LiFi Technology Application and Prospect in the Field of Medical

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Abstract. Light Fidelity (LiFi) technology utilizes visible light as a transmission medium with a large spectrum and resistance to electromagnetic interference. Due to its unique characteristics, the use of light emitted by light-emitting diodes (LED) to transmit data makes it very safe when transmitting data. LiFi technology plays an integral role in many fields, such as aerospace, underwater communications, defense and security, and medicine. This paper introduces the basic working principle of LiFi. LiFi technology is used as a modulation technique for data transmission, and the current status of LiFi technology in the medical field is briefly analyzed, along with the challenges and difficulties encountered in this field. Examples include a medical monitoring system based on LiFi technology and the transmission of images in the operating theater using LiFi technology. In the medical field, LiFi technology also faces challenges and difficulties, such as ensuring the stability and reliability of communication and achieving efficient signal processing and data transmission. The potential of multiple-input multiple-output (MIMO) technology for in-depth research is described.

Keywords: LiFi; medical; MIMO; optical wireless communication.

1. Introduction

Modern civilization is growing at a quick pace, and scientific and technological advancements are what keep society moving forward and changing. Wireless communication systems have penetrated every aspect of people's lives and have become an extremely critical component of personal and professional behaviors. The need for wireless communications has expanded tremendously during the last few decades, resulting in a shortage of radio spectrum below 10 GHz [1]. Against this backdrop, visible light communication has begun to receive widespread attention as an emerging wireless communication technology. Using light, which is ubiquitous in daily life, as a transmission medium, visible light communication not only has the ability to utilize a very large and unregulated spectrum resource but also effectively avoids electromagnetic interference, providing a creative alternative to solving the problem of congestion caused by insufficient radio spectrum for wireless communication. LiFi, as a subset of visible light communication, utilizes visible and infrared light for downlink and uplink transmission, respectively, enabling high-speed, bi-directional, absolutely secure wireless communication [1,2]. Compared to traditional radio wave transmission, visible light transmission data speeds can be increased by nearly 100 times or more [3].

In recent years, the medical field has begun to explore the application of visible light communication and has gradually shown great potential and value. From complex internal communications in the operating room to detailed patient monitoring data transmission, visible light communication can show stable and efficient transmission performance, without worrying about the impact of electromagnetic interference on precision medical equipment. Since light cannot penetrate walls, this characteristic gives visible light communication a natural advantage in safeguarding the security and privacy of medical data. Looking to the future, with the continuous progress of technology and expanding application scenarios, visible light communication in the medical Internet of Things, remote surgical guidance, high-precision medical positioning, and other areas of application prospects will be broader.

This paper delves into the current state of LiFi technology's applications in the medical field, examining the challenges and difficulties encountered. Additionally, it explores future developments. The purpose of this comprehensive research and analysis is to provide meaningful insights and

references for the future development and implementation of LiFi technology within the medical realm.

2. LiFi Technology

2.1. Working Principle of LiFi Technology

LiFi technology transmits data using light from light-emitting diodes. The visible light spectrum spans from 350 gigahertz (GHz) to 700 GHz [3], which means that LiFi technology can make use of very rich spectrum resources, and will not face the same dilemma as the increasingly tense RF network spectrum resources.

Figure 1 shows its working principle is the need to send data after digital modulation using light-emitting diodes (LED) to send data, LED lights on and off state represents the basic elements of the binary digits, when the LED are on behalf of the number 1, when the LED are off on behalf of the number 0, the LED of the brightness of the situation is constantly changing to form a binary coding method. The photo diode sensor receives the light signal and converts it into a digital signal for digital demodulation to complete the data transmission.

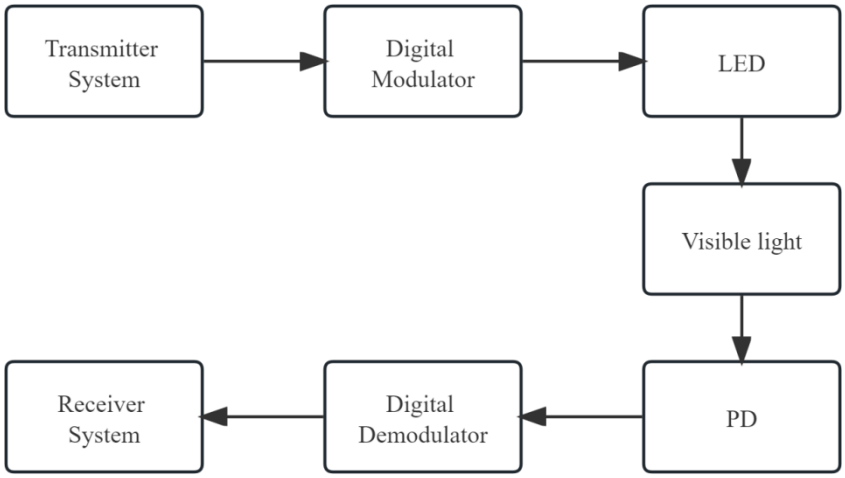


Fig 1. Diagram of the basic working principle of LiFi

2.2. LiFi modulation technology

The modulation technique used in LiFi technology is the process of converting electrical signals into optical signals for the transmission of data. In optical communications, the modulation technique is critical to improve transmission efficiency and reliability. LiFi technology can use either single carrier modulation (SCM) or multi carrier modulation (MCM) for modulated signal with process signal [4,5].

2.2.1. Single Carrier Modulation

SCM is the simplest modulation. It uses a single frequency or wavelength to transmit information. In LiFi system, SCM is usually transmit information by adjusting LED brightness. The benefits of this modulation technique include its simplicity, low cost, and good results when transmitted at short distances. It also has some drawbacks, being easily influenced to optical interference and multipath effects, resulting in a decrease in signal quality.

2.2.2. Multi Carrier Modulation

MCM uses many frequencies or wavelengths to transmit information concurrently. LiFi commonly employs multi-carrier modulation, which utilizes orthogonal frequency division multiplexing (OFDM)

techniques, multiple-input multiple-output (MIMO) techniques, and color-shift keying (CSK) [2,6]. By dividing a high-speed data stream into many slow sub-streams and individually modulating each one onto unique orthogonal sub-carriers, OFDM is a very efficient modulation technology. Multiple data signals can be transmitted concurrently and demodulated at the receiving end. The advantages of multi-carrier modulation are high-speed data transmission and better anti-interference ability. It is better able to adapt to different channel conditions because it uses many sub-carriers and provides better performance in complex transmission environments.

2.3. Security of LiFi technology

In wireless communication technology, protecting user secrets and data security is very important. LiFi has unique security advantages. Unlike traditional wireless communication technology, LiFi cannot penetrate walls, so data can only be transmitted within the room. The propagation distance of optical signals is relatively short, limiting the range of potential attackers. In addition, the directional transmission characteristics of optical signals mean that only specific photoelectric sensors can receive data. Therefore, LiFi technology has unique advantages in protecting user privacy and data security.

Researchers Hanaa Abumarshoud, Mohammad Dehghani Soltani, and others have deeply explored the security problems of LiFi systems [7], systematically analyzing the specific impact of the randomness of device direction and the partial knowledge of channel state information mastered by eavesdroppers regarding the system's effectiveness in terms of secrecy. For single eavesdropper and multi-eavesdropper scenarios, a detailed analysis is conducted on the changing law of secrecy ability and secrecy break-off probability. The results show that the number of eavesdroppers and the amount of channel state information they master have an effect on the secrecy feature of LiFi. Particularly in the case of several eavesdroppers, the secrecy capabilities of the system will be significantly impacted because the eavesdroppers may improve the signal's quality upon reception.

To improve the secrecy capacity of legitimate users, this paper innovatively proposes an access point selection algorithm based on machine learning. The algorithm fully considers the random behavior of the optical channel by optimizing the selection of access points, significantly improving the secrecy performance of the LiFi system. Experimental results show that the probability of an eavesdropper obtaining sensitive information can be effectively reduced by the reasonable selection of access points, providing a more solid security guarantee for the LiFi system.

2.4. Channel model for LiFi

In the communication system, it is very important to study the channel model because the channel is an indispensable part of data transmission. The channel model of LiFi is divided into indoor and outdoor. In the room, the channel model is generally composed of LED, air, and photoelectric sensors. The LED emits directional light signals, which travel through the air, and the photoelectric sensor receives the light signal. The indoor environment is stable, and there is no large amount of noise with high interference intensity, so the channel model is relatively simple when designing.

In the outdoor environment, there are different types and a large number of noises, such as sunlight, buildings, and temperature noise. These noises may cause optical effects such as refraction, reflection, and absorption of the optical signal, resulting in data transmission affecting the performance of the entire system. To ensure the reliability and stability of outdoor LiFi, it is crucial to understand the channel model. This not only helps to comprehend the propagation characteristics of optical signals in complex environments but also provides evidence for improving system performance.

Mohamed Amine Arfaoui, Mohammad Dehghani Soltani, and other researchers have studied a number of channel models and proposed several based on the measurement chamber to study the channel characteristics of indoor LiFi [2]. For static users, two channel models are proposed: MTL model and MB model. These two models consider the random orientation of the device and the location distribution of the user and explore both aspects, resulting in a gain effect on the channel. For mobile users, two other channel models are proposed: SMTG model and SMB model. The models

capture the effect of user mobility on channel gain. These channel models have profound academic significance because they not only take into account key parameters such as device orientation, user dynamics and statics, and location distribution but also provide a favorable reference for an in-depth understanding and accurate prediction of indoor LiFi system performance for today's research.

With the continuous progress of MIMO technology, LiFi combines MIMO technology to achieve multi-path transmission and spatial diversity, further improving the performance of communication systems. In MIMO, both the transmitting end and the receiving end can be configured with multiple antennas, and the parallel processing and spatial diversity of signals can be realized by multi-path transmission. This model not only significantly improves the signal transmission rate and reliability but also expands the coverage of the communication system.

3. LiFi application in the medical field

3.1. Smart Healthcare Monitoring

Real-time monitoring of patients' vital signs is essential in the intensive care units of hospitals. To achieve this objective, Mayasah R. Abdali, Ibrahim A. Murdas, and other researchers conducted a test in the intensive care unit (ICU) of a hospital [7]. The literature discusses a medical monitoring system using LiFi technology.

The system employs LiFi technology to transmit vital signs data from patients in the ICU to a cloud IoT platform at any time [8]. Through this platform, doctors and nurses can view patient-specific vital sign data online anytime to monitor and assess the patient's status.

Additionally, the system has an exceptional detection function. Once an abnormality is detected in a patient's vital signs, the system will send an alert to doctors and nurses via email or other means. This helps identify and deal with potential medical problems promptly, providing more timely and effective medical services to patients.

The medical monitoring system based on LiFi technology has a wide range of applications in intensive care units. It can provide doctors and nurses with a convenient, reliable, and anytime monitoring tool, improving the efficiency of medical services and the quality of patient care.

3.2. Medical Image Transmission

During surgery, doctors need comprehensive, any time information about their patients in order to make accurate medical decisions. This includes the use of various devices to obtain endoscopic images, ultrasound imaging, radiological images, and intraoperative pathological findings of the patient. The real-time transmission of these video messages is crucial for the smooth operation. As a result, higher demands are placed on network transmission performance, which is fast and efficient, especially for high-definition video data transmission.

In the operating theatre environment, scholars such as Sreelal Maravanchery Mana, Volker Jungnickel and others have conducted an in-depth study of the LiFi channel and verified the feasibility of using a multi-user MIMO (MU-MIMO) system.[6] The results of this research fully demonstrate the great potential of LiFi technology in hospital operating theatres. Through the application of MU-MIMO system, LiFi technology is expected to provide more stable and efficient data transmission services during surgery, thus providing surgeons with a more accurate basis for decision-making, and further enhancing the safety and therapeutic effects of surgery.

3.3. 3D indoor positioning

The blind community is a large and special needs group worldwide, and blind people face a variety of life challenges, especially navigation and positioning problems in indoor environments. They need a technology that can help them move freely and accurately in an indoor environment. Existing technologies such as WiFi and GPS have poor signals in indoor environments and cannot provide stable service. Therefore, indoor and outdoor location technology for blind people has become a research field of concern.

Although outdoor positioning technology has been relatively mature, 3D indoor positioning technology still faces many challenges. At present, there is no ideal implementation system that can provide high-precision indoor positioning, and the positioning speed is slow. To solve this problem, Xiaoxuan Qi, Li Du, and other researchers began to explore the use of LiFi technology to achieve indoor positioning [9]. Through the flashing of the LED light to transmit signals, when the LED light is rationally arranged in the building, it can not only achieve the lighting function but also transmit information. This technique provides a new way to solve the problem of indoor positioning. Based on LiFi technology, a concept for indoor positioning glasses is suggested. This plan distinguishes itself from other indoor locating systems, such as GPS and WiFi technology. The glasses have the potential to improve the quality of life for persons with visual impairments by providing accurate orientation and navigation inside indoor settings. The application of this technology will provide the blind with greater convenience and autonomy, enabling them to improve their quality of life.

The potential application value of LiFi technology in the field of indoor location for the blind is demonstrated. Through the reasonable arrangement of LED lights, combined with the transmission characteristics of LiFi technology, a highly effective and highly accurate indoor positioning solution can be provided for the blind. This not only improves the quality of life for those with visual impairments but also empowers them to navigate indoor spaces with greater convenience and autonomy. With the ongoing advancement and refinement of LiFi technology, anticipate witnessing more advancements and significant developments in its utilization within the medical domain.

4. Challenges of LiFi Technology

In the field of information transmission, LiFi technology stands out with its unique advantages, widely acknowledged for its safe and reliable data transmission method, high transmission rate, and rich spectrum realm. However, just like any technology, LiFi technology also has many inherent challenges.

In medical applications, LiFi technology faces the challenge of interference from many external light sources [6]. Strong light sources in the operating theatre, such as surgical searchlights, may have an impact on signal reception at the receiving end, resulting in inaccurate signals and large deviations. This interference poses a severe test for real-time data transmission during surgery.

LiFi technology is subject to some constraints, including visual impairment and a restricted coverage area caused by the specific properties of light propagation [10]. These limitations make LiFi technology restricted in some application scenarios. For example, the problem of occlusion needs to be solved, and the issue of multi-user access needs addressing to achieve wider coverage. The hybrid application of LiFi technology and Wi-Fi technology aims to find the balance point between the two [11], to leverage their complementary advantages, and to overcome the limitations of their respective technologies, providing a more stable and efficient data transmission solution in the field of healthcare and other fields.

5. Conclusion

Visible light communication technology has gained attention with the growing demand for wireless communication and the shortage of electrical spectrum. It uses light as a transmission medium with the advantages of a large spectrum and immunity to electromagnetic interference, providing innovative communication solutions for medical and other fields. This study examines the operational principles of LiFi technology and its modulation method. It also provides an in-depth analysis of the current status of the application of this technology within the domain of medicine. Additional investigation should prioritize the expansion of knowledge on MIMO modulation technology, aiming to facilitate the broader implementation of LiFi technology in the medical domain.

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