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PAPR reduction scheme for ACO-OFDM based visible light communication systems

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ABSTRACT

In this paper, we proposed a novel peak to average power ratio (PAPR) reduction scheme for the asymmetrically clipped optical orthogonal frequency division multiplexing (ACO-OFDM) visible light communications system. We implement the Toeplitz matrix based Gaussian blur method to reduce the high PAPR of ACO-OFDM at the transmitter and use the orthogonal matching pursuit algorithm to recover the original ACO-OFDM frame at the receiver. Simulation results show that for the 256-subcarrier ACO-OFDM system a ∼6 dB improvement in PAPR is achieved compared with the original ACO-OFDM in term of the complementary cumulative distribution function, while maintaining a competitive bit-error rate performance compared with the ideal ACO-OFDM lower bound. We also demonstrated the optimal parameter *C* of 2 for the recovery algorithm based on the tradeoff between the data rate and recovery accuracy. The recovery results show that using the proposed scheme the ACO-OFDM can faithfully be reconstructed judging by the very low value for the reconstruct error of 0.06.

1. Introduction

The rapid development of solid state lighting technologies has made the visible light communications (VLC) technology a promising complementary scheme to the radio frequency (RF) wireless communications. The VLC technology with unique multiple features of illumination, data communications and localization (mostly indoor) can be adopted in a number of applications including homes, offices, hospital, train, airplane [1,2], mines, tunnels, shopping mall and underwater communication [3,4].

The main technical challenge facing the VLC technology is the limited modulation bandwidth of white light emitting diodes (LEDs), which limits the transmission rate. In order to make good use of the limited bandwidth (up to 5 MHz) and enhance the transmission throughput, optical orthogonal frequency division multiplexing (O-OFDM) has been extensively investigated in VLC systems with some modifications to accommodate the intensity modulation direct detection (IM/DD) channel [5,6]. This is mainly because of minimize multipath induced inter symbol interference and immunity to fluorescent-light noise near dc [7]. However, the high signal peak to average power ratio (PAPR) associate with the OFDM signal is the most detrimental as it decreases the signal-to-quantization noise ratio (SQNR) of the analog-to-digital (A/D) and digital-to-analog (D/A) converters while wasting the large dynamic range of linear amplifiers [8]. High PARR can lead to nonlinear distortion and clipping in systems with peak-power limitations. This problem is especially distinctive in the O-OFDM systems since the system require the frequency domain symbols to be Hermitian symmetric such that the time domain signal is real but still in the bipolar format [9].

A number of techniques to mitigate the high PAPR requirement in O-OFDM have been reported in the literature including trellis coding, which reduces the average optical power [10] and block coding, which maps the vector of *k*-information bits to be transmitted and to the vector of symbol amplitudes modulated onto the *N*-subcarrier [11] at the cost of increased transmission bandwidth. Signal transformation based on selected mapping (SLM) has also been used to reduce the signal peak values in O- OFDM systems [12]. In [13] the signal peak values were reduced by embedding a pilot symbol (PS) phase rotation technique as part of the original OFDM signal. In [14] lower order modulation on subcarriers, which suffer the most distortion, were used to establish a high throughput for OFDM-VLC at a sampling rate of six times the available system bandwidth with reduced PAPR. The phase of PS was chosen based on the SLM algorithm while the maximum likelihood criterion was used at the receiver (Rx) to estimate the PS.

However, there is a well-known image processing algorithm known as Gaussian blur (GB) or Gaussian smoothing where edges and lines in various directions are treated similarly because of

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being very “smooth” and circularly symmetric [15,16]. GB is widely used in graphics software to reduce the image noise and detail by means of the convolution operation [17]. The concept of changing images from sharpness to blur could be adopted in ACO-OFDM to reduce the PAPR. Simulation results has shown that for 256-subcarrier ACO-OFDM a ~6 dB improvement in PAPR was achieved in term of the complementary cumulative distribution function (CCDF). Since in VCL the transmitted signals must be non-negative and real, then the asymmetrically clipped operation makes the negative values to be equal to zero, thus ACO-OFDM is the standard sparse signal in time domain [18]. Considering the sparsity characteristics of the ACO-OFDM signal, the recovery process can be realized by the sparse signal reconstruction algorithm such as orthogonal matching pursuit (OMP) at the Rx [19]. Simulation results show that, at a BER of 10^{-4}, the proposed algorithm requires only a ~2 dB of additional signal to noise ratio (SNR) compared to the ideal ACO-OFDM scheme and with the signal reconstruct error less than 0.1.

The rest of this paper is organized as follows; Section 2 describes details of ACO-OFDM based VLC systems while Section 3 focuses on the principle of GB and other PAPR reduction methods. Section 4 is all about the implementation of OMP recovery algorithm and in Section 5 the simulation results and discussions are provided. Finally, the concluding remarks are presented in Section 6.

2. ACO-OFDM based VLC system description

OFDM is widely adopted in RF and optical communications including free space optics and VLC due to its huge data transmission capability, high spectral efficiency and resilience to the channel induced impairments [20]. The block diagram of the proposed ACO-OFDM system is depicted in Fig. 1. In conventional ACO-OFDM systems, the time domain signal needs to be both real and unipolar. The bipolar signal at the output of IFFT is converted into unipolar by clipping the negative value to zero. Unlike the conventional ACO-OFDM system, in our scheme, the clipped output of IFFT is fed into GB module, to generate the alternative output sequence $S_i(n)$. Then the sequence $S(n)$ with the lowest PAPR is applied to the optical driver module.

At the receiver side, the received signal is influenced by the noise sources in a real scenario. The dominant noise source in an indoor wireless optical channel is the ambient light induced shot noise [21], which is modeled as the additive white Gaussian noise (AWGN). Thus, the received signal is given by:

$$y(n) = \eta \cdot S(n) \otimes h + Z(n), \quad S(n) = \phi \cdot x(n), \tag{1}$$

where η is the photoelectric conversion efficiency, $\varnothing \bullet x(n)$ is the matrix representation of the GB operation, $x(n)$ is the original ACO-OFDM signal, $S(n)$ is the output signal with the lower PAPR, h is the channel response, $Z(n)$ is AWGN with zero mean and variance of δ_z^2, and ⊗ denotes the convolution operation.

We assume that the channel state information is perfectly known in advance. According to the transmitter design of ACO-OFDM, a half of the transmitted signals are clipped to be zeros. Therefore, the time domain ACO-OFDM signal is standard sparse signal adopted in the compressed sensing (CS) theory. Considering the special time domain structure of ACO-OFDM symbols with the system complexity, we chose the OMP approach [22], which is widely used in sparse signal reconstruction, in our simulation parts for recovering the original ACO-OFDM signal. Following the FFT and demodulation process we regenerate the original binary data stream.

3. Reducing the PAPR using Gaussian blur method

PAPR is a key factor to limit the stability of the ACO-OFDM system. The PAPR of discrete ACO-OFDM signal $x(n)$ is defined as the ratio of the maximum instantaneous power to the average power, which is given by:

$$PAPR = \frac{\max |x(n)|^2}{E\left[|x(n)|^2\right]}, \tag{2}$$

where $E[]$ denotes the statistical expectation.

The simplest technique for PAPR reduction is amplitude clipping, which limits the peak envelope of the input signal to a predetermined value in order to mitigate higher PAPR at the cost of degradation of the system BER performance [23]. The amplitude clipped version of $x(n)$ is defined as:

$$x_{clip}(n) = \begin{cases} A, & x(n) \geq A \\ x(n), & x(n) < A \end{cases}, \tag{3}$$

where A is the pre-specified clipping level (CL). Note that $A \in [0, 1]$ following amplitude normalization process.

As it is well known, 2-dimensional GB operations are employed as the convolution in image processing to change images from sharpness to blur [24]. The 2-dimensional Gaussian Kernel is defined as:

$$G(x, y) = \frac{1}{2\pi\delta^2} \cdot e^{\frac{-(x^2+y^2)}{2\delta^2}}. \tag{4}$$

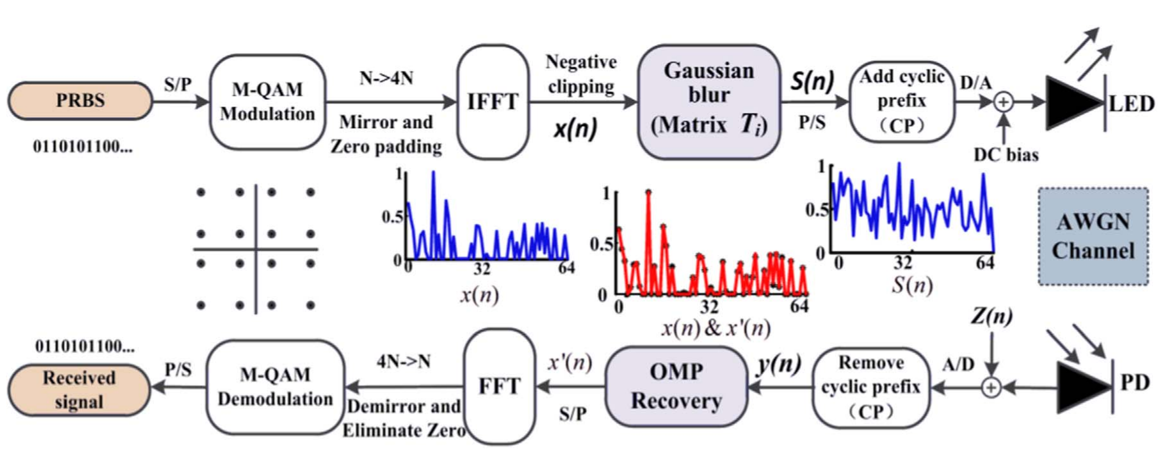

Fig. 1. Block diagram of ACO-OFDM system. S/P: serial-to-parallel converter, P/S: parallel-to-serial converter, PD: photodetector.