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An Integrated Indoor Visible Light Communication and Positioning System Based on FBMC-SCM

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***Abstract*—This paper proposes an integrated visible light communication and positioning (VLCP) system using filter bank multicarrier-based subcarrier multiplexing. Simulation results show that the proposed VLCP system achieves higher positioning accuracy and better bit error rate performance than the VLCP system using conventional orthogonal frequency division multiplexing-based subcarrier multiplexing.**

I INTRODUCTION

White light emitting diodes (LEDs) have grown very rapidly in the lighting market, which will gradually replace traditional light sources due to their attractive characteristics such as long lifetime, low power consumption, and high reliability. Besides lighting, white LEDs have also been applied for indoor visible light communication (VLC) and visible light positioning (VLP) [1]. On one hand, white LEDs based VLC has emerged as a promising technique for high-speed indoor wireless communications, due to its many distinctive advantages such as low cost, abundant unregulated bandwidth, and high security. Many techniques have been proposed to increase the capacity of VLC systems, such as multiple-input multiple-output transmission and orthogonal frequency division multiplexing (OFDM) using high-order constellations [2]. On the other hand, VLP using white LEDs has attracted great interest recently due to its high positioning accuracy and low cost [3], [4]. In addition, many algorithms have been proposed for VLP systems, such as received signal strength (RSS), time of arrival (TOA), angle of arrival (AOA), and phase difference of arrival (PDOA) [3], [4].

However, most work focused on the development of individual VLC [2] or VLP systems [3], [4], while it is desirable to provide both communication and positioning simultaneously in one system in practical indoor environments, etc. Recently, an integrated configuration for both VLC and VLP was proposed by using OFDMA [5], where received signal strength (RSS) algorithm is used for the position estimation. It is noted that RSS based method might not be able to achieve high positioning accuracy since the received signal power strongly depends on a few factors including transmitted power, receiver's orientation, etc. In addition, the high out-of-band interference (OOBI) of OFDM signal may result in severe inter-band interference (IBI) between adjacent subbands, which leads to communication performance degradation [6]. In order to reduce IBI, a guard band (GB) between two adjacent subbands is usually used. The use of GBs can substantially mitigate IBI, but the overall spectral efficiency (SE) of the integrated system is inevitably reduced [6]. Filter bank multicarrier (FBMC) has been applied in both optical access networks and VLC systems [6], [7], which can substantially reduce OOBI, In FBMC-based systems, each subcarrier is filtered to achieve low OOBI, and hence effectively suppress IBI. Thus, the required GB can be reduced substantially, resulting in improved overall SE.

In this paper, we propose a new integrated visible light communication and positioning (VLCP) system using FBMC-based SCM (FBMC-SCM). Moreover, an improved PDOA algorithm is used to estimate the location of the users where no local oscillators (LOs) are required at the receiver [4]. The feasibility of the proposed integrated VLCP system is verified by simulation.

II INTEGRATED VLCP SYSTEM

The block diagram of the proposed integrated VLCP system using OFDM-SCM/FBMC-SCM with four LEDs is depicted in Fig. 1. The total bandwidth is divided into five subbands and four GBs, where subband 3 is used for three-dimensional (3D) positioning and the remaining four subbands are reserved for VLC. The input data for VLC are first separated into four steams. Each data stream is then encoded to an OFDM or FBMC signal, while a sinusoidal signal for VLP is added with the OFDM/FBMC signal at each LED lamp after it is digital-to-analogue (D/A) converted. All the sinusoidal signals for VLP are synchronized. After

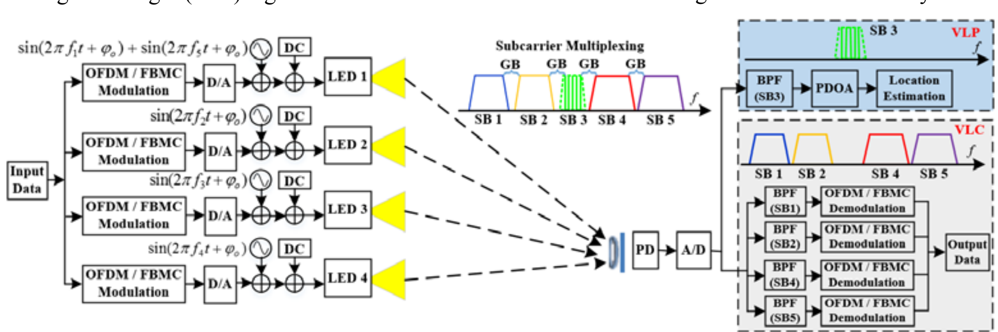


Fig. 1. Block diagram of the proposed integrated VLCP system. (SB: subband)

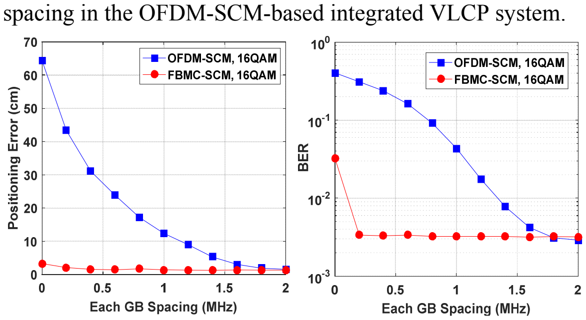
adding direct current (DC) bias, each resultant signal is modulated to an LED. There are five positioning frequencies in subband 3 for the PDOA based VLP, where f_1 and f_5 are modulated onto LED 1, while f_2 to f_4 onto LED 2 to LED 4, respectively. Note that the frequencies in subband 3 used for VLP are from 9.5 MHz to 10.5 MHz. Because the frequency is inversely proportional to the phase resolution, it is related to the positioning accuracy [3]. The bandwidths of subbands 1 and 2 are identical, and the bandwidths of subbands 4 and 5 are also identical, and the bandwidth of each GB is equal.

At the receiver, the received signal is detected by a photodetector (PD) and then converted back to digital signal. On one hand, the positioning data can be obtained after the received digital signal passing through a band pass filter (BPF), then the position of the receiver is calculated using the PDOA algorithm (refer to [4] for the details). On the other hand, the OFDM/FBMC signals in four subbands are first separated by respective band pass filters (BPFs). After that, the OFDM/FBMC signal in each subband is demodulated and further combined together to generate the output data for VLC. Hence, both communication and positioning purposes can be simultaneously achieved in our proposed system.

III Simulation Results

Simulations are carried out to evaluate the system performance. In a typical 5 m × 5 m × 3 m room, the locations of four LED lamps are [0, 0, 3], [0, 0.6, 3], [-0.5, -0.3, 3] and [0.5, -0.3, 3], respectively, where the units are all meters [4]. The receiving plane is 0.85 m above the floor. The LED transmitter semi-angle at half power is 60^o, and the PD has an active area of 1 cm^2 with a field of view (FOV) of 120 degree. The gain of the optical filter and the responsivity of the PD are 1.0 and 0.5 A/W, respectively. The system bandwidth is 20 MHz and 16-QAM mapping is used for VLC. For both OFDM and FBMC, the IFFT/FFT size is 128.

Figs. 2(a) and (b) present the positioning error and the average BER of the integrated VLCP system versus the GB spacing when the location of the receiver is set at [1, 1, 0.85]. As shown in Fig. 2, both the positioning accuracy and the BER of the FBMC-SCM-based integrated VLCP system outperform that using OFDM-SCM, especially when the GB spacing is relatively small. However, the BER and the positioning accuracy are much more sensitive to the GB spacing in the OFDM-SCM-based integrated VLCP system.



(a) (b)

Fig. 2. (a) positioning error and (b) BER performance versus GB spacing.

The positioning accuracy and BER performance of the OFDM-SCM-based integrated VLCP system will gradually improve with the increase of the GB spacing, nearly the same positioning accuracy and BER performance as the system using FBMC-SCM can be obtained when each GB spacing is about 1.8 MHz. As a result, The FBMC-SCM-based integrated VLCP system can achieve a much higher SE than the system using conventional OFDM-SCM.

Fig. 3 shows the cumulative distribution function (CDF) of the VLP positioning errors over the receiving plane in the integrated VLCP system, where GB between two subbands is 0.6 MHz. It can be seen that for 90% confidence, the positioning error for the system using OFDM-SCM is as high as 41.7 cm, while the positioning error is reduced to only 8.1 cm when FBMC-SCM is employed, indicating a significantly improved positioning accuracy

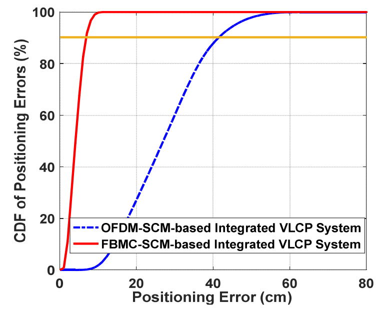


Fig. 3. Comparison of the CDF of positioning error.

IV Conclusions

We have proposed and investigated an integrated VLCP system based on FBMC-SCM, which can provide both indoor communication and positioning functions. Compared with the OFDM-SCM-based integrated VLCP system, the integrated VLCP system using FBMC-SCM can greatly reduce OOBI and hence requires a small GB, which greatly improves the overall SE and enhances positioning accuracy.

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References

[1] D. Karunatilaka, F. Zafar, V. Kalavally, and R. Parthiban, "LED based indoor visible light communications: State of the art," *IEEE Commun. Surveys Tuts.*, vol. 17, no. 3, pp. 1649–1678, 3rd Quart. 2015.

[2] C. Chen, W.-D. Zhong, and D. H. Wu, "Non-Hermitian symmetry orthogonal frequency division multiplexing for MIMO visible light communications," *IEEE/OSA J. Opt. Commun. Netw.*, vol. 9, no. 1, pp. 36–44, Jan. 2017.

[3] S. Y. Jung, and S. Hann, "TDOA-based optical wireless indoor localization using LED ceiling lamps," *IEEE Trans. Consum. Electron.*, vol. 57, no. 4, pp. 1592–1597, Nov. 2011.

[4] S. Zhang, W.-D. Zhong, P. Du, C. Chen, and D. H. Wu, "PDOA based indoor visible light positioning system without local oscillators in receiver," to be presented in CLEO-PR/OECC/PGC, 2017.

[5] B. Lin, X. Tang, and Z. Ghassemlooy, "Experimental demonstration of an indoor VLC positioning system based on OFDMA," *IEEE Photon. J.*, vol. 9, no. 2, Apr. 2017.

[6] S. Y. Jung et al., "Inter-cell interference mitigation in multi-cellular visible light communications," *Opt. Express*, vol. 24, no. 8, pp. 8512–8526, Mar. 2016.

[7] M. Bellanger et al., "FBMC physical layer: A primer," PHYDYAS, Tech. Rep. (2010).