Optical Spatial Modulation with Polar Coordinate for Optical Wireless Communication System

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Abstract— In this paper, we propose novel OWC-MIMO modulation scheme which efficiently uses the polar coordinate. Our new optical spatial modulation with polar coordinate is designed to easily adapt traditional complex modulation schemes like QAM/PSK to OWC-MIMO system and the proposed method can easily convert from complex signal to real positive signal without Hermitian symmetry operation. Simulation result shows that the proposed method has better BER and BPCU performance than the QCM.

Keywords—OWC; SM; QCM; polar coordinate; OSM-PC;

I. INTRODUCTION

Optical Wireless Communication (OWC), which once sounded like a futuristic concept, has now morphed into an emerging technology. The potential of this technology has been recognized by academia and industry and, hence, heavy investment has recently been made to develop it further [1]. The main catalyst behind the increasing interest in OWC technology is the deployment of light emitting diodes (LEDs) as access points for wireless connectivity. These LEDs are ecologically friendly and one of today's most energy-efficient technologies, hence enabling green wireless communication. However, their low intrinsic modulation bandwidth (BW) is limiting OWC from achieving extremely high data rates. Furthermore, adopting complex modulations such as M-QAM and quadrature phase shift keying (QPSK) to mitigate this limited BW is not feasible, due to the signaling waveform in OWC. It should be recalled that in OWC the input data is predominantly intensity modulated and transmitted across an optical channel, then the optical power is directly detected and converted into electrical current by using a photo detector (PD). This signaling strategy imposes constrains upon the transmitted signal to be real valued and positive, leading to the need to develop efficient solutions to make the complex modulations suitable for intensity modulation/direct detection (IM/DD) systems.

Multiple Input Multiple Output (MIMO) techniques appear attractive to improve limited modulation bandwidth of OWC by its spectral efficiency. In [2], MIMO techniques such as Repetition Coding (RC), Spatial Multiplexing (SMP) and Spatial Modulation (SM) are compared with each other for different indoor OWC channel condition. Especially, SM has benefits such as no Inter-Channel Interference (ICI), less detection complexity and no inter-antenna synchronization. For this reason, many researchers are interested in SM-MIMO system and various signaling schemes has been proposed. Signaling methods considered in multiple LEDs include space shift keying (SSK) and its generalization (GSSK), where the ON/OFF status of the LEDs and the indices of the LEDs which are ON convey information bits [3],[4]. Other signaling methods for multiple LED includes spatial modulation (SM), and generalized spatial modulation (GSM) [5],[6]. These algorithms consider real signal sets like M-ary pulse amplitude modulation (PAM) with positive-valued signal points in line with the need for the transmit signal in OWC to be positive and real-valued to intensity modulate the LEDs.

The use of complex signal sets like M-ary quadrature amplitude modulation (QAM) in OWC is studied extensively [7],[8]. A key constraint in the above techniques is that they perform hermitian symmetry operation for obtaining positive and real-valued signal. Hermitian symmetry operation increases the calculation complexity and reduces the bandwidth as half. In order to solve this problem, QCM method was proposed [9]. QCM is to use four LEDs to form a single modulation unit that simultaneously conveys the real and imaginary parts of a complex modulation symbol and their sign information.

In this paper, we propose the novel and efficient optical spatial modulation which is can easily convert from complex signal to real-positive signal by using polar coordinate.

II. SYSTEM MODEL

A MIMO system with NT LEDs (transmitter) and NR PDs (receiver) is considered. $\boldsymbol{x} = \begin{bmatrix} x_1 & x_2 & \cdots & x_{NT} \end{bmatrix}^T$ denotes the $NT \times 1$ transmit signal vector where x_i is the light intensity emitted by i-th LED. MIMO channel matrix is given by

$$\boldsymbol{H} = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,NT} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,NT} \\ \vdots & \vdots & \ddots & \vdots \\ h_{NR,1} & h_{NR,2} & \cdots & h_{NR,NT} \end{bmatrix} \quad (1)$$

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where $h_{i,j}$ is the channel coefficient between j-th LED and i-th PD, $j=1,2,\cdots,NT$, $i=1,2,\cdots,NR$. Since we consider only the line-of-sight (LOS) environment, channel coefficient $h_{i,j}$ is calculated as followings

$$h_{i,j} = \frac{n+1}{2\pi} \cdot \cos^n(\varphi_{i,j}) \cdot \cos(\theta_{i,j}) \cdot \frac{A}{R_{i,j}^2} \cdot \mathrm{rect}\left(\frac{\theta_{i,j}}{FOV}\right) \quad (2)$$

where $\varphi_{i,j}$ is the angle of emergence with respect to the j-th LED and n is the mode number of the radiating lobe given by $n=\frac{-\ln(2)}{\ln\cos\Phi_{1/2}}$, $\Phi_{1/2}$ is the half-power semi-angle of the LED. $\theta_{i,j}$ is the angle of incidence at the i-th PD, A is the area of the detector, $R_{i,j}$ is the distance between the j-th LED and the i-th PD, FOV is the field of view of the detector, and $\mathrm{rect}(x)=1$, if $|x| \le 1$, and $\mathrm{rect}(x)=0$, if $|x| > 1$.

The received signal $\boldsymbol{y}$ is given by

$$\boldsymbol{y} = \alpha \boldsymbol{H}\boldsymbol{x} + \boldsymbol{n} \quad (3)$$

where α is the responsivity of the detector and $\boldsymbol{n}$ is the real AWGN with zero mean and variance σ^2.

III. Proposed Signal Modulation Scheme

In this section, we firstly describe the polar coordinate which can covert complex signal to positive-real signal. Secondly, we show the proposed signal modulation method named Optical Spatial Modulation with Polar Coordinate (OSM-PC).

A. Polar Coordinate

In [9], QCM method conveys the real and imaginary parts of a complex symbol and their sign information using four LEDs. Representation of complex symbol in polar coordinates can be exploited instead. That is, it is adequate to convey only the magnitude and phase (r, φ) of a complex symbol, for which only two LEDs suffice.

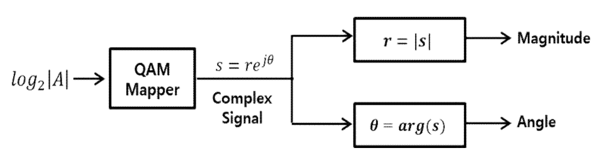

Fig. 1. Block diagram of polar coordinate

The block diagram of polar coordinate is given in Fig.1. The complex modulation symbol s is split in to two real and non-negative parts, namely, the magnitude of the complex symbol r and the phase of the complex symbol φ such that

$$s = \frac{(s_I + s_Q i)\beta}{K} = re^{j\varphi}$$
$$r = |s|, \; \varphi = \arg(s) \quad (4)$$

Where, $\varphi \in [0,2\pi)$. K is the normalization factor of QAM. β is the LED power limitation. By using polar coordinate, conversion from complex signal to real-positive signal is possible.

B. Proposed Modulation : OSM-PC

A system model for the OSM-PC scheme is shown in Fig.2. A generic $NT \times NR$ MIMO configuration is considered with NT and NR being the number of transmitting LEDs and receiving PDs, respectively.

Let $m = \log_2(NT^2 M)$ be the group of data bits to be transmitted at one particular time instant with M denoting the modulation order of arbitrary M-QAM/PSK. The incoming data bits are processed and partitioned into three groups. A signal constellation symbol is modulated by $\log_2(M)$ bits. In addition, two spatial constellation symbols are modulated each by $\log_2(NT^2)$ bits. The signal constellation symbol s is further decomposed to magnitude of the complex symbol r and the phase of the complex symbol φ. Then, r and φ are transmitted over LED which is corresponding active LED index #1 and #2, respectively. In SM, one LED is activated at each time instant to transmit PAM symbol and $\log_2(NT)$ bits are used to control the active LED element. While in OSM-PC, additional $\log_2(NT)$ bit are transmitted by utilizing that each component of polar coordinated symbol is transmitted from a specific LED.

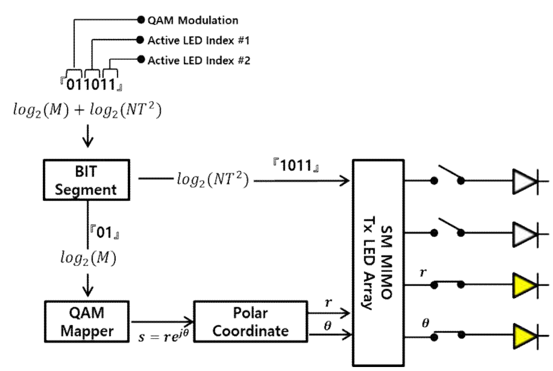

Fig. 2. Block diagram of OSM-PC modulation

An example of OSM-PC transmission is given in what follows. Assume that the following incoming data bits is [011011] are to be transmitted at one particular time instant using 4-QAM and four transmit LEDs. The first $\log_2(M)$ bits [01] modulate a 4-QAM symbol $x = -1 + j$. This symbol is divided further to magnitude $r = 1$ and phase $\varphi = 2.3562$, respectively. The second $\log_2(NT)$ bits [10] modulate the active LED index used $\ell_r = 3$ to transmit $r = 1$. The last $\log_2(NT)$ bits [11] modulated the active antenna index $\ell_\varphi = 4$ to transmit $\varphi = 2.3562$.

IV. Simulation Result

In this section, we provide the simulation result to demonstrate the performance of the proposed method via computer simulation. Four LEDs and PDs are used both at the transmitter and the receivers, respectively. The MIMO channel coefficient is assumed to know at the receiver. For MIMO detection, ML method is used. The detail simulation environment and simulation result are described in Table 1,2 and Figure 3, respectively.

TABLE I. Simulation Environments

LEDs and PDs location in Room	*LED/PD 1*	*[1m 1m]*
	LED/PD 2	*[1m 2m]*
	LED/PD 3	*[2m 1m]*
	LED/PD 4	*[2m 2m]*
Ceiling to floor distance		*2.5m*
half-power semi-angle of the LED		*60 degree*
The field of view of the detector		*70 degree*
Responsivity of the detector		*1*
LED power limitation		*1*

TABLE II. Comparison of BPCU and Average symbol magnitude according to modulation schemes

Modulation schemes		***QCM***	***Proposed Method (OSM-PC)***
BPCU		$NT\,\frac{\log_2(M)}{4}$	$\log_2\left(M \cdot NT^2\right)$
$\beta = 1$, $NT = 4$ case	4QAM	0.3536	1.5708
	16QAM	0.3162	0.7854
	64QAM	0.3086	1.0202

Figure 3 shows the BER performance of the QCM-4QAM, QCM-16QAM, QCM-64QAM and proposed method for 4x4 SM OWC-MIMO systems. From simulation result, proposed method is superior to QCM in terms of BER performance and transmission rate. However, from table 2, average symbol magnitude of the proposed method is about 4.4 times higher than the QCM at 4-QAM case. It means that power consumption of the proposed method is inferior to QCM. The implications of this result are that if there is no consideration of power consumption, the proposed method should be chosen than QCM.

V. Conclusions

In this paper, we introduced a simple and novel MIMO modulation scheme which efficiently uses the polar coordinate. The scheme is termed as OSM-PC (Optical Spatial Modulation – Polar Coordinate). It uses two LEDs. Each activated LED map to magnitude and phase of complex signal like QAM/PSK

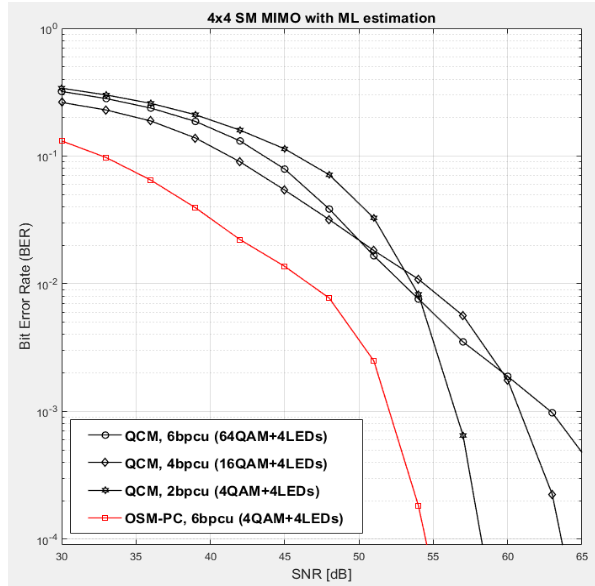

Fig. 3. The BER performacne of the proposed method, QCM-4QAM, QCM-16QAM and QCM-64QAM,

Symbol, respectively. The proposed method does not require to perform Hermitian symmetry operation to generate LED compatible positive real signals. Simulation results showed that the proposed method has better BER and BPCU performance than QCM.

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