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Applications of 5G technology in flexible electronics

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Abstract. As an emerging field in the industry, flexible electronics not only integrates technologies in fields such as electronic circuits, materials, and flat displays, but also spans industries such as semiconductors, materials, chemicals, and printed circuit boards. Its application importance in various fields such as information, energy, healthcare, and manufacturing are increasingly prominent. The main topic of this article is the implementation of 5G technology in the flexible electronics industry. To begin with, this article presents the traits of flexible electronics. Secondly, it stated the development of 5G and introduced its characteristics. The result shows that 5G is not only an air interface technology with higher rates, larger bandwidth, and stronger capabilities, but also an intelligent network for user experience and business applications. Then, combined with 5G and flexible electronics, they are applied in three aspects: mobile antennas, intelligent equipment, and remote medicine. Finally, the current problems and future prospects in the fields of flexible electronics and 5G were summarized. Currently, it faces challenges such as signal interference and power consumption due to the unique characteristics of flexible materials. And in the future, 5G can potentially enhance the performance of flexible electronics, leading to the creation of new products and services in various industries.

Keywords: 5G, Flexible Electronics, Internet of Things, Intelligent Wearable Device.

1. Introduction

A succinct definition of flexible electronics is an emerging electrical technology that creates electronic devices from organic or inorganic materials on flexible/ductile plastic or thin metal substrates. With its exceptional ductility, flexibility, and cost-effective manufacturing techniques, it offers a wide range of potential applications in industries like information, energy, and healthcare. The fifth-generation mobile communication technology, or 5G for short, is an improvement above 4G. After 2020, it will be the new generation of mobile communication system. Neither is it a single wireless access technology nor are all of the new wireless access technologies included. Zhang et al. reviewed the latest research progress of flexible electronics in Cardiovascular disease (CVDs) monitoring, focusing on four typical application scenarios of blood pressure, electrocardiogram, echocardiography and epicardial membrane, and summarized the challenges and development directions of flexible electronics in the cross-field of clinical application of CVDs [1]. Unlike silicon-based CMOS circuits, which are currently approaching the bottleneck of Moore's Law, flexible integrated circuits are still in the early stages of Moore's Law development curve. Therefore, there is expected to be significant room for improvement in terms of integration, performance, and power consumption in the future. According to a paper published by

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Interuniversity Microelectronics Centre (IMEC), a leading semiconductor research institution in Europe, when the feature size of future flexible integrated circuits develops to around 200nm, their power consumption can drop to a hundredth of what it is now, while their circuit performance is anticipated to increase by more than 20 times from what it is now [2]. By then, we can expect to see more powerful flexible integrated circuits, allowing intelligence to enter all daily objects. The adoption of 5G technology in the flexible electronics sector is the main focus of this essay. This article begins by outlining the characteristics of flexible electronics. Second, it described the evolution of 5G and gave an overview of its features.

2. Development of 5G

4G networks cannot meet the network requirements of 5G requirements and scenarios, because access network technology is limited and network architectural functions have become more solidified. The IMT-2020 (the legal name of 5G communication) promotion group has given the technical indicators of future 5G communication in terms of peak rate, edge rate, energy efficiency, reliability, communication delay, and other aspects [3]. For instance, compared to 4G communication, the top speed of 5G communication is at least 20Gbps. 5G networks can become more effective, adaptable, intelligent, and open through technological advancement and cooperative development in infrastructure platforms and network architecture.

The features of 5G technology include high speed, low latency, and high capacity. 5G networks offer faster data transfer speeds compared to previous generations. Users can experience download and upload speeds in the gigabit-per-second (Gbps) range, enabling quick file transfers, high-quality video streaming, and smooth browsing experiences. 5G aims to achieve ultra-low latency, reducing delays to a few milliseconds. The ability to respond quickly is essential for applications that demand real-time communication, such as gaming, remote surgery, and autonomous vehicles.

5G networks have the ability to support a massive number of connected devices simultaneously. This capability is essential for accommodating the increasing demand for IoT devices and smart homes. Network slicing technology enables the creation of multiple virtual networks over a shared physical infrastructure. It allows customization and optimization of network resources based on specific application or industry requirements.

5G networks bring in network functions virtualization (NFV) and software-defined network (SDN) technologies to create new infrastructure platforms on the same hardware facilities. This helps to reduce the cost of existing infrastructure platforms, improve resource management capabilities, and speed up service launch [4]. The network architecture in 5G scenarios is improved by combining control forwarding separation and control function reconstruction techniques. This redesign helps to enhance the performance of access networks (ANs). By simplifying the network structure of the core network (CN), the control forwarding functions become more flexible and efficient, the operation becomes more intelligent, and the network capabilities become more open. This ultimately enhances the overall service level of the entire network.

The 5G infrastructure comprises of two main components, the 5G core network (5GC) and the 5G radio access network (RAN), as shown in Figure 1. The 3rd Generation Partnership Project (3GPP) developed the key technologies for NR wireless network access and also reconsidered the system architecture between the radio access network (RAN) and the core network (CN), redefining and dividing the functions between the two. The wireless access network consists of next generation NodeB (gNB) for new radio (NR) and ng-eNB for EUTRAN. When the network adopts the dual-link architecture, the terminal will connect two kinds of nodes at the same time. gNB and ng-eNB are directly connected to each other through the Xn interface. The Xn interface is a "logical" interface composed of a series of protocol structures. Carriers and manufacturers map logical Xn interfaces to physical interfaces, such as optical fibers and copper cables, based on actual site conditions.

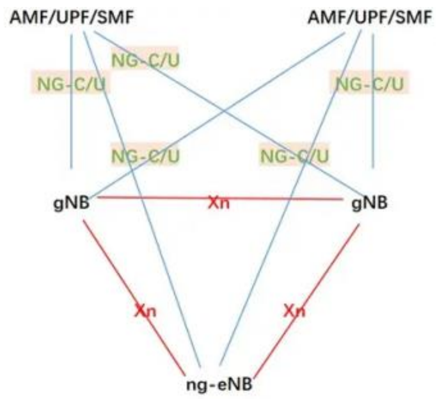

Figure 1. Framework of 5G network

3. Development of flexible electronics

Flexible electronics, also known as flexible or bendable electronics, refers to a field of technology that focuses on creating electronic devices that can be deformed or bent without losing their functionality. Traditional electronic devices are rigid and inflexible, typically built on rigid substrates like silicon wafers or printed circuit boards (PCBs). In contrast, flexible electronics utilize materials and fabrication techniques that allow for bending, folding, or stretching of the electronic components and circuits.

Flexible electronic devices are a component of the ubiquitous Internet of Things (IoT) ecosystem. In the human-computer interaction of the Internet of Things, the emergence and large-scale application of various flexible sensing devices will greatly expand the coverage of the Internet of Things, making the interaction with objects more convenient and comfortable. By integrating flexible electronic technology with material science, including advancements in biomimetic materials, it is possible to fully optimize the mechanical dynamic behavior of biomimetic systems. This can lead to the development of high-performance flexible electronic devices that can be used in a wide range of wearable and implantable devices, greatly enhancing the collection of health data and detection of diseases. As a result, the cross-integration of these fields can significantly enrich the methods used for health monitoring and disease diagnosis.

The development and commercialization of flexible electronics have led to numerous applications, including flexible displays, e-paper, wearable devices, flexible solar cells, biomedical sensors, and Internet of Things (IoT) devices. The International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) defines the Internet of Things as "an infrastructure of interconnected things, people, systems and information resources, combined with intelligent services that enable it to process and respond to information from both the physical and virtual worlds." [5]. Ongoing research in this field explores advancements in materials, manufacturing techniques, and integration methods to further expand the capabilities and potential applications of flexible electronics.

Flexible electronics has been a significant area of research and innovation, driven by the demand for lightweight, portable, and flexible electronic devices. The communication and bandwidth capabilities of 5G have reached unprecedented heights, making it an ideal solution for flexible electronics and Internet of Things applications that require wide coverage, high speed, and stability. Many IoT application technologies that are still in the theoretical or pilot stage can be put into use and made more widely known with the aid of 5G.

In the 5G era of the Internet of Things, more and more product scenarios require flexible display, touch, and other interactive functions. More flexible electronic devices are receiving attention, which is a flexible thin film chip.

4. Applications of 5G technology in flexible electronics

4.1. Flexible 5G antenna

At present, flexible electronics such as flexible circuits, flexible sensors, and flexible chips have good application prospects in wearable devices, implantable medical devices, soft robots, and other fields. As an important component of wireless communication, antennas can form flexible antennas if prepared using flexible substrate materials. Flexible antennas can be well integrated with other flexible electronic devices, achieving miniaturization, portability, flexibility, and foldability of equipment. Due to the thin substrate material of flexible antennas, the antenna design process needs to address issues such as bandwidth, gain, directionality, etc. in order to receive signals more conveniently in 5G sites network [6]. 5G base stations are distributed in a cellular manner, and on top of the existing 4G base stations, there are also many micro base stations to meet people's daily needs as shown in Figure 2 [7].

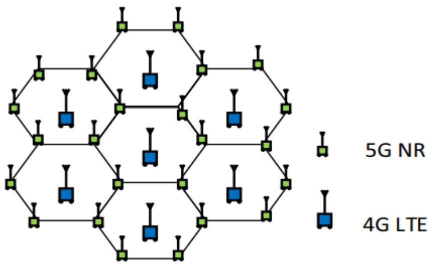

Figure 2. Web of 5G sites [7]

M. I. Ahmed et al. designed a dual-band millimeter wearable antenna for modern 5G applications to integrate on a smartwatch [8]. The antenna is a planar inverted-2F wearable antenna pasted on Jeans textile material. For the substrate, the dielectric constant $\varepsilon r = 1.78$, and loss tangent tan $\delta = 0.085$, which are measured using two different methods. This antenna is designed to operate at 28 GHz and 38 GHz with gain 1.45dB and 4.85dB, respectively. Moreover, the bending effect is studied. Flexible antennas can be installed in many places, such as clothing, backpacks, watches, and other wearable devices to receive signals. Compared with traditional antennas, flexible antennas have better flexibility and convenience.

4.2. Intelligent wearable device

Wearable electronics are currently quite popular among users as portable electronics. They can be worn directly as accessories on the body or decorated as clothing embellishments. The widespread adoption of intelligent wearable devices can be facilitated by the implementation of 5G technology [9]. In today's society where the number of users, connected devices, and data volume continue to grow exponentially, various applications such as cloud operations, virtual reality, augmented reality, intelligent devices, intelligent transportation, telemedicine, and remote control are increasingly demanding mobile communication. The mobility and IoT design of 5G technology can meet the growing demand for data. At the same time, 5G will form an intelligent, personalized, and large-scale communication network. At that time, intelligent wearable devices will achieve close and large-scale communication at the physical and network levels and will no longer rely on mobile phones or other devices as accessories to work.

Currently, the primary concerns regarding intelligent wearable device technology are centered around the implementation of new technologies, including data collection accuracy, data professional analysis ability, data transmission timeliness, personal privacy, and device security. By utilizing D2D (Device to Device) and Massive MIMO technologies, 5G technology can effectively address these issues. One of these technologies is D2D, which enables direct information exchange between nearby devices in communication networks. Another technology is Massive MIMO communication systems, also referred to as massive multiple input and multiple output technology [10].

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D2D technology is also known as Terminal Direct technology. D2D technology is a communication method where two user nodes communicate directly with each other as peers. Each user node in a decentralized network composed of D2D communication users has the ability to send and receive signals, as well as automatic routing functionality to forward messages. Participants in a network can process information, store it, and connect to other networks using a portion of their hardware resources. These shared resources offer the network services and resources, which other users can access directly without going via intermediary firms. In D2D communication networks, users can be aware of one another's existence and self-organize into a virtual or actual group thanks to the dual server and client functions that user nodes play. Massive data made available by 5G networks offer possibilities for the expert management of wearable intelligent devices. Users are divided into two categories in the D2D device research plan, restricted discovery and public discovery respectively. For restricted discovery users, users are prohibited from communicating with unfamiliar devices to ensure privacy and security; for publicly discovered users who are only neighboring devices, they can be detected and establish connections. The complexity of the connection is low, but the level of user privacy is poor in this mode. Both of these techniques are appropriate in certain circumstances. In situations where the network environment of the intelligent wearable device is good and there are many options available, limited discovery is used, while public discovery is used in situations where the network signal is poor or coverage is incomplete and when an emergency situation requires sending emergency information or requesting rescue.

Wireless transmission technology based on Massive MIMO can improve spectral efficiency and power efficiency by an order of magnitude on the basis of 4G while also improving transmission reliability. Multiple network users can leverage the spatial freedom offered by Massive MIMO to communicate with the base station concurrently on the same frequency resource when Massive MIMO technology is used to intelligent wearable devices. This greatly improves spectral efficiency without increasing the density or bandwidth of the base station. Moreover, beamforming technology can concentrate extremely low-energy beams in a small area, which greatly reduces the mutual interference between signals. Therefore, applying 5G technology to intelligent wearable devices will significantly improve their performance.

4.3. Remote Healthcare

The fast and low latency characteristics of 5G can better detect the health status of the human body, thus achieving remote medical treatment. Flexible sensors and wearable devices can collect health data and transmit it in real-time to medical professionals, enabling remote patient monitoring, accurate diagnosis, and timely treatment. The low latency and high reliability of 5G are crucial for seamless transmission of critical health data and support for remote surgery and consultation.

The flexible medical monitoring equipment prepared based on flexible electronic technology has rich functions, a light weight, a variable shape, and high adaptability to spatial structure. It can achieve functional flexibility and diversification through the components of the structurally flexible restructuring system and can conformally fit the human skin in shape. It can achieve functional flexibility and diversification through the components of the structural flexible restructuring system, and can conformally fit the human skin in shape. It has the capability to continuously monitor the human body over an extended period of time, without interfering with regular daily activities, and it can reduce measurement errors caused by changes in measurement position, meeting the requirements of precise measurement.

5. Discussion

The advent of 5G technology has enabled the rapid growth of the Internet of Things (IoT), but it has also presented significant challenges to communication security and privacy. The development and implementation of 5G networks must take into account potential future information security threats. For instance, user data is closely linked to user privacy, and during data transmission and exchange, different data access permissions must be established for different entities to facilitate data sharing while safeguarding the privacy of all participants. In summary, as the IoT continues to generate and transmit vast amounts of data, it is crucial to establish data confidentiality levels, clarify data ownership, and grant data rights to ensure the security and privacy of 5G communication networks and flexible devices. As far as current technology is concerned, it is not yet possible to produce large-scale integrated circuits using flexible electronics, so power and performance can be further improved. In the future, designing fully functional flexible electronics will be an important research direction.

6. Conclusion

Firstly, the 5G antenna designed with flexible electronic features can be more easily deployed in various places. Secondly, the high-speed and low latency characteristics of 5G and flexible detection equipment can better grasp the physical health status of patients, laying the foundation for remote medicine. Finally, 5G's D2D and Massive MIMO technologies have solved various technical issues of smart wearable devices, making them no longer dependent on mobile phones or other devices. This article only describes the application of 5G and flexible electronics in general, and there are many details about the technology that are not mentioned. In the future, flexible electronics combined with 5G will enter people's lives and provide better services. To improve performance, researchers are exploring new materials and technologies that can enhance signal transmission and reduce power consumption. Additionally, the integration of artificial intelligence and machine learning can enable more efficient use of network resources and improve the overall performance of 5G in flexible electronics. Overall, ongoing research and development efforts are focused on addressing the unique challenges of 5G in flexible electronics to unlock its full potential for future applications.

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