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A new precoding scheme for spectral efficient optical OFDM systems

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ABSTRACT

Achieving high spectral efficiency is the key requirement of 5G and optical wireless communication systems and has recently attracted much attention, aiming to satisfy the ever increasing demand for high data rates in communications systems. In this paper, we propose a new precoding/decoding algorithm for spectral efficient optical orthogonal frequency division multiplexing (OFDM) scheme based visible light communication (VLC) systems. The proposed coded modulated optical (CMO) based OFDM system can be applied for both single input single output (SISO) and multiple input multiple-output (MIMO) architectures. Firstly, the real OFDM time domain signal is obtained through invoking the precoding/decoding algorithm without the Hermitian symmetry. After that, the positive signal is achieved either by adding a DC-bias or by using the spatial multiplexing technique. The proposed CMO-OFDM scheme efficiently improves the spectral efficiency of the VLC system as it does not require the Hermitian symmetry constraint to yield real signals. A comparison of the performance improvement of the proposed scheme with other OFDM approaches is also presented in this work. Simulation results show that the proposed CMO-OFDM scheme can not only enhance the spectral efficiency of OFDM-based VLC systems but also improve bit error rate (BER) performance compared with other optical OFDM schemes.

1. Introduction

The demand of wireless communication technologies is constantly growing and expected to increase exponentially in the next years [1]. According to the recent Cisco report [1], global data traffic will increase sevenfold at a compound annual growth rate (CAGR) of 47 percent from 2016 to 2021. This makes it clear that the current radio frequency (RF) based wireless communication networks are not able to fully satisfy this traffic demand. In order to meet the future traffic demand, optical wireless communications such as visible light communication (VLC) systems are seen as potential complementary technology to the RF wireless communications. As VLC uses the unregulated visible light (380–780 nm) as a carrier for the data, this huge available spectrum enables VLC to achieve very high data especially when employing orthogonal frequency division multiplexing (OFDM) which is considered a good candidate for VLC systems due to its high spectral efficiency and capacity to combat inter-symbol interferences (ISI). Moreover, the data rate of the OFDM based VLC system could be further increased by using multiple input multiple output (MIMO) communication techniques instead of single input single output (SISO) architectures. Furthermore, the improvements of power efficiency and cost reduction of light emitting diode (LED) that used for both illumination and communication, making VLC an economic and ubiquitous data transmission solution. These features offer VLC the premise to be part of future 5G technologies [2]. However, OFDM signals need to be modified to work with optical systems that adopt intensity modulation and direct detection (IM/DD), where real and positive signals are required to drive the LEDs. Several optical forms of OFDM such as direct-current-biased optical OFDM (DCO-OFDM) [3], asymmetrically clipped optical OFDM (ACO-OFDM) [4], and unipolar OFDM (U-OFDM) [5] have been proposed to generate real and positive OFDM signals compatible with the LED characteristics and IM/DD system. In DCO-OFDM, a DC bias is added and the signal is scaled to obtain the positive signal [6]. In ACO-OFDM, the unipolar signal is obtained through clipping of all negative values at zero and modulating only odd subcarriers. Unfortunately, ACO-OFDM sacrifices a large portion of bandwidth to achieve the asymmetrical property. The U-OFDM scheme transmits the positive and negative halves of the DCO-OFDM signal in two separate parts in series but it has higher power efficiency. The spectral efficiency of ACO-OFDM and U-OFDM is about half the spectral efficiency of DCO-OFDM for the same order of Quadrature Amplitude Modulation (QAM). Another method called Non-DC-biased OFDM (NDC-OFDM) is proposed for MIMO scheme in [7] to

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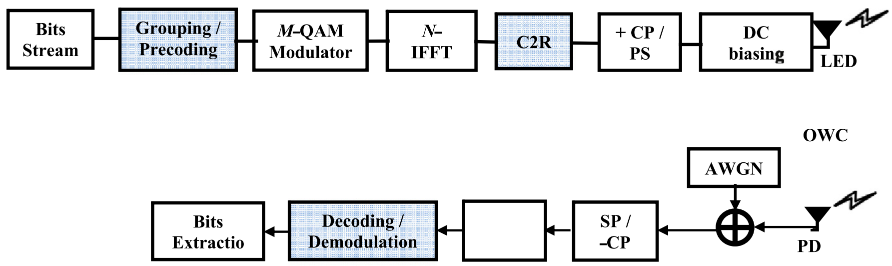

Fig. 1. Block diagram of the proposed CMO-OFDM scheme for SISO-VLC system.

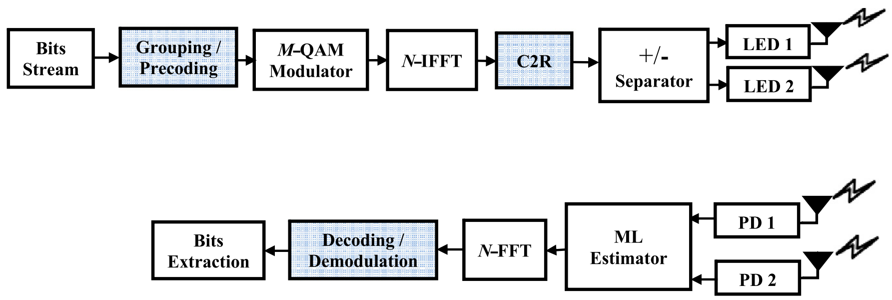

Fig. 2. Block diagram of the proposed CMO-OFDM scheme for 2×2 MIMO-VLC system with spatial multiplexing.

provide spectral efficiency higher than ACO-OFDM and to tackle the DC biasing issue of DCO-OFDM. In all these forms, the real valued time domain signal is achieved by constraining the input data vector of the inverse fast Fourier transform (IFFT) to have Hermitian symmetry by adding the conjugate of the complex signal before the IFFT. However, due to the use of Hermitian symmetry, the spectral efficiency (SE) of above schemes is still limited and more improvements are required. Contrary to mentioned methods above, the work in [8] proposes a smart scheme called generalized LED index modulation OFDM (GLIM-OFDM) that transmits the complex OFDM signals through optical MIMO channels through the separated signal components consisting of their real–imaginary and positive–negative parts by employing spatial multiplexing principle. A simple scheme has been presented in [9] to produce the real-valued OFDM signals by encoding the complex into real value without the use of Hermitian symmetry but without derivation in details. Motivated by this and in order to further improve the spectral efficiency, in this paper a novel precoding/decoding scheme is proposed for OFDM based VLC systems. We have mathematically modeled the complete precoding technique and show the results of simulation that evaluate the system performance are in agreement with the analysis presented. A comparison of the proposed system with other systems showed a considerable improvement in the results in terms of spectral efficiency and bit-error-rate (BER).

The rest of the paper is organized as follows: Section 2 gives an insight of system description and the block diagram of the proposed scheme is explained in detail. In Section 3, we discuss the encryption principle of a precoded OFDM-based VLC system along with the mathematical analysis of the precoding algorithm. In Section 4, calculation for spectral efficiency is presented. The performance enhancement of the proposed system and simulation results are discussed in Section 5. The conclusion is drawn in Section 6.

2. System description and mathematical analysis

The serial data bits are grouped into $\log_2(2M)$ bits, where M is the M-ary number, i.e. for 4-QAM, each group has 3 bits. Each group is simply converted to its equivalent decimal form which is one of the possible numbers in the set 0 to $2M-1$ (here 0–7). Now, each digit can be encoded using two digits each of them $\in 0, 1, \ldots, M-1$ according to proposed precoding/decoding scheme (explained later). These two digits are modulated using M-QAM modulator and then feed to a N-points IFFT, where the first modulated symbol represents the input to the kth IFFT and the second is the input to the $(N-k)$th IFFT. Using the proposed approach, the complex output of the IFFT can be converted to real value time domain signal using the complex to real conversion (C2R) that adds the real to the imaginary parts directly. However, the resulting real, but bipolar signals can be separated by using similar way used in conventional DCO-OFDM in which a DC-bias is added to generate unipolar signals before LED emission as demonstrated in Fig. 1. The sequences are scaled and biased to be compatible with the LED dynamic range after being appended with a cyclic prefix (CP) and parallel to serial (PS) converted.

Alternatively, and for this method, the bipolar signals can also be converted to unipolar by using the spatial multiplexing method [7,9], where the positive values are sent via the first LED and the absolute of the negative values are sent via the second LED (MIMO scenario) as shown in Fig. 2. Upon reception, the reverse process will be performed on the received signal by the photodetector (PD) after passing the optical wireless channel (OWC) with an additive white Gaussian noise (AWGN). The maximum likelihood (ML) is used for detection and the frequency domain symbols of FFT output are decoded and the source bits can be recovered using the same precoding/decoding lookup table that known by both transmitter and receiver. However, the PS/SP, AWGN, appending and removing the CP are included but not shown in Fig. 2 for simplicity. It is evident that, and for both proposed approaches, the inputs to IFFT are not necessary to have the Hermitian symmetry, as the complex signal can be converted to real later; therefore the numbers of bits per symbol is increased from $\log_2(M)$ to $\log_2(2M)$ in this case.

3. Spectral efficiency calculation

The spectral efficiency (SE) is defined as the amount of information bits transmitted per time unit per Hertz available bandwidth. The SE of ACO-OFDM is given by [10]

$$\eta_{ACO} = \frac{\eta_{DCO}}{2} = \frac{N-2}{4(N+N_{CP})}\log_2(M) \quad \text{bps/Hz} \tag{1}$$