Proceedings of the 4th International Conference on Computing Innovation and Applied Physics
DOI: 10.54254/2753-8818/80/2025.GL20171

The Historical Development and Applications Analysis of Wireless Communication Technology

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Abstract: Throughout history, advancements in communication technology have been instrumental in shaping human civilization. From the early days of radio transmission to the current era of 5G networks and the frontiers of 6G research, each leap forward has brought about significant changes in society. This paper seeks to delve deeply into the historical development and application of wireless communication technology, offering a thorough examination of its evolution. This paper provides historical experience and realistic guidance for the future development of communication technology, highlighting the importance of these advancements in shaping human society. It also reveals the important achievements and future trends in this field, shedding light on how these technologies have transformed various sectors, from personal communication to global data exchange. The analysis not only provides valuable experience and insights but also points out the direction for future research and practice, ensuring that we continue to harness the full potential of wireless communication to drive innovation and progress.

Keywords: Wireless communication technology, Historical development, Application

1. Introduction

Throughout history, advancements in communication technology have been instrumental in shaping human civilization. The evolution of communication methods, ranging from ancient correspondence to contemporary wireless systems, has significantly accelerated information dissemination and societal progress. Wireless communication, in particular, represents a groundbreaking advancement in the field, transforming not only individual lifestyles but also driving substantial growth and innovation across society as a whole [1].

The purpose of this paper is to discuss in depth the historical development and application of wireless communication technology, with a view to providing historical experience and realistic guidance for the future development of communication technology. This paper will first review the historical development of wireless communication technology, analyses the key technologies at each stage and their impact on society. Secondly, this paper will explore the significance of Maxwell's system of equations, the theoretical foundation of wireless communication technology, to the development of wireless communication technology. Thirdly, this paper will focus on its applications in daily life, healthcare, and transportation, as well as introduce the relevant wireless communication technologies. Finally, this paper will explore the challenges it faces and the future development prospects. By comprehensively analysing the history and application of wireless communication

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technology, this paper aims to provide readers with a clear picture of the technological development, as well as a deep insight into the future development of communication technology.

2. The History and Theoretical Foundations of Wireless Communication Technology

2.1. The History of Wireless Communication Technology

Wireless communication has a long history dating back to the early 1800s. The Danish physicist Hans Christian Oersted is credited with discovering the "electricity generates magnetism" effect in 1820. The electromagnetic hypothesis was established in 1831 when British scientist Michael Faraday discovered the phenomena of electromagnetic induction, or "magnetism generates electricity." The presence of electromagnetic waves was predicted by Scottish scientist James Clerk Maxwell in 1864 when he proposed Maxwell's equations, which characterize the electromagnetic field. Heinrich Hertz, a German physicist, created the first radio antenna and empirically verified the existence of electromagnetic waves in 1887. Guglielmo Marconi, an Italian physicist, successfully demonstrated wireless communication over the sea in 1897. In 1901, he was able to transmit radio signals across the Atlantic Ocean. Radio transmission started to be included into mass media in the early 20th century, and it significantly altered how information was disseminated. Wireless communication was essential to military strategy during World War II. Japan launched the first first-generation (1G) network in 1979. It marked the beginning of the analog cellular communication era. This early system had limitations like low voice quality, limited capacity, and no security measures, despite its crucial significance. The introduction of 2G in the early 1990s represented a major improvement over 1G [2].

Data transfer, encrypted communications, and improved audio clarity were all made possible by digital networks such as GSM.As a result, it made SMS and MMS services possible. Early in the new millennium, 3G networks were put into place. It paved the way for mobile internet access and accelerated data transfer rates. These networks made it possible to make video calls and enabled more widespread mobile internet use. With the advent of third (3G) and fourth (4G) generation technology at the turn of the twenty-first century, mobile networks' data transmission speeds have significantly risen. Consequently, it caused the proliferation of smartphone applications and mobile Internet. In 2020, China started using the fifth-generation (5G) technology for commercial purposes. It supports key technologies such as extremely high speeds, extremely high frequencies, Massive MIMO, and D2D. This technology accomplishes three primary application scenarios: enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine-type communications (MTC) [3]. Timeline of wireless communication technology development is shown in Figure 1.

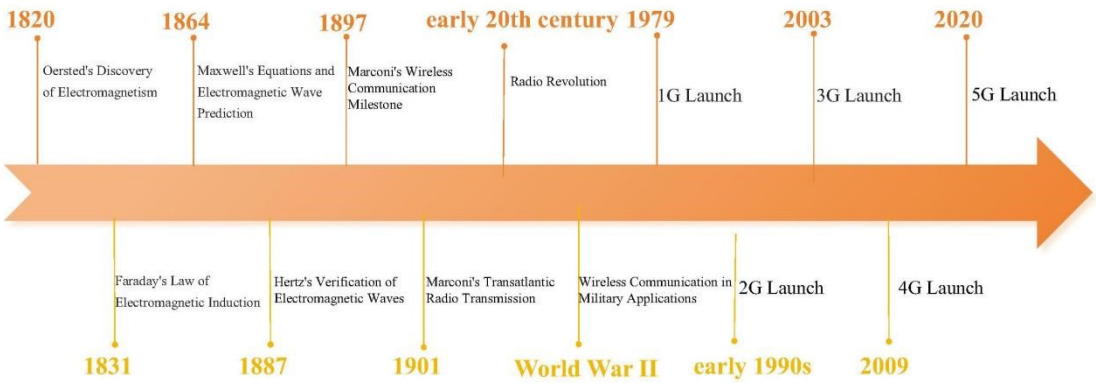

Figure 1: Timeline of Wireless Communication Technology Development

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Nowadays, Scientists and technicians are working hard to explore 6G technology, which will bring higher data transfer speeds, lower latency, broader connectivity, and smarter network services. Therefore, it will bring new transformations to society, including applications in industrial automation, smart cities, autonomous driving, and other fields.

2.2. The Theoretical Foundations of Wireless Communication Technology

Maxwell's equations describe the relationships between electric fields, magnetic fields, charge density, and current density. Maxwell's equations are the theoretical foundation of wireless communication technology because these formulas not only unify the phenomena of electricity and magnetism, and explain the propagation of electromagnetic waves, but also predict the existence of electromagnetic waves. Below, this paper will simply list Maxwell's equations and the derivation of the wave equation [4]. Maxwell's equations:

$$\begin{aligned} \nabla \cdot E &= \rho/\varepsilon_0 \\ \nabla \cdot B &= 0 \\ \nabla \times E &= -\partial B/\partial t \\ \nabla \times B &= \mu_0 J + \mu_0 \varepsilon_0 \partial E/\partial t \end{aligned} \tag{1}$$

Where E means the electric field, ρ means the charge density, ε0 means the electric constant, B means the magnetic field, t means time. μ0 means the magnetic constant, "∇·" means divergence, "∇ ×" means curl. Taking the curl of the third equation:

$$\nabla \times (\nabla \times E) = -\nabla \times \partial B/\partial t \tag{2}$$

Using the vector identity $\nabla \times (\nabla \times E) = \nabla(\nabla \cdot E) - \nabla^2 E$, and since $\nabla \cdot E = 0$, It can be got:

$$-\nabla^2 E = -\mu_0 \varepsilon_0 \partial^2 E/\partial t^2 \tag{3}$$

Thus, the wave equation for the electric field becomes:

$$\nabla^2 E - \mu_0 \varepsilon_0 \partial^2 E/\partial t^2 = 0 \tag{4}$$

Similarly, for the magnetic field, it can be got the wave equation:

$$\nabla^2 B - \mu_0 \varepsilon_0 \partial^2 B/\partial t^2 = 0 \tag{5}$$

Maxwell discovered that the form of this wave equation is similar to the wave equation that describes mechanical waves. However, the difference is that this wave equation does not require a medium to propagate. Furthermore, Maxwell discovered that the solution to this wave equation indicates that electromagnetic waves propagate at a constant speed, which is consistent with the known speed of light at the time. This suggested that light itself might be an electromagnetic wave. The hypothesis of the existence of electromagnetic waves was later experimentally demonstrated by German physicist Heinrich Hertz.

Wireless communication utilizes these principles to transmit and receive signals, such as television broadcasting, satellite communication, Wi-Fi, and other wireless technologies. Therefore, Maxwell's equations have had a profound impact on modern technological society.

3. Analysis of Wireless Communication Technology Application Scenarios

Wireless communication technology has a wide range of applications in modern life. This paper will focus on its applications in daily life, healthcare, and transportation, as well as introduce the relevant wireless communication technologies.

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3.1. The Smart Home System -- ZigBee Technology

ZigBee technology is an efficient, low-power, and cost-effective wireless communication technology that is favored in the field of wireless network communications. Due to its simple structure, low complexity, affordability, and high reliability, it plays a crucial role in smart home control systems. It enables a variety of functions such as home security, environmental monitoring, and appliance control [5].

The main products of smart home systems include controllers, handheld remote controls, and smart terminals. These products cover multiple functional areas like home security, environmental monitoring, and appliance control. The system is flexible and can meet users' diverse requirements. For example, Huawei's smart home system uses ZigBee networking technology in combination with a variety of sensors and actuators (such as temperature and humidity sensors, photosensitive sensors, human infrared sensors, and so on) to collect environmental data and achieve intelligent control and linkage. Specifically, smart switches can be connected to lighting devices such as smart bulbs and smart dimmers. Users can achieve remote switching of lights and adjustment of brightness through mobile phone AP's, voice control, etc. The smart home system allows users to conveniently control and manage their home appliances, thereby enhancing their quality of life [6].

3.2. Telemedicine -- 5G Technology & Bluetooth Technology

5G (The 5th Generation Mobile Communication Technology) is a new generation of high-speed wireless communication technology. Compared with 4G, 5G demonstrates higher transmission rates, lower latency, and a broader range of connections. Consequently,5G has been widely used in the medical field.

With the support of 5G technology, patients can undergo remote online consultations through images, videos, and other means. For instant, Mayo Clinic in America utilizes 5G technology to enhance remote consultations, virtual care, and medical education initiatives, extending its services across regions to benefit a great number of patients. It largely avoids long-distance travel and greatly facilitates home-based medical care [7]. At the same time, hospitals can use 5G technology to achieve multidisciplinary remote consultations and share medical records both within and outside the hospital. As a result, it provides patients with comprehensive health services, achieving timely treatment and reducing mortality. Currently, remote medical robotic assistance technology based on 5G technology has become a research hot spot, and its clinical application scope continues to expand, covering fields such as orthopedics and endoscopic surgery.

Bluetooth technology is one of the most commonly used wireless communication technologies today. It has had a significant impact on personal users and corporate communications. Due to its deficient power consumption, good anti-interference capabilities, and ease of use, Bluetooth technology has also been widely applied in the construction of medical monitoring systems, such as the continuous emergence of wireless blood pressure monitors, thermometers, heart monitors, and wearable devices [8]. These devices have the advantages of small size and strong interactivity, capable of real-time monitoring of a patient's blood pressure, respiration, and electrocardiogram parameters. Moreover, they can break through the limitations of time and space, establish communication connections between instruments through Bluetooth, and achieve the integration of various instrument software data for better analysis and management of patient information. For example, the Omnia implantable neurostimulator, created by Nevro Corporation, utilizes Bluetooth technology to connect with a patient's smartphone. A companion mobile app, powered by AI algorithms, customizes treatment parameters and facilitates safe implant operation, particularly during MRI procedures, by enabling users to switch the device to an MRI-compatible mode.

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3.3. Urban Transportation Systems -- SDH Technology & WiFi Technology

Wireless communication technology plays an essential role in ensuring that data communication activities proceed in an organized manner. It is also a crucial technology in the development of urban transportation systems. By optimizing technologies to meet the construction requirements of urban transportation, the communication systems can be continuously enhanced and developed. In the following analysis, the paper will focus on two typical technologies.

The first technology is SDH (Synchronous Digital Hierarchy). It is an important foundational network element in the composition of transmission networks, providing communication services for the operation of urban rail transportation. It ensures the effectiveness of information exchange, enabling the transmission network and transmission channels to achieve information transmission between stations and uploading data to a comprehensive management platform. In practical applications, SDH technology can set up multiple data collection points within key areas of different stations. Through Ethernet and PCM access methods, it can timely complete the internal train operation information transmission activities of the stations, transmit data to the control center, and provide a data foundation for the development of urban rail transit management activities. The SDH transmission channel allows relevant departments to make comprehensive assessments of the received data promptly and solve traffic problems promptly [9].

The second technology is WiFi technology. It is flexible and has a high degree of technical maturity. Through different terminals at stations or on trains, it can display operational data about the trains, as well as provide functions like weather forecasting and news broadcasting. However, since WiFi technology mobile TV, and PIS systems all operate in the 2.5 GHz frequency band, they can easily interfere with each other during operation. It is not conducive to improving communication quality and can also affect communication efficiency. Therefore, when using this wireless communication technology, it is necessary to manage interference. By adjusting the WiFi frequency band from 2.5 GHz to 5.8 GHz, the effectiveness of the technology can be ensured. In addition, by setting WiFi and urban transportation signal systems on different channels, interference issues can be effectively prevented [10].

Both SDH and Wi-Fi are significant to the efficient operation of urban transportation systems. They enable seamless communication between various components of the system, from passenger services to operational control. So, it ensures that data communication activities are conducted smoothly and effectively. As urban rail transit systems continue to evolve, the role of wireless communication technology will become even more significant, driving the need for continuous innovation and optimization in this field.

4. Challenges and Prospects

4.1. Challenges

Security and Privacy Protection: As wireless communication technology is increasingly applied in various fields; incidents of personal privacy theft and data leaks frequently occur. Protecting the security of user data has become a critical issue. Therefore, developing stronger encryption technologies, security protocols, and privacy protection measures are effective ways to prevent data breaches and cyber-attacks.

Environmental Adaptability: Wireless communication devices may not function stably in certain extreme environments. Thus, enhancing the stability and environmental adaptability of wireless communication devices is essential for their use in a broader range of scenarios, including extreme temperatures, humidity, pressure, and more.

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4.2. Prospects

Smart Electromagnetic Environments (SEME) is an emerging research field aimed at enhancing communication quality by intelligently manipulating electromagnetic waves in the wireless communication environment [11]. Such environments can use advanced electromagnetic materials and technologies to control and manipulate the propagation of electromagnetic waves. Thereby it can achieve higher data transmission rates and lower latency. For instance, by designing smart surfaces with specific electromagnetic properties, signals in certain directions can be enhanced or attenuated to improve the coverage and performance of wireless networks.

Future communication technologies may utilize electromagnetic nanonetworks that facilitate information transfer at the microscopic scale. They provide new solutions for wearable devices, implantable devices, on-chip communication, and even quantum communication [12].

5. Conclusion

This paper discusses the historical development and widespread application of wireless communication technology. And it also reveals the important achievements and future trends in this field. The analysis not only provides us with valuable experience and insights, but also points out the direction for future research and practice. With the continuous progress of technology, it is believed that wireless communication technology will continue to play a key role in driving human society forward.

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