Non-Orthogonal Multiple Access with Multicarrier Precoding in Visible Light Communications

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Abstract: *We propose a non-orthogonal multiple access method in visible light communications with multicarrier precoding and phase-amplitude predistortion. The proposed method eliminates the necessity of adaptive modulation while improving the system throughput.*
Keywords: *Multiple Access, NOMA, VLC, Precoding, Predistortion*

I. Introduction

Nowadays, visible light communication (VLC) is attracting wide attention among researchers as a potential key technology in the future communication systems, benefitting from its high volume, low-cost, reliability, and license-free [1]. Resembling other wireless communication technologies, appropriate multiple access strategies are indispensable for VLC to support multiple connections in one system. Recently in [2], we have proposed a novel scheme that can solve the dilemma between throughput and fairness, which is a main drawback of conventional multiple access technologies. In non-orthogonal multiple access (NOMA), the multiple access is granted according to different power levels of different users, particularly in every subcarrier of orthogonal frequency division multiplexing (OFDM) signal. We have also proposed a phase pre-distortion (PP) method to improve the system performance. However, the response across the whole OFDM spectrum is non-uniform. To accommodate different single-to-noise ratios (SNR) on different subcarriers, adaptive modulation formats are adopted on different subcarriers, thus largely complicates the NOMA process.

Recently, a multicarrier precoding (MP) method based on orthogonal circulant matrix transform (OCT) was proposed in [3] to flatten the SNR of all the subcarriers in an OFDM system. In this paper, we apply the MP method in NOMA to avoid the adoption of higher order modulation formats. A novel phase and amplitude predistortion (PAP) process is further proposed to enable the MP method under NOMA.

II. Principles

The system model of NOMA is depicted in Fig. 1(a), which is the same to that in [2]. The photo diode (PD), acting as the NOMA receiver, lies near to LED_1 but far from LED_2. The signal PD received from LED_1 (denoted as *S*) is stronger than the weaker signal from LED_2 (denoted as *W*). *S* and *W* are combined into a composite signal, which is denoted as *C*. Both *S* and *W* are in DC-biased optical OFDM (DCO-OFDM), which means only half of the whole OFDM subcarriers are used.

In MP process proposed in [3], an orthogonal circulant matrix, *Q*, is multiplexed to H_S and H_W before modulation onto the subcarriers, where $Q = \left(1/\sqrt{N}\right)\times[c_1,c_2,\cdots c_N;c_N,c_1,\cdots c_{N-1};\cdots;c_2,c_3,\cdots c_1]$, and each entry c_i corresponds to the element

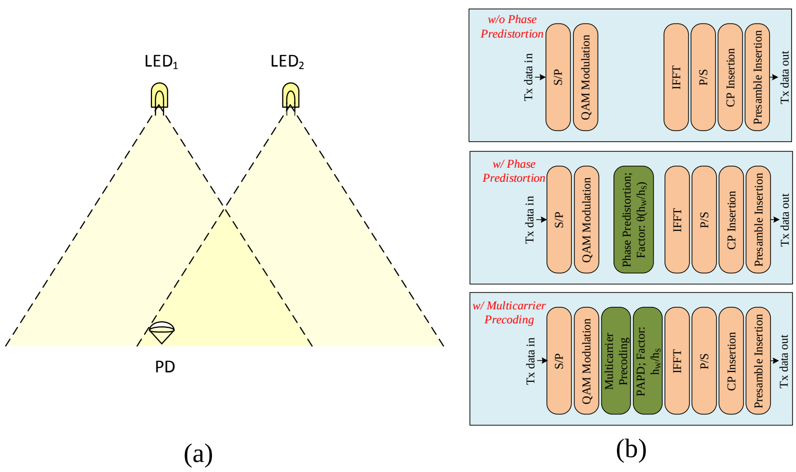

Fig.1. (a) System Model (b) DSP of *W* in three cases.

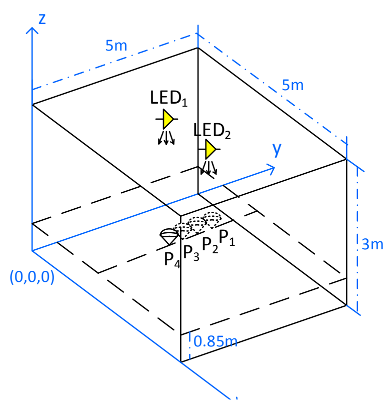

Fig.2. Simulation Setup

of the Zadoff-Chu (ZC) sequence in index of 1 and length of *N*. Unlike conventional NOMA, the introduction of MP interferes the decision of *S* in the first step of successive interference cancellation (SIC). As a solution, a PAP matrix, $H_W^{-1}H_S$, is multiplexed to *W* at the transmitter after the MP step. Fig. 1(b) shows the DSP process of the three cases: (1) NOMA without PP/MP, or conventional NOMA, (2) NOMA with PP, as in [2], (3) NOMA with MP and PAP.

III. NUMERICAL SIMULATIONS

(A) Simulation Setup

Fig. 2 shows the simulation setup of an indoor VLC system. Two LEDs are mounted on the ceiling for illumination and communication, while a PD is positioned on a plane with 0.85m in height to simulate the height of desk surface. Four PD positions are considered to simulate different receiving signal qualities. The simulation parameters are summarized in Table 1. The three DSP processes mentioned in the last section are studied in comparison. Two factors are controlled in the simulation: the location of PD, and the power of both two LEDs.

Table 1 Simulation Parameters

Parameter	Value
LED location	LED_1: (1.5,2.5,3); LED_2: (3.5,2.5,3)
PD location	P_1: (2,4,0.85); P_2: (2,3.5,0.85); P_3 (2,3,0.85); P_4: (2,2.5,0.85)
Detection area of PD	1 cm^2
Number of Rays	50000
Reflection coefficient (walls/floor/ceiling)	0.83/0.63/0.4
Max. reflection order	5
Receiver field of view	60 °
System sample rate	200MSa/s
DCO-OFDM bandwidth	100MHz
FFT size	256
CP length	32

(B) Simulation Results

We first investigate the effect MP brought to the SNR performance of the whole spectrum of OFDM. Fig. 2(a) and (b) shows the SNR comparisons of all the OFDM subcarriers, with and without the MP. Solid lines represent the case without MP, while dashed lines are the multicarrier-precoded SNRs. It could be observed that the SNRs of all the subcarriers in one OFDM transmitter could be equalized by MP. On the other hand, PD at P_4 enjoys higher SNRs as well as larger SNR differences between *S* and *W* over the whole band, while the SNRs and SNR differences at P_1 are smaller. Fig. 2(c) and (d) shows the BER performance when PD is placed at different positions in the simulation setup. Although different PD positions lead to different SNRs as well as different power ratios between *S* and *W*, in most cases the adoption of MP decreases the BER of *S* and *W* compared to those without PP/MP and without MP. Specifically, we compare the case with PP to that with MP. When PD is located at P_2 and the LED power is 1.5W, the BER of *S* drops from 5×10^{-3} to 2.5×10^{-3} while the BER of *W* drops from 1×10^{-2} to 6×10^{-3}, indicating minor improvements. When the LED power increases to 2W, the BER of *S* changes from 2×10^{-3} to 2×10^{-4}, while the BER of *W* decreases from 4×10^{-3} to 4×10^{-4}. This conclusion is further verified by simulating the BER performance in regard to the LED power. Fig. 2(e)

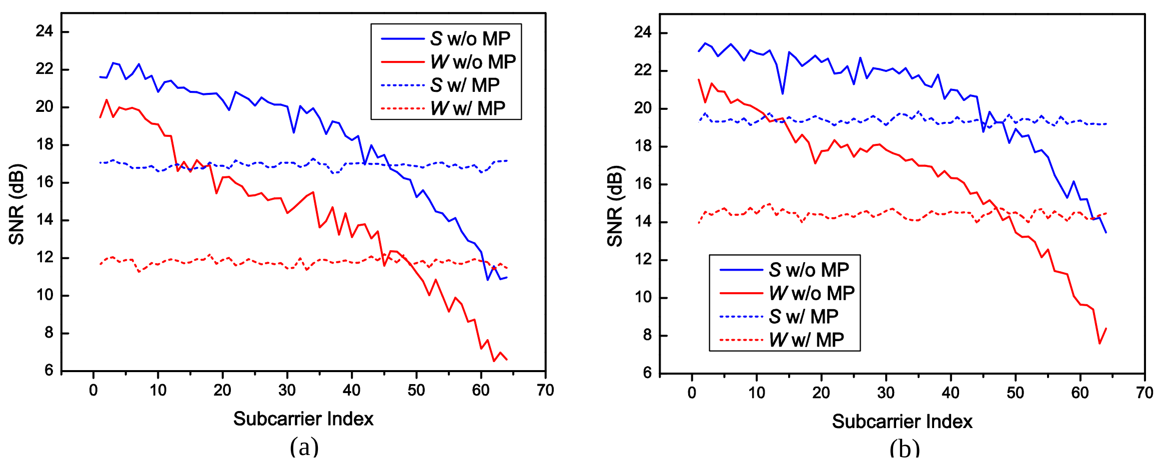

Fig.3. SNR of OFDM data subcarriers: (a) LED power=2W, PD at P_2, (b) LED power=2W, PD at P_4

and (f) shows the BER comparisons by fixing the PD at P_2 or P_4 and changing the power of LEDs. In both cases, the BER drops faster in MP case than PP case. It could be found that the improvement brought by MP is more significant under an appropriately better signal quality.

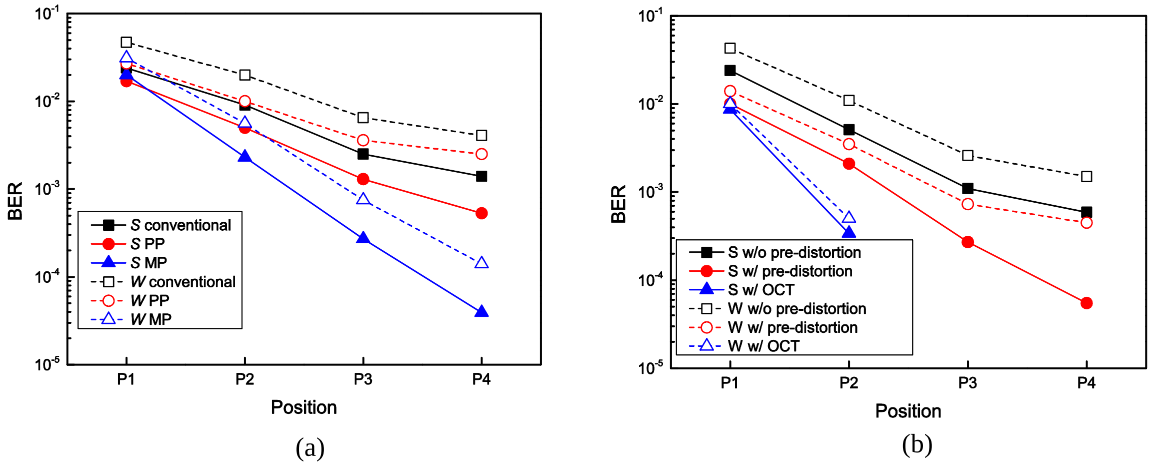

Fig.4. BER comparisons: (a) LED power=1.5W, (b) LED power=2W

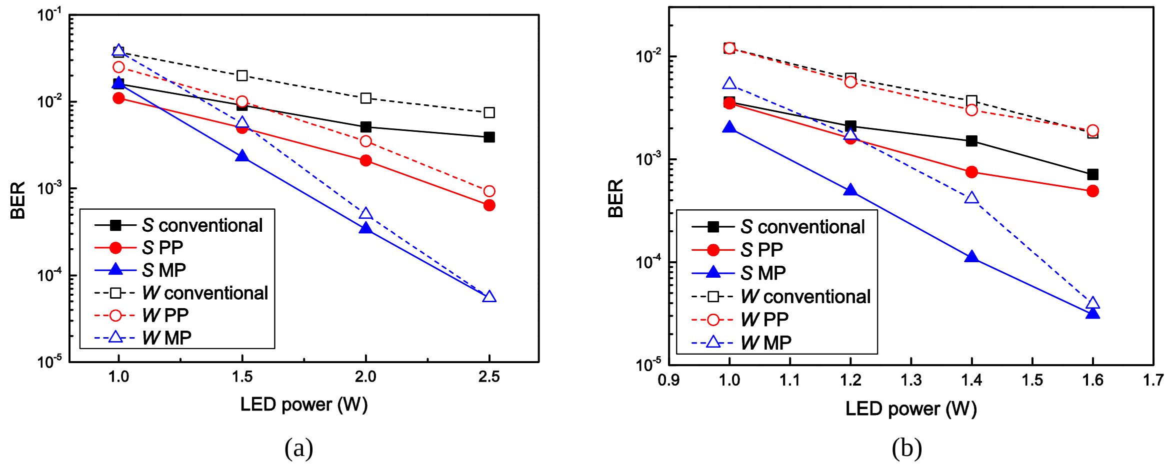

Fig.5. BER comparisons: (a) PD at P_2, (b) PD at P_4

IV. SUMMARY

We have proposed a multicarrier precoding scheme for NOMA in VLC. The proposed scheme combats the low-pass nature of VLC systems by keeping low BER, high throughput without introducing adaptive modulation formats. Simulation studies have proved the effectiveness of the proposed scheme. This work was partially supported by a research grant from Hong Kong Research Grants Council (Project No. 14200614).

REFERENCES

[1] A. Jovicic et al., "Visible light communication: opportunities, challenges and the path to market," IEEE Communications Magazine, vol. 51, no. 12, pp. 26-32, 2013.
[2] X. Guan et al., "Phase pre-distortion for non-orthogonal multiple access in visible light communications," in Proc. OFC, Paper Th1H.4, 2016.
[3] Y. Hong et al., "Experimental demonstration of an OCT-based precoding scheme for visible light communications," in Proc. OFC, Paper M3A.6, 2016.