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Improvement of positioning accuracy in visible light positioning system using orthogonal frequency division multiple access

Yitong Xu[1], Zixiong Wang[1*], Jiahui Sun[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 proposed a novel power allocation scheme to improve the positioning accuracy in VLP system using OFDMA. The signal's power is allocated to minimize the differences among errors of square of estimated transmission distances.

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1. Introduction and Principle

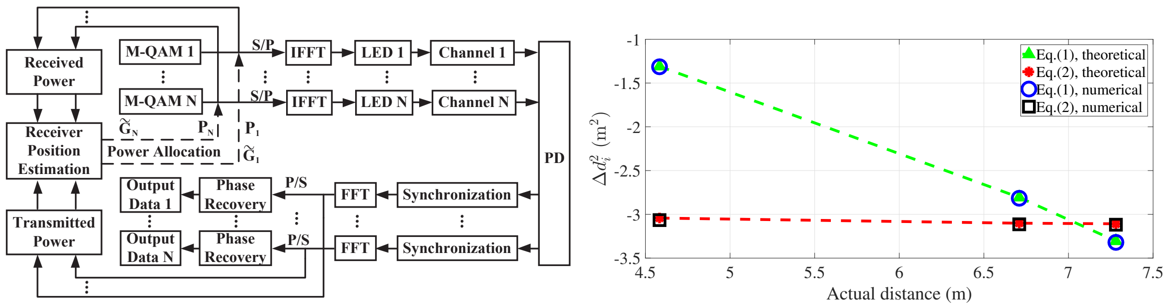
Light-emitting diode (LED) has the advantages of long lifetime, low energy consumption, and high bandwidth. It is an outstanding device for both illumination and communication. Visible light positioning (VLP) is carried out based on visible light communications (VLC) [1]. We have proposed a scheme to implement VLP and VLC simultaneously using orthogonal frequency division multiple access (OFDMA) [2]. In this paper, we propose a novel power allocation scheme to improve the positioning accuracy. The setup of VLP system using OFDMA is shown in Fig. 1(a). Suppose that there are N LEDs mounted in the ceiling. The whole bandwidth is divided into $2N$ subcarrier blocks, due to the Hermitian symmetry for real output of OFDMA signal. A pair of two subcarrier blocks are assigned to an LED. The LED's location is encoded in the indices of occupied subcarriers by using pulse position modulation (PPM) in the first frame. The receiver's location is estimated by using the locations of LEDs and the estimated transmission distance $\widetilde{d}$. $\widetilde{d}$ is obtained from the estimated channel gain $\widetilde{G}$ by comparing the power of received and transmitted signals in each subcarrier block. For the ith LED, the error of square of estimated transmission distance is $\Delta d_i^2 = \widetilde{d}_i^2 - d_i^2$, where d_i is the actual distance. It is shown that the differences among errors of square of estimated transmission distances $(\Delta d_i^2 - \Delta d_j^2, i, j = 1, 2, \ldots, N)$ are critical to the positioning accuracy [2]. The differences $\Delta d_i^2 - \Delta d_j^2$ are reduced by using power allocation scheme; hence the positioning accuracy is improved. In [2], the transmitted signal power P_i is allocated to let the received power for all subcarrier blocks be identical, *i.e.*,

$$P_i \widetilde{G}_i^2 = P_j \widetilde{G}_j^2 \tag{1}$$

In order to improve the positioning accuracy further, we propose a novel power allocation scheme to let the estimated errors of square of estimated transmission distances be identical $\Delta\widetilde{d}_i^2 = \Delta\widetilde{d}_j^2$, *i.e.*,

$$\widetilde{d}_i^2 \left[1 - \left(1 - \frac{\widetilde{\sigma}_N^2}{\widetilde{G}_i^2 P_i R^2 K^2} \right)^{-\frac{1}{m+3}} \right] = \widetilde{d}_j^2 \left[1 - \left(1 - \frac{\widetilde{\sigma}_N^2}{\widetilde{G}_j^2 P_j R^2 K^2} \right)^{-\frac{1}{m+3}} \right] \tag{2}$$

In Eq. (2), R is the responsivity of photo-detector (PD), K is the ratio of LED output power to its driving current, m is the order of Lambertian radiation pattern. The noise power $\widetilde{\sigma}_N^2$ is estimated by calculating the power of unused subcarriers, which include the unoccupied subcarriers in the first frame and the direct-current (DC) and Nyquist terms in the rest frames. Note that the power allocation schemes do not affect the total power of modulation signals.

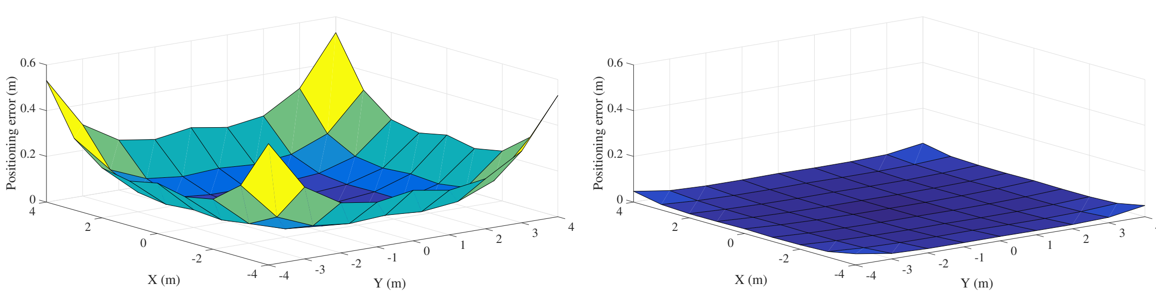


(a) (b)

Fig. 1. (a) VLP system using OFDMA, (b) Δd_i^2 under power allocation schemes in Eqs. (1) and (2).

2. Simulation Results

In the simulation, the four LEDs locations are $[2\text{ m}, 2\text{ m}, 5\text{ m}]^{\mathrm{T}}$, $[-2\text{ m}, 2\text{ m}, 5\text{ m}]^{\mathrm{T}}$, $[-2\text{ m}, -2\text{ m}, 5\text{ m}]^{\mathrm{T}}$ and $[2\text{ m}, -2\text{ m}, 5\text{ m}]^{\mathrm{T}}$. The launching power of each LED is 10 W. Three out of four LEDs are selected in each trial of VLP, by excluding the LED with longest estimated distance. The total bandwidth is 100 MHz. Fig. 1(b) shows the Δd_i^2 under two power allocation schemes in Eqs. (1) and (2), when the location of receiver is $[-4\text{ m}, -3\text{ m}, 1\text{ m}]^{\mathrm{T}}$. The Δd_i^2 under the power allocation scheme in Eq. (1) are -1.309 m^2, -2.806 m^2, and -3.305 m^2, respectively; while the Δd_i^2 under the power allocation scheme in Eq. (2) are -3.043 m^2, -3.101 m^2, and -3.108 m^2, respectively. The differences among Δd_i^2 under Eq. (2) are much smaller than those under Eq. (1). Consequently, the positioning error is reduced from 0.314 m under Eq. (1) to 0.024 m under Eq. (2). The positioning error in the whole room is shown in Fig. 2, where the maximum positioning error is at $[-4\text{ m}, -4\text{ m}, 1\text{ m}]^{\mathrm{T}}$. The maximum positioning error is 0.531 m under the power allocation scheme in Eq. (1). The maximum positioning error is reduced to 0.047 m under the power allocation scheme in Eq. (2), *i.e.*, the positioning accuracy are improved by 0.484 m.



(a) (b)

Fig. 2. Positioning error under power allocation schemes (a) in Eq. (1) and (b) in Eq. (2).

3. Conclusion

We proposed a novel power allocation scheme to improve the positioning accuracy of VLP system using OFDMA. This scheme reduces the differences among errors of square of estimated transmission distances, and reduces the positioning error consequently. The positioning accuracy are improved by 0.484 m at $[-4\text{ m}, -4\text{ m}, 1\text{ m}]^{\mathrm{T}}$.

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