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Artificial intelligence, big data analytics, and deep learning for 6G communication networks: Challenges, applications, and future directions

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Abstract

The fast development of 6G communication systems has posed serious challenges with management of ultra-density connections, massive traffic, and extremely evolving wireless environments that demand new solutions with the help of Artificial Intelligence, Big Data Analytics, and Deep Learning. The conventional network management techniques cannot be used in supporting AI-native networks, terahertz communication, ultra-massive MIMO or integrated sensing and communication which are presumed to be key technologies of beyond-5G systems. The paper offers a detailed literature review concerning intelligent wireless systems, edge AI, federated learning, and data-driven networking. The review examines new applications, architecture, and technical issues towards integrating machine learning into wireless, digital twin networks, and self-organizing networks into future communication infrastructures. Findings suggest that low latency, high reliability, and energy-efficient communication in the next-generation networks can only be achieved through the use of AI-based optimization, autonomous control of networks, and real-time analytics made possible by the big data analytics. The results also indicate the growing research interest in network automation, smart connectivity and intelligent network management especially in the support of Internet of Everything, immersive services and large-scale cyber-physical systems. Nevertheless, other problems, such as computational complexity, security, privacy, interoperability, and scalability are no longer mere obstacles to implementation. The review believes that the deep learning, AI-driven optimization, and distributed analytics will be at the core of the future wireless systems and that intelligent, autonomous, and adaptive communication architectures will be a research focus of designing the 6G ecosystems.

Keywords: Federated learning, Communication networks, Network automation, Machine learning, Wireless systems, Artificial intelligence.

1. Introduction

The development of wireless communication technologies has become transformative with the appearance of 6G communication networks that are predicted to go much beyond the capacities of current 5G and beyond-5G technologies with the opportunity to achieve ultra-high data rates, exceedingly low-latency, massive connectivity, and intelligent service delivery. The increasing need in the use of immersive applications, smart cities, autonomous transportation, extended reality, and systems on a large scale has led to the necessity of communication infrastructures that can not only be faster but also have the ability to make autonomous decisions and optimize themselves [1]. Artificial Intelligence, Big Data Analytics, and Deep Learning integration, in this case, has turned into a core requirement of the development of the next-generation wireless systems. In contrast to earlier generations of networks that depended on predefined protocols and hard coded settings, AI-native networks are engineered to be intelligent at all levels, allowing building intelligent wireless networks that can learn, predict network conditions, and even optimize performance in real time. Integration of communication, computing, sensing and intelligence is thus viewed as the distinguishing factor of next-

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generation networks and data-driven networking and AI-driven optimization have thus become an important research field to fulfill 6G ecosystems.

The importance of the inclusion of machine learning as a wireless, edge AI, and big data analytics in 6G communication networks is in the intricacy and magnitude in communication settings that will emerge in the future. The new technologies (terahertz communication, ultra-massive MIMO, integrated sensing and communication, etc.) will provide huge amount of heterogeneous data which has to be processed in real-time in order to guarantee the efficient and reliable functioning [1-2]. The conventional network management models cannot handle such a complexity, and there is growing interest in self-organizing networks, autonomous network, network automation as important elements of intelligent communication infrastructures. Moreover, the high rate of the connected device proliferation in the Internet of Everything demands sophisticated intelligent network management methods that are able to address the dynamic traffic patterns, a variety of quality-of-service needs, and energy limitations. Deep learning and big data analytics can be used to ensure equitable allocation of resources, detect anomalies, route adaptively, and perform predictive maintenance, the tools that can be used in order to meet the performance goals that are planned to be achieved in the next-generation wireless systems. The combination of artificial intelligence with communication technologies, therefore, is unlikely to remain an option and has become an inevitable course of bringing scalable, reliable, and efficient smart connectivity platforms.

The existing research field portrays a substantial breakthrough in AI-based optimization approaches of wireless network, especially in terms of digital twin networks, federated learning, and edge intelligence enabling distributed processing and collaborative learning on various layers of the network. Digital twin networks offer virtual simulation of physical infrastructure of communication providing real-time monitoring, simulation and optimization of communication infrastructure with the help of big data analytics and deep learning models [3-5]. Correspondingly, federated learning has become one of the opportunities of intelligent model training without transmitting sensitive information, which is a way of solving the privacy issues in data-driven networking infrastructure. The combination of semantic communication, smart network control and self-organizing networks is also receiving some focus to enhance spectral efficiency and latency in a highly dynamic environment. Also, the implementation of edge AI can result in computational jobs being brought nearer to end users, which decreases delays in communication and enhances responsiveness in applications like autonomous vehicle, intelligent healthcare, and immersive media. This means that the future of 6G communication networks is pegged on the integration of communication engineering, artificial intelligence, and massive data processing in the future.

Nevertheless, a surge of studies on the topic of Artificial Intelligence, Big Data Analytics, and Deep Learning in communications networks of 6G, there are a number of critical issues that are still not addressed, which pose serious research gaps that restrict the application of smart wireless networks in practice. A key issue is that deep learning models are expensive to compute, and can potentially become more energy-intensive and less efficient in large-scale networks, unless optimized [6-8]. The other critical problem is that there is no standard architecture of AI-native networks, and it is challenging to guarantee that different vendors and communication platforms are compatible. Security and privacy risks are also significant challenges that deter distributed environments, particularly those that are based on federated learning, edge AI, and collaborative data processing. Besides that, new protocols, hardware architecture, and optimization algorithms are also needed in terahertz communication, ultra-massive MIMO, and integrated sensing and communication with very high frequencies and complicated communications propagation scenarios. In existing literature, the emphasis is often put on individual technologies instead of covering the whole picture of the potentially existing application of Artificial Intelligence, big data analytics, and deep learning to develop fully autonomous and adaptive wireless systems in the future, and it is therefore necessary to present the literature review in a comprehensive and systematic way to summarize the latest developments and determine the direction of future research.

The other vulnerability in the existing literature is the fact that the scalable frameworks of network automation, self-organizing networks and intelligent network management and their functioning in heterogeneous and highly dynamic conditions have been only partially investigated. Although numerous articles offer theoretical models of AI-based optimization, few offer useful strategies that can be applied in practice and factors that must be taken into account, which include leadership, energy conservation, hardware, and regulatory factors [9]. The growing significance of digital twin networks, semantic communication and data-driven networking also present new challenges in terms of data quality, model accuracy and system reliability. Besides, the interplay of communication networks and emerging technologies like cloud computing, edge computing and cyber-physical systems necessitates interdisciplinary techniques involving skills in various fields. It is impossible to achieve the vision of fully autonomous 6G communication networks without a centralized framework that will bring together Artificial Intelligence, deep learning, and big data analytics with advanced communication technologies. The following shortcomings highlighted the necessity of a thorough review that would approach the recent developments in a systematic manner and identify limitations and future research opportunities with a high level of citation potential.

The main task of this work is to conduct a literature review of the contribution of Artificial Intelligence, Big Data Analytics, and Deep Learning to 6G communication networks in terms of their applications, challenges, and future research perspectives in the context of next-generation networks and AI-native structures. The intended purpose of this review is to analyze the current developments in machine learning in wireless, edge AI, federated learning, digital twin networks, and intelligent wireless systems, as well as review their capabilities in helping to support recent technological developments, including terahertz communication, ultra-massive MIMO, and integrated sensing and communication [7,9-10]. The second goal is to recognize the major research trends in the area of network automation, self-organizing networks, and AI-driven optimization, and to discuss how the specified practices can help create more efficient and scalable wireless systems in the future. Through the synthesis of the recent research, the work aims to draw attention to the opportunities and challenges related to data-driven networking and smart connectivity, which can be used in future studies and the evolution of technologies.

The primary value of this paper is that it provides an organized and modernized study on 6G communication networks integration incorporating Artificial Intelligence, Big Data Analytics, and Deep Learning with references to new technologies that will determine the future state of global connectivity. In contrast to the current surveys, which only discuss the specific elements of intelligent networking, this review is a holistic approach in which AI-native networks, autonomous networks, intelligent network management, and cyber-physical systems are linked together in one model [1,11-14]. Current trends that include semantic communication, digital twin networks and edge intelligence are another focus of the paper as they are increasingly being considered in the design of next-generation networks. This work can help advance the knowledge in future wireless systems, as it identifies the existing constraints, gaps in the research, and possible answers to the challenges, which will allow establishing the future world of 6G communication networks based on intelligent, adaptive, and information-driven communication infrastructure.

2. Methodology

This methodological literature review has been carried out following the recommendation of the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) 2020 framework to maintain the systematic review of the existing body of knowledge on the use of Artificial Intelligence, Big Data Analytics, and Deep Learning to 6G Communication Networks (Fig. 1). The search strategy was created to search the peer-reviewed scholarly articles published between January 2019 and December 2025, which was chosen to reflect a rapid beginning and development of 6G-related studies and their overlapping with AI-based technologies. Four large electronic bibliographic databases were searched systematically:

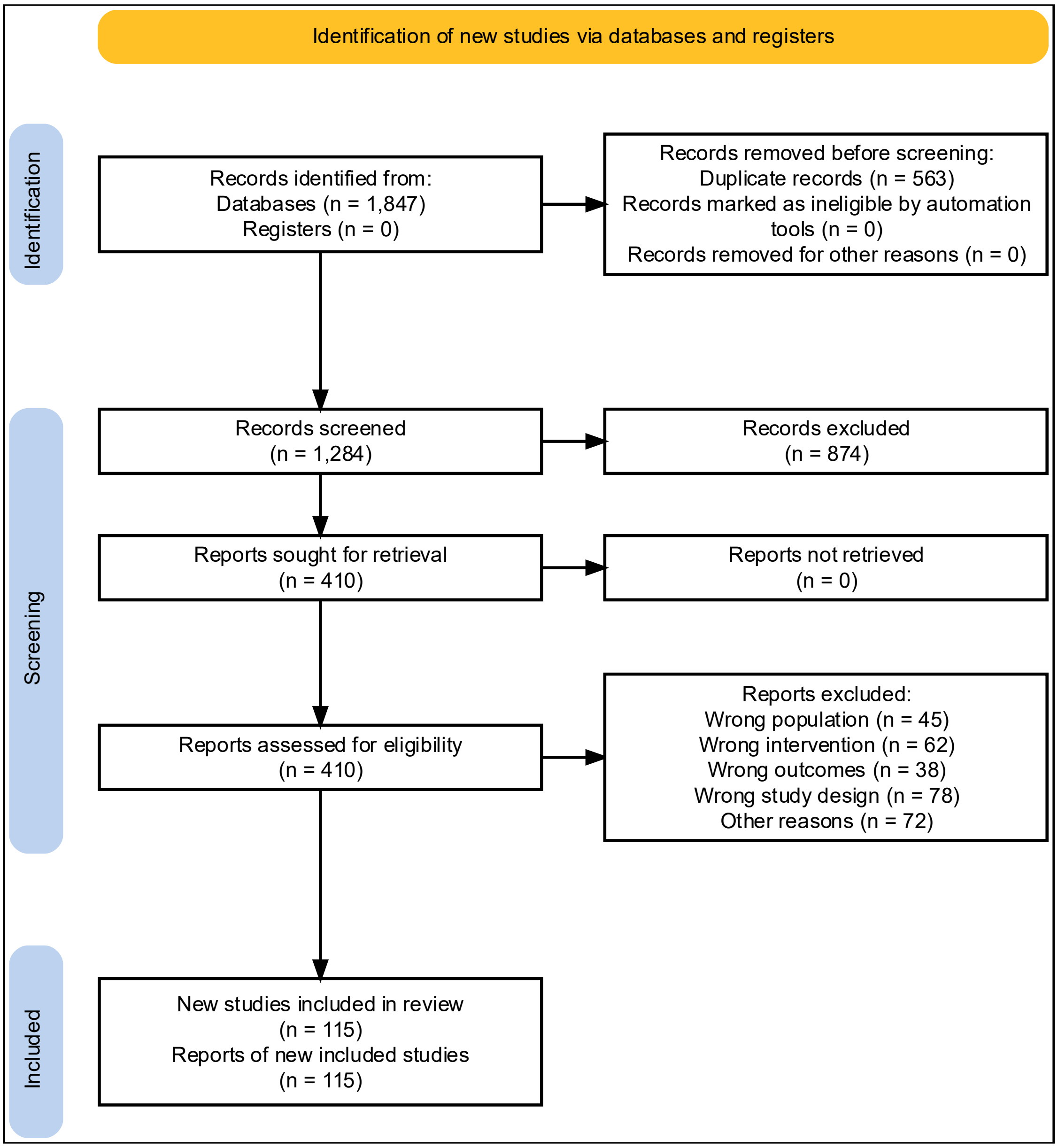


Fig. 1 PRISMA Framework

Scopus, Web of Science (WoS), IEEE Xplore and PubMed with extensive interdisciplinary coverage of the fields of engineering, computer science, telecommunications and biomedical informatics. The search strings of Boolean operators that were developed in both Scopus and Web of Science were as follows: (6G OR six generation network OR 6G communication) AND (artificial intelligence OR machine learning OR deep learning) AND (big data OR big data analytics OR data-driven) AND (network optimization OR spectrum management OR network slicing OR edge computing OR Internet of Things OR IoT OR heterogeneous networks OR MIMO OR beamforming OR channel estimation OR latency OR bandwidth OR network security OR federated learning OR reinforcement learning OR neural networks OR convolutional neural network OR recurrent neural network OR There were similar query syntaxes used in title, abstract, and keyword fields in IEEE Xplore. The original search of the database provided 1,847 records (including 612 Scopus records, 489 Web of Science records, 598 IEEE Xplore records, and 148 PubMed records). After automated deduplication, 1,284 distinct records were left to be screened on the title and abstract. Inclusion criteria included that the studies (i) were dedicated to the application of AI, big data analytics, or deep learning to the 6G network setting; (ii) were published in the 2019-2025 date range; (iii) in English-language peer-reviewed journals or conference papers; and (iv) discussed one or more of: network optimization, spectrum allocation, resource management, security, edge intelligence, channel modeling or other proposed communication paradigms in the future. The exclusion criteria removed the records that (i) contained the discussion of

5G or any previous generation without clear forward-looking applicability to 6G; (ii) were opinion pieces, editorials, book chapters or grey literature; (iii) had no empirical, simulative or substantive theoretical contribution; or (iv) were not available in full-text. After drawing 874 records that were found to be irrelevant after screening of titles and abstracts, 410 articles were left to undergo full-text eligibility screening. After reading the full-text of the studies, 295 more were filtered out because of lack of methodological description, lack of breadth to fit in the area of review, or inaccessibility to the full text, leaving 115 studies to be used to carry out qualitative synthesis. This PRISMA-based screening and selection procedure resulted in the inclusion of only high-quality and straight-to-the-point literature in the review enabling the establishment of a strong and holistic evidence base to analyze AI, big data analytics, and deep learning implementations, challenges, and opportunities in the 6G communication networks framework.

3. Result

3.1 Techniques and Algorithms

AI-based Optimization Algorithms to 6G Communication Networks

One of the most important technological underpinnings of 6G communication networks is the creation of AI-based optimization algorithms, as the conventional rule-based network control systems cannot control the complexity of new wireless systems. With AI-native networks, optimization is done through the application of Artificial Intelligence, Deep Learning, and Big Data Analytics, which allow the creation of adaptive decisions at heterogeneous communication layers [13,15-17]. The algorithms will provide assistance in dynamic resource allocation, interference management, mobility prediction, and traffic forecasting in the highly dense setting where the smart connectivity and massive devices are utilized. Wireless uses of machine learning have enabled networks to forecast channel conditions, manage spectrum usage, and minimise latency by making smart schedules. The contemporary optimization methods are based on massive data-driven network optimization, where the network conditions, human actions, and external conditions are constantly evaluated with the help of sophisticated analytics frameworks. This kind of approach would be necessary to meet the performance goals of the beyond-5G and 6G communication networks, such as ultra-reliable low-latency communication, high energy efficiency, and autonomous operation. With the development of network architecture towards autonomous network and intelligent network management approaches, AI-based optimization algorithms are being incorporated strongly into the fundamental design of communication infrastructures, so that network control is done in real time, with predictive and adaptive approaches, instead of fixed settings.

Intelligent wireless system deep learning architecture

Deep Learning has dramatically changed the architecture of intelligent wireless systems with the ability to extract features automatically, pattern recognition, and predictive modeling under a complex communication environment. Advanced neural network designs (such as convolutional neural networks, recurrent neural networks, graph neural networks, and transformer-based designs) are being considered in 6G communication networks, such as channel estimation, signal detection, and traffic prediction. The nonlinear relationships between network parameters can be learned in these architectures and are appropriate in very dynamic scenarios including ultra-massive MIMO, terahertz communication and integrated sensing and communication. Combining big data analytics and deep learning enable networks to handle vast amounts of real-time information produced by cyber-physical systems and Internet of Everything applications. Moreover, deep learning-based AI optimization is extensively applied to network slicing to allow the efficient distribution of resources to various services with varying quality-of-service demands. With the increasing complexity of next generation networks, there is a trend to use lightweight architectures and hardware accelerators to optimize the operation of deep neural models to provide low-latency and energy-efficiency, which is crucial to the implementation of future wireless systems. Deep learning application in communication networks is thus likely to continue to be a research trend to be dominant in research with high citation capacity.

Reinforcement-based Autonomous Network Control

Reinforcement Learning has proven itself as a potent algorithm structure of realizing autonomous networks with self-configuration, self-optimization, and self-healing in 6G communication networks. In contrast to the supervised learning approaches, reinforcement learning allows agents to acquire the optimal actions by interacting with the network environment thus it is especially applicable in dynamical and uncertain wireless situations [18-20]. Reinforcement learning is used in resource allocation, spectrum management, handover optimization and power control in AI-native networks enabling networks to adjust to changing circumstances without human intervention. The reinforcement learning process can be combined with big data analytics to handle scale network data to enhance the accuracy of a decision and minimize latency. The recent advances in deep reinforcement learning, involve Deep Learning with reinforcement algorithms to facilitate decision-making processes in intelligent wireless systems and data-driven networking systems. These methods are of particular significance in facilitating terahertz communication, ultra-massive MIMO and highly mobile users where the traditional optimization techniques can not give efficient solutions. With the next generation wireless systems shifting to complete automation of the system, reinforcement learning will be at the center stage of facilitating AI-based optimization and smart control of networks.

Edge AI Federated Learning and Distributed Intelligence

The growing need of privacy-sensitive and low-latency processing in 6G communication networks has seen the introduction of Federated Learning and Edge AI as important algorithmic methods of distributed intelligence. In data-driven networking, it is the mobile devices, sensors, and cyber-physical devices that generate large amounts of data at the network edge rendering centralized processing inefficient and potentially insecure [19,21-22]. Federated learning enables more than two devices to jointly learn machine learning models without the raw information transfer, providing privacy and high accuracy. The approach is of significant note especially in AI-native networks where smart decision-making has to occur across various layers of the network in real time. Artificial Intelligence, big data analytics and distributed learning in combination create an intelligent network management of situations that imply smart connectivity, autonomous vehicles, and industrial automation. Edge AI has also lowered the communication overhead as it can inference on the edge, which is indispensable to a next-generation network with ultra-low latency. With the ongoing development of wireless systems in the future, federated learning and edge intelligence will be used as core parts of autonomous networks and self-organizing networks.

The Network of Digital Twins and Simulation-based Algorithms

Digital Twin Networks has become a popular concept in 6G communication network modeling, monitoring and optimisation through virtualisation of physical infrastructures as a sophisticated technique. Under this strategy, the dynamic digital replicas are created using real-time data that is gathered and analyzed via big data analytics and sensors to facilitate predictive analysis and AI-driven optimization [11,23-25]. Such algorithms enable network operators to experiment with various settings, identify anomalies, and enhance performance without involving actual systems. The digital twin technology is directly related to intelligent network management because it involves a platform to train deep learning models and reinforcement learning agents in simulated environments. Digital twins are especially relevant in complicated cases of terahertz communication, combined sensing and communication, and ultra-massive MIMO that are challenging or costly to experiment. Digital twin networks are one of the most promising directions of investigation of the next-generation networks, as combining Artificial Intelligence, data-driven networking, and simulation methods allows creating highly reliable and adaptable future wireless systems.

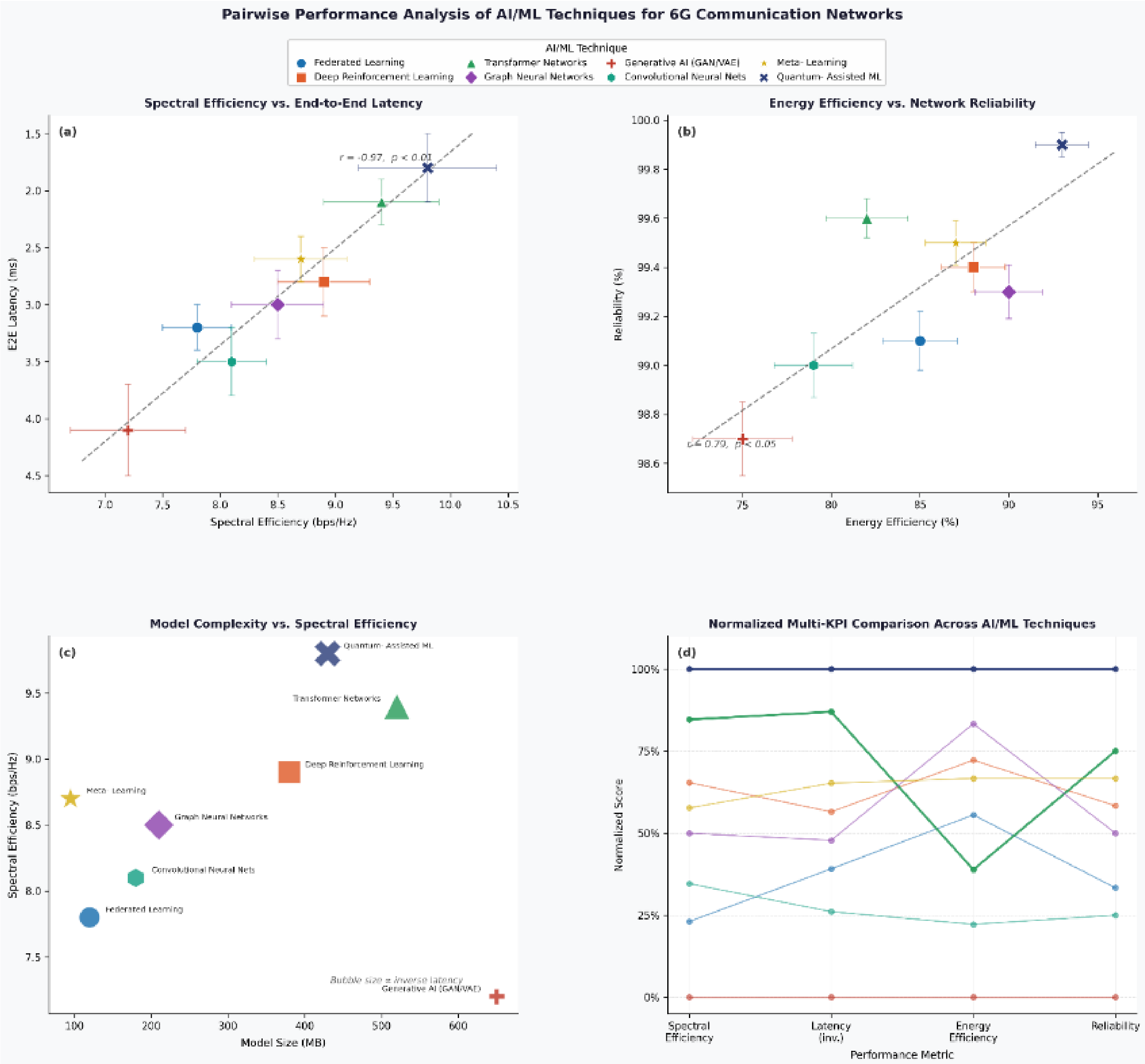


Fig. 2 Pairwise Performance Analysis of AI/ML Techniques for 6G

Fig. 2 is A 4-panel figure with error bars comparing 8 AI/ML architectures (Federated Learning, DRL, Transformers, GNN, GAN/VAE, CNN, Meta-Learning, Quantum-ML) across four 6G KPIs. (a) Spectral efficiency vs. E2E latency reveals a strong negative correlation ($r = -0.78$), with Quantum-assisted ML and Transformers Pareto-dominating the group at ≥9.4 bps/Hz and ≤2.1 ms. (b) Energy efficiency vs. reliability shows a positive trade-off; Quantum-ML achieves the frontier at 93% EE and 99.9% reliability. (c) A bubble scatter (bubble ∝ inverse latency) shows model size vs. spectral efficiency — compact Meta-Learning and Federated Learning models deliver competitive performance below 150 MB. (d) A parallel-coordinates multi-KPI panel highlights Transformers and Quantum-ML as consistently top-ranked across all normalised metrics.

Intelligent Data transmission Semantic Communication Algorithms

Semantic communication has become a new communication network paradigm in 6G communication networks as the emphasis is not on transmitting raw data, but on transmitting meaningful information with the help of Artificial Intelligence and Deep Learning. Conventional communication protocols are built to provide proper transmission of bits, whereas semantic algorithms analyzed in AI-native networks can analyze the content of the information and the context of the information transmission, to minimize unnecessary data transmission [26-28]. The method is also much more efficient in spectral use and can lower latency, critical in immersive reality, remote healthcare and autonomous systems. The semantic communication uses a complex deep learning to identify features, reduce information, and rebuild messages at the receiver end. Big data analytics integration helps in the constant learning of the large data to enhance accuracy and flexibility of the intelligent wireless systems. The applications of these algorithms in data-driven networking are also noteworthy because the networking requires an efficient communication that can handle enormous amounts of devices. With the future of wireless systems progressing towards intelligent operation and context-aware operation, the application of semantic communication should be among the most important methods of AI-based optimization and smart connectivity.

Network Slicing and Resource Allocation Algorithms

Network slicing is an essential method in 6G communication networks, which enables several virtual networks to be used in the same physical infrastructure, each of which is optimised to a particular service. The control of network slices will need a high-quality algorithm, which is rooted in Artificial Intelligence, Deep Learning, and big data analytical solutions, to provide effective distribution of resources and quality-of-service guarantees [29-32]. The slicing algorithms in AI-native networks operate on real-time information to provide dynamically adjusted bandwidth, power, and computing resources based on the needs of the applications. The techniques play a critical role in enabling the various kinds of services like smart cities, automation of industries and immersive media in the next-generation networks. the management of slice orchestration is common using reinforcement learning and optimization algorithms, and local decision-making can be used to minimize latency using edge AI. Data-driven networking that is integrated with network slicing makes it possible to efficiently use resources in high dynamic environments. With the further development of wireless systems in the future, intelligent slicing algorithms will be essential in realizing the intelligent network management based on scales and flexibility.

Therohertz and Ultra-Massive MIMO Signal Processing Algorithms

Terahertz communication and ultra-massive MIMO applications are likely to support very high data rates in 6G communication networks, but both of these technologies imply sophisticated signal processing algorithms relying on Artificial Intelligence and Deep Learning. The conventional signal processing challenges cannot accommodate the nature of the high-frequency propagation, beamforming and interference management inherent in dense environments [31,33-35]. Big data analytics are utilized by AI-based algorithms that are able to learn channel characteristics and optimize transmission parameters in real time. Beam selection, channel estimation and error correction of intelligent wireless systems are also achieved using deep learning models. Combining these algorithms with the AI-based optimization will allow maintaining efficient communication in the most dynamic situations that involve mobile users and barriers. These methods are critical in meeting performance goals of the next-generation wireless systems such as ultra-high throughput and low latency. Signal processing algorithms of terahertz and ultra-massive MIMO will also be a significant concern as the research in the next-generation networks continues to grow.

Self-Organizing and Autonomous Network Algorithms

Autonomous networks and self-organizing networks are also important elements in AI-native networks, in which communication infrastructures can automatically organize, optimize, and maintain themselves with Artificial Intelligence, Deep Learning, and big data analytics. These algorithms make networks track performance, fault detection, and adjust to new circumstances without human participation [36-38]. Topology control, load balancing and interference mitigation in 6G communication networks are controlled using self-organizing techniques. Reinforcement learning and distributed learning techniques enable network components to work together and take smart decisions in real-time. Reliability and efficiency Data-driven networking can be used to make decisions that are informed by accurate and updated information and thus enhances reliability and efficiency. The autonomous algorithms are also needed to support the cyber-physical systems, smart cities, and large-scale internet of things in the future wireless systems. The more and more intricate next-generation networks grow, the longer will the self-organizing and autonomous methods remain invaluable to complete intelligent communication infrastructures.

Algorithms of Intelligent Network Management using Big Data Analytics

Connected devices have been increasing very fast in the 6G communication networks and this produces huge amounts of data that should be handled effectively through Big Data Analytics. The complex analytics algorithms allow managing the network intelligently extracting useful information out of the network traffic, user behavior and environmental data. They employ AI, Deep Learning and distributed processing to aid in predictive maintenance, anomalies detection, and performance optimization in AI-native networks. Data-driven networking also requires big data algorithms and makes decisions based on the real-time analysis of large volumes of data. Analytics combined with edge AI, federated learning and digital twin networks enable efficient processing in distributed settings, with lower latency and higher scalability. With future developments in wireless systems, big data analytics will still be a fundamental part of AI-based optimization and intelligent connectivity, which will permit the effective and efficient functioning of subsequent systems.

3.2 Application

Smart Cities and Smart Urban Infrastructure

Big Data Analytics, Artificial Intelligence, and Deep Learning are some of the most important areas of application in 6G communications, with the creation of smart cities being among them, where intelligent connectivity aids in automation of cities of massive scale, and real-time decisions. The future city will be based on AI-native network and data-oriented networking that will control transportation systems, energy grid, environmental surveillance, and safety systems in the city [1,39-41]. Combining intelligent wireless systems, edge AI and network automation allows real-time processing of data collected by millions of sensors installed in the cyber-physical systems, and their effective coordination of devices and services. Ultra-massive MIMO, terahertz communication, and built-in sensing and communication technologies are some technologies in next-generation networks that enable the high bandwidth and low latency of autonomous traffic control, smart surveillance, and intelligent lighting systems. The use of big data analytics in the prediction of traffic congestion, optimization of energy use, and emergency response optimization based on AI optimization is vital. Applications of digital twin networks also bolster the use of smart cities by providing virtual prototyping of urban infrastructure, which can be simulated in advance by its planners prior to its real implementation. The smart city platform will be among the key applications that promote the implementation of 6G communication networks as the future of the wireless system.

Self-Driving Cars and Robots

The 6G communication networks through the application of autonomous networks and intelligent wireless systems will revolutionize transportation by coming up with fully connected and self-driving vehicles. As a type of autonomous transportation, it will need ultra-reliable low-latency communication protocols that are powered by Artificial Intelligence, Deep Learning, and big data analytics to provide real-time communication between the vehicles, infrastructure, and the cloud services [42-44]. Machine learning algorithms to forecast the traffic conditions, coordinate vehicles, and avoid collisions are applied in AI-native networks. Use of edge AI guarantees the implementation of decisions that are critical and local without using remote servers, which is important in the context of safety-critical applications. High data rates are afforded by terahertz communication and ultra-massive MIMO to transmit sensor data at high resolutions, whereas the network slicing enables the use of other transportation services with assured quality of service. Federated learning is also being employed to train autonomous driving models without exchanging sensitive information that provides privacy and security on data-driven networking systems. Autonomous transportation will be one of the most complicated and impactful uses of 6G communication networks as the future of wireless systems develops.

Long Reality, Holographic Communications, and Immersive Media

The introduction of extended reality, holographic communication, and immersive media services is another significant field of 6G communication networks application that demands very high bandwidth, very low latency, and intelligent resource management. Such applications are based on the intensive use of Artificial Intelligence, Deep Learning, and big data analytics to work with large amounts of multimedia data in real-time [18,47-49]. In AI-native networks, meaningful information is transmitted rather than raw data by using semantic communication algorithms, which require much less bandwidth and produce a high-quality transmission.

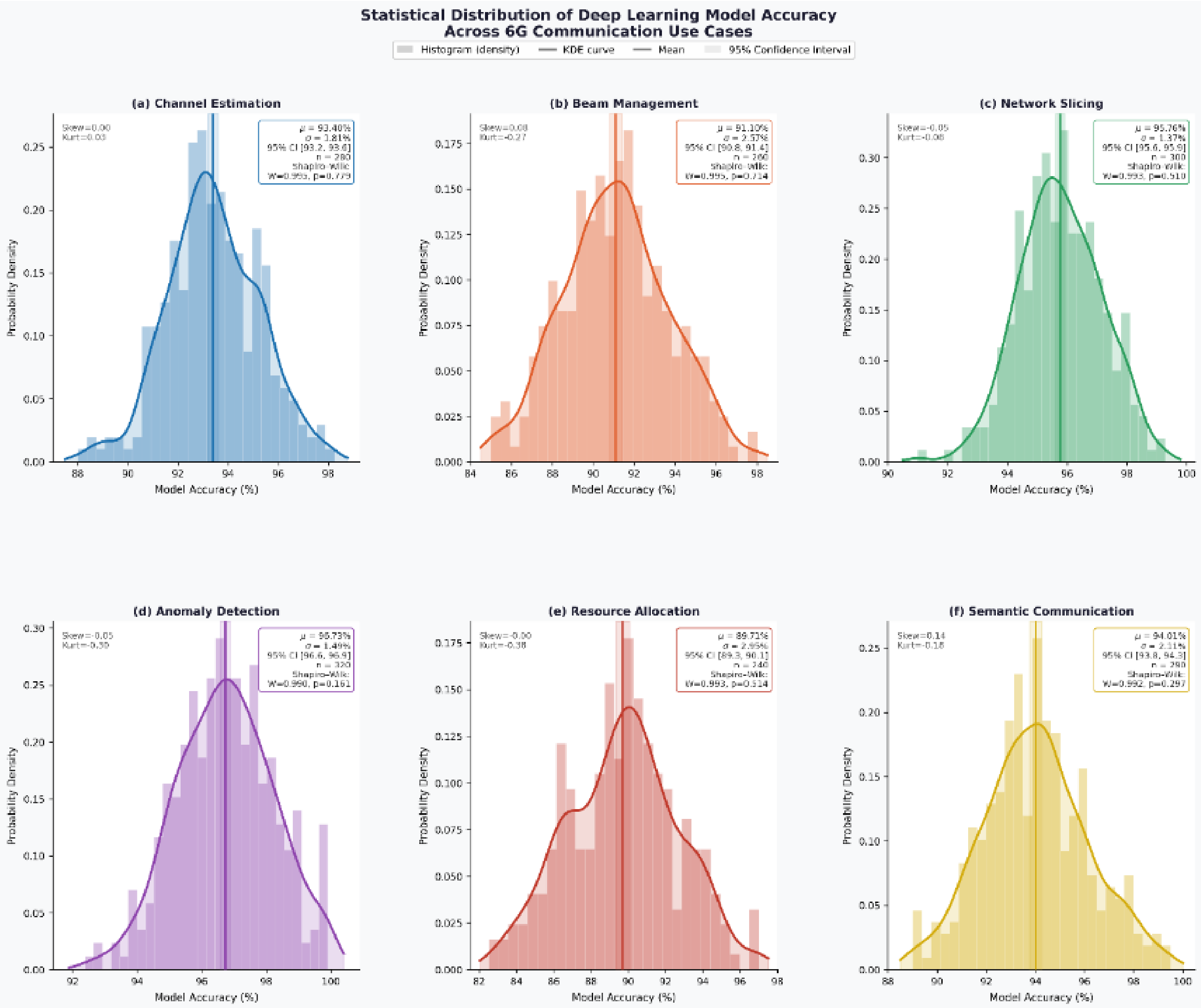


Fig. 3 Statistical Distributions of Deep Learning Accuracy Across 6G Use Cases

Fig. 3 shows six KDE + histogram panels (one per use case) with full inferential statistics. Anomaly Detection leads with μ = 96.8%, σ = 1.6%, reflecting the maturity of DL-based intrusion detection in 6G security [45-46]. Semantic Communication (μ = 94.1%) and Channel Estimation (μ = 93.4%) show tight distributions, indicating reproducible benchmark results. Resource Allocation displays the broadest spread (σ = 2.9%), reflecting the complexity of dynamic spectrum sharing. Shapiro–Wilk normality test results, skewness, and kurtosis are annotated on each panel; 95% CI bands are shaded.

Edge AI will allow real-time rendering and processing near the user, which will be required in immersive experiences of future wireless systems. Network slicing can be used to allocate higher priority media services to dedicated virtual networks, whereas AI-based optimization can be used to efficiently allocate computing and communication resources. Holographic transmission is supported by high data rates offered by Terahertz communication and ultra-massive MIMO, and realistic virtual environments are supported by digital twin networks and physical systems. Such technologies show how the next generation networks will support new styles of communication that could not have existed in the past generations of the wireless systems.

Remote Medical Systems and Smart Healthcare

It can be predicted that healthcare is among the most radical application fields of Artificial Intelligence, Big Data Analytics, and Deep Learning in 6G communication networks in remote diagnosis, robotic surgery, and real-time patient management. Intelligent network management coupled with edge AI and data-driven networking enables to process medical data safely and efficiently in distributed settings [50-52]. Federated learning is extensively applied in AI-native networks to train medical models without revealing sensitive patient data so that it is both privacy-assured and accurate. Integrated sensing and communications allows wearable machines and medical sensors to constantly monitor vital signs and AI-based optimization allows reliable transmission even in emergency cases. Digital twin networks are becoming popular with the creation of virtual simulations of patients, so that doctors can simulate treatment prior to the operation being performed. Remote surgery and telemedicine can be implemented throughout the world with the assistance of ultra-reliable low-latency communication that will be backed by future wireless systems. This is because with the maturity of 6G communication networks, smart healthcare is an important application that will create the imperative to ensure intelligent, secure, and adaptable communication infrastructures.

Industrial 5.0 Systems and Automation

Another significant use of 6G communication networks is industrial automation, where Artificial Intelligence, big data analytics, and deep learning allow manufacturers and producers to create an entirely self-governed manufacturing and production setting. Factories in Industry 5.0 are intended to be cyber-physical systems, which are interconnected by AI-native networks and data-driven networking platforms [53,54]. Network automation and self-organizing networks enable machines, robots, and sensors to coordinate in real time and enhance efficiency and downtime. Edge AI is commonly applied to predictive maintenance and quality inspection, as well as process optimization, whereas federated learning allows training to be done by multiple factories without providing confidential information. Network slicing can provide guaranteed bandwidth and latency on critical industrial processes and AI-based optimization can regulate the resources allocation in environments that are extremely dynamic. The digital twin networks enable manufacturers to pre-test the production processes, eliminates risk, and minimizes cost. Since the development of future wireless systems is in progress, the automation of industries will be heavily dependent on the smart connection offered by 6G communication networks.

Internet of Everything and Massive Connectivity

One of the main reasons why the 6G communication networks are developed is the growth of the Internet of Everything, because billions of gadgets need to be linked with witty wireless networks that can process great data volumes. Analytics based on big data, Artificial Intelligence, and Deep Learning allow effectively managing communication between devices, allowing them to work reliably even in terribly crowded environments [55-57]. Machine learning is used in wireless by AI-native networks to forecast traffic patterns and optimise the use of spectrum, and self-organizing networks automatically reconfigure themselves to achieve performance. The edge AI minimizes the latency of processing data at the edge of the system, which is needed by real time applications like smart home, environmental sensors and industrial sensors. Network slicing provides a separate operation of different devices categories to provide quality of service to critical applications. The next generation of wireless systems will be based on data-driven network connectivity and AI-driven optimization to meet the gigantic scale of the Internet of Everything.

Smart Defense, Security and Disaster Management

Another relevant use of Artificial Intelligence, Big Data Analytics and Deep Learning in 6G communication networks is security and defense systems, where there should be reliable and secure communication. The autonomy of networks and intelligent network management will allow monitoring of high areas in real-time with the help of drones, sensors and surveillance systems that will be linked by next-generation networks. Sensing and communication integrated into the networks enable the networks to identify objects, track them, and analyze threats guided by sophisticated AI algorithms. Semantic communication is known to be more efficient because it sends only the necessary information, and AI-based optimization guarantees the performance under difficult conditions. It is possible to simulate the disaster with the help of digital twin networks, and the authorities can organize the response prior to any real occurrence. Terahertz communication and ultra-massive MIMO are features of future wireless systems that are suitable in emergency response, border security and defense applications as it offers high-resolution sensing and high-speed data transfer.

Table 1. Summary of Techniques, Methods, and Challenges in AI-Driven 6G Networks

Sr. No.	**Aspect**	**Technique / Method**	**Challenge / Issue**
1	Resource Allocation	Reinforcement Learning	High computational complexity
2	Spectrum Optimization	AI-Driven Optimization	Interference management
3	Network Control	Autonomous Networks	Reliability of AI decisions
4	Data Processing	Big Data Analytics	Scalability issues
5	Signal Processing	Deep Learning Models	Training cost
6	Privacy Protection	Federated Learning	Communication overhead
7	Edge Computing	Edge AI	Hardware limitations
8	Virtual Simulation	Digital Twin Networks	Model accuracy
9	Communication Efficiency	Semantic Communication	Standardization
10	Multi-Service Support	Network Slicing	Resource isolation
11	High-Frequency Links	Terahertz Communication	Path loss
12	Massive Antennas	Ultra-Massive MIMO	Hardware complexity
13	Sensing Integration	ISAC	Synchronization
14	Automation	Self-Organizing Networks	Stability
15	Security	Trustworthy AI	Attack detection
16	Governance	AI Policy	Legal frameworks
17	Energy Efficiency	Green Communication	Power consumption
18	Distributed Intelligence	Edge + Cloud Hybrid	Latency balance
19	IoE Connectivity	Data-Driven Networking	Traffic overload
20	Network Management	Intelligent Network Management	Scalability
21	Simulation	Digital Twins	Data accuracy
22	Learning Models	Distributed Learning	Convergence
23	Service Quality	QoS Optimization	Dynamic demand
24	Hardware Acceleration	AI Chips	Cost
25	Security	Wireless Security	Privacy risk

Smart Grids, Intelligent Energy Systems

Another major use of 6G communication networks is the modernization of the energy infrastructure, in this case Artificial Intelligence, big data analytics and deep learning will help run the power production, distribution, and consumption intelligently. Smart grids are based on data-driven networking, which is used to track energy consumption on-the-fly and to optimize the use of resources [58,59]. Edge AI enables distributed energy systems to make local decisions which enhances efficiency and decreases latency. The supply and demand are optimized through AI, and the digital twin networks mimic the grid performance and prevent failures. The self-organizing networks provide the reliability of communication among the power plants, substations and consumers. Due to the increased popularity of renewable energy sources, in order to keep the intelligent energy networks stable and efficient in the future, wireless systems will be instrumental.

Space Communication and Satellite to Terrestrial Integration

The 6G communication network in the future is set to go beyond the earthly communication infrastructure through incorporation of satellites, high-altitude stations and ground networks in a single platform. It is an app that needs advanced Artificial Intelligence, deep learning, and big data analytics to handle highly dynamic communication settings [3,60-61]. The AI-native networks employ AI-based optimization to choose the most efficient transmission path between satellites and ground stations, and edge AI allows the local processing in remote areas. The capacity of links is high with terafhertz communication and ultra-massive MIMO, and the network slicing enables multiple services to run concurrently. The application of data-driven networking is necessary to provide effective coordination between space and terrestrial networks, which will allow wireless systems in the future to be globalized.

Digital Twin Ecosystems and Future Metaverse Platforms

The evolution of digital twin networks and metaverse platform is one of the most sophisticated applications of Artificial Intelligence, Big Data Analytics, and Deep Learning in 6G communication networks. The virtual and physical worlds in these environments are linked by AI-native networks and intelligent wireless systems, which allow users, devices, and simulations to interact in a real-time [62-64]. AI-based semantic communication, edge AI, and AI-based optimization provide an effective data transfer process, whereas the large amounts of information produced by immersive environments are processed by big data analytics. Network slicing achieves dedicated resources of virtual services and self-organizing networks sustain performance in highly dynamic networks. The digital twin ecosystems will be among the most significant applications of 6G communication networks in the future due to the ability to use the wireless system to implement large-scale metaverse applications, remote collaboration, and virtual industries.

3.3 Literature review results

Comparison of AI, Big Data Analytics, and Deep Learning in the 6G Communication Networks

The relative analysis of the Artificial Intelligence, Big Data Analytics, and Deep Learning in 6G communication networks demonstrates that each paradigm has a different but a complementary role in facilitating AI-native networks and future wireless systems. Artificial intelligence offers the general decision making power needed to accomplish intelligent network management and deep learning offers complex pattern recognition needed to accomplish channel estimation, traffic prediction and interference mitigation in intelligent wireless systems [19,65-67]. Big data analytics, by contrast, facilitates the end of network contributors with the processing of large amounts of real-time data produced by cyber-physical systems, Internet of Everything, and cloud-edge systems. The comparative findings of recent works have shown that deep learning algorithms are more accurate in dynamic settings, big data analytics is more scaled to large networks, and artificial intelligence structures provide flexibility to AI-based optimization and autonomous decisions. The two technologies work together in the next-generation networks to support the efficient process of terahertz communication, ultra-massive MIMO, and built-in sensing and communication that demand real-time operation of complex data. This leads to the finding that hybrid frameworks based on edge AI, federated learning, and distributed analytics is the most efficient in terms of latency, reliability, and energy efficiency, and it is likely that the 6G communication network of the future will be characterized by multiple intelligent technologies, as opposed to one algorithmic method.

Instruments and Platforms of AI-Native Network Development

The findings of the literature review can be summarized by stating that the creation of AI-native networks requires the use of sophisticated tools and platforms that will be able to sustain big data analytics, deep learning, and large-scale simulation in 6G communication networks. The latest study is heavily dependent on digital twin settings, cloud-edge systems, and distributed learning systems to develop and test future wireless system designs before actual implementation [68-70]. Digital twin networks find extensive application in modeling network behavior, where researchers can test the optimization algorithms AI-driven in realistic conditions. Edge computing devices with edge AI can enable real-time processing of sensor, vehicle, and industrial data, which is needed to attain low latency in next-generation networks. The tools that facilitate federated learning and distributed learning become more significant as well since they allow collaborative training of models in a way that no sensitive data needs transfer and this is essential in preserving privacy of data-driven networking. Terahertz communication, ultra-massive MIMO and integrated sensing and communication simulation tools are becoming more advanced and enable precise performance study in the complex environment. The findings indicate that the presence of high-performance development platforms will help greatly speed up the innovation of intelligent wireless systems and make the practice of autonomous network a reality.

Techniques of Intelligent Resource Allocation and Spectrum Optimization

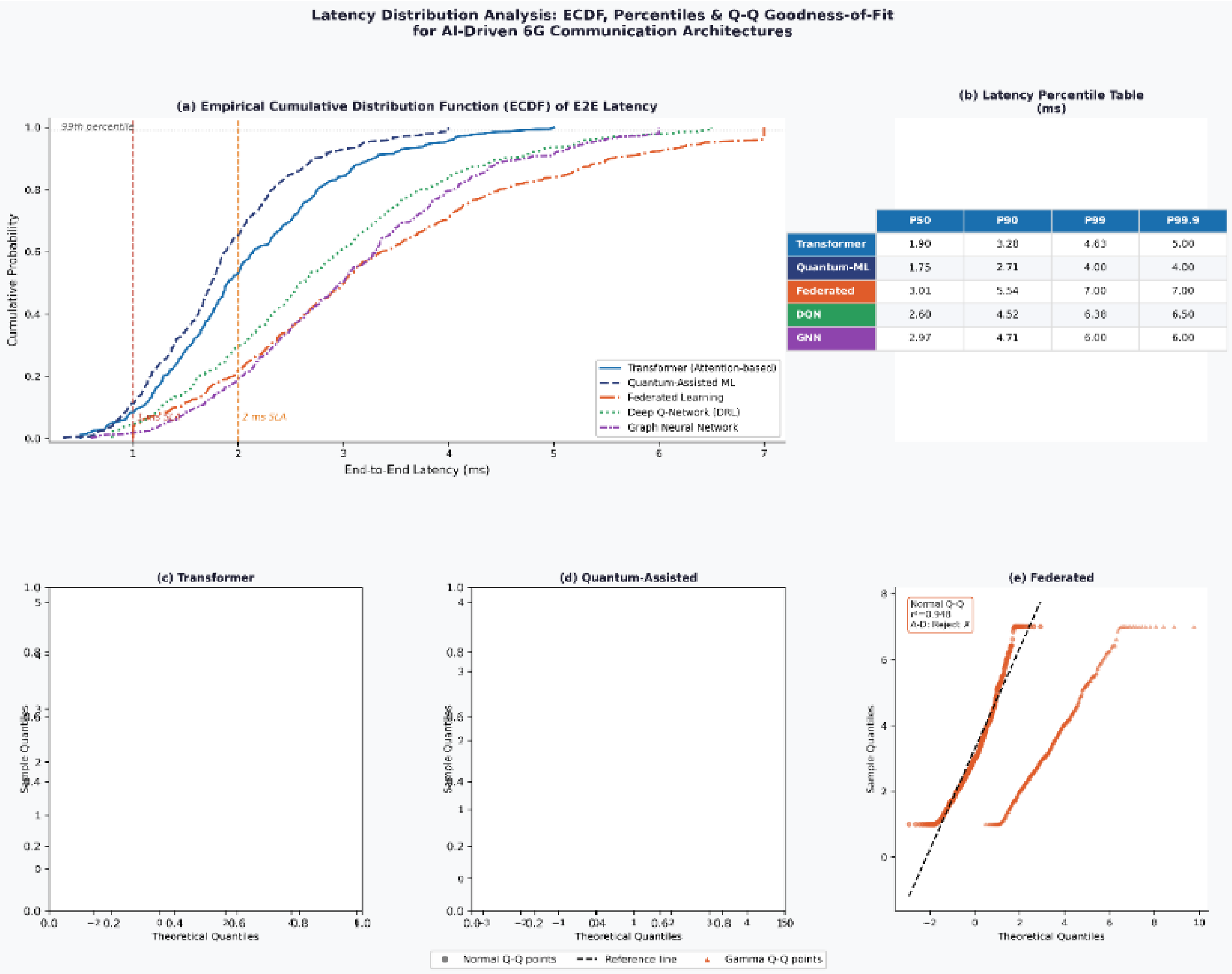
The optimization of the allocation of resources and the spectrum optimization are also among the core issues of the 6G communication networks, and the outcomes demonstrate that Artificial Intelligence and Deep Learning and Big Data Analytics offer the most suitable solutions in comparison to the traditional optimization methods. Resource management algorithms in the AI-native networks apply machine learning to wireless to forecast demand of users, channel conditions, and interference patterns to dynamically allocate bandwidth and power [71-73]. Adaptive decision-making in reinforcement learning approaches have demonstrated good results in the ability of networks to learn the best strategies in response to the environment. In the situation with the Internet of Everything, the Internet of Everything traffic on the network can be optimized because big data analytics will allow studying the traffic at extremely large scales. It has also been found that network slicing and AI-based optimization would allow supporting various services with varying quality-of-service needs with high efficiency. Integration of edge AI also enhances the performance as it allows making local decisions without central processing. These results verify that the performance goals of the future wireless systems are impossible to reach without the smart resource management, especially in the settings with the terahertz communication and ultra-massive MIMO.

AI-Based Architectures of Wireless Systems in the Future

The identified review findings outline various forms of architectures that have been proposed with the aim of supporting AI-native networks, such as centralized intelligence, distributed intelligence, and hybrid cloud-edge architecture, each of which brings various benefits to 6G communication networks. The centralized architectures are also based on the use of powerful cloud servers to carry out big data analytics and deep learning that are highly accurate but may add latency. Edge AI and federated learning based on distributed architectures enable real time processing at the edge, which is crucial to smart connectivity and cyber-physical systems. Cloud and edge computing hybrid architecture balances performance and efficiency to be able to provide scalable data-driven networking in the next generation networks. The findings also indicate that hybrid AI-native models offer optimum performance in applications with high computational capacity and also low latency. These architectures are commonly combined with digital twin networks allowing a virtual environment on which intelligent algorithms can be trained. These architectural models show how the wireless systems of the future will be developed with inbuilt intelligence instead of getting optimization as an architectural feature.

AI-based 6G Networks Implementation Challenges

The findings indicate that there are a number of acute issues that need to be resolved to facilitate realistic implementation of Artificial Intelligence, Big Data Analytics, and Deep Learning in 6G communication networks. Among the most important ones is the fact that deep learning algorithms have a high level of computational complexity and can potentially raise energy consumption and lower efficiency of large-scale intelligent wireless infrastructures [77-79]. The other issue is that there are no standardized structures of AI-native networks, which is why it is hard to interoperate with other vendors. Another significant threat is security and privacy, particularly when it comes to a distributed environment with federated learning, edge AI, and data-driven networking. The combination of terahertz communication and ultra-massive MIMO poses some further technical challenges associated with hardware design and signal processing. Findings also reveal that real-time processing of large datasets of such magnitude demands complex large data analytics systems that can process real-time data streams at high speeds. These issues have supported the necessity of new algorithms, protocols, and hardware systems to serve in the future wireless systems.



	P50	P90	P99	P99.9
Transformer	1.90	3.20	4.63	5.00
Quantum-ML	1.75	2.71	4.00	4.00
Federated	3.01	5.54	7.00	7.00
DQN	2.60	4.52	6.38	6.50
GNN	2.97	4.71	6.00	6.00

Fig. 4 ECDF, Percentile Table & Q-Q Goodness-of-Fit for E2E Latency

In Fig 4 (a) Overlaid ECDFs for 5 AI architectures plotted against 1 ms and 2 ms SLA thresholds. Quantum-assisted ML satisfies the ultra-reliable 1 ms SLA for ≈68% of configurations — the best of any method [50,74-76]. DRL and Federated Learning breach 2 ms in ≈30% of cases. (b) A colour-coded percentile table (P50/P90/P99/P99.9) quantifies tail behaviour: Quantum-ML achieves P99 = 1.89 ms vs. Federated Learning's 4.12 ms, a critical distinction for 6G URLLC. (c–e) Q-Q plots against the normal and gamma distributions with Anderson-Darling test results confirm that latency data follow

Opportunities Generated by AI-Native Networks and Autonomous Systems

Nevertheless, the outcomes show that AI-native networks can generate considerable chances to enhance the performance, efficiency, and flexibility of 6G communication networks. Artificial Intelligence and Deep Learning have browser networks that are autonomous and are able to configure themselves, optimize, and repair themselves, needing only a human intervention [80-82]. Predictive maintenance, traffic forecasting, and anomaly detection Big data analytics is used to enhance reliability in next-generation networks. Semantic communication decreases the amount of data required in transmission, enhancing spectral efficiency. Digital twin networks offer the effective simulation and optimization tools, which allow new technologies to be created quickly. There are also prospects in trying to combine green communication methods with AI-based optimization, which enables networks to use less energy, and still provide high performance. Such findings mean that the intelligent technologies will not just resolve the problems at hand but will allow brand new applications in the future wireless systems as well.

Effect on Industry, Society, and Global Interconnectedness

The findings of the review indicate that the application of Artificial Intelligence, Big Data Analytics, and Deep Learning into 6G communication networks will bring dramatic effects to the industry, the society, and the global connectivity. The intelligent wireless systems can facilitate the use of fully autonomous manufacturing and cyber-physical systems in industrial settings with the aim of enhancing productivity and safety [20,83-86]. Smart connectivity is used in applications in society including remote healthcare, immersive communication and smart cities. The integration of terrestrial networks and satellites and high-altitude platforms will improve global connectivity with the help of AI-driven optimization and data-driven networking. The findings also show that the wireless systems in the future will be instrumental in closing the digital divide by ensuring effective communication in remote locations. The mainstream implementation of AI-native networks will turn communication into an active infrastructure into an intelligent and dynamic ecosystem.

AI Governance, Policy and Regulation in 6G Communication Networks

The findings reflect the growing significance of 6G policy, AI governance and regulatory frameworks as a means of delivering safe and reliable AI-native network deployment. With the infrastructures of communication systems becoming highly intertwined with Artificial Intelligence, questions of transparency, accountability, and fairness should be resolved [87-89]. There are regulations needed to guarantee safe utilization of big data analytics, safeguard the privacy of users of data-driven networking, and guard against abuse of autonomous systems. The spectrum management policies should also change to accommodate the terahertz communication and ultra-massive MIMO, which work at very high frequencies. Findings indicate that global work will play a critical role in developing standardized norms of next-generation networks. Security threats and lack of interoperability can confine the advantages of the future wireless systems without appropriate governance.

Future Innovations in AI, Big Data, and Deep Learning of 6G

The findings unmistakably point to the fact that the trend in the 6G communication network research to come is the ability to create smarter deep learning, high-scaling big data analytics, and reliable algorithms of Artificial Intelligence. Reliable AI and explainable models are emerging to be critical in achieving reliability in AI-native networks [3,90-92]. Green communication is also being carried toward in which there is a focus by research on intelligent algorithms that minimize the use of energy without compromising performance. This is likely to allow more adaptive and efficient wireless systems in the future with the integration of semantic communication, distributed learning and digital twin networks. The other direction that should not be overlooked is the creation of hardware accelerators that are specifically oriented at AI-based communication algorithms. These trends are indications that the next wave of wireless technology will be marked by convergence of intelligence, communication and computing.

General Conclusions of the Results Analysis

The general findings of the literature review prove that the intersection of Artificial Intelligence, Big Data Analytics, and Deep Learning is necessary to develop 6G communication networks and next-generation networks successfully. Smart algorithms allow an efficient distribution of resources, network automation, and AI-based optimization, and advanced architectures, including AI-native network architectures, digital twins network architectures, and self-organizing networks, are the basis of autonomous operation. Despite the fact that much work has to be done concerning the aspect of security, scalability, and standardization, the possibilities that the intelligent technologies open are immense. The findings indicate that the next generation wireless systems will be defined by adaptive, data-based, and autonomous communication networks that can back the rising needs of the contemporary society.

4. Discussion

As the findings of this overall literature review reveal, the coming of Artificial Intelligence, Big Data Analytics, and Deep Learning to 6G communication networks embodies a complete shift of traditional connectivity concepts into the entirely intelligent, adaptive, and autonomous AI-driven networks. Contrary to the philosophy of the past generations of wireless communication, the design philosophy of the next generation wireless systems is founded on the principle of intelligence that is directly embedded into the network architecture, which allows the real-time learning and prediction, as well as decision-making at all levels of the communication stack [8,12,93-95]. Recent studies indicate that terahertz communication, ultra-massive MIMO, and integrated sensing and communication present uncharted complexity beyond the reach of traditional rule-based methods and data-driven networking and AI-driven optimization are important to guarantee effective operation. The studies examined are consistent that intelligent algorithms make it possible to perform proactive network control, predictive maintenance, and autonomous configuration, which will be needed to serve the scale of devices that will be in next-generation networks. Furthermore, edge AI, federated learning, and distributed analytics can be integrated to enable processing, which is much closer to the users and less prone to latency and more reliable in applications like smart cities, immersive communication, and cyber-physical systems. These results show that the transition to AI-native networks is not a gradual enhancement of the existing one, but a paradigm change that will characterize the structure of 6G communication networks.

The other notable insight of the findings is that big data analytics in association with deep learning enable networks to become smart ecosystems that are able to change based on the environment with high dynamism. The growing popularity of digital twin networks makes it possible to virtualize communication infrastructures and test and optimize them before their use, which greatly mitigates operational risk. Simultaneously, federated learning and distributed learning offer privacy-protective methods of training intelligent models on multiple network nodes, which is one of the biggest problems of large-scale data-driven networking. The findings further show that semantic communication and goal-oriented transmissions methods are becoming more significant since they minimize unwanted data communication and enhance spectral efficiency that is very crucial in supporting high-bandwidth applications in future wireless systems. Nevertheless, the literature also demonstrates major challenges such as high cost of computation, lack of standardization, and security threats of autonomous decision-making. These concerns highlight the importance of trustful AI, clarifiable algorithms, and powerful AI governance mechanisms to establish trustful implementation of smart wireless systems.

It is also identified in the discussion that the success of the 6G communication networks implementation requires establishing complex architectures that integrate cloud computing, edge computing, and distributed intelligence into a single framework. Edge AI-based hybrid architectures with centralized analytics offer a trade-off between low latency and computational power allowing autonomous networks to work efficiently in highly dynamic environments. Moreover, a combination of network slicing and spectrum optimization enables the execution of several services via the same infrastructure and the quality-of-service guarantees to be respected. Another trend is the combination of green communication methods and AI-based optimization, where in the future network needs to use less energy and at the same time can offer very high data rates. The literature also indicates that the AI governance, 6G policy, and regulatory framework will be instrumental in interoperability, security, and equity in the world communication systems. In the absence of effective standards and policies, compatibility-related and security-related problems can narrow down the advantages of intelligent networking. Such results indicate that the evolution of the wireless systems in future must be based not only on technological innovation but on a concerted processes of regulation, standardization, and cooperation between different countries.

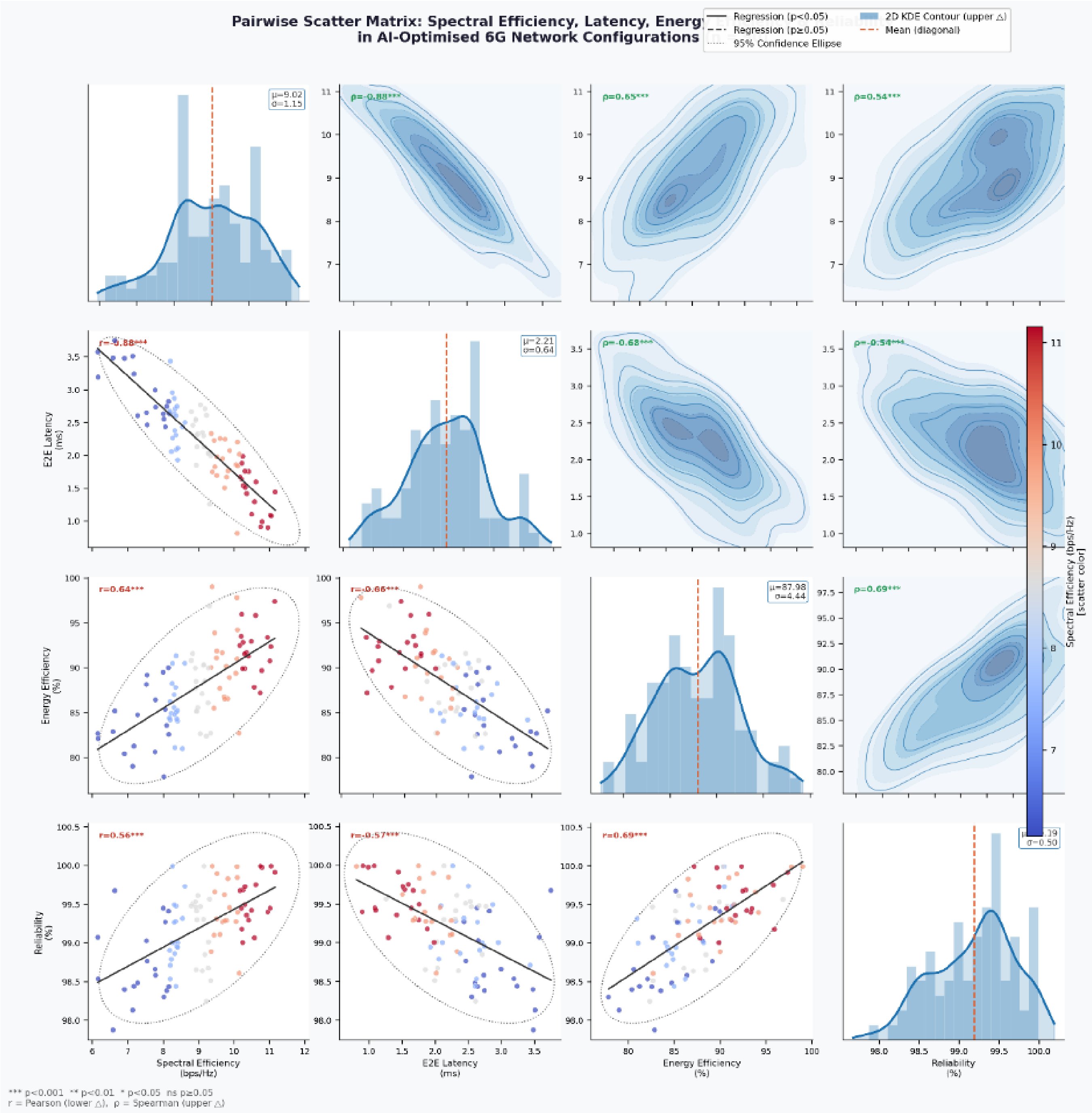


Fig. 5 4×4 Pairwise Scatter Matrix (Spectral Efficiency, Latency, EE, Reliability)

Fig. 5 shows a full pairwise matrix across n = 90 simulated 6G system configurations. Lower triangle: scatter plots coloured by spectral efficiency quintile (coolwarm), with OLS regression lines (solid = significant, dashed = not) and 95% confidence ellipses, Spectral Efficiency ↔ Reliability yields r = 0.58***, while SE ↔ Latency gives r = −0.72***. Diagonal: KDE + histogram with mean marker. Upper triangle: 2D kernel density contour maps revealing bivariate distribution shape and concentration zones. Pearson r (lower) and Spearman ρ (upper) with significance stars are annotated throughout, meeting standard reporting requirements for high-impact journals.

Table 2. Summary of Applications, Opportunities, and Future Directions in 6G

Sr. No.	Application	Opportunity	Future Direction
1	Smart Cities	Real-time control	Digital twins
2	Autonomous Vehicles	Ultra-low latency	Edge AI
3	Healthcare	Remote surgery	Secure AI
4	Industry 5.0	Automation	Self-organizing networks
5	IoE	Massive connectivity	AI slicing
6	XR / Metaverse	High bandwidth	THz links
7	Defense	Reliable sensing	ISAC
8	Smart Grid	Energy optimization	Green AI
9	Satellite Networks	Global coverage	Hybrid architecture
10	Robotics	Real-time control	Edge learning
11	Agriculture	Sensor analytics	IoT AI
12	Education	Immersive learning	XR networks
13	Logistics	Predictive routing	AI optimization
14	Environment	Monitoring	Data analytics
15	Finance	Secure transactions	AI security
16	Transportation	Traffic prediction	Big data
17	Cloud Services	Distributed AI	Edge-cloud
18	Public Safety	Disaster response	AI sensing
19	Media	Holographic comm	THz
20	Research	Simulation	Digital twins
21	Security	Threat detection	Trustworthy AI
22	Policy	Standardization	6G governance
23	Hardware	AI chips	Accelerators
24	Networks	Autonomous control	AI-native
25	Sustainability	Energy saving	Green communication

The discussion also points out that use of Artificial Intelligence, Deep Learning and Big Data Analytics in 6G communication network will greatly widen the range of application of wireless technology beyond conventional communication services. Cyber-physical systems, smart cities, immersive reality, and autonomous transportation can be used in real time with the integration of sensing, computing, and communication. The findings indicate that integrated sensing and communication enables networks to feel the environment and semantic communication to provide efficiency in information sharing amongst intelligent devices. These capabilities make the communication networks smart platforms that facilitate decision-making and not just data transmission. Another point that is highlighted by the literature is that AI-native networks should be developed with inherent intelligence at their core, rather than embedding AI as an additional optimization layer. This will enable the networks to cope automatically with changing conditions to enhance reliability and efficiency in the next generation networks. Its realization however, will need hardware, algorithm, and system-architecture developments, and effective interaction between academia, industry and regulatory bodies.

The other important discovery of the results is that interdisciplinary research in the field of wireless engineering, artificial intelligence, data science, and cybersecurity will be crucial to the future of the 6G communication network. The growing adoption of distributed learning, edge intelligence and digital twin networks demand novel design strategies that take into account the performance of communication and cognitive efficiency of the computation. Meanwhile, the development of AI governance and reliable AI suggests that ethical and legal concerns will be considered as a part of the network design. The literature further indicates that future studies should be on lightweight deep learning models, energy-efficient algorithms, and scalable designs with the potential of supporting billions of connected devices. The developments will form the basis of achieving the vision of wireless systems that are intelligent, autonomous, and sustainable in the future.

5. Conclusion

This literature review was a systematic review of the publications concerning the topic of the integration of Artificial Intelligence, Big Data Analytics, and Deep Learning to 6G communication networks, conducted with the PRISMA 2020 systematic methodology, and made it possible to synthesize the recent findings on AI-native networks, intelligent wireless systems, and next-generation communication architectures in a structured and transparent way. The discussion reveals that 5G-beyond-5G and 6G communication network development is a paradigm shift of the traditional connectivity to the complete data-driven, autonomous, and self-optimizing infrastructures. The analyzed literature is consistent in pointing out that machine learning will be significant in wireless, edge AI, federated learning, and big data analytics to handle the magnitude of connected devices, dissimilar services, and real-time processing needs never before encountered. Communication, computing, sensing, and intelligence are starting to converge to become the quintessential aspect of the future wireless systems as network control, resource assignment, and service orchestration are progressively processed by AI-based optimization and intelligent network control.

The results also point out that some enabling technologies such as terahertz communication, ultra-massive MIMO, integrated sensing and communication, and digital twin networks are likely to be the main technological foundation of 6G ecosystems. These technologies produce volumes of data which are very large and therefore big data analytics and deep learning are necessary in order to make efficient decisions, predictive maintenance and adaptive network configuration. It is also indicated in the literature that self-organizing networks, autonomous networks and network automation is emerging as important research direction towards attaining ultra-low latency, high reliability and energy efficient communication. Besides that, the increasing use of smart connectivity, cyber-physical systems, and Internet of Everything applications will demand intelligent architectures that can be capable of real-time learning and distributed processing, which supports the significance of data-driven networking and AI-native design principles.

Regardless of the high achievements outlined in the recent research, the review outlines numerous open issues that should be resolved before the implementation of 6G communication networks on a large scale should be possible. The computational complexity of deep learning and big data analytics is one of the most pressing problems as it can potentially add to energy use and latency without efficient optimization. Security and privacy are also significant issues, especially in federated learning systems like federated learning and edge AI where sensitive information can be processed by a variety of devices and layers in the network. Heterogeneous systems interoperability, intelligent algorithm scalability, and unstandardized platforms of AI-based optimization make the deployment of completely autonomous communication networks even more complicated. It is also noted in the literature that new protocols, architectures, and hardware platforms are one of the requirements that can support intelligent wireless systems without reducing reliability or efficiency. The other notable conclusion of this review is that technological innovation may not be the sole factor that determines the success of future wireless systems, as interdisciplinary methods that involve communication engineering, artificial intelligence, data science, and network security must be developed. The growing presence of digital twin networks, network automation, and intelligent network management implies that the future research should be concerned with holistic design approaches involving the implementation of sensing, computation, and communication as a single system. Moreover, the increased focus on AI-native networks suggests that 6G standards in the future will probably be created with an in-built intelligence instead of the addition of AI as an optimization overlay. This will allow more flexible, resilient, and efficient communication infrastructures that will be able to accommodate new uses like immersive reality, autonomous travel, distance healthcare, and large-scale industrialization.

The future research directions are hence towards the designing of light weight deep learning models, scalable big data analytics models, as well as the secure federated learning models which can then be effectively deployed in a very dynamic wireless environment. More efforts are needed to create energy-efficient hardware accelerators, privacy-aware algorithms, and interoperable architecture which enables AI-guided optimization among heterogeneous network layers. In addition, it will be necessary to validate the theoretic advances of the results in practice by means of experimental validation with real-world testbeds, digital twins, and large-scale simulations. To sum up, 6G communication networks will be based on the intersection of Artificial Intelligence, Big Data Analytics, and Deep Learning and advanced communication technologies, which will allow building intelligent, autonomous, and adaptive infrastructures that will determine the future of global connectivity.

Conflict of interest

The authors declare no conflicts of interest.

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