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The Integrated Development of Wireless Networks and AI

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Abstract: This paper combines the current research status of wireless networks and artificial intelligence, delving into the state of wireless network research and its impacts, and highlights the importance and necessity of the integrated development of wireless networks and AI. The aim is to provide readers with an understanding of the current situation and challenges of wireless networks. With the increasing number of mobile communication users, spectrum resources are becoming increasingly scarce, network security issues are more prominent, and the complexity of network architecture and business processes has significantly increased, making it difficult for traditional operations and maintenance methods to meet these demands. Therefore, leveraging AI to build a new mode of communication network operation has become an inevitable choice. The intelligent evolution of wireless networks is an unstoppable trend. In the future, full intelligence will be achieved through digital infrastructure, knowledge introduction, and digital twins, driving the efficient development of wireless networks.

Keywords: Wireless Network, AI, 5G, Mobile Communication,Communication Engineering.

1. Introduction

With breakthroughs in algorithms, enhanced computing power, and support from internet data, artificial intelligence has made significant progress in the second decade of the 21st century, attracting global attention. Meanwhile, wireless communication systems, with their robust connectivity capabilities, have not only facilitated communication between people but have also ushered in a new era of the Internet of Things. In this process, wireless communication systems generate vast amounts of data, collectively building a massive digital world that provides strong momentum for the further development of AI. On one hand, AI technologies can offer intelligent decision-making and optimization capabilities to communication systems, enhancing communication efficiency and service quality. On the other hand, communication systems can provide robust foundational support in communication and computing power for AI, accelerating the rapid development of an intelligent society[1].

AI is currently the most focused frontier technology and a hot research direction. After decades of exploration and development, AI has achieved major breakthroughs in areas such as image recognition, speech recognition, and intelligent control. More and more industries are beginning to explore and embrace AI, hoping to empower themselves through it. The communications industry is no exception. In recent years, many telecom companies, including equipment manufacturers and

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operators, have increased their investment in AI research, seeking to explore future scenarios of "communication + AI" and gain a competitive edge, especially operators.

The urgent demand for AI in the telecommunications industry is driven by the current state and future of network development. Following the advancements of 2G, 3G, and 4G, we now face an unprecedentedly complex heterogeneous multi-domain network. Various technologies are intertwined, resulting in bloated network architectures and cumbersome business processes, which impose significant maintenance pressures. Now, with the arrival of 5G, a new generation of mobile communication standards, we see substantial improvements in network performance and flexibility, but it also introduces even greater complexity. In terms of air interface, 5G employs higher frequency bands and more flexible resource allocation methods, along with Massive MIMO antenna array technology[2]. Effective beamforming control and optimizing air interface efficiency present challenges for engineers.

Regarding network architecture, the introduction of Service-Based Architecture (SBA), NFV/SDN, and slicing technologies have made networks more flexible, yet maintenance has become more complicated. Service-Based Architecture (SBA), Network Functions Virtualization (NFV) / Software-Defined Networking (SDN), and network slicing are critical architectures and technologies in modern communication networks. Together, they form a highly flexible, programmable, and modern network architecture that meets the diverse requirements of 5G and future networks. Managing and scheduling virtual machines and slice resources, as well as modifying network parameters, are all tedious tasks that carry significant risks[3]. If these changes brought by 5G continue to rely on traditional operations and maintenance methods and human labor, they will be unsustainable. Telecommunications operators, as the main entities managing the network, face high operating costs while needing to invest in 5G, leading to greater financial pressure and a critical turning point in development. Therefore, leveraging AI to build new business models for communication networks is essential to meet these challenges.

Based on existing research, this paper will discuss the current state and impact of 5G and wireless networks, delve into the research status and applications of the integration of wireless networks with artificial intelligence, and finally, forecast the future of the convergence of wireless networks and AI.

2. G's impact on today's society

2.1. 5G boosts digital investment

Digital technologies such as 5G, cloud computing, artificial intelligence, and big data are rapidly integrating into all areas of the economy and society, driving the robust development of the digital economy. Various industries are seizing opportunities for digital transformation, continuously increasing their investments in digital technologies, products, and services. As a result, digitization is gradually becoming a key revenue focus for telecommunications companies.

2.2. 5G promotes new types of consumption

5G is fostering the growth of new consumer applications and industries, cultivating future growth points. As 5G network coverage in hotspot areas gradually improves and the computing power of smart devices continues to rise, innovative personal applications are emerging. Among them, naked-eye 3D technology offers users a wearable-free, immersive interactive experience. Currently, the core technology for naked-eye 3D has matured, with products like naked-eye 3D laptops, monitors, and tablets being released. Naked-eye 3D is expected to become one of the driving forces behind the flourishing development of 5G consumer applications. The integration of large model capabilities into 5G smartphones will bring a new user experience, as manufacturers actively promote the inclusion of AI large models in these devices to provide intelligent and personalized services. In 2023,

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Vivo launched the vivo X100 equipped with the Blue Heart large model, becoming one of the first phones to support a large AI model in the industry. MediaTek also released the Dimensity 9300 flagship 5G generative AI mobile chip, which supports running AI large language models with parameters of 1 billion, 7 billion, 13 billion, and up to 33 billion.

2.3. 5G promotes the intelligent development of manufacturing

5G supports the high-end, intelligent transformation and upgrading of the manufacturing industry. Firstly, leveraging the high bandwidth, low latency, and high reliability of 5G networks, digital technologies such as artificial intelligence, cloud computing, and big data are deeply integrated into applications like visual inspection, remote collaboration, intelligent patrol, and remote operation and maintenance, helping manufacturing companies improve quality and efficiency. For example, 5G combined with visual inspection enhances the efficiency, accuracy, and precision of quality checks and defect identification, while continuously improving model robustness through AI algorithms and collected data, thus elevating the standardization of inspection operations. Additionally, 5G-enabled remote collaboration can be realized through AR glasses, facilitating real-time, location-based interactions where experts can remotely guide on-site personnel in equipment installation, inspection, diagnosis, and maintenance, significantly improving the efficiency of equipment repair and assembly assistance[4]. Currently, these applications are developing on a large scale within manufacturing enterprises, with industry stakeholders actively promoting the standardization and large-scale deployment of related technologies, products, and solutions.

3. Wireless network development status and challenges

Wireless network technology is one of the rapidly developing fields in recent years, significantly changing people's lifestyles and providing more business opportunities for enterprises and organizations.

Firstly, wireless network technology plays a crucial role in mobile communication. With the widespread adoption of smartphones and the rapid growth of mobile data traffic, the demand for high-speed and stable wireless networks is continually increasing. Currently, 4G networks have become mainstream, offering faster download and upload speeds. However, 4G is still insufficient to meet future demands. With the rise of cloud computing, virtual reality, and the Internet of Things, the need for network bandwidth will further escalate. Therefore, the research and commercialization of 5G networks are receiving significant attention.

Secondly, the Internet of Things is another important application area for wireless network technology. The IoT connects various devices and sensors, enabling them to communicate and share data with one another[5]. Wireless network technology supports the IoT and accelerates its widespread adoption. For example, smart home devices can interconnect via wireless networks, allowing for remote control and intelligent management. In the industrial sector, smart manufacturing also relies on wireless network technology to enable real-time communication and data transmission between devices. As the IoT continues to evolve, wireless network technology will keep creating more business opportunities and social value[6].

However, the development of wireless network technology also faces several challenges. Firstly, there is the limitation of spectrum resources. As the number of mobile communication users continues to grow, existing spectrum resources will become strained[7]. To meet the demand for higher-speed wireless networks, new frequency bands need to be explored and developed. Secondly, network security is a critical concern in the development of wireless network technology. With the widespread adoption and increasing applications of wireless networks, security threats have become more severe. Protecting users' personal information and ensuring the security of network data is one of the important tasks[8]. Finally, the development of wireless network technology must also address technical challenges such as transmission speed, network capacity, and signal interference.

4. The necessity of wireless network intelligence

Influenced by factors such as algorithms, computing power, and demand, early mobile communication systems did not involve artificial intelligence applications. It was not until 2008, when 3GPP began defining Self-Organizing Network (SON) functions, that the telecommunications field started to explore various AI algorithms for SON applications. SON is an automatic network management technology aimed at reducing human intervention and optimizing network performance through automation[9]. In the early stages of research, distributed optimization algorithms such as genetic algorithms, evolutionary algorithms, and multi-objective optimization algorithms were primarily used to optimize network coverage and capacity. Subsequently, machine learning technologies were introduced as key methods for achieving self-organization, self-configuration, self-optimization, and self-healing in networks[10].

However, the real leap in telecommunications AI began in 2017. In that year, the first version of the 5G NR standard was officially released at the 78th plenary meeting of 3GPP RAN, marking the birth of the world's first commercially deployable 5G standard. With its significant features of massive connectivity, low latency, and high speed, along with the cloudification and slicing of networks, 5G technology is gradually becoming a key driver of digital transformation across industries.

Thanks to the joint efforts of various stakeholders in the industry chain, the development around three major application scenarios—enhanced mobile broadband, massive machine-type communication, and ultra-reliable low-latency communication—is expected to give rise to more industry forms and innovative applications[11]. Meanwhile, as telecom networks transition to virtualization and cloud computing, and as 5G and IoT technologies integrate deeply, network architectures and technologies are undergoing profound changes and facing unprecedented challenges. In this context, artificial intelligence, with its exceptional data analysis and information extraction capabilities, can not only help operators convert data dividends into information dividends but also internally address efficiency and capacity issues within telecommunications networks, while intelligently providing integrated digital and information services externally[12]. By integrating AI technologies, communication networks will gain a smart brain, advancing toward network intelligence.

As mobile networks continue to evolve toward 5G, network capabilities will further upgrade, supporting an increasing number of services, which will significantly enhance network complexity. Three structural challenges in mobile networks will become more pronounced.

Firstly, the spectrum resources for mobile networks are becoming increasingly abundant, ranging from low to mid-band frequencies, with future introductions of 6 GHz and millimeter-wave high frequencies. A single operator may possess more than ten frequency bands. Secondly, stations are continually advancing towards multi-antenna configurations, evolving from 4T and 8T to Massive MIMO. Additionally, various scenarios need to be considered, such as the differences between indoor and outdoor environments and variations during peak and off-peak times, all of which increase the complexity of operators' operations and maintenance. The traditional linear improvement in human-operated maintenance efficiency can no longer cope with the exponentially growing complexity of operations and maintenance[13].

Furthermore, as mobile networks penetrate various industries, the number of application scenarios is surging, including traditional applications like video, gaming, and XR, as well as industry-specific needs such as remote control and machine vision. The diversity of services leads to varied network demands; some services require high-speed uplink transmission, while others need stable low latency

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or high-precision positioning. These diverse requirements complicate spectrum selection and network architecture.

Lastly, user demand for mobile network traffic is consistently growing at a high rate, with estimates suggesting that by 2030, the Daily Average Usage (DOU) will reach 600 GB, driving an increase in the number of sites, spectrum, and channels. Consequently, wireless network energy consumption is also expected to rise[14]. However, operators hope that as network traffic grows, the increase in network energy consumption will be minimal.

Therefore, it is necessary to leverage intelligent spatial and temporal prediction capabilities, as well as correlation analysis, to detect potential network operations and maintenance issues in advance and provide solutions, thereby improving operational efficiency. By using real-time network sensing and proactive prediction, combined with fixed expert knowledge and intelligent analysis and forecasting capabilities, flexible intelligent strategies can be formed to ensure the quality of experience for diverse applications.

5. Typical application of wireless network intelligence

5.1. The application of AI at the physical layer

AI-based channel modeling: Achieving high-precision modeling of physical channels using AI technology can effectively reduce system feedback overhead and improve spectrum efficiency.

AI-based cell search and random access enhancement: As communication frequencies increase, the number of beams in each cell grows, leading to increased latency and power consumption during cell search and random access, which are major concerns for manufacturers. In the future, AI models could be considered to reduce latency and energy consumption in cell search and random access.

AI-based receiver algorithms: Using AI technology to optimize or enhance existing receiver algorithms, such as multiple-input multiple-output (MIMO) reception algorithms and demodulation and decoding algorithms.

5.2. Application of AI in access network

Intelligent 6G wireless communication systems can be divided into two types: "AI for Network" and "Network for AI." "AI for Network" refers to the empowerment of networks through artificial intelligence, which involves using AI technologies to enhance and optimize the performance and management of wireless networks. "Network for AI," on the other hand, refers to networks enabling artificial intelligence, meaning that wireless networks support and enhance the operation and performance of AI applications.

The focus of "Network for AI" is to provide high bandwidth, low latency, and high reliability in network infrastructure to support complex AI applications, such as real-time data analysis, edge computing, distributed learning, and the interconnectivity of intelligent terminal devices. By optimizing network architecture and transmission technologies, the aim is to provide robust network support for AI applications, resulting in more efficient and intelligent service delivery. Future 6G wireless communication networks need to meet the requirements of federated learning architectures and distributed learning architectures, ensuring the reliability and low latency of AI-related data and model transmission.

5.3. Application of AI in the core network

The fusion of AI and 6G technology will support the further advanced self-intelligent evolution of networks, enabling key characteristics of intelligent networks such as intent-driven capabilities and closed-loop assurance. Intent-driven means that by deeply understanding user intentions, the network can provide customized solutions based on users' needs and preferences. Users only need to focus on achieving their goals without worrying about how to accomplish them. Closed-loop assurance involves implementing mechanisms for real-time monitoring, assessment, analysis, and decision-making within the network, using intelligent methods to minimize human intervention and maximize network performance.

Through automation and intelligence, these approaches help operators simplify business deployment and enable networks to possess self-configuration, self-optimization, self-healing, and self-evolution capabilities. Currently, the main use cases are limited to specific scenarios and are still in the research and validation stages. Research is ongoing to enhance the generalization capabilities of models to facilitate large-scale applications[15].

6. The future of wireless network and AI integration

According to a report by research firm Tractica, the annual revenue generated by AI applications in the telecommunications industry is expected to grow from $315.7 million in 2016 to $11.3 billion by 2025, with a compound annual growth rate (CAGR) of 48.8%. The report also predicts that global investments in AI hardware, software, and services in the telecommunications sector will reach $36.7 billion by 2025. Another consulting firm, Analysis Mason, claims that 80% of operators expect to achieve over 40% automation in network operations by 2025, with about one-third of them anticipating network automation will exceed 80%. The combination of telecommunications and AI is an inevitable trend.

Currently, the three major domestic operators and leading equipment vendors in China are making significant investments in AI, yielding promising results. China Mobile's Jiutian AI platform, China Telecom's CTNet2025 2.0, and China Unicom's Zhilifang CUBE-NET 2.0+ are all AI-focused ecological platforms. They aim to empower developers through these platforms, attracting more users to their AI engines and thus forming a robust ecosystem.

7. Conclusion

The intelligent evolution of wireless networks is an inevitable trend, and currently, the intelligence of wireless networks is still in its early stages. We believe that the complete intelligence of wireless networks will be systematically achieved in three areas.

First, it is essential to solidify foundational functions such as base station profiling to achieve the digitalization of RAN (Radio Access Network). At the same time, powerful computing capabilities need to be provided on the network element side to research and develop algorithms and use cases that deliver value to customers, allowing AI to address real-world problems.

Second, knowledge must be introduced in a vertical dimension. This involves collecting pre-processed data and raw data at different levels of the RAN, then converting this data into knowledge through machine learning (ML) and utilizing that knowledge for decision-making.

Finally, digital twins should be introduced to enable intelligent closed-loop operations within wireless networks. The development of wireless network intelligence is a gradual process, and equipment vendors should adhere to principles of openness, cooperation, and win-win collaboration, working together with operators and partners to drive the advancement of wireless network intelligence.

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