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On improving the accuracy of Visible Light Positioning system based PAPR reduction schemes

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Abstract—DC-biased optical Orthogonal Frequency Division Multiplexing (DCO-OFDM)-based visible light positioning (VLP) technology along with the Received Signal Strength(RSS) positioning algorithm is widely used to achieve centimeter level positioning accuracy for incoming 5G era, especially indoor environment. However, the DCO-OFDM has the peak-to-average power ratio (PAPR) issue which imposes the nonlinear distortion and it will directly affect the positioning accuracy in the VLP system. The PAPR reduction scheme is urgently needed. Therefore, in this paper, the impact of PAPR reduction scheme on positioning accuracy is investigated. The positioning accuracy with and without the selected mapping (SLM)-based PAPR reduction method are compared. The preliminary simulation results show that the positioning accuracy has been improved by 7.07 cm after using the SLM-based PAPR reduction method.

Index Terms—5G, Visible Light Positioning(VLP), Visible Light Communication(VLC), Received Signal Strength, Localization, DC-biased optical orthogonal frequency division multiplexing (DCO-OFDM), peak-to-average power ratio (PAPR), selected mapping (SLM)

I. INTRODUCTION

With the explosive growth of internet connected devices and stronger user dependence on wireless connections, 5G is expected to meet these demands with the ultra-low latency, the ultra-broadband, the ultra-high reliability and the large-scale connection for various scenarios, especially in indoor environment [1]. Apart from the above requirement, the indoor positioning also plays an important role in future 5G era. The 5G white paper is already more specific about the positioning accuracy: from 10 m to less than 1 m for 80 % of occasions, and better than 1 m for indoors [1].

However, the well-known indoor positioning techniques such as Global Navigation Satellite System (GNSS) [2], Wi-Fi, Bluetooth, Zigbee, Radio Frequency Identification (RFID), and Ultra-Wideband (UWB) cannot provide users with high positioning accuracy in indoor environment due to the attenuation and reflection by buildings [3], [4].

Therefore, the indoor positioning technique for incoming 5G era is widely discussed recently [5]. The visible light positioning (VLP) technology is considered as the most promising candidate because of many attractive features [3], [6]. For example 1) compared to the RF-based positioning techniques, the light wave used in VLP is less vulnerable to multipath

fading to achieving high positioning accuracy of 0.1 to 1 meter [7]; 2) it utilizes the existing lighting facilities without additional cost 3) no RF interference will be generated by LED [8]. On account of this we can conclude that the VLP system is an appealing solution to satisfy the communication as well as the indoor positioning accuracy requirements for 5G and beyond networks.

Received Signal Strength(RSS) positioning algorithm has been widely developed in VLP system [9]. The RSS-based method uses the received optical power as input to calculate the receiver's position.

However, the received optical power is strongly depending on the transmitted optical power, hence the positioning accuracy is significantly affected when the transmitted optical power changes [10]. This change is usually caused by the modulation schemes. In order to adapt the intensity modulation and direct detection (IM/DD) in VLP system and meet the aforementioned positioning requirement, the OFDM-based modulation schemes are widely used to generate the real and non-negative positioning signals such as DCO-OFDM. But high PAPR is the inherent disadvantage of OFDM-based technology [11]. High PAPR of positioning signal is very sensitive to the LED nonlinear devices, which imposes the nonlinear distortion and leads to the change of transmitted positioning signal power. It will directly affect the positioning accuracy in the VLP system. To address the PAPR issue, different PAPR reduction schemes are investigated such as clipping [12]–[14], signal scrambling [15], [16], coding schemes [17] and deep learning [18]. Among these PAPR reduction schemes, the selected mapping (SLM) method is widely used in many literatures because it does not introduce signal distortions [19], [20].

To the best of our knowledge, few work considers the impact of PAPR reduction schemes on positioning accuracy in indoor VLP system. Thus, in this paper, we take the DCO-OFDM modulation scheme as an example, compare the positioning accuracy with and without SLM-based PAPR reduction method in VLP system. Simulation results show that the positioning accuracy with the SLM-based PAPR reduction method has been improved up to 7.07 cm.

The organization of this paper is as follows. Section II describes the VLP system model, the SLM method and the RSS-based positioning algorithm. Section III gives the details

of the simulation testbed. The preliminary simulation results and analysis will be presented in Section IV. Section V gives the conclusions.

II. VLP SYSTEM MODEL AND SLM METHOD

A. VLP System Model

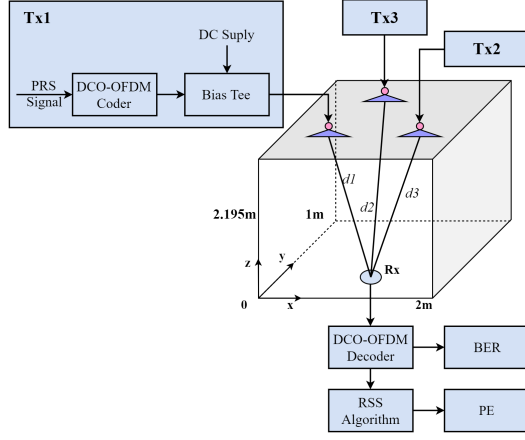


Fig. 1. System Model

Fig. 1 shows a generic VLP system model. Three LED transmitters are placed on the same level in a room. The modulated positioning signal is transmitted from LED optical transmitter to photodiode receiver through optical wireless channel (OWC). As the input of the positioning algorithm, RSS will be used to calculate the coordinates of the receiver and get the positioning error.

B. SLM Method

Selective mapping (SLM) is a favorable PAPR reduction scheme for DCO-OFDM VLP system. Fig. 3 shows the block diagram of SLM technique for DCO-OFDM VLP system. To meet IM/DD requirement in VLC system, the Hermitian symmetry is imposed on the frequency domain of DCO-OFDM to generate the real-valued signals in time domain. Here, consider an DCO-OFDM VLC system with N subcarriers. The complex data signal, $\mathbf{X} = [X_0, X_1, X_2, \dots, X_{N-1}]$ is multiplied with U different phase rotation factors $P^u = [P_0^u, P_1^u, \dots, P_M^u]^T$ where $P_v^u = e^{j\varphi_v^u}$ and $\varphi_v^u \in [0, 2\pi)$ for $v = 0, 1, \dots, M$ and $u = 1, 2, \dots, U$ which produce a modified data block \mathbf{s} . IFFT of U independent sequences \mathbf{s} are taken to produce the sequences $\mathbf{x}^u = [x^u[0], x^u[1], \dots, x^u[N-1]]^T$ among which the one $\tilde{\mathbf{x}} = \mathbf{x}^{\tilde{u}}$, the one which possess the lowest PAPR is selected for transmission [14], [21]. Its mathematical expression is given as $x_{PAPR_{min}} = \text{argmin}_{1 \leq m \leq M} (\text{PAPR}((x_m)))$, where $\text{argmin}(\cdot)$ represent the argument of its value is minimized.

C. Positioning Algorithm

RSS-based positioning algorithm has been widely employed in indoor positioning systems and VLP systems thanks to its lower implementation complexity compared to other positioning algorithms [3].

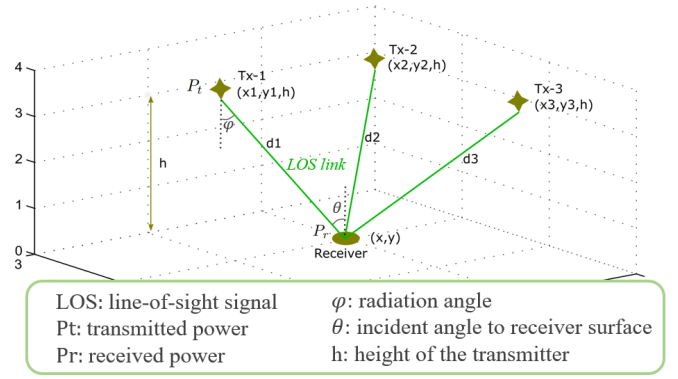


Fig. 2. Typical trilateration positioning algorithm model

Fig. 2 gives a typical RSS-based positioning algorithm model. According to the requirement of RSS-based positioning algorithm, minimum three transmitters with known locations are needed. We assume that all transmitters follow the Lambertian distribution and only light-of-sight (LOS) is considered. Thus three distances d between receiver and transmitters can be calculated by equation (1) as follows:

$$\begin{cases} (x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2 = d_1^2 \\ (x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2 = d_2^2 \\ (x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2 = d_3^2 \end{cases} \quad (1)$$

where x_i represent i^{th} LED transmitter ($i = 1, 2, 3$), (x, y, z) is the coordinate of the receiver, d_i is distance between receiver and i^{th} LED transmitter. These linear equations in x and y can be written as in equation (2):

$$AX = B \quad (2)$$

where

$$X = \begin{bmatrix} x \\ y \end{bmatrix} \quad (3)$$

$$A = \begin{bmatrix} 2x_2 - 2x_1 & 2y_2 - 2y_1 & 2z_2 - 2z_1 \\ 2x_3 - 2x_1 & 2y_3 - 2y_1 & 2z_3 - 2z_1 \end{bmatrix} \quad (4)$$

$$B = \begin{bmatrix} d_1^2 - d_2^2 - x_1^2 + x_2^2 - y_1^2 + y_2^2 - z_1^2 + z_2^2 \\ d_1^2 - d_3^2 - x_1^2 + x_3^2 - y_1^2 + y_3^2 - z_1^2 + z_3^2 \end{bmatrix} \quad (5)$$

By using Least Square method, the estimated position of receiver $\begin{bmatrix} \hat{x} \\ \hat{y} \end{bmatrix}$ can then be calculated as follows:

$$\begin{bmatrix} \hat{x} \\ \hat{y} \end{bmatrix} = (A^T A^{-1}) A^T B \quad (6)$$

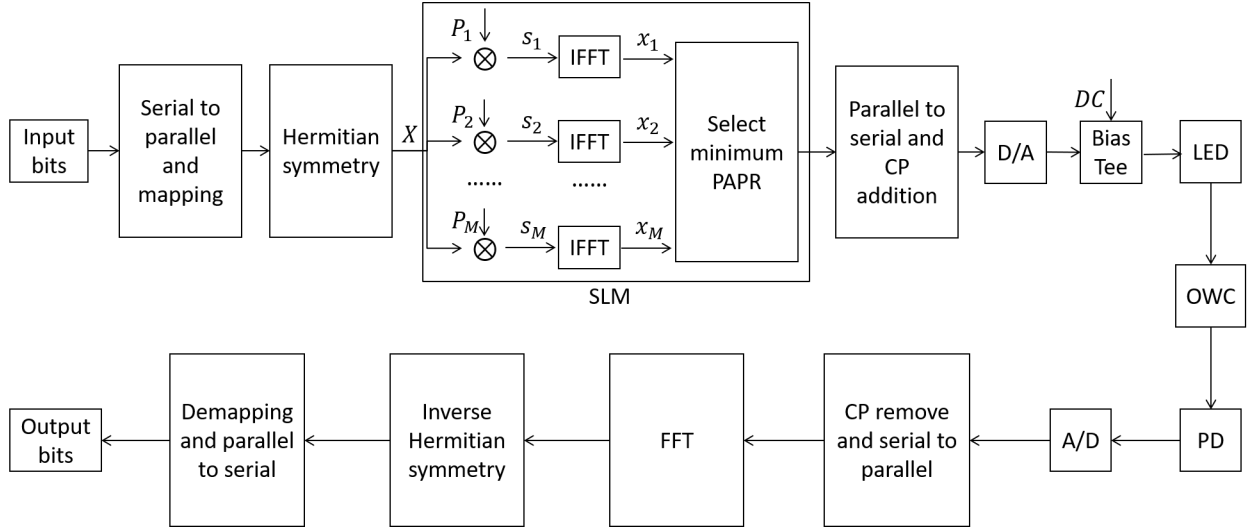


Fig. 3. Block diagram of SLM technique for DCO-OFDM VLP system

III. SIMULATION TESTBED

The simulation testbed is illustrated in Fig. 4. We assume an indoor simulation environment where three transmitters and one receiver are placed, whose parameters is summarized in Table I. 6×11 test points cover the entire experimental plane, which are set as the height of 0.085 m.

TABLE I
PARAMETERS OF THE INDOOR POSITIONING SYSTEM

Parameter	Value
Positioning unit size (LWH)/ m^3	$4 \times 4 \times 6$
Positions of four LEDs (x, y, z)(m)	LED1 (-0.5, 0.6, 2.195) LED2 (-0.5, 0.25, 2.195) LED3 (0.5, 0.25, 2.195)
Height of the receiver(m)	0.085
Plane range of the receiver (m)	(-1,0) to (1,1) (resolution: 0.2)
Original power of each LED (W)	26
The half-power angles of LED (deg)($\varphi_{1/2}$)	70
The half-power angles of receiver (deg)($\theta_{1/2}$)	70
The FOV of the receiver (deg)	70
The effective area of PD (cm^2)	1.0
The order of Lambert's luminous	$(-\log_{10} 2)/(-\log_{10}(\cos \theta))$

We consider the DCO-OFDM modulation scheme with 128 subcarriers and QPSK mapping. There are 10000 DCO-OFDM symbols used to generate all simulation results. An LOS channel is used as the VLC OWC.

In SLM-based PAPR reduction method, we set $U = 2$ and $U = 4$ with the phase rotation factor $[\pm 1, \pm j]$. The positioning accuracy is evaluated by contrast with and without the PAPR reduction. The preliminary simulation results will be discussed in the following section.

IV. SIMULATION RESULTS AND ANALYSIS

The distribution of the real positions and its estimated positions are shown in Fig. 5. Three figures represent respectively

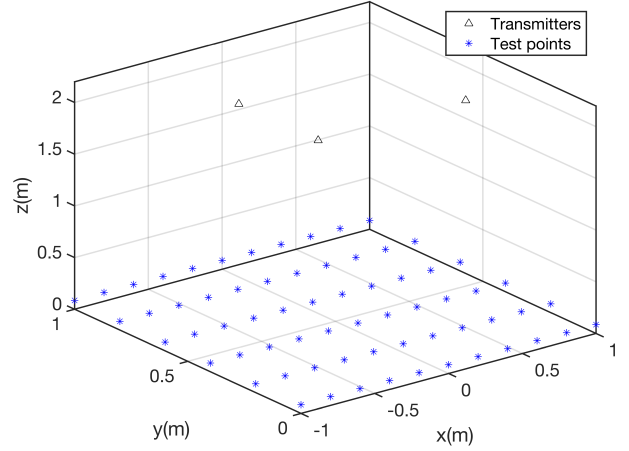


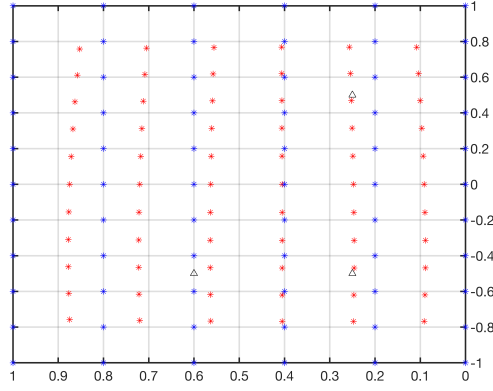
Fig. 4. Simulation testbed

a) SLM with $U = 2$ b) SLM with $U = 4$ c) original, where the red sign "*" represents estimated points and the blue sign "*" represents reference points. The average positioning error of the system can be expressed as the standard error of the reference coordinate and the estimated coordinate, which is given by

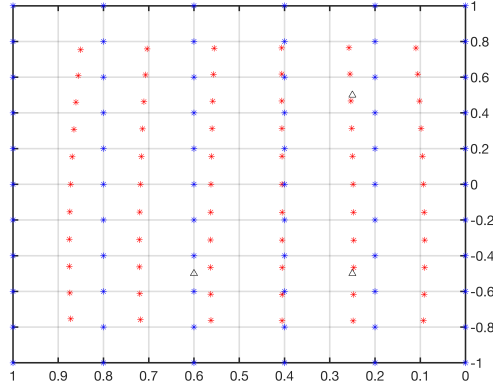
$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n (\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2 + (\hat{z}_i - z_i)^2} \quad (7)$$

where $n = 66$ (66 test points), (x_i, y_i, z_i) is the reference coordinate of each test point, while $(\hat{x}_i, \hat{y}_i, \hat{z}_i)$ is the estimated coordinate.

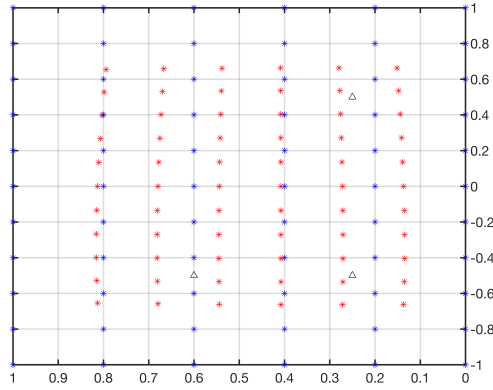
Overall results of two test sets based PAPR reduction are inferior to the result of original. As indicated in Fig. 5(a), the average error of 66 test points is 15.04 cm with a maximum error of 28.37 cm and a minimum error of 0.53 cm. As shown



(a)



(b)



(c)

Fig. 5. The distribution of reference positions and its estimated positions of (a) SLM with $U = 2$ (b) SLM with $U = 4$ (c) original

in Fig. 5(b), The average error of 66 test points is 15.30 cm while the maximum error is 28.8 cm and the minimum error is 0.54 cm. In Fig. 5(c), The average error of 66 test points in the test area is 22.11 cm with a maximum error of 40.26 cm and a minimum error of 0.80 cm.

Fig. 6 shows simulated cumulative distribution func-

tion(CDF) of the positioning error with and without PAPR reduction. The figure shows that the positioning accuracy can be significantly improved by the reduction of PAPR. By using SLM scheme, when $U = 2$, if 90% is assumed as an acceptable service coverage rate, the mentioned algorithm will be able to deliver an accuracy of less than 23.83 cm. When $U = 4$, if 90% is assumed as an acceptable service coverage rate, it will be able to deliver an accuracy of less than 24.22 cm in the same test area. Without using any PAPR reduction method, if 90% is assumed as an acceptable service coverage rate, it will be able to deliver an accuracy of less than 34.59 cm. Comparing results of three modulations, it can be concluded that received signal with PAPR reduction can significantly improve the positioning accuracy in indoor VLP system.

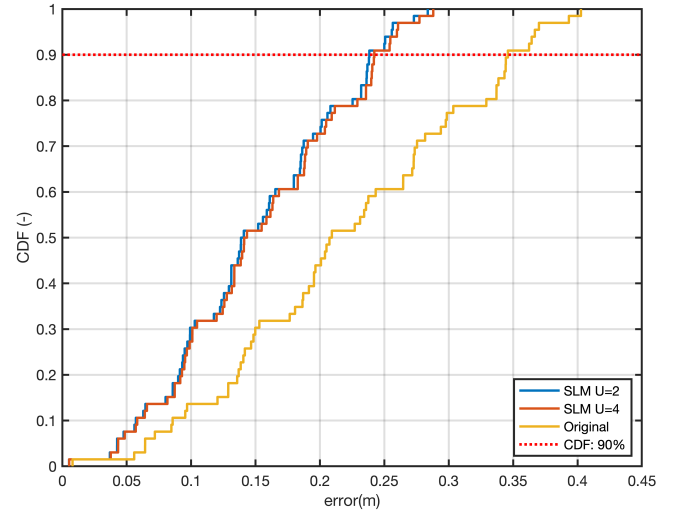


Fig. 6. CDF of positioning error for three modulation test sets

V. CONCLUSION

In this paper, a novel indoor visible light positioning algorithm considering the impact of PAPR is proposed and studied. By using the SLM-based PAPR reduction method, the positioning accuracy can be improved around 7.07 cm by comparing without PAPR reduction. The algorithm proposed in this paper is aimed to reduce the impact of PAPR in RSS positioning algorithm. Future work includes improve this algorithm to three-dimensional positioning algorithm and optimize algorithm to guarantee the error distance for every unknown position is less than 1 cm.

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