



## Research Article

# A Systematic Survey on Artificial Intelligence in 6G Wireless Networks: Security, Opportunities, Applications, Advantages, Future Research Directions and Challenges

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## ABSTRACT

Artificial Intelligence (AI) has emerged as a transformative force in wireless communication, paving the way for unprecedented capabilities in the forthcoming 6G networks. AI is set to revolutionize 6G wireless networks by enabling intelligent, adaptive, and efficient communication systems. This article presents a comprehensive survey of AI's role in 6G, covering its security implications, opportunities, applications, advantages, challenges, and future research directions. It explores how AI enhances network optimization, real-time decision-making, and personalized services while addressing critical security and privacy concerns. The survey highlights the advantages of AI, such as energy efficiency, low latency, and robust security, alongside challenges like high computational demands, scalability, and ethical considerations. Future research directions focus on energy-efficient algorithms, adaptive models, privacy-preserving techniques, and AI's integration with emerging technologies. This survey provides valuable insights into the transformative potential of AI in shaping 6G networks, offering a roadmap for researchers and industry stakeholders to realize intelligent, secure, and sustainable wireless communication.

## 1. INTRODUCTION

The evolution of wireless communication has been marked by a relentless pursuit of higher data rates, lower latency, enhanced reliability, and seamless connectivity. As the world prepares for the sixth generation (6G) of wireless networks, the integration of Artificial Intelligence (AI) has emerged as a cornerstone in addressing these demands. 6G is expected to go beyond traditional communication paradigms by enabling immersive applications such as holographic telepresence, pervasive Internet of Things (IoT), autonomous systems, and ultra-reliable low-latency communication (URLLC). These advancements necessitate intelligent, adaptive, and efficient network management, which AI is uniquely positioned to deliver [1].

AI has already demonstrated its potential in various facets of communication systems, including spectrum management, predictive maintenance, resource allocation, and security. In 6G, AI's role expands further, leveraging machine learning (ML), deep learning, and reinforcement learning to enable self-organizing networks, real-time decision-making, and optimization of complex operations. However, the integration of AI in 6G is not without its challenges, such as computational complexity, ethical concerns, and the need for robust standardization frameworks [2].

This survey aims to provide a comprehensive exploration of the synergies between AI and 6G wireless networks. It delves into the opportunities presented by AI, its applications in diverse sectors, and the potential security implications. Furthermore, it highlights the advantages of adopting AI in 6G, the challenges that must be addressed, and the future research directions needed to fully realize the promise of AI-driven 6G systems. By offering a systematic overview, this work serves as a valuable resource for researchers, developers, and policymakers navigating the rapidly evolving landscape of next-generation wireless technologies [3].

The advent of 6G wireless networks promises to revolutionize connectivity with ultra-low latency, massive device density, and extreme data rates. AI stands at the forefront of enabling these advancements by providing tools for intelligent decision-making, adaptive optimization, and real-time analytics. This survey aims to systematically evaluate how AI integrates with 6G, addressing its potential and associated challenges.

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## 2. INTRODUCTION TO 6G

6G wireless networks represent the next frontier in wireless communication, building on the foundations established by previous generations, such as 5G, but pushing the boundaries to enable entirely new possibilities in connectivity, performance, and applications. 6G is expected to deliver unprecedented speeds, ultra-low latency, massive connectivity, and intelligent, adaptive communication systems [4].

6G wireless networks represent a monumental leap forward in the capabilities of mobile communication, pushing the boundaries of speed, latency, connectivity, and intelligence. While significant challenges remain in terms of technology, security, and infrastructure, the development of 6G will unlock transformative applications across industries and societies. The combination of AI, quantum communication, and advanced network technologies will redefine how we interact with the digital world, paving the way for a hyper-connected, intelligent future [5-6].

### 2.1. Key Features of 6G Networks

- *Ultra-High Data Rates:* 6G networks are expected to offer data rates that exceed 100 Gbps per user, enabling applications such as ultra-high-definition holography, immersive augmented and virtual reality (AR/VR), and real-time 3D communication.
- *Ultra-Low Latency:* Latency in 6G is anticipated to be in the sub-millisecond range, enabling real-time communication with minimal delays. This is crucial for applications like autonomous driving, industrial automation, and remote surgery [5].
- *Massive Connectivity:* 6G will support an even larger number of devices than 5G, with trillions of connected devices, particularly in the Internet of Things (IoT), wearables, and smart cities. It will enable ubiquitous connectivity, allowing for efficient communication in dense environments.
- *Terahertz (THz) Band Utilization:* To achieve the extreme data rates, 6G networks are expected to leverage the terahertz frequency spectrum (0.1 to 10 THz), which offers higher bandwidth and capacity than the millimeter-wave spectrum used in 5G [6].

### 2.2. AI and Machine Learning in 6G

- *Network Optimization:* AI-driven algorithms will autonomously optimize resource allocation, spectrum management, and energy efficiency in real time, ensuring that the network adapts dynamically to changing conditions [7].
- *Intelligent Connectivity:* AI will enable smart decision-making for the network, ensuring seamless connectivity across diverse environments, such as urban, rural, and remote areas. AI models will predict and address congestion, interference, and demand spikes to maintain network performance.
- *Security and Privacy:* AI will play a significant role in enhancing the security and privacy of 6G networks by detecting potential threats, predicting security breaches, and applying adaptive defense mechanisms in real-time.

### 2.3. Applications of 6G Networks

- *Holographic Communications:* 6G will enable holographic telepresence, allowing users to interact with 3D holograms in real time, which is expected to transform industries such as healthcare, entertainment, and education.
- *Tactile Internet:* The tactile internet will allow for real-time remote control of objects with sensory feedback, vital for applications in fields like remote surgery, industrial automation, and robotics.
- *Autonomous Systems:* 6G will support autonomous vehicles, drones, and robots, providing real-time communication and low-latency control for mission-critical applications in transportation, logistics, and emergency response [8].
- *Smart Cities:* 6G will underpin the development of smart cities, enabling intelligent traffic management, energy efficiency, environmental monitoring, and seamless integration of urban infrastructure through massive IoT networks [9].
- *Extended Reality (XR):* 6G will facilitate immersive experiences in AR/VR, offering extremely high-resolution, low-latency, and realistic interactions for gaming, entertainment, education, and professional training.

### 2.4. Challenges in 6G Networks

- *Spectrum Scarcity:* Although 6G will leverage the THz spectrum, managing and utilizing these high-frequency bands will present challenges in terms of signal propagation, power consumption, and interference.

- *Energy Consumption:* As 6G networks grow in size and complexity, managing energy efficiency, especially with AI-driven systems and large-scale IoT, will be crucial to ensuring sustainability.
- *Security and Privacy:* With massive connectivity and new applications, safeguarding the network from cyber threats, data breaches, and ensuring user privacy will be paramount.
- *Integration with Legacy Systems:* Ensuring seamless interoperability with existing 5G and older network systems, devices, and infrastructure will require careful planning and standardization.
- *Standardization and Global Collaboration:* Developing common standards, protocols, and regulations for 6G systems will be essential to ensure interoperability and encourage global adoption.

## 2.5. Technological Innovations for 6G

- *Advanced Antennas and MIMO Systems:* 6G will use advanced multiple-input multiple-output (MIMO) antenna systems and beamforming technologies to support high-capacity communications across multiple frequency bands.
- *Quantum Communication:* 6G will likely integrate quantum communication technologies to enhance security through quantum key distribution (QKD), offering potentially unbreakable encryption methods for sensitive communications.
- *AI-Driven Autonomous Networks:* Self-organizing and self-healing networks (SONs) powered by AI will become central to 6G, enabling the network to adapt and recover from failures or congestion autonomously.
- *Blockchain for Secure Communication:* Blockchain technology could play a role in securing data exchanges, enhancing trust in decentralized applications, and providing immutable records of network activities in 6G systems [10].

## 2.6. Economic and Social Impact

- *Digital Transformation:* 6G will facilitate widespread digital transformation in industries such as healthcare, education, finance, and manufacturing, enabling new business models and services that were previously not possible.
- *Global Connectivity:* With its ability to connect remote areas and underserved populations, 6G could help bridge the digital divide, providing internet access and opportunities to marginalized communities.
- *Workforce Transformation:* As 6G enables automation, remote work, and immersive experiences, it will reshape the global workforce, requiring new skills and changing the way people work and interact.

## 2.7. Future Research Directions in 6G

- *AI-Powered Optimization:* Researchers are working on developing AI algorithms that can dynamically optimize network performance, resource allocation, and security in real-time.
- *THz Communications:* Research is ongoing to develop technologies that can overcome the challenges of using the THz frequency band, including improving signal propagation, minimizing interference, and increasing power efficiency [11].
- *Sustainability in 6G:* A major research direction is focused on ensuring that 6G networks are energy-efficient and sustainable, addressing concerns over the growing energy consumption of advanced networks.
- *Quantum Networks and Security:* As quantum technologies mature, they are expected to be integrated into 6G networks to offer enhanced data security and unprecedented computational power for AI and machine learning applications.

## 3. ARTIFICIAL INTELLIGENCE (AI)

AI denotes the emulation of human cognitive functions by computers, particularly computer systems. These processes encompass learning (the acquisition of facts and rules for application), reasoning (the use of rules to derive approximate or definitive conclusions), and self-correction. AI has emerged as a transformational technology with extensive uses and ramifications across all sectors.

### 3.1 Principal Domains of AI

- *Machine Learning (ML):* A branch of AI that allows computers to acquire knowledge and enhance performance via experience without direct programming. Common methodologies encompass supervised, unsupervised, and reinforcement learning.

- *Deep Learning*: An sophisticated subclass of machine learning that emphasizes neural networks with numerous layers to analyze intricate data, including pictures, sounds, and text.
- *Natural Language Processing (NLP)*: Facilitates machines in comprehending, interpreting, and responding to human languages. Applications encompass chatbots, virtual assistants, and translation systems.
- *Computer Vision*: The capacity of machines to understand and analyze visual information, including photos and movies. It is extensively utilized in facial recognition, autonomous cars, and medical imaging.
- *Expert Systems*: AI systems engineered to replicate human decision-making through rule-based reasoning.
- *Robotics*: Integrates AI with engineering to develop intelligent robots capable of executing tasks independently or semi-autonomously.
- *Generative AI*: Concentrates on producing novel material, such graphics, music, or writing, by analyzing patterns from pre-existing data. Instances encompass OpenAI's ChatGPT and DALL-E.

### 3.2 Applications of AI

- *Healthcare*: AI assists in diagnostics, drug discovery, personalized medicine, and robotic surgery.
- *Finance*: AI algorithms power fraud detection, stock market predictions, and automated trading.
- *Manufacturing*: Used for predictive maintenance, quality control, and optimizing production processes.
- *Transportation*: Found in autonomous vehicles, traffic management systems, and logistics optimization.
- *Education*: Personalized learning platforms and virtual tutors enhance the learning experience.
- *Entertainment*: AI-driven recommendation engines power platforms like Netflix and Spotify.

### 3.3 Challenges in AI

- *Ethical Concerns*: Bias in data, privacy issues, and potential misuse.
- *Explainability*: Many AI systems, especially deep learning models, act as "black boxes," making it hard to understand their decision-making processes.
- *Regulation and Governance*: Balancing innovation with appropriate oversight.
- *Computational Resources*: Advanced AI models often require significant computational power and energy.

### 3.4 Future of AI

AI continues to evolve with innovations like quantum computing, edge AI, and advancements in generative AI models. It is expected to play a crucial role in addressing global challenges such as climate change, sustainable development, and healthcare disparities. However, its growth demands responsible development to ensure inclusivity, fairness, and safety.

## 4. SECURITY IMPLICATIONS OF AI IN 6G

The integration of AI into 6G wireless networks introduces both groundbreaking security opportunities and significant challenges. AI-enhanced systems have the capability to revolutionize threat detection and prevention by identifying anomalies, predicting potential vulnerabilities, and responding to attacks in real time. These capabilities enable 6G networks to address sophisticated cyber threats with unprecedented speed and accuracy. Techniques such as ML and DL facilitate the deployment of intelligent intrusion detection systems (IDS) and automated threat mitigation protocols, making 6G networks more robust and resilient [13].

However, the adoption of AI also exposes 6G systems to new vulnerabilities. Adversarial attacks, where malicious actors manipulate AI models to produce erroneous outcomes, pose a critical threat. Data poisoning, model inversion, and privacy breaches further complicate the security landscape. Moreover, as AI systems rely heavily on vast amounts of data, ensuring data integrity and protecting sensitive user information becomes a paramount concern. Federated learning and differential privacy offer promising solutions by enabling secure, decentralized data processing while preserving user confidentiality. AI's dual role as both a tool for enhancing and a potential target of cyber threats necessitates a holistic approach to security in 6G. This includes the development of robust algorithms capable of resisting adversarial attacks, designing secure data-sharing protocols, and fostering collaboration between AI and cybersecurity experts to address emerging challenges. By addressing these security implications proactively, AI can significantly enhance the trustworthiness and resilience of 6G wireless networks.

- *AI-Enhanced Threat Detection* : AI algorithms can detect and mitigate cyber threats in 6G environments through real-time anomaly detection, intrusion prevention systems, and predictive analytics.
- *Vulnerabilities of AI Systems* : Despite its advantages, AI introduces vulnerabilities such as adversarial attacks, data poisoning, and model inversion, necessitating robust countermeasures.

- *Privacy Preservation* : AI techniques like federated learning and differential privacy are critical for safeguarding user data in highly distributed 6G networks.

## 6. APPLICATIONS OF AI IN 6G

AI finds extensive applications in 6G wireless networks, driving innovations across multiple domains to enable next-generation connectivity and services. One prominent application is in network optimization, where AI algorithms dynamically manage network resources such as spectrum allocation, power control, and load balancing to ensure seamless connectivity and high efficiency. AI is also vital in autonomous network management, empowering self-organizing networks (SONs) to adapt to changing conditions, repair faults, and optimize performance without human intervention. Another critical application is in intelligent signal processing, where AI techniques like deep learning improve channel estimation, beamforming, and error correction for enhanced data transmission. AI also underpins personalized services by analyzing user behavior and preferences, enabling context-aware applications such as immersive augmented reality (AR), virtual reality (VR), and smart environments. In edge computing and IoT, AI supports distributed intelligence, facilitating low-latency processing and real-time decision-making for devices in applications like autonomous vehicles and industrial automation. Furthermore, AI enhances network security by detecting anomalies, predicting threats, and implementing adaptive defense mechanisms to safeguard data and infrastructure. AI also enables predictive maintenance in 6G systems by forecasting equipment failures and reducing downtime. Additionally, its role in enabling futuristic applications such as holographic communications, tactile internet, and remote surgery showcases its transformative impact. By leveraging AI, 6G networks can deliver unprecedented levels of intelligence, efficiency, and user-centricity, marking a paradigm shift in wireless communication technology [14-15].

- *Smart Cities* : AI-powered 6G networks facilitate intelligent traffic management, energy optimization, and public safety systems in smart cities.
- *Healthcare* : Remote diagnostics, telemedicine, and AI-enabled health monitoring benefit from the low latency and high reliability of 6G.
- *Autonomous Systems* : From self-driving cars to unmanned aerial vehicles, AI and 6G enable seamless operation and communication in autonomous systems.
- *Industry 4.0* : AI applications in manufacturing, logistics, and robotics leverage the URLLC capabilities of 6G.

## 7. ADVANTAGES OF AI IN 6G

AI offers numerous advantages in 6G wireless networks, revolutionizing their performance, scalability, and user-centric capabilities. One of the most significant advantages is enhanced network efficiency, where AI optimizes spectrum usage, power allocation, and resource scheduling, ensuring maximum throughput and minimal energy consumption. AI also brings ultra-low latency by enabling real-time decision-making through intelligent edge computing, crucial for applications like autonomous vehicles, telemedicine, and immersive extended reality (XR) experiences. Improved network reliability is another key advantage, as AI-driven predictive maintenance and fault detection ensure consistent service quality and minimize downtime. Furthermore, AI enables autonomous network management, reducing the reliance on manual interventions by implementing self-healing, self-optimizing, and self-configuring networks. It also provides robust security and privacy enhancements, detecting and mitigating cyber threats using advanced anomaly detection and threat prediction models. AI empowers personalized user experiences by analyzing user behavior and offering context-aware services tailored to individual needs, enhancing satisfaction and engagement. Additionally, AI facilitates seamless integration of heterogeneous networks, allowing 6G systems to unify diverse communication technologies and devices efficiently. Its ability to support futuristic applications like holographic communications, tactile internet, and smart city ecosystems demonstrates its transformative potential. Overall, AI in 6G networks drives innovation, adaptability, and intelligence, setting the stage for an unprecedented leap in wireless communication [16].

- *Efficiency* : AI improves the operational efficiency of 6G networks by automating complex processes and optimizing resource allocation.
- *Scalability* : AI-driven algorithms ensure that 6G networks can accommodate an exponential increase in connected devices.
- *Resilience* : AI strengthens network resilience against failures, cyberattacks, and dynamic environmental conditions.
- *Energy Savings* : By optimizing power consumption, AI contributes to the sustainability of 6G networks.



## 8. CHALLENGES

The integration of AI in 6G wireless networks, while transformative, poses several challenges that need to be addressed for successful deployment. One major challenge is the enormous computational and energy requirements of AI models. The complex algorithms used for tasks such as real-time resource allocation, network optimization, and intelligent decision-making demand substantial processing power and energy, which may strain network infrastructure and devices, particularly those with limited resources.

Another significant issue is data privacy and security. AI models rely heavily on vast amounts of data to learn and adapt, but this data often includes sensitive user information. Ensuring the privacy of this data and protecting it from breaches or misuse is a critical concern, especially in decentralized architectures like edge computing where data is processed closer to the user.

The scalability of AI solutions is also a challenge. As 6G networks aim to support billions of connected devices and a wide variety of applications, ensuring that AI algorithms scale efficiently without compromising performance or accuracy is a daunting task. Moreover, the heterogeneous nature of 6G environments—including diverse devices, communication protocols, and network standards—further complicates the design of universal AI solutions.

AI in 6G also faces the challenge of model training and real-time adaptability. Training advanced AI models requires vast datasets and computational resources, and once deployed, these models must adapt in real-time to dynamic network conditions, user demands, and emerging threats. Achieving this balance between pre-training and adaptability is complex and resource-intensive.

Additionally, there is a lack of standardized frameworks for integrating AI into 6G networks. Without clear standards, it becomes difficult to ensure interoperability, reliability, and seamless collaboration among AI-driven components from different vendors. This challenge is compounded by the rapid pace of AI advancements, making it hard to establish stable benchmarks and guidelines.

Lastly, there are concerns regarding ethical and societal implications. The autonomous decision-making capabilities of AI raise questions about accountability and fairness, particularly in critical applications like healthcare or autonomous vehicles. Ensuring transparency, mitigating biases in AI algorithms, and establishing robust regulatory frameworks are essential but challenging tasks.

- *Computational Complexity* : AI algorithms require significant computational power, which may strain the resources of 6G networks.
- *Data Availability and Quality* : The effectiveness of AI depends on the availability of high-quality data, which can be difficult to obtain and manage in 6G systems.
- *Ethical Concerns* : Bias in AI models, transparency issues, and ethical dilemmas pose challenges to the widespread adoption of AI in 6G.
- *Standardization* : The lack of standardized protocols and frameworks for AI implementation in 6G hinders interoperability and deployment.

## 9. FUTURE RESEARCH DIRECTIONS

Future research in AI for 6G wireless networks focuses on addressing challenges and unlocking the full potential of intelligent, adaptable, and efficient communication systems. The future of AI in 6G wireless networks lies in addressing existing challenges through innovative research. By focusing on energy efficiency, real-time adaptability, security, standardization, and integration with emerging technologies, researchers can enable AI to revolutionize 6G networks. These efforts will not only enhance network performance and scalability but also pave the way for transformative applications that redefine how we communicate and interact in a hyper-connected world. Several key directions are shaping this evolving field [17].

- *Energy-Efficient AI Algorithms* : A critical research direction is the development of energy-efficient AI algorithms tailored for 6G networks. As 6G aims to support a massive number of devices and applications, reducing the energy consumption of AI-driven processes is essential. Researchers are exploring lightweight machine learning models, federated learning (FL), and other distributed AI techniques that can minimize computational demands while maintaining high performance, particularly for energy-constrained devices at the network edge.
- *AI for Real-Time Decision Making* : Real-time decision-making is paramount for applications like autonomous vehicles, remote surgery, and immersive virtual reality. Future research focuses on optimizing the latency of AI models by integrating edge and cloud computing, developing faster inference techniques, and leveraging technologies like neuromorphic computing to process data in real time.
- *Self-Learning and Adaptive AI Models* : With the dynamic and heterogeneous nature of 6G networks, self-learning AI models that can adapt to changing conditions without extensive retraining are a priority. Reinforcement

learning (RL), transfer learning, and continual learning techniques are being explored to enable AI systems to evolve and adapt autonomously in complex environments.

- *AI for Network Security and Privacy* : Strengthening security and privacy in AI-driven 6G networks is another critical area of research. Advanced AI models capable of detecting and mitigating sophisticated cyber threats, such as adversarial attacks, need to be developed. Privacy-preserving AI methods, such as differential privacy and homomorphic encryption, are also being investigated to ensure data confidentiality without compromising performance.
- *Standardization and Interoperability of AI in 6G* : The lack of standardized frameworks for integrating AI into 6G systems is a significant challenge. Future research must focus on creating unified standards and protocols to ensure interoperability among AI-driven components from various vendors. Collaborative efforts between academia, industry, and regulatory bodies will be essential to establish these frameworks.
- *AI for Multi-Domain and Multi-Objective Optimization* : 6G networks will need to handle multi-domain challenges such as optimizing spectrum usage, energy consumption, and user experience simultaneously. Multi-objective optimization using AI, which balances conflicting requirements while maximizing overall network performance, is a promising research avenue.
- *Explainable and Trustworthy AI* : As AI takes on critical roles in decision-making within 6G systems, ensuring that these decisions are transparent and interpretable is crucial. Research into explainable AI (XAI) seeks to make AI models more understandable to stakeholders, thereby enhancing trust and accountability. This is especially important in applications involving safety or ethical considerations.
- *Integration of AI with Emerging Technologies* : AI's integration with emerging technologies like quantum computing, blockchain, and terahertz (THz) communication is another future direction. Quantum AI can provide breakthroughs in processing speed and problem-solving capacity, while blockchain can enhance the security and transparency of AI-driven systems in 6G.
- *AI for Human-Centric Applications* : Research is also focused on leveraging AI to enable human-centric applications in 6G, such as personalized healthcare, smart cities, and enhanced user experiences in the metaverse. This involves developing context-aware AI models that can understand user preferences and deliver tailored solutions.
- *AI-Powered Green Communication* : Achieving sustainability in 6G networks is a key priority. Future research will emphasize the role of AI in green communication by optimizing energy usage across the network, facilitating energy harvesting, and reducing the carbon footprint of communication systems.

## 10. CONCLUSION

AI is poised to play a pivotal role in shaping the future of 6G wireless networks. By addressing the challenges and harnessing the opportunities, AI and 6G can jointly unlock new frontiers in connectivity, intelligence, and efficiency. This survey underscores the importance of interdisciplinary research to realize the full potential of AI-driven 6G systems. This article highlights the transformative potential of AI in shaping the next generation of wireless communication. It emphasizes that AI will be the backbone of 6G networks, enabling intelligent decision-making, real-time optimization, and personalized services to meet the demands of an increasingly interconnected world.

The integration of AI offers immense opportunities, such as enhanced efficiency, robust security, and the support of futuristic applications like holographic communication and the tactile internet. However, significant challenges remain, including high computational demands, data privacy concerns, and the need for scalable, adaptive, and explainable AI solutions. The survey stresses the importance of continued research in energy-efficient AI algorithms, real-time adaptability, privacy-preserving models, and the standardization of AI frameworks. By addressing these challenges through innovative research and collaboration among academia, industry, and policymakers, AI can unlock unparalleled possibilities in 6G networks. The survey underscores the critical role of AI in driving technological advancements that will redefine wireless communication, delivering seamless, secure, and intelligent connectivity for diverse applications and services.

## Conflicts Of Interest

The author's affiliations, financial relationships, or personal interests do not present any conflicts in the research.

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