Incorporate Visible Light Communication into Visible Light Positioning Using Orthogonal Frequency Division Multiple Access

Yitong Xu[1], Zixiong Wang[1*], Jian Chen[2], Shiying Han[3], Changyuan Yu[4], Jinlong Yu[1]

[1]*School of Electrical and Information Engineering, Tianjin University, Tianjin 300072, China*
[2]*School of Telecommunications and Information Engineering, Nanjing University of Posts and Telecommunications, Nanjing 210003, China*
[3]*College of Electronic Information and Optical Engineering, Nankai University, Tianjin 300350, China*
[4]*Department of Electronic and Information Engineering, The Hong Kong Polytechnic University, Hong Kong SAR*

[*]*Email: wangzixiong@tju.edu.cn*

Abstract: We propose a scheme to incorporate VLC into VLP using OFDMA. The VLP accuracy is improved by measuring the average RSS on subcarrier block. The feasibility of simultaneous VLC has been investigated.

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1. Introduction

Visible light is a good candidate for both indoor positioning and high-speed communications [1, 2]. In visible light positioning (VLP), received signal strength (RSS), time of arrival (TOA) and angle of arrival (AOA) are the main techniques to obtain the distances between light-emitting diodes (LEDs) and receiver. Furthermore, the least square estimation (LSE) is usually applied in RSS for its well-known effectiveness. In order to improve the positioning accuracy using LSE, Wu *et al* proposed to exclude the LED with the least RSS [3]. Without conveying any data information, the LEDs transmit positioning signal in different time slots. Therefore, it can be regarded as a pure positioning system using time-division multiplexing. However, this approach needs more response time, and thus could not localize the mobile receiver timely. Hence, VLP in frequency domain is preferred.

In this paper, we propose a scheme that incorporates visible light communications (VLC) into VLP. The orthogonal frequency division multiple access (OFDMA) is adopted, and the multiple LEDs occupy different subcarrier blocks. Compared with the case that single subcarrier is used for positioning, the fluctuation of RSS is mitigated by averaging all RSSs of subcarriers in a subcarrier block, which can improve the positioning accuracy. Considering that only the received signal power is required in RSS-based VLP, we adopt random data sequence with constant average power as positioning signal, which conveys data information simultaneously. Both the improvement of VLP accuracy and the feasibility of VLC are investigated.

2. Principles

Fig. 1 describes the proposed scheme in which four LEDs using OFDMA are considered. Let N_{FFT} be the FFT size. The subcarriers are assembled into eight subcarrier blocks, each of which contains continuous $\frac{1}{8}N_{\mathrm{FFT}}$ subcarriers. Each LED occupies two subcarrier blocks, where Hermitian symmetry is employed to guarantee the real output of optical orthogonal frequency division multiplexing (OFDM) signal. The subcarrier blocks are occupied by the LEDs exclusively, as shown in Fig. 2(a). After inverse fast Fourier transform (IFFT), the cyclic prefix (CP) is added to the time-domain modulation signal, which modulates the corresponding LED with proper bias current. The LED's output light propagates through the indoor channel to the photo-detector (PD). Since the PD collects lights simultaneously from all the four LEDs with various propagation delays, proper synchronization should be carried out four times to extract the signal from a particular LED. After fast Fourier transform (FFT), the receiver can obtain the frequency-domain signal in the full bandwidth. The average power of each subcarrier block as described in Fig. 2(a) is analysed. By comparing the average power of pairwise subcarrier blocks of transmitter and receiver, the transmission distance is estimated. The longer transmission distance lowers the received signal power and the noise effect on signal power becomes more significant. Therefore, such long transmission distance will introduce positioning error when the LSE is

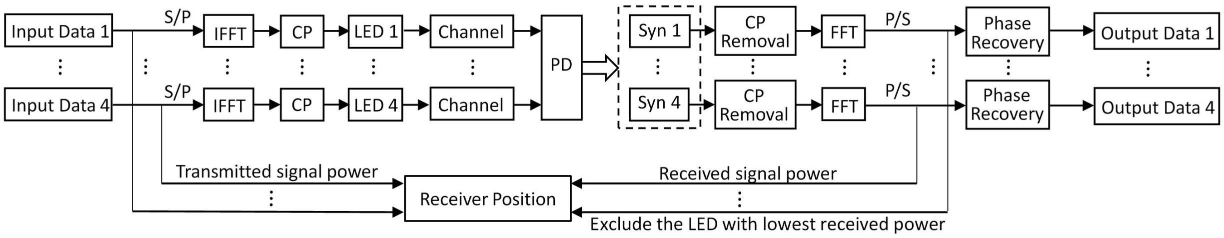
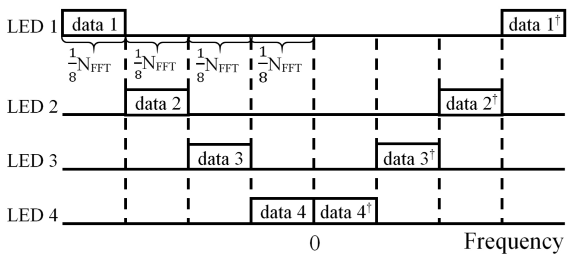
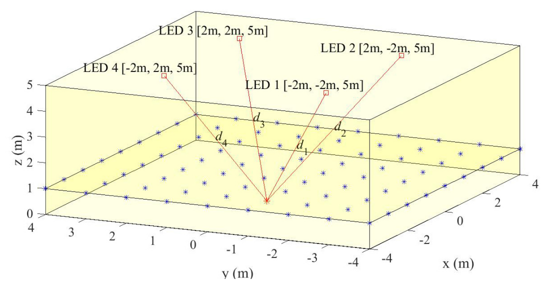


Fig. 1. Schematic of simultaneous implementation of VLP and VLC. Syn: synchronization.



(a) OFDMA for VLP. †: Hermitian symmetry



(b) LED configuration. Asterisk: receiver. Red: [-3 m, -1 m, 1 m]

Fig. 2. VLP using OFDMA.

employed. Since only three LEDs are required to find the two-dimensional receiver position in LSE, it is reasonable to exclude the LED with longest transmission distance, *i.e.*, with lowest received power, to get more accurate estimated position. Suppose that the distance d_3 between LED 3 and the receiver is longest. As shown in Eq. (1), the four equations to estimate the receiver's location is reduced to three equations, and the positioning accuracy is improved.

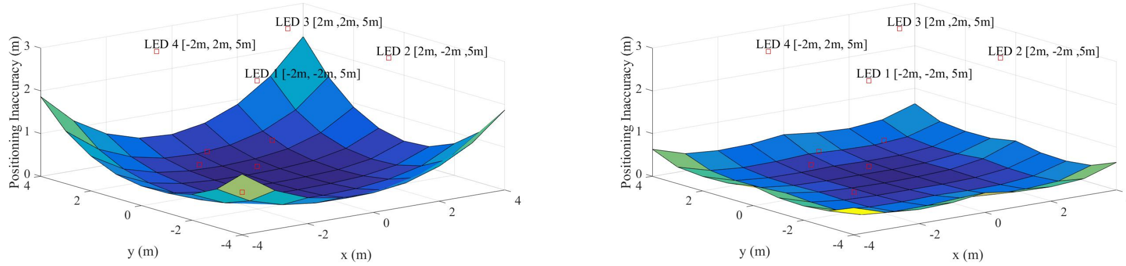
$$\left\{\begin{array}{l}(x-x_1)^2+(y-y_1)^2=d_1^2\\(x-x_2)^2+(y-y_2)^2=d_2^2\\(x-x_3)^2+(y-y_3)^2=d_3^2\\(x-x_4)^2+(y-y_4)^2=d_4^2\end{array}\right. \xrightarrow[\text{with lowest average power}]{\text{exclude LED 3}} \left\{\begin{array}{l}(x-x_1)^2+(y-y_1)^2=d_1^2\\(x-x_2)^2+(y-y_2)^2=d_2^2\\(x-x_4)^2+(y-y_4)^2=d_4^2\end{array}\right. \quad (1)$$

Besides positioning according to power, the received data sequence can be detected for communication after FFT. The proper synchronization and CP removal before FFT help the the receiver to recover the phase of signal. And the bit error rate (BER) performance of each subcarrier block is evaluated after decision.

3. Simulation Results and Discussions

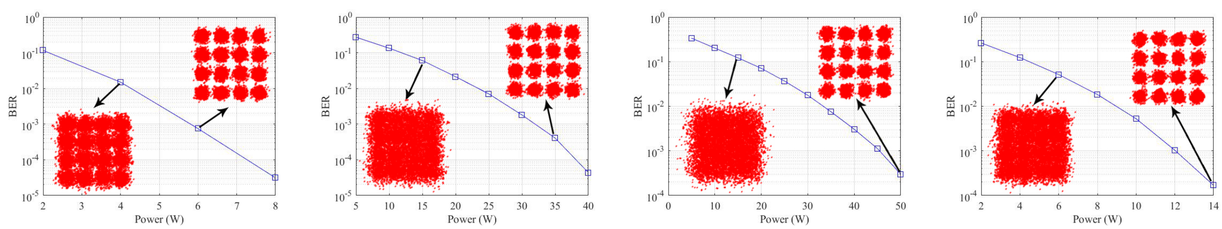
In the simulation, the room is assumed to be large enough so that the reflection can be ignored. The height of receiver is 1 m, and the locations of LEDs are shown in Fig. 2(b). The accuracy of positioning is evaluated in the space of 8 m × 8 m × 5 m. Fig. 3 compares the positioning accuracy with and without excluding the LED with lowest received signal power. It can be observed that excluding the LED with lowest received signal power will improve the positioning accuracy. For instance, at the location [-3 m, -1 m, 1 m] when the LED launching power is 15 W, the positioning error is reduced from 0.1784 m to 0.1219 m, implying that the positioning accuracy is improved by 0.0565 m. Furthermore, when the receiver moves outside the region of the LEDs' projections on the receiver plane, the improvement of positioning accuracy becomes more significant. When the receiver is at [-4 m, -4 m, 1 m], the positioning errors are 1.422 m and 0.6365 m for the cases that includes and excludes the LED with lowest received signal power, respectively. The improvement of positioning accuracy is as large as 0.7855 m.

We further investigate the performance of VLC on each subcarrier block, which is shown in Fig. 4. Since the PD collects light from all the LEDs simultaneously, the additive white Gaussian noise (AWGN) that consists of both shot



(a) Including all the four LEDs (b) Excluding the LED with lowest received power

Fig. 3. Positioning inaccuracy when the launching power of LED is 15 W.



(a) LED 1 (b) LED 2 (c) LED 3 (d) LED 4

Fig. 4. BER performances for subcarrier blocks at receiver location [-3 m, -1 m, 1 m].

noise and thermal noise are identical for all the transmitted signals. Therefore, the average noise on all the subcarriers are the same. The BER performance of each subcarrier block only depends on the power of received signal. At location [-3 m, -1 m, 1 m], the transmission distances from the receiver to LEDs follow $d_1 < d_4 < d_2 < d_3$. So the received signal power is $P_1 > P_4 > P_2 > P_3$. The signal from LED 1 is with the best BER performance, whilst the BER performance of signal from LED 3 is worst. As shown in Fig. 4, when the launching power of LED 1 is 6 W, the BER is 7.4×10^{-4}; when the launching power of LED 4 is 14 W, the BER is 1.8×10^{-4}. Thus for the LED with 15-W launching power whose positioning performance is studied in Fig. 3(a), error-free transmission can be achieved with the help of forward error correction (FEC) for LED 1 and LED 4. However, with 15-W LED launching power, the signals from LED 2 and LED 3 can not achieve BER of 10^{-3}. The LED launching power has to be boosted to 35 W and 50 W, respectively, to compensate the signal attenuation brought by the longer transmission distances.

4. Conclusion

In this work, we propose the scheme that incorporates VLC into VLP using OFDMA, where the LEDs occupy subcarrier blocks exclusively. The positioning accuracy is improved by averaging the RSS of subcarriers in the subcarrier block and excluding the LED with the lowest averge RSS. Moreover, we find that the signal BER performance is determined by the LED launching power and the location of the receiver. Thus, given the receiver location, each LED has its threshold of launching power for communication. When the LED launching power is larger than the threshold, the VLC can be incorporated into the VLP successfully. This work was supported by National Natural Science Foundation of China (NSFC) under Grants 61601321, 61601247 & 61271239.

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