a huge number of flexible smart low-power devices. As a result, advanced energy management strategies are critical in 6G networks. AI techniques have the potential to aid these infrastructures and devices in improving their energy management strategy and prolonging their useful life by intelligently managing the amount of power they use or through energy harvesting. As a result, power management is an important yet complex topic for 6G networks [36].

6.7. Public Trust and Responsible Development

Future research in AI-enabled 6G communication networks must prioritize building public trust and ensuring responsible development. This entails developing transparent and explainable AI models that clarify decision-making processes, detecting and mitigating biases to promote fairness, and establishing robust ethical governance frameworks. Security measures, including advanced encryption and real-time threat detection, are crucial for protecting user data and network integrity. Additionally, involving users in the design process can enhance usability and alignment with societal values. International standards and regulatory compliance frameworks will be essential to ensure ethical AI deployment across diverse applications and regions. Addressing these priorities will not only advance the capabilities of 6G networks but also uphold transparency, fairness, and security, fostering trust among users and stakeholders alike.

6.8. Human AI

In the realm of Human–AI interaction, future research must focus on fostering trust and ensuring responsible integration. Key priorities include developing AI systems that are transparent and explainable, enabling users to understand and trust AI-driven decisions. Detecting and mitigating biases in AI algorithms is essential to uphold fairness and equity in human–AI interactions. Ethical guidelines and governance frameworks need to be established to govern the ethical use of AI in various applications, ensuring that AI systems respect user autonomy, privacy, and societal norms. Robust security measures, including data protection protocols and privacy-enhancing technologies, are crucial for safeguarding sensitive information in human–AI interactions. Additionally, involving stakeholders in the design and development of AI systems can enhance usability and acceptance. International standards and regulatory frameworks should be developed to promote consistent ethical practices and accountability across different sectors and jurisdictions. By addressing these challenges, research in human–AI interaction can pave the way for a future where AI technologies enhance human capabilities while maintaining ethical standards and fostering trust among users and communities.

6.9. AI-Enabled 6G for IoT

In the domain of AI-enabled 6G Internet of Things (IoT), future research must prioritize building trust and ensuring responsible deployment. It is crucial to develop AI systems that are transparent and explainable, allowing stakeholders to comprehend the decision-making processes within IoT networks. Detecting and mitigating biases in AI algorithms is essential to ensure fairness and equity across IoT applications. Establishing robust ethical frameworks and governance mechanisms will be pivotal in guiding the ethical use of AI in diverse IoT scenarios, safeguarding user privacy and autonomy. Enhanced security protocols, including advanced encryption and real-time threat detection, are critical to protect sensitive IoT data and maintain network integrity. Engaging stakeholders in the design and development phases can enhance the usability and acceptance of AI-enabled IoT solutions. International standards and regulatory frameworks should be established to promote ethical practices and accountability in the deployment of AI across global IoT infrastructures. Addressing these challenges will not only advance the capabilities of AI-enabled 6G IoT networks, but also foster trust among users and stakeholders, ensuring that these technologies contribute positively to society while upholding ethical standards and privacy considerations.

Table 2 shows the future of AI-enabled 6G IoT research is poised to drive significant advancements in several key directions. Firstly, AI-driven network management is expected to optimize network performance and resource allocation, leading to more efficient and resilient networks. Integrating 6G IoT with emerging technologies like virtual/augmented reality (VR/AR) and autonomous systems will open new applications and enhance user experiences. Developing sustainable IoT solutions focuses on eco-friendly technologies, aiming to reduce environmental impact and promote sustainable growth. Creating advanced security mechanisms is crucial for building robust security protocols that increase trust and adoption of IoT technologies. Finally, designing human-centric IoT applications ensures that solutions are tailored to user needs and experiences, improving satisfaction and usability. These research directions are essential for realizing the full potential of AI-enabled 6G IoT and addressing the challenges of the future.

Table 2. Future Directions for AI-enabled 6G IoT Research.

Research Direction	**Description**	**Expected Outcomes**
AI-Driven Network Management	Using AI to optimize network performance and resource allocation	More efficient and resilient networks
Integration with Emerging Technologies	Combining 6G IoT with technologies like VR/AR and autonomous systems	Enhanced user experiences, new applications
Sustainable IoT Solutions	Developing eco-friendly IoT technologies	Reduced environmental impact, sustainable growth
Advanced Security Mechanisms	Creating robust security protocols for AI-enabled IoT systems	Increased trust and adoption of IoT technologies
Human-Centric IoT Applications	Designing IoT solutions with a focus on user needs and experiences	Improved user satisfaction and usability

7. Discussion

This study offers a comprehensive investigation of the convergence of Artificial Intelligence (AI) and sixth-generation (6G) wireless networks, emphasizing the revolutionary possibilities and related obstacles of this cooperative effort. To support the wide range of anticipated applications, such as virtual reality, online gaming, smart cities, autonomous vehicles, UAV communication, smart robotics, and smart agriculture, the planned 6G networks seek to utilize frequencies between 100 GHz and 1 THz. This will greatly increase the amount of spectrum that is available. In order to optimize these applications and improve network speed, efficiency, and user experience, key artificial intelligence technologies like machine learning, predictive analytics, and real-time data processing are essential. However, there are significant obstacles to the rollout of 6G networks with AI capabilities. The exponential growth in connected devices and data quantities has made scalability a serious problem. Robust solutions are necessary to address security problems, namely those related to intelligent routing, botnet detection, and network traffic prediction. Careful control and oversight are required, due to ethical concerns such algorithmic bias and data privacy. The necessity for a complete infrastructure that promotes mutual enhancement is highlighted by the dynamic interplay between AI and 6G technologies. In order to overcome these obstacles and fully utilize AI-enabled 6G networks, future research will need to focus on computing efficiency enhancement, real-time video analytics, big data analytics, hardware development, and energy management. In order to manage the complexities and guarantee responsible and creative breakthroughs in this field, cooperation between researchers, industry players, and policymakers will be crucial.

Table 3 shows the summary of challenges in AI for 6G and IoT networks. The integration of AI with 6G technologies in the Internet of Things (IoT) ecosystem presents several challenges that must be addressed to unlock its full potential. Key issues include data privacy and security, scalability, interoperability, energy efficiency, and regulatory and ethical concerns. Advanced encryption and blockchain technology can enhance data protection, while edge computing and hierarchical architectures improve scalability by processing data closer to the source. Standardization and open protocols are essential for interoperability, ensuring seamless communication between diverse IoT devices. Energy-efficient hardware designs and AI-driven power management can extend the battery life of IoT devices. Clear regulations and ethical guidelines are crucial to address the legal and ethical implications of AI and IoT, fostering public trust and ensuring compliance. By addressing these challenges through technological innovation, regulatory oversight, and industry collaboration, the AI-enabled 6G IoT ecosystem can achieve its full potential.

Table 3. Challenges in AI-enabled 6G IoT.

Challenge	Description	Potential Solutions
Data Privacy and Security	Ensuring the protection of sensitive data in IoT systems	Advanced encryption, blockchain technology
Scalability	Managing the vast number of IoT devices and data generated	Edge computing, hierarchical IoT architecture
Interoperability	Ensuring seamless communication between diverse IoT devices	Standardization, open protocols
Energy Efficiency	Reducing the energy consumption of IoT devices and networks	Energy-efficient hardware, AI-driven optimization
Regulatory and Ethical Issues	Navigating the legal and ethical implications of AI and IoT	Clear regulations, ethical guidelines

8. Conclusions

In conclusion, the combination of sixth-generation (6G) wireless networks and artificial intelligence (AI) is a major advancement in the field of communication technologies, with the potential to transform a wide range of industries, including online gaming, robotics, agriculture, autonomous vehicles, smart cities, robotics, and UAV communication. While

AI presents significant problems including scalability, security, and ethical issues, it also has the unmatched potential to optimize network performance, improve user experiences, and spur novel applications. Strong and proactive solutions that include developments in big data processing, real-time analytics, hardware development, energy management, and computing efficiency are needed to meet these problems. AI and 6G have a dynamic and mutually beneficial interaction, which emphasizes the need for an infrastructure that is well-supported and cooperative efforts between researchers, industry stakeholders, and legislators. The full revolutionary potential of AI-enabled 6G networks may be fully realized by carefully managing these difficulties, opening the door to an era of never-before-seen connectedness, efficiency, and creativity.

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References

1. Akhtar, M.W.; Hassan, S.A.; Ghaffar, R.; Jung, H.; Garg, S.; Hossain, M.S. The shift to 6G communications: Vision and requirements. *Hum.-Centric Comput. Inf. Sci.* **2020**, *10*, 1–27. Available online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7750912/ (accessed on 5 June 2024). [CrossRef]
2. Elmeadawy, S.; Shubair, R.M. 6G Wireless Communications: Future Technologies and Research Challenges. In Proceedings of the 2019 International Conference on Electrical and Computing Technologies and Applications (ICECTA), Ras Al Khaimah, United Arab Emirates, 19–21 November 2019; pp. 1–5. [CrossRef]
3. Gallagher, J.C.; DeVine, M.E. Federation of American Scientists. Available online: https://sgp.fas.org/crs/misc/R45485.pdf (accessed on 22 August 2023).
4. Bakare, B.; Bassey, E. (PDF) A Comparative Study of the Evolution of Wireless Communication Technologies from the First Generation (1G) to the Fourth Generation (4G). Available online: https://www.researchgate.net/publication/355397163_A_Comparative_Study_of_the_Evolution_of_Wireless_Communication_Technologies_from_the_First_Generation_1G_to_the_Fourth_Generation_4G (accessed on 22 August 2023).
5. Agarwal, A.; Agarwal, K. The Next Generation Mobile Wireless Cellular Networks—4G and beyond. *Am. J. Electr. Electron. Eng.* **2014**, *2*, 92–97. Available online: https://pubs.sciepub.com/ajeee/2/3/6/index.html (accessed on 23 August 2023). [CrossRef]
6. Sahoo, S.S.; Hota, M.K.; Barik, K.K. 5G Network a New Look into the Future: Beyond All Generation Networks. *Am. J. Syst. Softw.* **2014**, *2*, 108–112. Available online: https://pubs.sciepub.com/ajss/2/4/5/ (accessed on 23 August 2023).
7. Solyman, A.; Yahya, K. Evolution of Wireless Communication Networks: From 1g to 6G and Future Perspective. Available online: https://www.researchgate.net/publication/362397204_Evolution_of_wireless_communication_networks_from_1G_to_6G_and_future_perspective (accessed on 23 August 2023).
8. Shahjalal, M.; Kim, W.; Khalid, W.; Moon, S.; Khan, M.; Liu, S.; Lim, S.; Kim, E.; Yun, D.W.; Lee, J.; et al. Enabling technologies for AI empowered 6G massive radio access networks. *ICT Express* **2023**, *9*, 341–355. [CrossRef]
9. UMahamod; Mohamad, H.; Shayea, I.; Othman, M.R.; Asuhaimi, F.A. Handover parameter for self-optimisation in 6G mobile networks: A survey. *Alex. Eng. J.* **2023**, *78*, 104–119. [CrossRef]
10. Ismail, L.; Buyya, R. Artificial Intelligence Applications and Self-Learning 6G Networks for Smart Cities Digital Ecosystems: Taxonomy, Challenges, and Future Directions. *Sensors* **2022**, *22*, 5750. [CrossRef]
11. Farhad, A.; Pyun, J.-Y. Terahertz Meets AI: The State of the Art. *Sensors* **2023**, *23*, 5034. [CrossRef]
12. Singh, P.R.; Singh, R.; Yadav, R.; Chaurasia, S. 6G networks for artificial intelligence-enabled smart cities applications: A scoping review. *Telemat. Inform. Rep.* **2023**, *9*, 100044. [CrossRef]
13. Maduranga, M.W.P.; Tilwari, V.; Abeysekera, R. Improved RSSI Indoor Localization in IoT Systems with Machine Learning Algorithms. *Signals* **2023**, *4*, 651–668. [CrossRef]
14. Deebak, B.D. Drone of IoT in 6G Wireless Communications: Technology, Challenges, and Future Aspects. 2020. Available online: https://www.semanticscholar.org/paper/Drone-of-IoT-in-6G-Wireless-Communications:-and-Deebak-Al-turjman/efb4a9ce2be6699605e4397e3ca1707abdb058d3 (accessed on 5 June 2024).
15. Huo, Y.; Lin, X.; Di, B.; Zhang, H.; Hernando, F.J.L.; Tan, A.S.; Mumtaz, S.; Demir, Ö.T.; Chen-Hu, K. Technology Trends for Massive MIMO towards 6G. *Sensors* **2023**, *23*, 6062. [CrossRef]

16. Al-Ansi, A.M.; Al-Ansi, A. An Overview of Artificial Intelligence (AI) in 6G: Types, Advantages, Challenges and Recent Applications. *ResearchGate* **2023**, *5*, 67–75.
17. Kamruzzaman, M.M.; Hossin, M.A.; Alruwaili, O.; Alanazi, S.; Alruwaili, M.; Alshammari, N.; Alaerjan, A.; Zaman, R. IoT-Oriented 6G Wireless Network System for Smart Cities. *Comput. Intell. Neurosci.* **2022**, *2022*, 1874436. [CrossRef] [PubMed]
18. Advances of 6G Technology in Electric cars—TechTeamZ—IT Solution. Available online: https://techteamz.io/advances-of-6g-technology-in-electric-cars/ (accessed on 20 August 2023).
19. Haseeb, K.; Rehman, A.; Saba, T.; Bahaj, S.A.; Wang, H.; Song, H. Efficient and trusted autonomous vehicle routing protocol for 6G networks with computational intelligence. *ISA Trans.* **2023**, *132*, 61–68. [CrossRef]
20. Gupta, R.; Nair, A.; Tanwar, S.; Kumar, N. Blockchain-assisted secure UAV communication in 6G environment: Architecture, opportunities, and challenges. *IET Commun.* **2021**, *15*, 1352–1367. [CrossRef]
21. New one6G Position Paper on 6G Robotics—one6G—Taking Communications to the Next Level. 26 January 2023. Available online: https://one6g.org/new-one6g-position-paper-on-6g-robotics/ (accessed on 20 August 2023).
22. Hadžić, A.; Popović, G. 6G—Sixth Generation Mobile Networks. *Nauka i Tehnol.* **2023**, *11*, 1–7. [CrossRef]
23. Admin. The Role of 6G in Advancing Smart Agriculture and Food Systems. isp.page. 20 March 2023. Available online: https://isp.page/news/the-role-of-6g-in-advancing-smart-agriculture-and-food-systems/ (accessed on 29 August 2023).
24. Admin. The Impact of 6G on Virtual and Augmented Reality. isp.page. 18 March 2023. Available online: https://isp.page/news/the-impact-of-6g-on-virtual-and-augmented-reality/ (accessed on 20 August 2023).
25. What 6G Will Do for Mobile Gamers—TCI Entertainment. Available online: https://tcientertainment.com/news/2022/05/03/what-6g-will-do-for-mobile-gamers/ (accessed on 20 August 2023).
26. TECHDesign. 6G: The Next Generation of Wireless Communication. TECHDesign Blog. 9 January 2023. Available online: https://blog.techdesign.com/6g-next-generation-wireless-communication/ (accessed on 20 August 2023).
27. Mucchi, L.; Shahabuddin, S.; Albreem, M.A.; Abdallah, S.; Caputo, S.; Panayirci, E.; Juntti, M. Signal Processing Techniques for 6G. *J. Sign. Process. Syst.* **2023**, *95*, 435–457. [CrossRef] [PubMed]
28. Sharma, A.; Aggarwal, R.; Kamath, H.S. Big Data Analytics For 6G. *Int. J. Sci. Res. Sci. Technol. (IJSRST)* **2020**, *7*, 158–164. [CrossRef]
29. Dogra, A.; Jha, R.K.; Jha, K.R. Intelligent routing for enabling haptic communication in 6G Network. In Proceedings of the 2023 15th International Conference on COMmunication Systems & NETworkS (COMSNETS), Bangalore, India, 3–8 January 2023; pp. 419–422. [CrossRef]
30. Lee, Y.L.; Qin, D.; Wang, L.-C.; Sim, G.H. 6G Massive Radio Access Networks: Key Applications, Requirements and Challenges. *IEEE Open J. Veh. Technol.* **2021**, *2*, 54–66. [CrossRef]
31. Ahmad, I.; Rodriguez, F.; Huusko, J.; Seppänen, K. On the Dependability of 6G Networks. *Electronics* **2023**, *12*, 1472. [CrossRef]
32. Banafaa, M.; Shayea, I.; Din, J.; Azmi, M.H.; Alashbi, A.; Daradkeh, Y.I.; Alhammadi, A. 6G Mobile Communication Technology: Requirements, Targets, Applications, Challenges, Advantages, and Opportunities. *Alex. Eng. J.* **2023**, *64*, 245–274. [CrossRef]
33. Uysal, D.T.; Yoo, P.D.; Taha, K. Data-Driven Malware Detection for 6G Networks: A Survey From the Perspective of Continuous Learning and Explainability via Visualisation. *IEEE Open J. Veh. Technol.* **2023**, *4*, 61–71. [CrossRef]
34. Slimani, K.; Khoulji, S.; Kerkeb, M.L. Advancements and Challenges in Energy-efficient 6G Mobile Communication Network. *E3S Web Conf.* **2023**, *412*, 01036. [CrossRef]
35. Yang, H.; Alphones, A.; Xiong, Z.; Niyato, D.; Zhao, J.; Wu, K. Artificial-Intelligence-Enabled Intelligent 6G Networks. *IEEE Netw.* **2020**, *34*, 272–280. [CrossRef]
36. Tevyashev, A.; Shostko, I.; Zemlyanyy, O. Intelligent video analytics of air objects in real time. *Transf. Innov. Technol.* **2021**, *4*, 111–114. [CrossRef]