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Implementation of differentiated services in indoor visible-light communication using interchannel interference

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ABSTRACT

To facilitate differentiated services in visible-light communication systems, we propose an authorization method in the physical layer using interchannel interference based on polarization division multiplexing and a newly proposed signal-mapping process. The proposed system experimentally demonstrated that a 100-Mbit/s broadcasting signal transmission for a lower class user and two types of 100-MBd signal transmission for different higher class groups could be simultaneously enabled using pulse-amplitude modulation. Analysis of the performance of the lower and higher class signals' according to the polarization state of the receiver and the transmitted signal power imbalance is discussed. The proposed authorization method in the physical layer can be applied to many areas because classes can be subdivided when the number of channels increases by using wavelength division multiplexing. Furthermore, the ratio between the lower and higher class signals can be controlled in accordance with the environment.

1. Introduction

Security provisioning is an essential function in the design of any communication methods, networks, and database systems. It is even more critical for wireless communication systems. For software or hardware vendors, specialized information of products, source code, and specific diagrams must be kept confidential. In addition, owing to private financial information in banks and patent applications in research laboratories, such users cannot afford to take chances with regard to data theft. A break-in over the network can cause critical damage in a very short time. Thus, nowadays, prevention of data leaks to the outside world by unauthorized or unnoticed users has become increasingly important [1–3].

One of the advantages of a visible-light communication (VLC) system is its high security compared with radio frequency (RF)-based wireless communication systems. Visible light does not penetrate building walls. Thus, the signal isolation property can be utilized to enhance communication security by preventing eavesdropping on in-building communications. VLC can protect private information and provide security against tapping and jamming [4–6]. These characteristics can also provide a high degree of spatial reuse. VLC signals in adjacent rooms will not interfere with each other, thus, potentially providing a higher spatial density of communication rates compared with an RF-based system. However, one limitation of VLC is that it is unidirectional. Hence, users can receive a downlink signal without any request and approval to access points. Even if encryption is used, the received signal may not be decrypted at the same time by eavesdroppers; however, it can be collected using simple optical receivers (Rx's) and data storage devices. The collected data can be decrypted later using post-processing. Thus, if eavesdroppers or visitors are present in the same space (see Fig. 1), we may expect security issues to surface, and additional security enhancement or authorization method is required. Turning off the lights for security purposes is impossible because the main functions of an indoor VLC system are lighting and communication. Thus, research on security systems for VLCs has been conducted by many groups [6–8]. However, in these studies, either the illuminance distribution in an indoor environment was change or every person in a non-communication zone was prevented from communicating, even though some users may not be eavesdroppers [8]. In addition, general information is blocked. Thus, research regarding the provision of differentiated services (DiffServ) according to the user class is required.

In a VLC system, additional optical wireless channels can be secured using wavelength division multiplexing (WDM) based on an RGB light-emitting diode (LED) and an optical filter, polarization division multiplexing (PDM) based on a linear polarizer, or frequency division multiplexing using subcarriers or sub-bands. The main purpose of these studies is to reduce the interchannel interference between adjacent channels [9–14]. However, the user-class levels of each channel are equal, and an additional independent channel is

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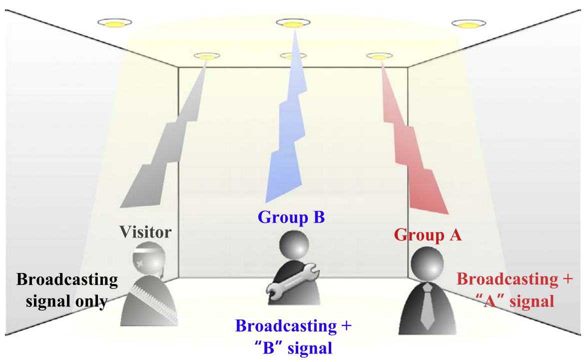

Fig. 1. Example of DiffServ to enhance indoor security.

required to transmit general information to all users. Nevertheless, a user cannot simultaneously access two different channels. Thus, we propose the DiffServ system to effectively utilize optical wireless channels. The proposed system uses the interference among different channels in the physical layer. In this system, users are classified into different privilege classes. Lower class users such as visitors, outsiders, and even eavesdroppers do not belong to any group. They can only access general information but, not specific group signals. Higher class users belong to a specific group that is allowed to obtain specific information. They can access each group signal as well as general information. The higher class group users can share lower class signals, but they cannot access the equal-class group signals among themselves.

In this paper, we propose and experimentally demonstrate the physical-layer authorization method for DiffServ in VLC using inter-channel interference, where a 100-Mbit/s broadcasting signal (for lower class users) and two different 100-MBd pulse-amplitude modulation (4-PAM) signals, including a broadcasting signal (for higher class users), are simultaneously transmitted. The proposed system is based on PDM to maintain a white lighting environment. For practical implementation, the polarization filter of Rx is automatically rotated using mechanical rotator based on the user class and polarization state information from the transmitter (Tx). The performance of proposed DiffServ based on the PDM can be degraded when the polarization axis between the Tx and Rx is mismatched or the received signal power is unequal due to the position of the user, the Rx rotation, and the state of Tx. Thus, we experimentally confirmed that system performance variation occurs according to the polarization axis difference between the Tx and Rx and received signal power imbalance cases.

This paper comprise five sections. In Section II, the pre-experimental and simulation results are shown, and the mapping process for the proposed DiffServ is described. Section III demonstrates the experimental setup and parameters. In Section IV, the experimental results of the proposed system with regard to the lower and higher classes are discussed. The conclusions are presented in Section V.

2. Background and signal-mapping process

The optical Rx converts the luminance intensity into a photocurrent based on the intensity modulation and direct-detection method. Thus, the received signal power is determined by the received optical intensity. According to Malus' law, namely, $I_R = I_O\cos^2\theta$ (where I_O is the initial optical intensity of polarized light), received optical intensity I_R is determined by polarization axis difference θ between the Tx and Rx. Fig. 2 shows that the experimentally received RF signal power as a function of the polarization axis difference between the Tx and Rx well matched with the simulation results based on Malus' law.

Crosstalk among orthogonal polarization channels does not occur in the optical wireless channel. Thus, if a single polarization component can extract an Rx portion using optical filtering, Tx's can transmit the two different types of higher class signals without interference. Moreover, we can possibly transmit a lower class signal that is independent of the polarization state of the Rx using the proposed signal-mapping process; thus, DiffServ can be realized. Considering two different higher class "Groups" and a single lower class "user," the signal mapping for DiffServ is listed in Table 1 when the modulation format is 4-PAM, which has a modulation order of two. Fig. 3 shows the concept of the proposed signal-mapping process. The broadcasting signal for all users maps the first bit, and the different "Group" signals map the second bit. Thus, the modulated 4-PAM has a common first bit and different second bits. These two different signals are transferred to each Tx after time synchronization of the device and transmitted by s- and p-polarized lights without crosstalk because the polarization-state orthogonality between the two optical signals is maintained. The lower class "user," who does not have information on the polarization state of the Tx's and without a polarization filter, receives a mixed polarized light. The simple optical Rx can only detect the intensity of lightwave, thus it cannot distinguish the polarization state of an incident light; therefore, the received signals for each Tx has linearly superposed. Nevertheless, the "user" can access the broadcasting signal because it is determined by the common first bit of the 4-PAM signals. As listed in Table 1, the received signal intensity from two different Tx's is distributed from zero to two when the broadcasting signal is zero or from four to six when the broadcasting signal is one without a polarization filter. Thus, the broadcasting signal can be demodulated using maximum likelihood estimation (MLE) and the threshold value.

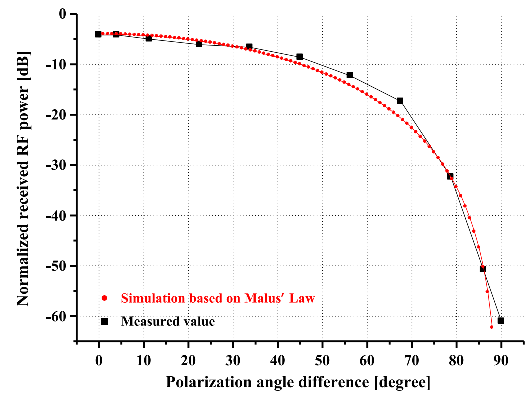

Fig. 2. Theoretical and experimental received RF power variation according to the polarization angular difference between the Tx and Rx.

Table 1
Signal Mapping for the Proposed DiffServ System.

Broadcasting signal	Group A signal	Group B signal	Transmitted signal intensity for Group A	Transmitted signal intensity for Group B	Received signal intensity of lower class user
0	0	0	0	0	<u>0</u>
0	0	1	0	1	<u>1</u>
0	1	0	1	0	<u>1</u>
0	1	1	1	1	<u>2</u>
1	0	0	2	2	<u>4</u>
1	0	1	2	3	<u>5</u>
1	1	0	3	2	<u>5</u>
1	1	1	3	3	<u>6</u>

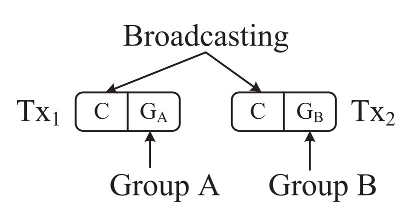

Fig. 3. Proposed mapping process for DiffServ.

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