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Overview of Visible Light Communication: Past, Present, and Future

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Abstract: Visible light communication (VLC) is an efficient wireless communication with great development prospects, which is closely related to our daily lives especially for indoor applications. This paper first introduced the development process of VLC, and some significant milestones were emphasized. Then some key technologies, including OOK, VPPM, CSK, OFDM, PWM, were mentioned to provide readers with a deeper understanding of the working principle of VLC. In addition, the paper discussed some prospects of VLC, as well as its practical applications classified based on technical principles. Moreover, the author also pointed out the current difficulties and challenges, specifically mentioning the difficulties faced by OFDM technology in VLC system and its current development process. Some suggestions were proposed for future advancement. With continuous exploration and research, VLC will flourish in future wireless communications.

Keywords: Visible light communication (VLC), Wireless communication, LED, OFDM.

1. Introduction

From the introduction of the VLC concept in 1999 to the establishment of major global organizations and from the creation of OWC to the gradual improvement of indoor navigation systems, VLC has got on the long road and finally gained worldwide recognition. Researchers are currently exploring ways to break down the technological barriers of VLC. Such as optimizing core technologies to improve performance of the whole system, or reducing the impact of external interference on VLC through methods such as optimizing coding. This paper can provide a clear perspective to understand the current development status of VLC, which is beneficial for further research. It also predicts the development trend of VLC and opens up new avenues for future VLC research.

Grantham Pang from the University of Hong Kong proposed visible light communication in 1999, which was the first time this concept was introduced [1]. In 2000, Japanese scholars proved the feasibility of LED in home lighting, and the Wireless Home-link was proposed [2]. In no time, The Visible Light Communication Consortium (VLCC) was officially established in 2003 [3]. Two years later, the optimal combination and application of diversity technology in outdoor OWC was created [4]. In 2008, the International Infrared Data Association (IrDA) developed specification standards with VLCC [5]. In 2010, Japanese researchers practiced the application of GPS

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technology in VLC for indoor use [6]. In 2015, The United States has optimized the application of OFDM for indoor positioning, which improved the efficiency of indoor VLC [7].

Through literature review, this paper mainly discusses several key technologies of VLC, and mentions the applications and optimization solutions of these technologies, as well as solutions to some serious existing problems. The past development, current situation, and future trends of VLC have been introduced. VLC has been developing rapidly since its proposal. Due to its energy-saving and efficient characteristics, it is highly likely to be the mainstream communication method in the future. Since there are still some technological barriers, many issues have not been resolved. With the improvement of technology and optimization of solutions, VLC will definitely stand out and have great development prospects.

2. The key technologies Of VLC

2.1. On–Off Keying (OOK)

In this OOK process, it transmits data information by controlling the on and off of the light. Specifically, a light on represents1, while a light off represents 0. This is a common modulation method that is easy to implement and has a lower cost, which is widely used in human life [8]. OOK technology will also be further optimized in the near future. For example, improving modulation schemes and encoding techniques are a good way to make OOK more compatible with VLC.

2.2. Variable Pulse Position Modulation (VPPM)

This modulation variable pulse position modulation (VPPM) is similar to PPM, but the control allows changing the frequency signal value and expressing it as linear value with the basic signal value and distinguishing the ease of decoding and modulation design. But the signal is highly susceptible to the effect of noise and the transmitter signal is prone to loss because of the disadvantages of amplitude modulation, the pulse width supported by dim light [9]. Due to the low communication rate of VPPM, researchers have proposed the VPPM-CSK encoding modulation method, which can effectively ensure the frequency of white light output [10].

2.3. Color shift keying (CSK)

This is a modulation technique that utilizes the color shift of RGB LEDs to transmit information. CSK technology has a high communication rate and low transceiver manufacturing cost. And one of the disadvantages of this system is the complexity of synchronization technology at the receiving end [11]. With the pursuit of green environmental protection concepts, VLC combined with CSK technology will play a more significant role in multiple fields such as indoor positioning and intelligent transportation.

2.4. Orthogonal Frequency Division Multiplex (OFDM)

OFDM can effectively improve spectrum utilization by dividing high-speed data streams into multiple low-speed data streams and transmitting them in parallel on each orthogonal subcarrier, which is particularly significant for visible light communication. Through OFDM technology, algorithms can adjust power allocation dynamically, which can improve the reliability of the system. However, the overall design and implementation are both very complex. So more reasonable algorithms and techniques are needed to alleviate these problems. It is important to improve peak-to-average power ratio (PAPR) reduction techniques. A novel PE-ASCO OFDM scheme is

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proposed to reduce PAPR and improve spectral efficiency. It is a big success because it not only improves the impact of PAPR, but also controls the bit error rate (BER) [12].

2.5. Pulse Width Modulation (PWM)

In visible light communication, PWM can be used to modulate the light signals emitted by light sources such as LEDs, convert digital signals into changes in the strength of the light signals, and achieve wireless data transmission [13]. PWM technology can save energy and protect the environment while ensuring illumination. It is not only efficient but also highly adaptable. But concern is that it may also generate noise and harmful flicker to the human body.

3. Prospects and typical applications

It is obvious that VLC is closely related to every aspect of human life. For instance, Space Networks, Car Networks, Terrestrial Networks, and so on. Due to the extremely fast propagation speed and high cost efficiency of light, optical communication has always been a hot topic of concern for the public. And it is believed that it will continue to be a topic worth studying with great potential.

Visible light communication is closely connected to daily lives and has many common practical applications. For example, in Underwater Communication, light penetrates through water and the divers for data transfer purpose can combine use of the Li-Fi technology [14]. This paper classified them as follows based on their technical principles.

3.1. Application based on optical signal modulation and demodulation

This application mainly uses visible light sources (such as LED lights) to emit flickering signals. Convert digital signals into optical signals for transmission through modulation, and then convert the optical signals back into electrical signals through demodulation at the receiving end. This process can restore the original information in an efficient way. Considering the limited mobility of visually impaired individuals, an indoor navigation system that can provide directional assistance for them walking was established. This system can identify an individual's location within a building and guide them to their destination, which greatly facilitates the mobility of visually impaired individuals [15].

3.2. Application of MIMO technology

MIMO is a common technique that can utilize multiple LED lamps or receivers for data transmission in VLC. This way the speed and reliability of data transmission can be improved greatly. For example, In environments with severe electromagnetic interference (such as hospital operating rooms) or somewhere confidential communication is required, visible light communication combined with MIMO technology can be an effective alternative solution to provide stable and secure communication conditions. However, the combination of VLC and MIMO technology requires hardware innovation, which poses some difficulties in implementation. It may require designing efficient LED array layouts or high standards for receiver accuracy. It has great potential for development if technical issues can be overcome.

3.3. Application of CDMA technology

CDMA technology can encode signals from multiple users for data transmission at the same time, improving communication efficiency. In Multi User Communication, multiple users can send and receive information simultaneously or alternately. At present, there may be relatively few specific

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application cases and actual effects of CDMA in visible light communication. However, with the continuous development of VLC, multi-user communication technology will be applied and promoted in more fields.

4. Open research issues and challenges

Although visible light communication has greatly facilitated human lives, the fact is that there are still many problems and challenges to be solved. In order to further develop VLC, the key is to identify existing problems, determine their importance according to their severity. After proposing some solutions, screen them and conduct experimental research to determine feasibility. Here are some selected typical problems and brief scheme ideas.

4.1. Flicker

Flicker has a negative impact on human health, especially on the visual and nervous systems [16]. Long term exposure to flicker is most commonly accompanied by eye strain and headaches. Severe patients may experience sleep disruption and apparent slowing of motion. It has an impact on communication quality as well, since flickering can cause frequency instability and provides users with a poor experience. It also has difficulties in system design and implementation. To reduce these negative impacts, it is necessary to optimize system design, improve the stability and consistency of flicker frequency, as well as enhance environmental adaptability. For example, it is a good way to use the On off Manchester coded keying method to modulate data signals [17].

4.2. Light conditions

Lighting conditions have different requirements in different circumstances. Due to the dependence of VLC on visible light, its functionality is limited at night when there is insufficient illumination. Another example is that when the lighting is too strong, additional interference and noise may be introduced, which can also bring negative impact to the communication quality. The intensity of light directly affects the signal strength of VLC [18]. At the same time, the stability of lighting affects the signal stability of VLC. So it is important to take into account technical issues such as light source selection, sensitivity improvement at the receiving end, multipath effects and interference suppression, and so on.

4.3. Channel coding schemes

Channel coding schemes are closely related to bit error rate and transfer rate. It also determines the complexity and feasibility of the entire system. When choosing a coding scheme, it is necessary to consider comprehensively based on specific requirements. According to Babalola, a new coding scheme was proposed, which is flicker-free and improves the transmission efficiency for VLC [19].

4.4. Noise

Noise seriously affects the overall communication efficiency of the system. It can not only reduce system stability, but also provide users a poor experience. It is a good way to introduce noise suppression and filtering techniques to process the received signal, reducing noise components. According to S. Das, Manchester encoding is used to minimize the noise so that the communication quality could be improved [20]. Besides, the layout and the light source can be optimized to reduce the scattering and reflection of light signals during transmission, which also help minimize noise interference.

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5. Conclusion

This paper reviewed some major advances, key technologies, practical applications, and challenges of VLC. With the development of technologies and the upgrading of equipment, it is believed that VLC will have a bright future in wireless communication systems. Despite the fact that there are still many unresolved issues, VLC remains one of the most inspiring innovations for the future.

At the same time, there are also some issues such as insufficient references and lack of experimental research. In the future, this paper will collect more relevant research materials, expand and polish the data, and also improve the persuasiveness.. The main research direction in the future will focus on optimizing and improving the application of visible light communication technology in traffic management. There is hope for improvements in traffic congestion and emergency response to traffic accidents.

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