Application Analysis of Indoor Visible Light Communication System

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Abstract. The technology of using light-emitting diodes as light source for visible communication is one of the hot spots in the field of optical wireless communication. This paper analyses the characteristics of visible communication technology, focuses on the key technologies needed for the realization of visible communication system in a specific room, and studies the feasibility and application prospects of indoor visible communication combined with the development status at home and abroad.

Keywords: Light Emitting Diode, Visible Light Communication, Indoor Wireless Communication

Introduction
At present, Bluetooth, Wi-Fi, WiMax and LTE are the main technologies for indoor wireless communication applications. However, with the development of society towards high-power light-emitting diodes (LED) based on solid-state lighting, engineers with innovative thinking put forward a proposal: Why not use LED to transmit data? This proposal is the theoretical basis of Visible Light Communication (VLC). Visible communication system transmits information by using high-speed light and dark flickering signals emitted by fluorescent lamp or white LED, which can not be seen by naked eyes. Wire devices connected to the network are connected to lighting devices, and can be used by inserting power plugs. The system can cover the range of indoor lighting, and the computer does not need wires to connect. In this paper, some specific problems of indoor application of VLC system are studied and analyzed to a certain extent.

1. Research Status and Characteristics of VLC

1.1. Research Status of VLC Technology
The research work on the VLC system composed of white LED lighting was first carried out in Japan and received the attention of the Japanese government. The Ministry of General Affairs plans to work with NTT Research Institute and NEC Company to develop a "visible light communication" system that uses lighting to transmit high-speed information, according to the Science and Technology Daily. The Japanese government will popularize this technology as the next generation broadband network, which is expected to be practical in five years [1].
After the announcement of VLC technology in Japan, Germany, Britain and the Netherlands realized its importance and started their work one after another, and established a professional technical forum to conduct extensive exchanges and cooperation on VLC. On the basis of the achievements made in Japan, they focus on the technical difficulties of how to improve the communication performance [2]. The United States also launched VLC technology research. A US government-sponsored “Smart Lighting” project, involving researchers from more than 30 universities, attempted to use visible light beams to communicate between wireless devices and LED lighting devices. Moreover, in 2008, IEEE established a special visible light communication group (IEEE802.15.7). At present, the main research institutions are the Semiconductor Research Institute of the Chinese Academy of Sciences. The researchers include Ke Xi-zheng of Xi'an University of Technology, He Sai-ling of Zhejiang University, Chen Zhen-qiang and Chen Chang-ying of Jinan University [3].

1.2. Technical Characteristics of VLC

Compared with the current wireless local area network (WLAN), the visible light communication system can use lighting equipment to replace the base station of WLAN to transmit signals. Its characteristics are as follows:

First, the speed of communication is fast: up to tens of megabits to hundreds of megabits per second. German researchers recently set a new record of 500 megabits per second for visible optical communication transmission, and the use of multiple computers at the same time will not affect the speed of communication [4].

Second, low cost: VLC system has no requirements for network operators and computer equipment, as long as it is an ordinary external network can access. At present, the white LED lamp sold on the market only has lighting function. If it is used for communication, it only needs to install a small "instrument" on the white LED, so that it can achieve high-frequency flicker. The working frequency of white light is between 380 and 780 nm, and there is no harm to human eyes in this frequency band.

Third, the construction speed is fast: using dedicated computers and mobile information terminals which can receive and transmit signals, as long as the indoor light shines, high-definition video and animation data can be transmitted. The communication signal is directly carried in the area where the district wires are connected. At that time, whether the street lamp of the district or the indoor lighting lamp, the network signal can be sent.

Fourth, High security and reliability: Cover the light with curtains, and the information will not leak out to the outside. In addition, because of the non-use of radio frequency signal communication, airplanes, hospitals and other places sensitive to electromagnetic signals can freely use the system without any hidden dangers.

Fifth, Green environmental protection: The coverage area of traditional wireless networks depends largely on the capability of wireless routers. Wireless routers emit radio frequency signals when they are used. Although this kind of radio wave has not been proved harmful to human body, it is not green after all. In contrast, the use of LED for indoor visible light communication, in order to meet the requirements of people’s daily lighting (such as light regulation), no harm to the human eye, no impact on the surrounding environment [2].

2. Feasibility Analysis of VLC System Applied in Indoor

2.1. The LED Lighting Market is Becoming Larger and Larger

Despite the high efficiency of LED lighting, the scale of the lighting market has been very small in the initial application due to the high price. But in recent years, the price of LED lighting system has been declining. More importantly, because of the energy-saving advantages of LED lighting products, its market demand is huge under the escort of a series of policies. With the overall promotion of low-carbon economy, green lighting has been highly valued by governments. That is to say, government policies and subsidies will attract more commercial markets. In recent years, Japan’s "21st Century Light Plan", "Next Generation Lighting Plan" of the United States, EU’s "Rainbow Plan" and Korea’s "GaN
Semiconductor Luminescence Plan" have been launched and developed rapidly. The "Development Opinion of Semiconductor Lighting Energy Saving Industry" jointly issued by the National Development and Reform Commission and the Ministry of Science and Technology of China also puts forward a clear goal: by 2015, semiconductor lighting energy saving will be achieved. The average annual growth rate of industrial output value is about 30%, and functional lighting is about 20% \cite{5}.

Overall, the development of LED lighting industry in the world has reached a large-scale level. The key technical products have matured. The quality and reliability of products have been significantly improved, and their share in the lighting market has become larger and larger.

The expansion of LED in the lighting market will inevitably bring great opportunities for the development of LED-based VLC system.

2.2. Indoor Communication Environment is Suitable for VLC System

VLC system is generally divided into outdoor communication and indoor communication. This paper mainly studies indoor VLC system. VLC system has the following advantages in indoor communication:

I. Indoor non-interference channels are suitable for VLC systems

VLC system is really difficult to implement because it chooses the most complex channel - atmosphere to transmit data. Atmospheric components are complex and vulnerable to weather changes, which will certainly bring many variables to wireless optical communication, and reliability will be affected by many external factors \cite{6}. For example, heavy rain, smoke or dust on the links of visible light systems can destroy the integrity of information. However, the indoor atmospheric channel is good, and the external interference is very small. Therefore, if VLC system is applied indoors, there is no such interference problem.

II. Indoor Communication Distance Suitable for VLC System

VLC system is limited by the emission power of white LED. It is impossible to transmit too far. In previous experiments, the maximum distance of signal transmission is 1 km~2 km \cite{7}. If it is applied outdoors, it is insufficient. It needs relay technology. But when it is applied indoors, the communication distance of 1 km fully meets the requirements.

Therefore, the application of visible light communication system in outdoor also needs to do in-depth research on white LED materials and other factors. If it is applied indoors, it can be achieved by using existing laboratory technology.

2.3. Laboratory Research has been Successful

Japan is the pioneer of VLC technology, and has taken the lead in a series of basic theoretical research, using LED arrays to achieve single-tube transmission rate of 5 Mbit/s data transmission \cite{8}; Germany, Britain and other European countries in Japan on the basis of a series of research and development on improving the performance of VLC communication, to achieve point-to-point communication based on white LED; the United States has developed a point-to-point communication based on LED lights. Demonstration system of point data transmission. These successful experiments show that VLC technology has the possibility of practicality.

3. Design of Indoor VLC System
Figure 1. Distribution diagram of indoor computers

For the convenience of discussion, a specific laboratory is given as an example, assuming that the computer layout in a laboratory is shown in Figure 1. If the traditional way of networking is adopted, dozens of twisted pairs are needed to connect the local area network of dozens of computers through switches or routers, and the layout and placement of cables need to be considered. If the VLC system is adopted, the problem of cable need not be considered, and it has the advantages of fast construction, fast transmission rate, security, environmental protection and so on.

The structure of indoor VLC system is shown in Figure 2. It consists of computer, VLC Hub, VLC adapter, white LED array, photoelectric detector and corresponding signal processing unit.

Figure 2. VLC system schematic diagram

3.1. Working Principle of VLC System
The information of computer end users is transmitted to the photoelectric detector on the ceiling by VLC adapter; the photoelectric detector converts the received optical signal into electrical signal and sends it to the VLC hub; the VLC hub then simply processes the received user’s optical signal and transmits it by broadcasting through the white-light LED array light source (4 white-light LED arrays in Figure 2). At the receiving end, the VLC adapter of the computer demodulates the received information and sends it to the end user (each computer) to realize the communication in the LAN. In the process of establishing communication link, in order to identify different user information, multiple access technology (OCDMA) is adopted as the system’s multiple access communication mode [9].

3.2. Working Principle of VLC Hub and Adapter
VLC hub is the core component of VLC system. On the one hand, the unit receives information from computer users. On the other hand, the received information is transmitted by broadcasting through white LED array light source in different time periods. Computer users in the network receive the information of white LED array light source, and judge whether the information belongs to themselves by user address, and if so, receive it.
VLC adapter is a communication device for computer users to send and receive optical signals. In order to make full use of the resources of the existing wired LAN, 10Base-T Ethernet card is chosen as the interface card between the adapter and the computer. When transmitting data, the data format conversion unit first converts Manchester differential signal of Ethernet into non-return-to-zero code suitable for visible light transmission. After conversion, the corresponding spread spectrum code is selected according to the destination address to spread spectrum. After spread spectrum, the driver circuit drives the user light source to send out light signal. When receiving data, the photoelectric detector receives the light signal of white LED array light source and converts it into the corresponding electrical signal, and then recovers the original signal after filtering and demodulation. Because the white LED array light source transmits the signal by broadcasting, the received signal is not necessarily the signal needed by the user, and must be processed by the despreading unit. If the address code of the signal matches the local address code, the user information can be recovered correctly, otherwise it will be discarded. After the data format conversion unit, the recovered user information can be sent to the terminal computer through the Ethernet card.

3.3. Light Source Design and Layout
In this system, there are two kinds of light sources: user light source and LED array light source. Each computer’s VLC adapter has a user light source. The user light source can use a single white LED lamp. The LED array light source installed on the ceiling needs to be designed as an array composed of multiple white LEDs to take into account the lighting requirements and luminous power.

In order to cover the whole room, a large radiation angle is usually used in the design of white LED lamps for indoor lighting. However, due to human activities and equipment occlusion, it will form a "shadow" on the surface of the receiver, affecting the communication effect. For lighting, the more lights installed in the room, the brighter the room will be. It can also effectively solve the "shadow" problem, and the receiving power will increase day by day. But for communication, blindly increasing the number of lights will cause interference between signals. Because different light sources and receivers have different paths, multiple different paths will cause multipath delay, resulting in intersymbol interference (ISI). The more the number of lights, the more serious the ISI. Therefore, the number of white LED lamps must be selected reasonably. Literature [3] after studying the shadow problem, the simulation results show that when the system code rate reaches 800 Mbps, the optimal number of lights is 3-4. This system takes into account the size of the room and the size of the house, and uses four LED array light sources.

In order to achieve the optimal communication effect, it is necessary to arrange the layout of LED array light source reasonably so as to minimize the variation of light power distribution on the same horizontal plane in the room. Assuming that the position of any point on the horizontal plane with the height of H is (x, y, h) and the four white-light LED arrays on the ceiling are symmetrically distributed (the power of each LED in the array is the same), the coordinate position of a white-light LED array light source is (X, Y, H). The "average deviation" of the power at each point is expressed by the variance D of the received power. The expression can be obtained from reference [1]:

\[
D = \frac{1}{S} \sum_{i=1}^{N} \iint_{L} \left( f(u_i, v_i, x, y) - \overline{P_r} \right)^2 \, dx \, dy
\]  

(1)

Among them: S is the area of the room, L is the area, \( \overline{P_r} \) is the average power of each point on the plane, and N is the number of LED lights. The partial derivatives of X and Y can be obtained by formula (1). When \( \frac{\partial D}{\partial X} = \frac{\partial D}{\partial Y} = 0 \), the optimal X and Y can be obtained, so that the optimal layout of each white LED array light source can be determined.

3.4. Photoelectric Detector (PD)
Photoelectric detectors are used for receiving and converting optical signals. At present, the commonly used photodetectors are PIN photodiode and avalanche photodiode (APD). In the design, APD is used as
light detection, which has strong ability to detect weak light signals. The light-emitting power of LED is generally relatively small, so this feature of APD is very suitable for indoor VLC system. Experiments show that in the system shown in Figure 2, when the emission power of four sets of LED lamps is 20 mW, the surface area of APD is 1.0 cm and the photoelectric conversion efficiency is 0.53A/W, the data with code rate of 200 Mbps can be received effectively\cite{5}.

3.5. Adaptive Orthogonal Frequency Division Multiplexing Technology

Orthogonal Frequency Division Multiplexing (OFDM) modulation technology can be introduced to improve the data rate of VLC system. The basic principle of OFDM technology is to transform high-speed serial data into multiple relatively low-speed parallel data and modulate different carriers. For VLC systems, multipath transmission is the main reason for introducing ISI, which limits the communication transmission rate. Because OFDM has a strong anti-multipath capability, the use of OFDM can also reduce the impact of ISI\cite{10}.

In reference\cite{2}, an adaptive OFDM technology is proposed. Fixed threshold method and optimal modulation mode selection criteria are used for system analysis. The simulation results show that the performance of the adaptive OFDM system is better than that of the fixed modulation mode OFDM system. The latest information shows that the OFDM modulation increases the redundancy of VLC system to some extent, but the simulation experiments prove that the adaptive OFDM technology can stabilize the bit error rate at a lower level under the same signal-to-noise ratio.

4. Application Prospect Analysis of Indoor VLC System

4.1. Benefiting from the Development of Lighting

White-light LED lamp itself has high luminous efficiency, low power consumption, green, environmental protection, highlighting its advantages of "energy saving and emission reduction", and "energy saving and emission reduction" is an urgent problem faced by all countries both now and in the future. Therefore, using white-light LED for lighting is the future development trend, and the indoor VLC system based on white-light LED also has great potential. Force, but also to solve the existing radio band resources shortage provides a new way of thinking, therefore, indoor VLC system development prospects are bright.

4.2. Breakthroughs have been Made in Experimental Technology

In July 2010, "Military and Civil Dual-Use Technology and Products" reported: "Japan Outstanding Technology Company successfully completed the transmission of 13km long-distance analog speech signal using a LED light source\cite{11}.

According to the Science and Technology Daily, "German Siemens Co. issued a communique on January 15, 2010 that scientists from the company and Heinrich Hertz Institute have made light emitting diodes (LEDs) scintillate at high frequencies in a special way. Nearby photodetectors will receive such light signals and convert them into electric pulses, with the speed of information transmission reaching 500 megabits per second."\cite{5}

According to the above two points, visible light communication technology has achieved great breakthroughs in transmission distance or transmission speed. Although only low-speed analog speech signals are used in experiments in Japan, the distance of high-speed transmission in Germany is not clear, but I believe that with the further development of science and technology, high-speed, large-capacity and long-distance visible light communication distance practicality will be closer and closer.

The above shows that the application of Visible Light Communication (VLC) system not only meets the requirements of global energy saving and emission reduction, but also invests manpower and material resources in various countries. The development of technology is very rapid, and VLC system is gradually on the road of practicality.

5. Conclusion
When VLC system is used in indoor environment, there are many kinds of interference such as reflection and diffuse in enclosed space, which leads to high bit error rate of communication. In order to overcome these problems, it is necessary to improve the transmission quality and efficiency by improving peripheral circuits, optical systems and some error correction coding techniques. However, with China's "energy saving and emission reduction issues" included in the "Twelfth Five-Year Plan" of the major research topics, LED indoor lighting will become more and more popular, set lighting and data transmission in one of the dual functions of indoor visible light communication (VLC) system facing technical problems will soon be resolved, VLC system will have a broad application prospects.

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