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A CNA-based blind equalization scheme for ACO-OFDM in VLC system

Jing He [a,*], Rui Zhang [a], Jin Shi [a], Zuo Chen [a], Yun Cheng [b]

[a] College of Computer Science and Electronic Engineering, Hunan University, Changsha, Hunan, China
[b] Department of Information Science and Engineering, Hunan University of Humanities, Science and Technology, Loudi, Hunan 417000, China

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ABSTRACT

In this paper, a blind equalization scheme based on the constant norm algorithm (CNA) is proposed for asymmetrically clipped optical orthogonal frequency division multiplexing (ACO-OFDM) in visible light communication (VLC) system. At the receiver, the CNA can be used to improve system spectral efficiency due to the free of training symbols. The simulation results indicate that for ACO-OFDM signal, the CNA-based blind equalization scheme achieves better mean square error (MSE) performance than that of constant mode algorithm (CMA). Moreover, the CNA-based blind equalization scheme outperforms the CMA scheme in the term of bit error ratio (BER) under same data rate in VLC system.

1. Introduction

Currently, due to the rapidly growing demand for bandwidth of end-users, the spectrum congestion has become a serious issue in radio frequency (RF) technologies. Visible light communication (VLC) technology has been paid more attention due to its broad bandwidth, unlicensed visible light spectrum and inherent security [1–3].

In VLC system, advanced modulation format such as orthogonal frequency division multiplexing (OFDM) is widely used due to its some advantages as high spectral efficiency and robustness to inter-symbol interference (ISI) [4–7]. Intensity modulation is applied in VLC system, in order to generate real-valued signals, Hermitian symmetry is imposed on all subcarriers [8,9]. Furthermore, to obtain non-negative signals, some schemes are proposed, such as DC-biased optical OFDM (DCO-OFDM) [10] and asymmetrically clipped optical OFDM (ACO-OFDM) [11]. In DCO-OFDM, the positive signal is obtained by adding a DC bias, which will suffer from the loss of energy efficiency [9]. For ACO-OFDM, the non-negative signal is obtained by clipping at zero, and transmitting only positive parts of OFDM waveforms [12,13]. It has lower spectral efficiency due to its special frame construction. However, the ACO-OFDM signals retain the properties that make OFDM resilient in a dispersive or multipath channel. And an additional bias is not required for ACO-OFDM. Thus, it is more power-efficient than that of DCO-OFDM.

For VLC system, the high peak-to-average power ratio (PAPR) of OFDM in combination with the non-linear characteristics of light emitting diodes (LEDs) will seriously impact bit error rate (BER) performance. The technique focusing on PAPR reduction and non-linear mitigation is proposed in VLC system, such as pilot-assisted methods [14]. However, it requires a certain training sequence so that it will reduce data rate. In addition, blind equalization technique is proposed [15]. It aims to recover distorted signals adaptively without the use of training sequence. And it can improve system bandwidth-efficiency. As a classical blind equalization scheme, the constant mode algorithm (CMA) with low complexity is proposed [16]. Moreover, the convergence speed of CMA is analyzed [17]. It is clear that CMA-type algorithms are constellation dependent. In order to apply to any constellation, constant norm algorithm (CNA) is proposed [18]. It shows that the performance of CNA scheme can outperform that of the CMA.

In this paper, a CNA-based blind equalization scheme is proposed for ACO-OFDM in VLC system. The initialization value and step size parameter are analyzed to search the optimal values that can achieve faster convergence speed. It can improve system spectral efficiency. It is due to without an additional training sequence. Simulation results illustrate that the CNA-based blind equalization scheme achieves better mean square error (MSE) performance than CMA in ACO-OFDM VLC system. In addition, BER performances of CNA-based, CMA-based blind equalization scheme and pilot-aided equalization scheme are compared for ACO-OFDM signal in VLC system.

2. Principle

2.1. ACO-OFDM generation scheme

Fig. 1 shows the data allocation and zero clipping in ACO-OFDM. The input serially frequency domain data $X = [X_0, X_1, X_2, \dots X_{N/4-1}]$ is initially converted into parallel data sequence. In ACO-OFDM, only the

* Corresponding author.
E-mail addresses: hnu_jhe@hotmail.com, jhe@hnu.edu.cn (J. He).

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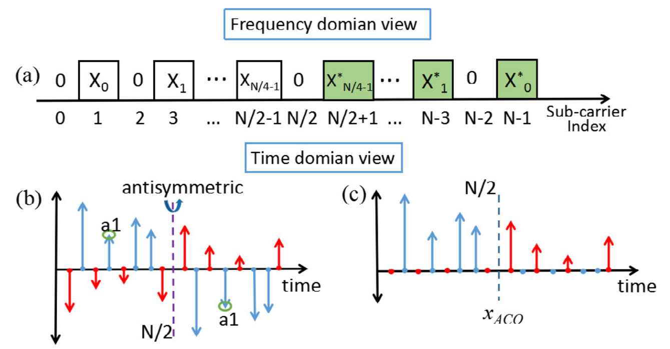

Fig. 1. (a) Frequency domain view of original signals; (b) Time domain view of original signals; (c) The signals after zero clipping.

odd subcarriers carry data. Before an N-point inverse fast Fourier transform (IFFT), to obtain the real value, the complex data has Hermitian symmetry (as shown in Fig. 1(a)). It is given by

$$X_h = X^*_{N\text{-}h} \tag{1}$$

where h equals $0, 1, 2, \ldots, N/2$ and N is the number of points on the IFFT. And the components of X_0 and $X_{N/2}$ are set to zero, i.e., $X_0 = X_{N/2} = 0$. After performing N-point IFFT, the real value signal x_k is obtained. In ACO-OFDM system, x_k is an anti-symmetric time sequence [7] (as shown in Fig. 1(b)), and it is expressed as

$$x_k = -x_{k+N/2} \qquad k = 0, 1, \ldots, \frac{N}{2} - 1. \tag{2}$$

Then, ACO-OFDM signal x_{ACO} makes it unipolar by simply clipping it at the zero, as shown in Fig. 1(c). It is given by

$$x_{ACO} = \begin{cases} x_k & x_k \geq 0 \\ 0 & x_k < 0. \end{cases} \tag{3}$$

It can be shown theoretically that asymmetrical clipping reduces the amplitude of each of the odd frequency subcarriers by exactly half of their original value but that they are undistorted. While a new clipping noise interference appears on the even subcarriers [11].

2.2. Channel model for VLC system

Assuming that the model space is 5 m × 5 m × 3 m. Due to the light power reflected by the wall and ceiling is much smaller than power of the channel noise, the reflection power is not taken into account. So the reflection of the light is ignored. Only direct light is considered. The current channel gain can be expressed as [19]

$$H(0) = \begin{cases} \dfrac{(m+1)A}{2\pi D_d^2} \cos^m(\Phi) T_s(\psi) \dfrac{n^2}{\sin 2(\psi)} \cos(\psi), & 0 \leq \psi \leq \psi_c \\ 0, & \psi > \psi_c \end{cases} \tag{4}$$

where m is the Lambert coefficient of transmitter, A is the physical area of the detector in a photo-detector (PD), D_d is the distance between a transmitter and a receiver, ψ is the angle of incidence, Φ is the angle of irradiance, $T_s(\psi)$ is the gain of an optical filter. Ψ_c and n are the width of the field of vision (FOV) at the receiver and the index of refraction, respectively. The received optical power can be written as $P_r = H(0)P_t$, where P_t is the transmitted optical power. After PD, the signal-to-noise ratio (SNR) of the output electrical signal can be written as [20]

$$SNR = \frac{(RP_r M_{index})^2 (\overline{x_{ACO}})^2}{\sigma^2} \tag{5}$$

where R is the responsivity of PD, M_{index} is the modulation index. The Gaussian noise N consisting of shot noise and thermal noise. It can be seen as a function of equivalent noise bandwidth B and received optical power P_r. It is written as [19,20]

$$N = \sigma^2_{shot} + \sigma^2_{thermal} = 2q\left(RP_r(1 + M_{index}\overline{x_{ACO}}) + I_{bg} I_2\right) B + \sigma^2_{thermal} \tag{6}$$

where q is the electronic charge, I_{bg} and I_2 are the background current and noise bandwidth factor, respectively.

The generalized VLC channel consists of LED, free-space channel and PD. A PD detects and converts the received light wave into an electrical current. The optical wireless channel model is expressed as

$$y_{m,n} = x_{ACO} \otimes h(t) + N \tag{7}$$

where $y_{m,n}$ represent n_{th} received OFDM symbol of the m_{th} subcarriers, x_{ACO} denotes the ACO-OFDM signal of the transmitter, ⊗ is the convolution operation, $h(t)$ is the impulse response, N is an additive white Gaussian noise (AWGN).

2.3. CNA-based blind equalization scheme

At the receiver, to recover the transmitted signal, the blind equalization is to iteratively update the equalizer coefficient by using only few features of the received signal. For the ACO-OFDM signal, this iterative process is carried out independently on each subcarrier, as described in Fig. 2. The output of the equalizer is expressed as

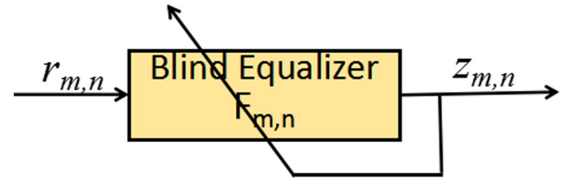

Fig. 2. The block diagram of CNA-based Blind equalization scheme.

$$z_{m,n} = F_{m,n} r_{m,n} \tag{8}$$

where $r_{m,n}$ is the received signal after the fast Fourier transform (FFT) and removing cyclic prefix. $F_{m,n}$ is the equalizer coefficient of the m_{th} subcarriers.

For CNA-based blind equalization scheme, it is the comparison of a function of the equalizer's output with a constant. Then the cost function of CNA-based blind equalization can be written as

$$J(z_{m,n}) = \frac{1}{ab} \left| \left\| z_{m,n} \right\|^a - R \right|^b \tag{9}$$

where ‖.‖ is the norm [21] and R is a real value that depends on the constellation size. a and b are two degrees of freedom of the algorithm. The values of a and b are set to 2 [18]. Since $x_{m,n}$ is taken from a 16-QAM constellation, the R is written as

$$R = \frac{E\{\left\| x_{m,n} \right\|^{2a}\}}{E\{\left\| x_{m,n} \right\|^{a}\}} \tag{10}$$

R is valid for all norms. In the paper, we chose p-norm for analysis. Then the complex $z_{m,n}$ can be expressed as

$$\left\| z_{m,n} \right\|_P = \sqrt[P]{\left|\text{Re}\{z_{m,n}\}\right|^P + \left|\text{Im}\{z_{m,n}\}\right|^P}. \tag{11}$$

Fig. 3 illustrates the 16-QAM constellation and the unit ball of some norms, where $p = 2$ and 6. The equalizer's coefficient updating algorithm of CMA can be expressed as

$$F_{m,n+1} = F_{m,n} - \mu(\left|z_{m,n}\right|^2 - R) z_{m,n} r^*_{m,n}. \tag{12}$$

The μ is the step-size parameter of the updating algorithm. In the case of p equaling 6, CNA is obtained. In this paper, the mapping method of 16-QAM is discussed in the simulation. The reason is that