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Research Paper

Study on non - audible acoustic communication uplink for bidirectional visible light communication

Doohee Han [1] *, Kyujin Lee [2]

[1] *Kyung Hee University, Seocheon-dong, Giheung-gu, Yongin-si, Gyeonggi-do, 446-701, Republic of Korea*
[2] *Professor, Department of Electronic Engineering, Semyung University, 65 Semyung-ro, Jecheon-siChungcheongbuk-do, 27136, Republic of Korea*
**Corresponding author E-mail: hdh9038@khu.ac.kr*

Abstract

Background/Objectives: In this paper, we present a problem of conventional unidirectional visible light communication and limited bidirectional visible light communication, and propose a suitable uplink feedback communication structure.
Methods/Statistical analysis: In the visible light communication environment using only the conventional LED, bidirectional communication for feedback of user data information between the transmitter and receiver is limited. When all the receiving devices transmit the feedback information through the LED light source, it is inconvenient for the users due to the unnecessary light source generation in the indoor lighting environment due to the characteristics of the visible light communication system performing both the communication and the illumination. In addition, interference due to a plurality of light sources occurs, and the performance of the system is deteriorated.To solve this problem, we propose the uplink system configuration using the non - audible band acoustic wave communication in the visible light communication system.
Findings: The uplink transmission is a necessary function for transmitting the feedback information of the terminal, and a transmission scheme capable of ensuring sufficient transmission distance, interference elimination of LED illumination, and power efficiency should be used. In this paper, we have solved the problem of optical interference between downlink transmission and uplink transmission by securing transmission distance using non - audible band acoustic communication.In addition, the problem of the conventional unidirectional visible light communication can be solved by actively transmitting a signal to a channel state change due to communication distance or communication environment change through state information and position information feedback of devices using non-audible sound wave communication.
Improvements/Applications: The non-audible sound wave communication uplink system can be applied as fusion technology to various environments such as an IoT network environment requiring a bidirectional network or an indoor small-scale network configuration and a home network configuration.

Keywords: *Visible Light Communication; Uplink; Non-Audible Sound Wave Communication; Fusion Technology; Two-Way Communication*

1. Introduction

Recently, visible light communication has attracted attention as an illumination-IT fusion technology due to the development of LED devices. With the development of smart devices, IoT technology has become a hot topic, and with the advent of next-generation convergence technology, active research is underway. KSR is a technology that simultaneously provides communication with lighting using LEDs. It is a high-value-added technology because it can build a network environment.Because it uses LED which has high-speed response characteristic, it does not use RF, so it does not need frequency permission, can use wide LED bandwidth without existing frequency interference, has excellent physical security function and can transmit high-speed multimedia data. Is considered as a next-generation home networking medium to replace radio waves.[1]The development of technology for visible light communication started in 2000 with the publication of the results by Keio University in Japan and the VLCC in Japan. VLCC (Visible Light Communication Consortium) is a consortium in Japan for standardization of visible light wireless communication and technology development. Under the leadership of Keio University, industry-academy and research institutes such as NTTDoCoMo, KDDI, Matsushita, NEC, Casio, AvagoJapan, Sony, and Toshiba joined VLCC. Keio University is the first place to start research on visible light communication. We developed the position detection visible light communication system which collaborates with Nippon Electric and Matsushita Electric to form the structure and channel modeling for the visible light communication in the indoor lighting environment and to provide the accurate position of the terminal by modulating the position information to the illumination light. In recent years, research is being conducted on a structure that increases transmission distance and speed by receiving different data emitted from 64 LEDs using a 2D image sensor instead of a PD. However, in the visible light communication environment using only the conventional LED, bidirectional communication for feedback of user data information between the transmitting and receiving sections is limited. As a fusion technology, a bi-directional communication system is indispensable for application to various fields of networking infrastructure. However, due to the characteristics of the visible light communication system that simultaneously performs the functions of communication and illumination, if all the receiving devices transmit feedback information through the LED light source, unnecessary light sources are generated in the indoor lighting environment, The performance of the system is deteriorated. In this paper, we present a problem of conventional unidirectional visible light communication and limited bidirectional visible light communication, and suggest a suitable uplink feedback communication structure. The problem of unidirectional visible light communication which is difficult to cope with occurrence of shadow region or data discontinuity is solved through uplink user data feedback using non-audible band acoustic wave communication, and a technique of satisfying the condition of uplink required in bidirectional visible light communication Respectively.

2. Bidirectional visible light communication system environment

2.1. Channel model

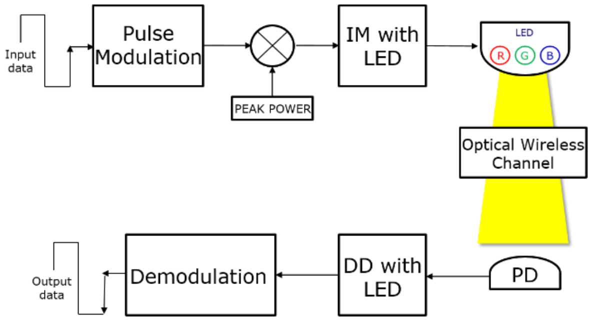

Fig. 1: VLC System Structure.

Figure 1 shows the overall structure of the VLC system. In the VLC downlink system, the transmitter and the receiver transmit and receive information using the LED illumination light source. The transmitter converts an information signal from an electric signal to an optical signal and transmits the signal. The receiver uses a direct modulation / demodulation scheme in which a light source containing information is received through a PD and converted into an electric signal. The speed at which LEDs convert electrical signals to light signals is about 30 ns to 250 ns, which enables data communication through data modulation through this fast on-off switching. The channel between the transmitter and the receiver is an air surface, consisting of a line of sight (LOS) channel, a None Line of Sight (NLOS) channel, and background noise from other sources. Background noise from other light sources is assumed to be a white Gaussian noise model. The reflection light reflected from the wall is modeled by the Lambertian radiation intensity pattern. The VLC channel is a white Gaussian noise (AWGN) model.[2], [3], [4] The receiver uses a narrow band optical filter. The transmission quality in the optical channel is affected by shot noise. The effect of shot noise coming from the ambient light source in the system can be neglected as a Gaussian noise process. For this reason, the received signal is expressed as follows.

$$R(t) = \gamma S(t) * G(t) + N$$

R(T)denotes a received signal, and S(t) denotes a transmitted optical pulse signal. N denotes AWGN, $*$ denotes a convolutional code, and γ denotes an optical / electrical (O / E) conversion efficiency value.

The position of the transmitter is represented by $S = (r_s, n_s, n)$ (position vectorr_s, direction vectorn_s, mode number of radiation loben), $D = \{r\_D, \hat{n}\_D, A\_D, FOV\}$ (position vectorr_D, direction vector$\hat{n}_D$, receiving areaA_D, field of view (FOV)). In an indoor environment with a reflective surface, the channel impulse response can be expressed as:

$$G(t;S,D) = \sum_{k=1}^{\infty} G^{k}(t;S,D)$$

Here, $G^{(k)}(t)$ represents the impulse response of the signal that is reflected k times. The high-order terms of the channel impulse response considering the LOS signal are expressed as follows.

$$G(t;S,D) = \int G^{(0)}(t;S,\{r,\hat{n},\pi/2\},dr^2\} * G^{(k-1)}(t;\{r,\hat{n},1\},D)$$

Here, r represents the position vector on all the reflection surfaces S. $\hat{n}$ represents the unit normal vector at the position r in the reflection plane S, and dr^2 is the diffraction plane at the positionr of the reflection surface.

2.2. Unidirectional visible light communication system transmission model

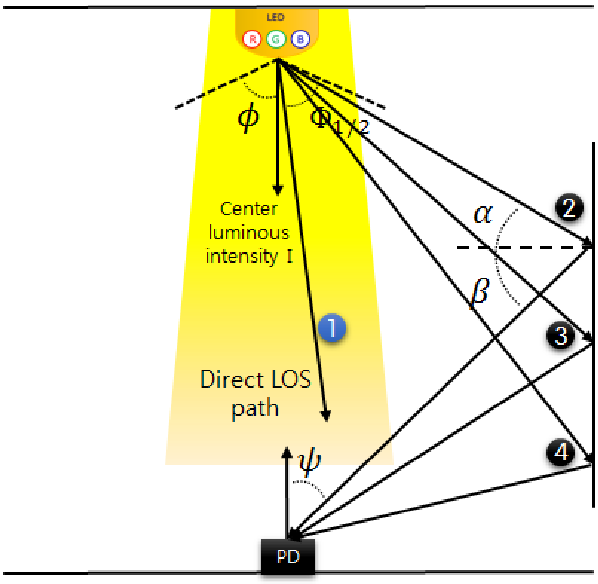

Fig. 2: Optical Transmission Model of Visible Light Communication.

Figure 2 shows a typical transmission model of visible light communication. In general, light has a characteristic that it is widely dispersed indoors and can function as illumination by the emission of such light. In the visible light wireless communication using LED illumination, the received signal by the light source forms different optical paths according to the delay characteristics of the direct light and the reflected light as shown in the figure. Here, the reception signal by the direct light is an environment in which there is no obstacle obstructing the light between the LED illumination and the receiving PD like the (1) signal. ②, ③, and ④ signal are received signals by reflected light and refer to the environment where light is reflected by obstacles such as walls, windows, and tables in the room. In general environment, the signal of ① is higher than the signal of ②, ③ and ④, so there is no special problem due to interference. [5], [6]

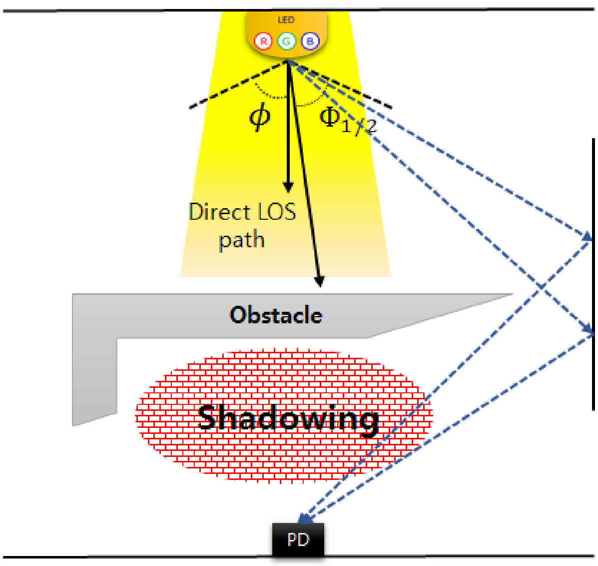

Fig. 3: Creation of Shaded Areas Due to Obstacles.

However, as shown in Fig. 3, when an obstacle is generated between the transmitter and the receiver, a shadow area is generated in the direct light path and a temporary communication disconnection occurs. However, since it is difficult to transmit the channel feedback in the uplink in the environment of the uni-directional visible light communication, it is difficult to variably cope with the degradation of the data reception rate due to the shadow area, and the performance of the system is significantly degraded.

In addition, since it is difficult to configure a networking environment that requires feedback of user data, there are many restrictions to be used in constructing a network infrastructure in various fields.

2.3. Bidirectional visible light communication system

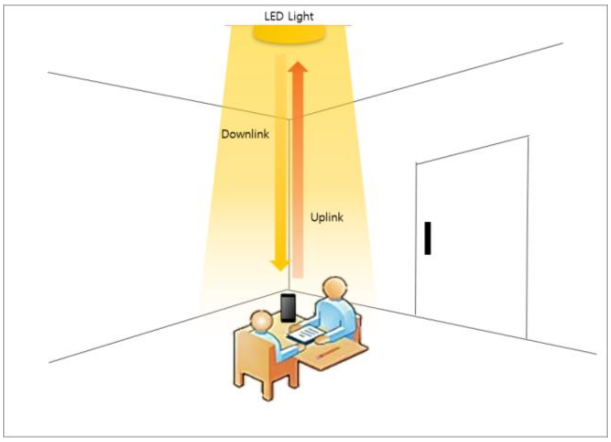

Fig. 4: Bidirectional Visible Light Communication System.

As described in figure 4, in the unidirectional visible light communication, since the channel state feedback or the user data can not be transmitted in the uplink, the use range is extremely limited. In a typical networking environment, an uplink is required. However, one of the problems of the bidirectional visible light communication implemented up to now is that it is not easy to transmit upward from the terminal to the illumination direction. As shown in Fig. 5, each of the devices having mobility, unlike the transmission bridge fixed at the upper end, can prevent the transmission distance due to the degree of condensation when using the visible light in the uplink, the interference caused by the transmission light source, The system malfunctions occur. In the case of RF or Bluetooth, it is not suitable for use in a visible light communication environment having an advantage of free from radio interference since an environment in which radio waves are used must be added. Upward transmission is a necessary function for networking requiring bidirectional transmission, and a transmission method capable of ensuring sufficient transmission distance, interference elimination of LED illumination, and power efficiency should be used.[7]

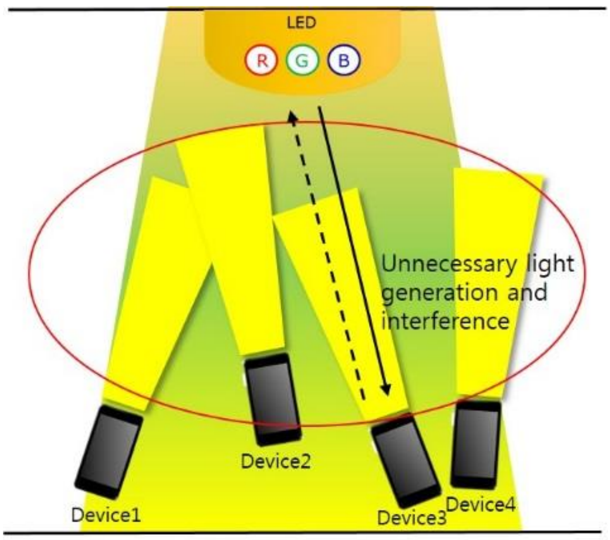

Fig. 5: Bidirectional Visible Light Communication System Environment.

Upward transmission attempts have been made using several methods, but satisfactory solutions have not been proposed yet. Upstream transmission is also excluded in the visible light communication standard created in IEEE 802.15.7.

3. Uplink for bidirectional visible light communication

Bidirectional communication refers to communication capable of simultaneously implementing downlink transmission and uplink transmission. In the case of configuring visible light communication in the form of an illuminated light, transmission from a fixed AP (Access Point) including a LED lighting lamp to a mobile STA is referred to as downlink transmission, and transmission from an STA to an AP is referred to as uplink transmission. In the case of a terminal used for uplink transmission, mobility is considered, so that a relatively small amount of data is fed back to the uplink, and the asymmetric link configuration is considered do.

3.1. Non-audible sound wave communication uplink feedback

The conventional visible light communication system is generally a unidirectional communication or a transmission model in which uplink is not considered due to limited bidirectional communication. Recently, studies on visible light communication uplink have been actively conducted, but it has been difficult to construct a system satisfying a special environment using a visible light source. As described in Section 2, visible light communication using only LED light source in actual indoor environment is poor in flexibility and system performance is degraded due to interference between a plurality of light sources.

In this paper, we propose a method to satisfy the advantages and specificity of existing visible light communication system by constructing uplink through non - audible sound wave communication to solve this problem.

3.2. Non-audible sound wave communication

Sound wave communication is a communication technology that transmits information by using a sound wave as a medium, and it is divided into an underwater sound communication and a standby sound wave communication depending on the kind of a medium in which sound is propagated. The sound wave has the characteristics that the propagation speed is faster and the transmission range is larger in the medium of high density. Therefore, in the past, research has focused on underwater sound communication such as underwater sonar detection technology and marine ecosystem monitoring sensor network. However, as interest in the sound communication in the air utilizing the built-in audio interface of smart devices has increased recently, related researches are actively being carried out. In the air, sound wave communication is a technique of communicating by placing information on sound waves in the air. Compared to underwater sonar communication using water, the transmission distance is as much as 10 meters because of the large loss of sound waves in the air. For this reason, different transmitters can be used depending on the communication operating frequency. Ultrasonic transceivers are used for 22 kHz or more, and general audio interfaces for reproducing and recording audio for 22 kHz or less. [8].

3.3. Transmission signal model of sonic communication

Most microphones in our audio and smart devices that we have easy access to can usually play or record frequencies up to 22.05kHz. However, the inherent characteristics of the frequency response of these devices are different. In the case of a microphone built in a general speaker or a smart device, communication performance in a non-audible band is relatively low because the microphone is optimized for components up to the audible range. In the case of the PSK signal, the transmission efficiency of the signal is very good, and it is mainly used in the mobile communication fields such as CDMA and LTE. However, unlike the mobile communication field, in the case of the sound wave communication, since the frequency band of the signal uses a frequency band relatively lower than that of the mobile communication field, the possibility of signal distortion is considerably high. On the other hand, the chirp signal has a merit that it is simple in structure due to the technology based on the analog circuit, so the throughput is relatively low and the power consumption is not high.

Chirp signal is a signal widely used in RADAR communication because of its ability to separate multiple receiving components by multipath propagation. The chirp signal has a feature of sweeping not only one frequency component but also a specific frequency band. This chirp signal, also referred to as a linear filter, is referred to as an up-chirp when the frequency linearly increases and a down-chirp when the frequency linearly decreases. The expression of this linear chirp signal is as follows. [9], [10]

$$S_1(t) = \cos(2\pi f_L t + (\mu t^2)/2) \quad 0 \leq t \leq T$$

$$S_2(t) = \cos(2\pi f_H t + (\mu t^2)/2) \quad 0 \leq t \leq T$$

Here, $S_1(t)$ is the up chirp and $S_2(t)$ is the down chirp equation. The expression of μ, which means the amount of frequency change, is as follows.

$$\mu = (2\pi(f_H - f_L))/T = 2\pi B/T$$

Where B is the frequency band and T is the duration of the symbol. f_L means the lowest frequency in the frequency band, and f_H means the highest frequency in the frequency band.

3.4. Non-audible sound wave communication uplink model

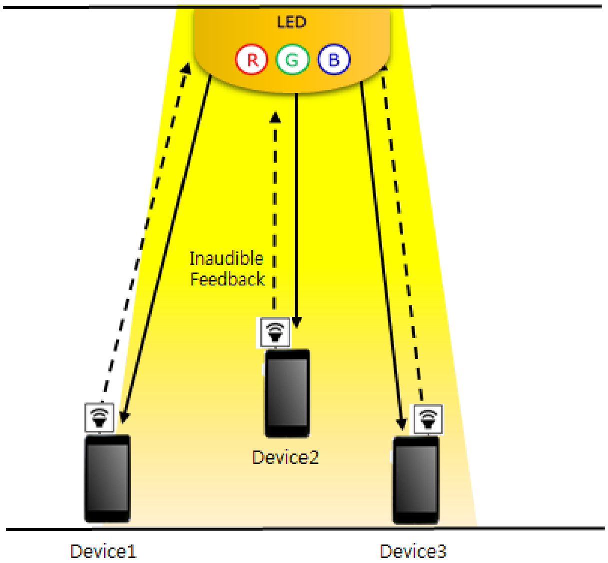

Fig. 6: Non - Audible Sonic Communication Uplink Model.

The condition of visible light communication uplink should satisfy the following environment.

1) Satisfaction of the specificity of visible light communication used as lighting
2) Ensure free communication in RF-free environment
3) Excellent security due to limited local area communication
4) Securing mobility and power efficiency in terminal uplink

Figure 6 shows an uplink feedback system model using non-audible sound wave channel feedback that satisfies these conditions. Since non-audible sound signals can not communicate far away, acoustic signals can be perceived only within a limited range, allowing communication to be easily specified. . In the communication method, the frequency shift keying (FSK) or the phase shift keying (PSK) method may be used when the sound signal waveform is tone, but the linear chirp which has a high signal to noise ratio and simple circuit, Signal is used to ensure power efficiency. In addition, since it uses general audio interface, most of them are excellent in versatility for terminals.

Since it does not use RF, it can be used in a communication environment where the use of radio waves is restricted. Since it does not use any other light source, it meets the special characteristic of visible light communication that provides a communication environment simultaneously with a light.

The sound wave signal repeats a certain frame and transmits through the speaker. The frame of the signal is composed of n symbols and one preamble, and the frequency band is 18.5 kHz to 20 kHz.

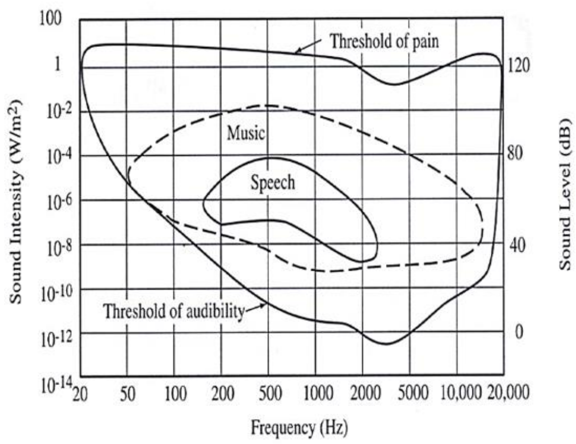

Fig. 7: The Sound Pressure Level of Human Overfrequency [11].

Figure 7 shows the level of sound pressure sensed by the human ear with respect to the acoustic signal frequency. Normally, the human audible frequency band is known as 20 Hz to 20 kHz, but there is a tendency to not recognize the high frequency band depending on the age, and there are individual differences. Especially in the audible frequency band, as shown in Fig. 7, the acoustic signal of 2kHz ~ 5kHz can perceive even a small sound rather than the same frequency depending on the frequency.
Therefore, in order to confirm the human perception of an arbitrary acoustic signal, the audio frequency band should not be treated the same. [11].
For audio signals with a frequency of about 21 kHz or higher, thosecan not be received at the normal audio interface and a microwave transceiver must be used. Therefore, it is necessary to use a lower frequency, so that it can be detected by the user because it corresponds to the audio frequency band. Furthermore, when a broadband acoustic signal is used or discontinuous data or a PN code is transmitted, a harmonic wave is generated in the acoustic signal generator and a signal exists in the audible frequency band. Therefore, it is important to design the acoustic signal waveform so that the size of the signal recognized in the possible audible frequency bands is small.
In addition, the sound wave signal has stronger characteristics in the shaded area than the optical based signal, and has an advantage of being more flexible than visible light or other optical signals in the transmission signal integration drawing.

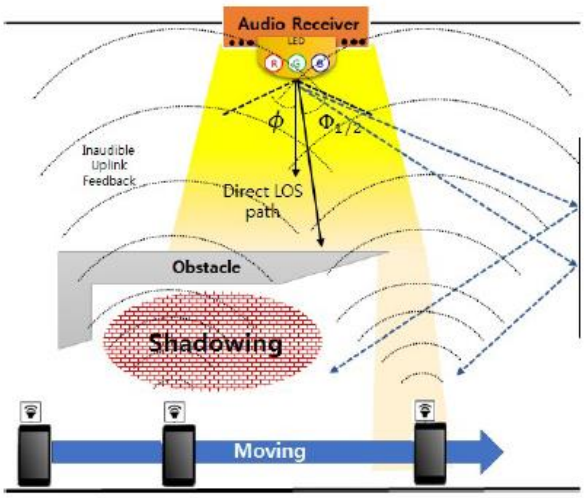

Fig. 8: Conceptual Diagram of the Proposed System.

For audio signals with a frequency of about 21 kHz or higher, they can not be received at the normal audio interface, and a microwave transceiver must be used. Therefore, it is necessary to use a lower frequency, so that it can be detected by the user because it corresponds As shown in FIG. 8, the terminal feeds state information to the transmitter through the uplink of the audio interface, allocates a valid channel according to the position of the device and the channel state when a data interruption occurs due to the occurrence of a shadow area due to an obstacle or a decrease in reception sensitivity Energy loss can be minimized and the problem of the existing unidirectional system can be solved.
It is expected that this non-audible sound wave communication uplink system will be applied as convergence technology to various environments such as IoT network environment requiring a bidirectional network, indoor small-scale network configuration, and home network configuration.

4. Conclusion

One of the problems of visible light communication is that it is not easy to transmit upward from the terminal to the illumination direction. The uplink transmission is a necessary function for transmitting the feedback information of the terminal, and a transmission scheme capable of ensuring sufficient transmission distance, interference elimination of LED illumination, and power efficiency should be used. In this paper, we propose a technique to secure the transmission distance by using non - audible band acoustic wave communication and to solve the problem of optical interference between downlink transmission and uplink transmission. In addition, through the status information of the devices using non-audible sound wave communication and the feedback of the position information, the signal is actively transmitted according to the change of the channel state according to the change of the communication environment such as the communication distance or the occurrence of the shadow area, Can be solved. However, in the case of the sound wave communication, since the bandwidth of the signal is very small, the data transmission speed is slow and it is not suitable to transmit and receive a large amount of information. In this paper, we propose a system model that can feedback user data and device state information. However, in order to transmit more data in uplink, researches on improvement of transmission rate and transmission rate of sound wave communication are required in various aspects. If this part is improved, it is expected that various applications can be applied in the uplink and downlink of visible light communication.

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