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## A Novel Semi-Distributed OFDMA for Indoor Visible Light Communications

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Abstract. In this paper, a novel OFDMA architecture based on the characteristics of the indoor visible light communication network is introduced. It is characterized by a microcell structure and frequent terminal switching. The OFDM proposed in this paper adopts DCO-OFDM modulation technology, which is determined by the consideration of the nonlinear and nonnegative signal transmission characteristics of LEDs, and the SLM algorithm is also introduced to reduce PAPR. The simulation results demonstrate that the SLM algorithm can effectively reduce the PAPR of DCO-OFDM, which increases the probability that the signal in the entire system is lower than the PAPR threshold. Compared with the SLM algorithm, its CDF probability is increased by about 40%, and the SNR is also improved by 2.5 dB. The proposed OFDMA is a semi-distributed structure that is controlled by the DME to allocate subcarriers to each AP, and each has the ability to allocate subcarriers independently. Based on this architecture, an idea of dynamic subcarrier allocation is proposed, and uses the optical power received by the terminal as the SIR index to allocate different subcarriers to different SIR terminals and optimize the utilization of resources. The results of the modeling and simulation indicate that when the subcarrier allocation algorithm and method of reducing PAPR via SLM are combined, the BER of the system is significantly improved; when the SNR is 13 dB, the BER can be reduced to less than 10-6. This method can help the system reach the perfect communication target with a lower SNR, allowing the system to achieve better BER performance with less power consumption.

#### 1. Introduction

The growing requirements of mobile applications have encouraged the development of wireless communication. Wireless communication is typically achieved by radio frequency (RF) signal transmission; however, the RF spectra of protocols are licensed and may be congested. For additional applications and economical considerations, it may be preferable to develop new techniques for wireless communication, especially indoor visible light communication (VLC) [1]. Recently, VLC techniques using a light-emitting diode (LED) or laser diode (LD) source have drawn much attention in both academia and industry due to the development of LED/LD technology for indoor solid-state lighting and the simultaneous potential for high-speed wireless data transmission [2]. It is known that each fabricated LED/LD device has a minimum threshold value at which to open the light emission, which is called the turn-on voltage. Below this voltage, the LED/LD is considered to be in a cut-off

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region and has no conducting current; above this voltage, the output light power of LEDs/LDs presents a linear relationship with the driving voltage. Thus, the light output of the LED/LD decreases and slowly approaches a steady-state value, which limits the dynamic modulation range. Once the signal exceeds the LED's limited linear region, distortion will occur by the clipping of the LED [3]. To adapt to the linear region of LED/LDs, O-OFDM, such as DCO-/ACO-/ADO- and U-OFDM [4-7], has been studied by many scholars. Moreover, experiments of a real-time gigabit OFDM-VLC system have been previously conducted based on FPGA [8]. These factors reveal the feasibility of OFDM-VLC, and it is the future research trend of VLC high-speed transmission.

The remainder of this paper is organized as follows. In Section 2, the proposed semi-distributed OFDMA is introduced, and the OFDMA transmission techniques and rules of dynamic subcarrier allocation are briefly presented. In Section 3, the performances of various terminals are demonstrated, and detailed numerical results that SLM the operation and subcarrier allocation of the proposed semi-distributed DCO-OFDM are presented and analysed. The paper is concluded in Section 4.

#### 2. Proposed Semi-Distributed OFDMA

#### 2.1. System Model

Assuming that there are 4 LEDs in room 1 as Aps, which are defined as ap1-1 to ap1-4, several terminals need to be connected to the network through the APs under the coverage of four cells. The traditional method is that when a terminal applies for access to the network, the base station will update the number of terminals in the current network and equally distribute the useful subcarriers to each terminal. In this case, the resource utilization rate is low because the subcarriers are not allocated reasonably according to the channel conditions of each terminal. For an indoor VLC network in particular, its microcell coverage is small, cell switching is frequent, and the number of terminals in each room is different. For this kind of application scenario, the use of only a simple average subcarrier allocation scheme cannot achieve the optimal use of resources, which has inspired the development of the method proposed in the present study. According to the optical power received by the terminal, the signal to interference ratio (SIR) of the current location in the cell can be judged, and the SIR can dynamically allocate the subcarriers; even after moving, it will be updated to obtain new subcarriers. Before introducing the SIR calculation method, the modulation of the OFDM signal on an LED must be considered.



Figure 1. System model.

There are many OFDM methods for VLC, and in this regard this paper is not innovative; however, the DC compensation of DCO-OFDM, which is characterized by high spectral efficiency, is innovatively utilized. Although additional DC compensation must be provided, its implementation is simple. Because it provides DC compensation, which causes the PAPR problem of the DCO-OFDM signal itself to become more serious, a high PAPR is always one of the key problems to be overcome

in DCO-OFDM systems. In a VLC system, a higher PAPR will make the system more vulnerable to nonlinear distortion and lead to a great reduction of system reliability. The reason for the occurrence of high PAPR is that after OFDM is added by N modulation carriers, the superposition of wave crests and wave troughs may occur, leading to a relatively high peak power. In contrast, when N carriers are added in phase, the peak power will reach N times that of the single carrier; the higher the value of N, the higher the PAPR. However, this situation is not conducive to the realization of subcarrier allocation; therefore, after DCO-OFDM modulation but before subcarrier allocation, selected mapping (SLM) must be carried out to adjust the carrier phase, the transmission sequence with the minimum PAPR is selected, and the transmission is implemented.

First, the input signal needs to be converted into n-channel parallel symbol  $X_i$ , and M-QAM is used to acquire  $X_i^* = Ae^{j\phi}$  on N subcarriers corresponding to the n-channel. After  $X_i^*$  is transformed via inverse fast Fourier transform, 2N equivalent complex digital sequences of  $X_n^*$  are generated, and the sample value of discrete signal S(k) will be obtained after  $X_n^*$  is converted by series/parallel:

$$S(k) = \frac{1}{\sqrt{K}} \sum_{n=0}^{K-1} X_n^* e^{j\left(\frac{2\pi}{K}\right)nk} \quad k = 0, 1...K-1$$
(1)

The frequency domain signal S(k) is multiplied by different phase rotation factors  $P_m(i) = e^{j\varphi_{mi}}$ , and m vector sequences of  $P_M = [P_M(0), P_M(1), P_M(3), \dots, P_M(k-1)]$  of length K are obtained; m = 1, 2,...,m. Then, after phase rotation, the output sequence can be obtained as follows:  $S_m = S(k) \odot P_M = [S(0) P_M(0), S(1) P_M(1), \dots, S(K-1) P_M(K-1)]$ . Finally, IFFT conversion is performed on  $S_m$ , and the minimum PAPR value is selected to obtain the output  $S_{M-OUT}$  sequence.

#### 2.2. Simulation Model

Based on the above criteria, a simulation environment was built in MATLAB (version R2018a), the framework structure of which is presented in Figure 2. In a 10\*10\*3 m room, seven LEDs are arranged as APs with locations of Pos\_LED = [0, 2.5+1.25j, 2.5j, -2.5+1.25j, -2.5-1.25j, -2.5j, 2.5-1.25j]. It is assumed that there are 10 terminals in the room that move in a random direction at a rate of 1 m/s. The time interval of position update t0 is 0.05 s, and the calculation of which is completed in "The initial position" module and "The position after moving" module. In consideration of the characteristics of the VLC system network proposed in this paper, the channel quality depends on the optical power received by the terminal because the optical power received, namely the signal strength, is strong. Therefore, the location of the terminal and the received optical power must be calculated in real time, which will be completed in the "Distance and power" module. The last step is to complete the signal shaping of DCO-OFDM according to the "DCO-OFDM with SLM" module processing, and to calculate the PAPR and phase adjustment SLM algorithm to select the minimum PAPR carrier output. The FFT number of DCO-OFDM and number of subcarriers (because DCO-OFDM must be processed symmetrically via Hermite matrix, 128 is a useful number of subcarriers) are both 256, while the frame number is 100, and each frame carries 7 DCO-OFDM symbols.



Figure 2. Framework structure based on MATLAB.

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The most important and innovative component of the entire structure is that the simulation requires the real-time calculation of the location of the terminal to obtain the maximum optical power in the mobile state, which is used to determine the coverage of which LEDs it is in (i.e., to determine which AP it is connected to). The specific algorithm is presented in Table 1. As conveyed in Line1 to Line13, the initial position POS (i) of each terminal is required, and the position coordinates are updated every time unit t0 to obtain the new position POS (i2) of each terminal (the specific calculation method has been described in the existing literature [11]). According to the LED Lambert radiation model, the optical power Pr\_calc received by the terminal under the current position POS (i2) is calculated, and the location\_index at which the terminal received the maximum power is recorded and reported to the DME of the semi-distributed OFDMA. Based on the location index, the channel link status is determined so that subcarriers can be allocated. As conveyed in Line14 to Line20, after obtaining the location of the terminal receiving the maximum power, it is necessary to determine which AP the subcarrier is connected to, which records the terminals in the cell, counts the number of terminals, and equally distributes the number of subcarriers (average\_SC) to each terminal in the cell to obtain its subcarrier index in each cell. This is the method used to calculate the average allocation of subcarriers.

Table 1. Obtain the maximum optical power in the mobile state.

1. for i = 1:num ue  $pos(i) = pos_initial(r1)$ 2. 3. end 4. for i1 = 1:Num t0 r2 = v \* t05. 6. for i2 = 1:num ue pos(i2) = pos mobile(pos(i2), r1, r2)7. 8. for i3 = 1:num location 9. dist(i3) = abs(pos(i2)-pos l(i3))10. Pr(i3) = Pr calc(Pt,dist(i3),h)11. end [pl(i2),location\_index(i2)] = max(Pr) 12. 13. end 14. for i2 = 1:num location 15. UE index $\{i1,i2\}$  = find(1 index == i2)16. active ue  $n(i2) = length(UE index{i1,i2})$ 17. average sc n(i2) = use sc/active ue n(i2)18. for i3 = 1:active us n(i2)19. subcarrier index  $\{i2,i3\} = 1+i3$ : active use n(i2): use sc 20. end 21.end

Each OFDM symbol has len\_SC subcarriers, while only half of the number of useful DCO-OFDM subcarriers are defined as use\_sc. Therefore, if there are n\_user terminals under an LED, the use\_sc useful subcarriers are divided into n\_user parts, and each terminal has use\_sc/n\_user subcarriers. However, the method of average subcarrier allocation presented above cannot make effective use of resources; The definition is as follows:

$$SIR = \frac{p\_sig}{p\_inf\_sum}$$
(2)

where  $p_{sig}$  is the power of the signal converted to units of dB, and SIR\_dB = 10\*log10 (SIR). Each terminal has a SIR\_dB, the value of which will be taken as a standard. A high SIR\_dB indicates that the user is in the position of strong signal intensity in the current LED illumination range, and its channel conditions are better than those of other terminals; more subcarriers can be allocated to it, and fewer subcarriers can be allocated to the terminals with low SIR dB.

#### **3. Numerical Results**

The following performances were determined through MATLAB modeling and simulation calculation. Figure 3a indicates that with the increase of the signal to noise ratio (SNR), the bit error ratio (BER) of the DCO-OFDM system presents a significant decreasing trend. Under the same BER, the SNR of the DCO-OFDM after the use of the proposed SLM algorithm is increased by about 2.5 dB. Figure 3b shows that the system throughput is significantly reduced after the SLM algorithm is added; this is because the SLM algorithm is a non-distortion PAPR reduction algorithm, which needs to transmit auxiliary phase information, ultimately resulting in system throughput reduction.



Figure 3. Performances of DCO-OFDM with SLM.

Figure 4 presents the simulated BER performances of the following four different schemes in the same environment: (1) there is neither SLM nor allocated subcarriers; (2) there is SLM but no allocated subcarriers; (3) there is no SLM but there are allocated subcarriers, and (4) there are both SLM and allocated subcarriers. It is evident from the figure that the BER performance of the scheme with both SLM and allocated subcarriers is the best. When the SNR is greater than 10 dB, the BER is less than 10<sup>-4</sup>. In contrast, when the SNR is about 13 dB, the BER can be less than 10<sup>-6</sup>, thus achieving a perfect communication index; this means that the system can achieve better BER performance with less power consumption. By comparing the average distribution subcarrier and the dynamic distribution subcarrier with the same SLM, it can be concluded that both have good BER performances. However, when the SNR is greater than 13 dB, and especially when it is greater than 15 dB, there is an obvious advantage of dynamic subcarrier allocation. When BER =  $10^{-6}$ , the dynamic subcarrier allocation scheme has a gain of about 3 dB as compared with the average allocation scheme.

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Figure 4. BER performance of four schemes.

#### 4. Conclusion

The OFDM proposed in this paper adopts DCO-OFDM modulation technology, which is determined by the consideration of the nonlinear and non-negative signal transmission characteristics of LEDs, and the SLM algorithm is also introduced to reduce PAPR. The simulation results reveal that the SLM algorithm can effectively reduce the PAPR of the DCO-OFDM, which increases the probability that the signal of the whole system will be lower than the PAPR threshold. Compared with the SLM algorithm, its CDF probability is increased by about 40%, and the SNR is also improved by 2.5 dB.

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#### References

- [1] Sung, J. Y., Yeh, C. H., Chow, C. W., Lin, W. F., & Liu, Y. (2015). Orthogonal frequencydivision multiplexing access (ofdma) based wireless visible light communication (vlc) system. Optics Communications, 355, 261-268.
- [2] Gao, M., Li, C., & Xu, Z. (2019). Performance enhancement of led-based indoor ofdm-vlc system using digital chaotic scheme. Optics Communications, 439, 21-26.
- [3] Elgala, H., Mesleh, R., & Haas, H. (2010). An led model for intensity-modulated optical communication systems. IEEE Photonics Technology Letters, 22(11), 835-837.
- [4] Eltoukhi, E. A., Abd-Elnaby, M., El-Dolil, S. A., & Abd El-Samie, F. E. (2018). Efficient coding techniques for ado-ofdm in im/dd systems. Photonic network communications, 36(1), 128-139.
- [5] Patel, D., Singh, V. K., & Dalal, U. D. . (2017). Assessment of the dc bias to mitigate the clipping noise in dco-ofdm, aco-ofdm; and non-linear distortion of dfb laser transmitted through dispersive single mode fibers in im/dd systems. Wireless Personal Communications.
- [6] Ranjha, B., Zhou, Z., & Kavehrad, M. (2014). Performance analysis of precoding-based asymmetrically clipped optical orthogonal frequency division multiplexing wireless system in additive white gaussian noise and indoor multipath channel. Optical engineering, 53(8), 086102.1-086102.12.
- [7] Mao, T., Jiang, R., & Bai, R. (2017). Optical dual-mode index modulation aided ofdm for visible light communications. Optics Communications, 391, 37-41.
- [8] Deng, R., He, J., Chen, M., & Zhou, Y. (2018). Experimental demonstration of a real-time gigabit ofdm-vlc system with a cost-efficient precoding scheme. Optics Communications, 423, 69-73.