Demonstration of Optical Wireless Communications Using Spatial Modulation with Signal Space Diversity

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***Abstract*—Spatial modulation with signal space diversity is proposed and experimentally demonstrated using 4-CAP modulation for indoor optical wireless communications. An improved data rate of 7.5 Gb/s is achieved using 2.5 GB/s CAP modulation with rotated CAP constellation and diversity interleaving to enhance BER performance.**

***Keywords*—optical wireless communications, spatial modulation, signal space diversity**

I. Introduction

Dramatic increase in both data traffic and connectivity speed is highly demanded in future indoor communications by the advent of super high-definition streaming such as virtual reality and augmented reality. Wireless connectivity is required in such ultra-broadband applications to provide enhanced flexible user interactions. Optical wireless communication (OWC) is a promising candidate for realizing such scalable high-bandwidth wireless connectivity [1], where existing radio frequency based wireless technologies typically face limited bandwidth, and the radio-frequency radiation can be prohibited to avoid interference [2].

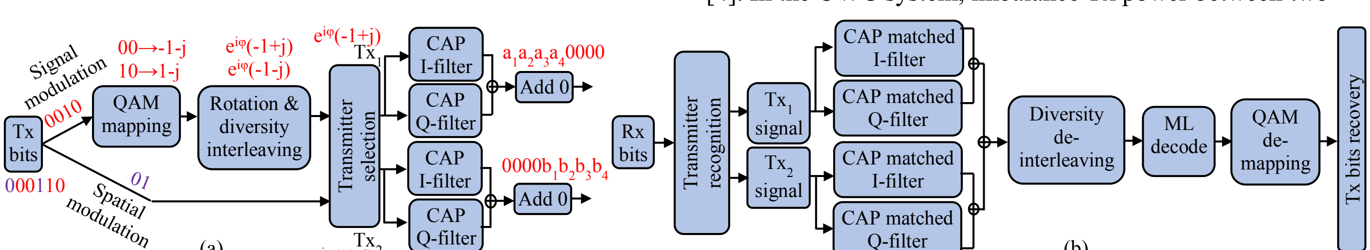
For the typical line-of-sight link configuration in the OWC, enhanced link performance can be realized by spatial diversity at the cost of spatial redundancy. In this paper, we aim to provide this diversity using signal space diversity (SSD) [3], and hence, the released spatial resources can be used to increase data rate via spatial modulation (SM). Experimental results show that, 7.5 Gb/s 2×1 multiple-inputs-single-output (MISO) infrared laser OWC system using 2.5 GB/s Carrierless Amplitude and Phase (CAP) modulation is achieved. Compared with conventional SM with CAP modulation, improved BER performance can be obtained by SSD with diversity interleaving and rotated CAP signal constellation within 20° rotation angle.

II. Principles

The block diagram of the signal generation is shown in Fig. 1. At the transmitter side, as illustrated in Fig. 1 (a), bit sequence is firstly divided into sets of 6 bits (e.g. 000110), where 3 consecutive bits form one subset (e.g. 110). Within each subset, the first bit is the SM bit (e.g. 1 in purple font) and the remaining two bits are the signal modulation bits (e.g. 10 in red font). Assuming that two consecutive data subsets are routed to two transmitters, the signal modulation bits then pass through QAM (Quadrature Amplitude Modulation) mapping to form a complex symbol (e.g. -1-j, 1-j). The SSD including signal constellation rotation φ and diversity interleaving is done next by exchanging the imaginary part of Transmitter 1's (Tx_1's, represented by SM bit 0) signals with the real part of Transmitter 2's (Tx_2's, represented by SM bit 1) signals (e.g. $e^{i\varphi}(-1+j)$, $e^{i\varphi}(-1-j)$). Then the exchanged rotated signals from each transmitter are modulated with In-phase (I) and Quadrature-phase (Q) filters (up-sampling=4) of CAP and routed to the corresponding Tx according to the SM bits. At each transmitter, four zeros are added to the time slot when the corresponding transmitter is not active to emulate the SM scheme.

At the receiver side, as illustrated in Fig. 1 (b), signals from different transmitters are first recognized by different channel gains. After demodulation with matched I /Q filters of CAP, the signals from two transmitters are combined for diversity deinterleaving. For the maximum likelihood decoding as the next step, the possible symbols are the rotated CAP constellation (with regard to the transmitted signal rotation). Finally, the transmitted bit sequence is recovered with the demapped QAM signal combined with the corresponding SM bits.

The proposed scheme can achieve increased data rate by SM with enhanced bit-error-rate (BER) by SSD. It is worth noting that the SSD in this paper is different from the SSD reported in [4]. In the OWC system, imbalance Tx power between two



Tx - Transmitter; Rx - Receiver; ML-Maximum Likelihood

Fig. 1. Block diagram of the signal generation for the proposed SM with SSD (optical wireless link in between is not shown) (a) Transmitter; (b) Receiver.

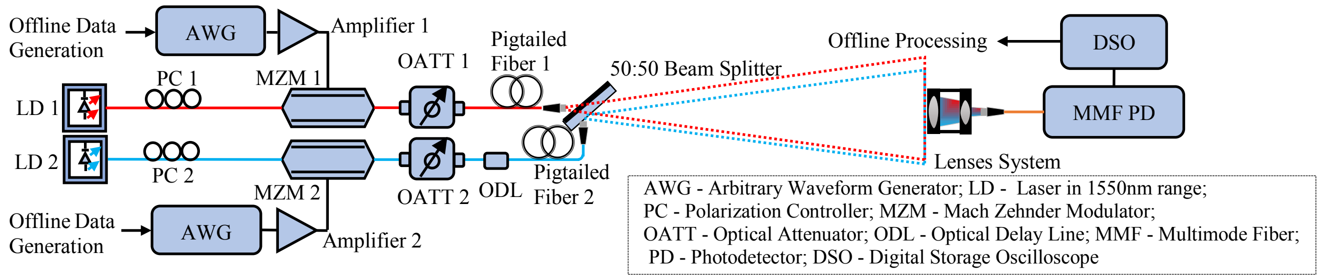


Fig. 2. Experimental setup of the proposed OWC system.

channels lead to independent, real-valued channel gains, diversity interleaving is employed in such a way that the same part (real or imaginary) of QAM mapping signals from two transmitters are transmitted in the same channel by exchanging the imaginary part of one signal with the real part of the other signal in one data set. Therefore, combined with signal constellation rotation, diversity interleaving signals are more robust against channel gain difference, since two signals do not degrade together.

III. EXPERIMENTAL SETUP AND RESULTS

The experimental setup used for demonstrating the proposed scheme is shown in Fig. 2. 2.5 GB/s 4-CAP SSD data with SM were generated offline and fed to 1549nm and 1550nm lasers, respectively. An optical attenuator was used in each channel to provide imbalanced Tx power to distinguish signals from two transmitters by different channel gains. An optical delay line was used in one channel for fine channel synchronization tuning. Each optical signal propagating through 1.2 m free-space had a 16° divergence with a total of 7 dBm optical power (within the eye safety limit). Then both optical signals were captured at the receiver end and fed into oscilloscope (oversampling=4) for offline processing.

Partial received data sequence is shown in Fig 3, where the modulated signals from two channels come after the training sequence (TS). The TS includes the synchronization frame as well as the channel recognition frame. From Fig 3, it can be seen that the power gains from different channels are distinct (about 2dB difference), which is used to recognize different channels.

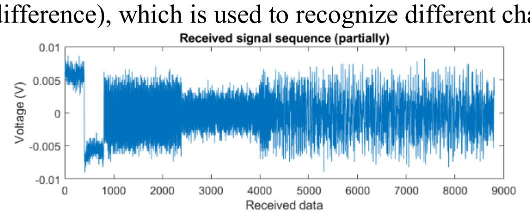


Fig. 3. Received data sequence with channel gain difference.

The BER of the proposed OWC system with SSD using different transmitted constellation rotation angles are shown in Fig. 4 (a). The power gain difference between two channels was about 2 dB. It can be seen that with larger rotation angles in the 20° rotation range, the BER with respect to SNR (dB), which is estimated by the error vector magnitude (EVM), is improved. The reason can be explained by the comparison of constellation point distributions in Fig 4 (a) with 0° rotation and in Fig 4 (b) with 20° rotation. It is shown that when the transmitted signal is not rotated, the received signal constellation distribution due to different channel gains is more spread and not concentrated before deinterleaving, making the results worse for the following ML decoding, which affects the measured BER.

The BER performances of the OWC system using SM with and without SSD are shown in Fig. 4 (b), it can be seen that SSD in 20° rotation angle provides a significant BER improvement. The SM with SSD in 0° rotation angle has comparable BER with that of the SM only, which is because that similar signal constellation distributions are achieved using SM only and SM with 0° SSD after deinterleaving (shown in Fig 4 (a)).

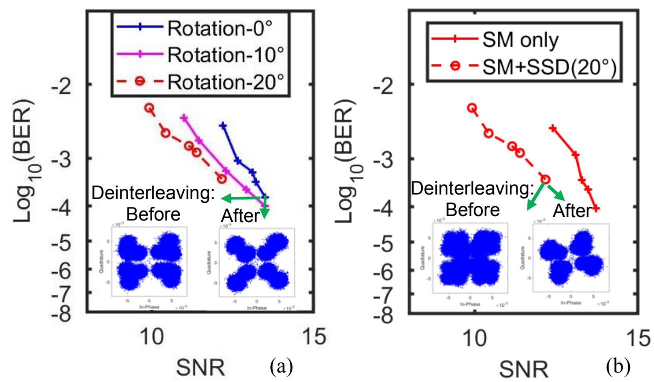


Fig. 4. Measured BER vs SNR (dB) by EVM with ~2dB power gain difference between two channels (a) SM with SSD using different transmitted constellation rotation angles; (b) SM only and SM with SSD.

IV. CONCLUSIONS

A novel SM scheme with SSD in indoor OWC systems has been proposed and experimentally demonstrated, where SSD provides enhanced BER performance and SM achieves increased data rate. Experimental results have shown that for 7.5 Gb/s gross transmission data rate based on 2.5 GB/s CAP modulation, the BER performance can be improved by increasing the constellation rotation angle within 20° range with about 2dB channel gain difference at the receiver.

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