Experimental Demonstration of Optical MIMO NOMA Visible Light Communications

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Abstract—**We experimentally demonstrate an optical MIMO NOMA-VLC system, which offers a high throughput and system capacity. The effect of the inter-user interference with high-order modulation is investigated. MIMO NOMA-VLC with 6 users is demonstrated.**

Keywords-Visible light communications(VLC); non-orthogonal multiple access(NOMA); multiple inputs multiple outputs(MIMO);

I. INTRODUCTION

Visible light communications (VLC) has emerged as a promising candidate to complement conventional radio frequency (RF) communication, especially for short-range indoor applications [1-4]. Power domain multiple accesss, also known as non-orthogonal multiple access (NOMA) has recently been proposed as a promising solution to enhance the spectral efficiency for the 5th generation (5G) wireless networks, due to its high spectral efficiency and high throughput [5]. The NOMA has also been adopted for downlink VLC systems to enhance the throughput and improve the system capacity [6]. In [7], a phase pre-distortion method was proposed to improve the symbol error rate performance of NOMA uplink with successive interference cancellation (SIC) decoding in VLC. In [8], we proposed a NOMA scheme combined with OFDMA for bidirectional VLC, which offers flexible bandwidth allocation and a higher system capacity. In addition, optical multiple inputs multiple outputs (MIMO) is becoming popular to increase the data rate for VLC due to the availability of a large number of LEDs in indoor environment. In this paper, we introduce the NOMA scheme for non-imaging multiple inputs multiple outputs (MIMO)-VLC systems. The MIMO demultiplexing and interference cancellation are simultaneously realized at frequency domain based on time-domain multiplexing preamble structure. The feasibility of the MIMO NOMA-OFDMA VLC is verified with experiment demonstration. The effect of the inter-user interference on the system performance with high-order modulation is investigated. In addition, MIMO NOMA-VLC with 6 users is experimentally demonstrated.

II. TECHNIQUE PRINCIPLE

Figure 1 shows the schematic diagram of MIMO NOMA-VLC with N users for each transmitter (Tx). In each Tx, the source data for each user is mapped and encoded into OFDM symbol ($x_1, x_2, \ldots, x_N$) prior to power allocation, respectively. The frequency domain representations of which are $X_1, X_2, \ldots, X_N$, respectively. The final transmitted time-domain signal for each Tx can be written as:

$$x = \sum_{i=1}^{N} \sqrt{p_i}\, x_i \;, \tag{1}$$

where p_i and x_i are the allocated power and the transmitted time-domain OFDM signal for user i, respectively. The combined digital OFDM signal with a direct current (DC) bias is used for intensity modulation (IM) of a LED. At the receiver (Rx), the two optical OFDM signals are detected by two photo-detectors simultaneously. After frame synchronization, the MIMO demultiplexing is performed using estimated MIMO channel frequency response to obtain the frequency-domain representation of the received signal for each receiver (Rx), which can be written as:

$$\begin{bmatrix} Y(Rx1) \\ Y(Rx2) \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix}^{-1} \times \begin{bmatrix} R_1 \\ R_2 \end{bmatrix}, \tag{2}$$

where R_1 and R_2 are the frequency-domain representations of received optical signals after photoelectric conversion. We assume that $p_1 > p_2 > p_3 \ldots > p_N$. At each Rx, the received signal for user 1 can be obtained from MIMO demultiplexing (i.e. $Y_1 = Y$). The transmitted signal of user 1 (i.e., s_1) for each Tx is recovered after demapping Y_1. After removing the term of $\sqrt{p_1}X_1$ from Y, the received signal for user 2 can be written as:

$$Y_2 = Y - \sqrt{p_1}X_1 \,. \tag{3}$$

The transmitted signal of user 2 (i.e., s_2) for each Tx can be recovered after demapping Y_2. The decoding order of SIC is in the order of increasing user index. Finally, the received signal for user N can be written as:

$$Y_N = Y - \sum_{i=1}^{N-1} \sqrt{p_i}\, X_i \;. \tag{4}$$

The transmitted signal of user N (i.e., s_N) for each Tx can be obtained after demapping Y_N without inter-user interference.

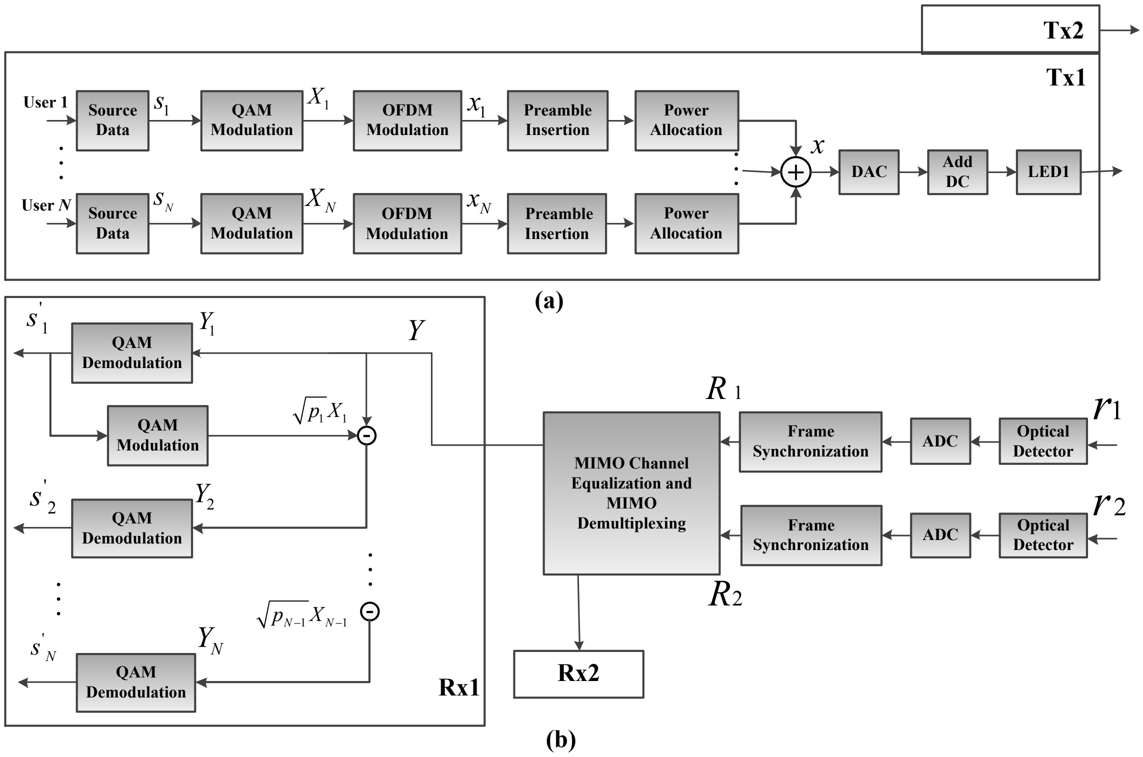

Fig. 1 Block diagram of (a) transmitter and (b) receiver for 2×2 MIMO NOMA-VLC. (DAC: digital-to-analog converter, ADC: analog-to-digital converter, DC: direct current, modules shown within Tx1 and Rx1 also applied to Tx2 and Rx2, respectively)

III. Experiment Setup and Results

The experimental setup for MIMO NOMA-VLC is shown in Fig. 2. For each user in each Tx, 1.7-Mbaud baseband OFDM signals are three times up-sampled and then up-converted to 1.25 MHz. The transmitted OFDM signals are combined after power allocation and then uploaded to an arbitrary waveform generator (AWG) operating at 5 MS/s. The discrete Fourier transform (DFT) and cyclic prefix (CP) sizes are 256 and 8, respectively. The generated two waveforms are DC-level shifted using the bias Tee prior to IM of two commercially available phosphorescent white LED, respectively. Then the optical outputs of the two Txs are passed

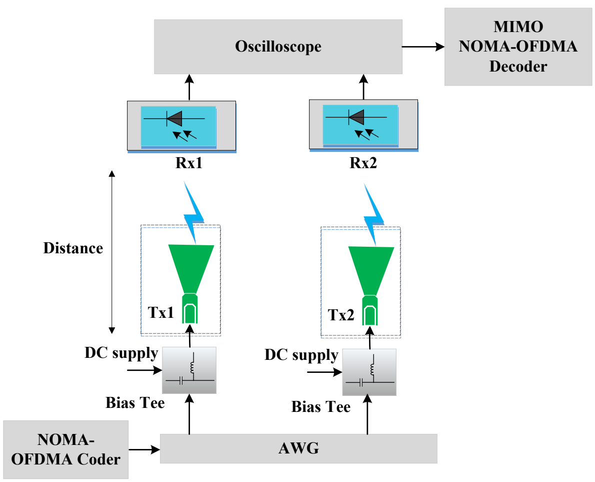

Fig. 2 Experiment setup for MIMO NOMA-VLC.

through free space channel and detected by two photo-detectors. Then a real-time digital oscilloscope is used to capture the two waveforms for offline signal processing. The distances between the two LED and the two Rx are both 13.5

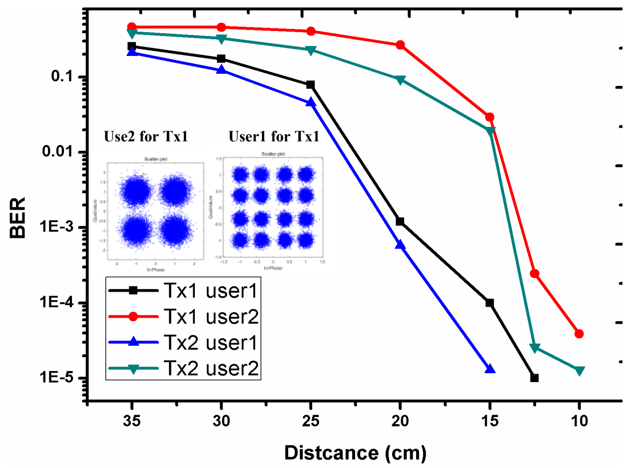

Fig. 3. BER performance with 4-QAM mapping for user 1 & 2.

cm. Figure 3 shows the bit error rate (BER) as a function of transmission span in the case of two users for each Tx. 4-QAM are adopted for all the users. The relative power ratio of user 1 to user 2 is 3.45, which is the optimum value. The constellations of user 1 and 2 for Tx1 are captured with a transmission span of 12.5 cm. Due to the interference from user 2, the constellations for user 1 in Tx1 and Tx2 look like 16-QAM constellation. User 1 is allocated with more power, so the data of which is decoded firstly with the interference from user 2. If the data of user 1 cannot be accurately demodulated, the data of user 2 cannot be recovered with error free. Therefore, the BER performance of user 1 is better than user 2 for both Tx1 and Tx2.

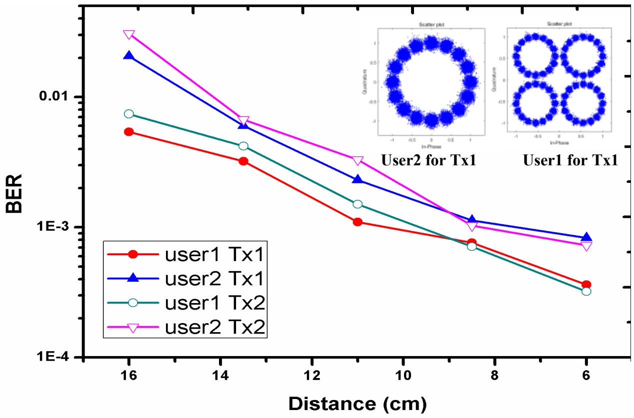

Fig. 4. BER performance with 4-QAM and 16-PSK mapping for

It should be pointed out that high-order modulation format such as 16-QAM cannot be adopted for both user 1 and 2 due to large inter-user interference. In order to improve the spectral efficiency, the constellations for the users should be carefully designed to reduce the interference. Figure 4 shows the BER performance in the case of two users for each Tx, where 4-QAM is adopted for user 1 while 16- phase shift keying (PSK)

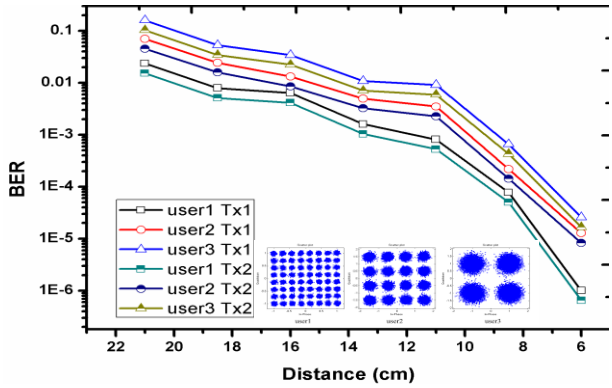

Fig. 5. BER performance for NOMA MIMO-VLC with 6 users.

is adopted for user 2. The optimum relative power ratio of user 1 to user 2 is about 3.33. The constellations of user 1 and 2 for Tx1 are captured with a transmission span of 6 cm. As shown in Figs. 3 and 4, higher order modulation format requires higher signal to noise ratio (SNR) to combat the inter-user interference and noise. If 16-QAM is adopted for user 2, the inter-user interference is more difficult to eliminate. Figure 5 shows the BER performance of MIMO NOMA-VLC with 3 users for each Tx. The relative power ratios of user 1 to user 3 and user 2 to user 3 for each Tx are 15.7 and 3.92, respectively. The constellations with a transmission span of 6 cm for user 1, 2 and 3 for Tx1 are shown in Fig. 5. Due to the interference from user 2 and 3, the constellation for user 1 looks like 64-QAM constellation. While the constellation for user 2 looks like 16-QAM constellation because of the interference from user 3. If the data demodulation of user 1 cannot be accurately realized, the data of user 2 and 3 cannot be recovered with error free. As such, the BER performance of user 1 is better than that of user 2 and 3 as shown in Fig. 5.

IV. Conclusion

We first time introduced the NOMA scheme for MIMO-VLC system. The feasibility of proposed scheme was experimentally verified. The MIMO demultiplexing and interference cancellation were simultaneously realized in the same step at frequency domain. The experiment results showed that the constellations for the users with high-order modulation should be carefully designed to reduce the inter-user interference. With the increase of the user number, the obtainable transmission distance was reduced, since more SNR is required to eliminate the inter-user interference.

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