COMPUTATIONAL COMPLEXITY COMPARISON BETWEEN DC-BIASED OPTICAL OFDM AND ASYMMETRICALLY CLIPPED OPTICAL OFDM IN VISIBLE LIGHT COMMUNICATION

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Abstract

Optical wireless systems are constrained to send real and positive values to the optical transmitter as only intensity of a signal is used to carry information. Therefore, conventional OFDM cannot be directly applied in optical systems. To combat multipath distortion, several modified OFDM systems have been studied, such as DC-biased optical OFDM (DCO-OFDM) and asymmetrically clipped optical OFDM (ACO-OFDM). In order to transmit real signal in optical environments, there is a Hermitian symmetric constraint with Discrete Fourier Transform (DFT). This paper compares transceiver complexity of ACO-OFDM with that of DCO-OFDM which is used in Visible Light Communication (VLC), and it is found that for the same number of subcarriers, computational complexity is higher in ACO-OFDM.

Keywords: Visible light communication (VLC), DC-biased optical OFDM (DCO-OFDM), Asymmetrically clipped optical OFDM (ACO-OFDM)

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1. Introduction

Visible light communication (VLC) is a type of telecommunication where light is used to carry information. Due to availability of around 670THz of license-free spectrum, optical wireless communication (OWC) has huge potential of very high speed communication. In VLC, total occupancy of spectrum is 375nm to 750nm which results in nearly 10,000 times higher frequency bandwidth than Radio Frequency (RF) bandwidth. VLC uses light emitting diodes (LED) as transmitters and photo-diodes (PD) as receivers. Here, electrical signal is first converted to optical signal before sending it through LED. The received optical signal from PD is converted back to electrical signal. Recently, OWC has been seen as a promising complementary for RF in short-range communications (Randel et al., 2010). Optical wireless technology is seen as a viable candidate to cope with the future demand of indoor wireless access generated through real-time bandwidth-intensive applications, such as voice over IP (VoIP), streaming video and music, network attached storage (NAS). Also, use of RF is not suitable for certain locations as hospitals or navigation equipment in airplanes. The OWC overcomes such restrictions and is safe in such locations (Mesleh et al., 2011). LEDs are the popular choice for indoor applications compared to laser diodes (LDs). Simple and low cost optical carrier modulation and demodulation are usually achieved through intensity modulation (IM) with direct detection (DD). Modulation is done onto the instantaneous power of the optical carrier and the detector generates proportional current where only the intensity is detected without frequency or phase information (Kahn and Barry, 1997).

OWC systems fall into diffuse or line of sight (LOS). In LOS, high data rates can be achieved (Akbulut et al., 2001), but because of their directionality the system is vulnerable to blockage and shadowing. This is not a problem in diffuse OWC system since several paths exist. But multipaths create inter-symbol interference (ISI) which ultimately limits the achievable data rate (Kahn et al., 1995). OFDM (Orthogonal Frequency Division Multiplexing) for OWC systems has been proposed in Tanaka et al., 2003 and it comes as a solution to multipath distortion as well

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as higher data rate without bandwidth expansion. But the output of the OFDM modulator is complex and bipolar. In IM optical systems, quadrature modulation is not possible. Thus, we need to have real baseband signal. Also, to intensity-modulate the LED, variations in the OFDM signal envelope are utilized and it requires that the bipolar signal must be converted to unipolar signal. Therefore, traditional OFDM as used in RF must be modified for OWC (Mesleh et al., 2011). In order to satisfy the VLC constraints, several modified OFDM-based solutions have been proposed. These include asymmetrically clipped optical OFDM (ACO-OFDM), direct current biased OFDM (DCO-OFDM), unipolar OFDM (U-OFDM), enhanced unipolar OFDM (eU-OFDM) and Position Modulating OFDM (PM-OFDM).

A real time domain OFDM signal can be generated by imposing Hermitian symmetry on the carriers in the frequency domain. The real bipolar signal thus generated must be converted to unipolar for which a number of different techniques are available.

A straightforward approach is called DCO-OFDM. It involves the addition of a bias current to the bipolar signal making it unipolar. However, the addition of the direct current (DC)-bias increases the power dissipation of the time domain signal significantly compared to the bipolar case. In order to avoid this DC bias, alternative techniques, such as asymmetrically clipped optical OFDM (ACO-OFDM), can be used and they exploit the properties of the OFDM frame to generate a signal that does not need biasing.

In ACO-OFDM, only the odd subcarriers in the frequency domain are modulated, and this leads to a symmetric time domain signal. The symmetry allows negative values to simply be set to zero without affecting the encoded information as all distortion falls on the even subcarriers in the frequency domain (Burchardt et al., 2014).

2. Methodology

In this paper, comparison of the transceiver complexity between ACO-OFDM and DCO-OFDM was done. The BER performance of the mentioned OFDM techniques in VLC has been done in Mesleh et al., 2011 and therefore paper only focuses on transceiver complexity comparison between ACO-OFDM and DCO-OFDM.

The study has been be carried out with the methodological approach as shown in Figure 1.

At the transmitter side, the binary data are converted from serial to parallel. In the modulator, modulation is performed by using M-QAM technique where M is the order of QAM (M = 2^n , n = 2,3,4,. . .). IFFT is carried out on modulated signals to convert frequency domain signal to time domain signal for the transmission. After the IFFT operation, parallel to serial signal will be achieved, and DC bias will be added to the DCO-OFDM, and peak and zero clipping will be carried out. The peak clipped signal is converted from digital to analog and transmitted by LED.

At the receiver side, the Additive White Gaussian Noise (AWGN) will be added to the transmitted signal received by the photodiode.

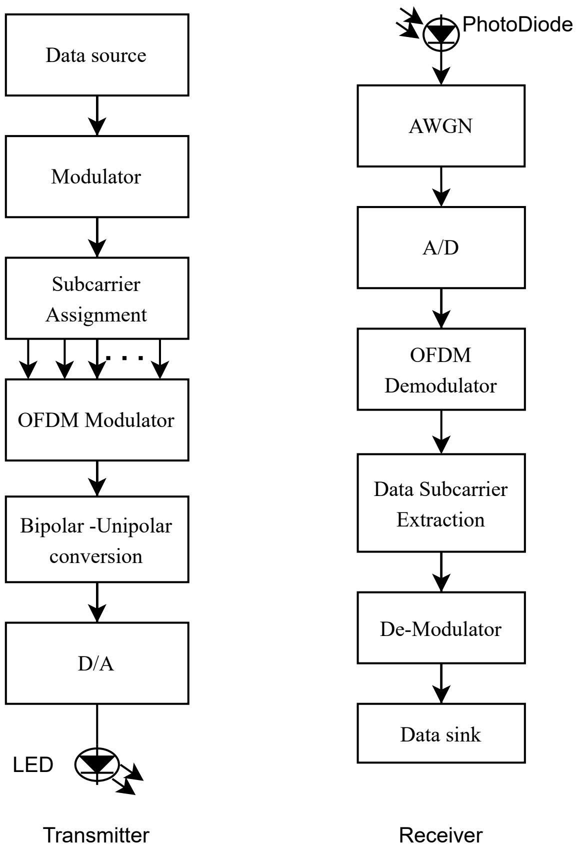

Figure 1. Indoor OWC OFDM system model.

The received signal before the analog-to-digital converter (A/D) is given by Equation (1).

$$Y = h\Theta S + W \tag{1}$$

Where Θ denotes linear convolution; S is the received signal; h = [h(0) h(1) . . . . . . .h(L -1)] is the L-path impulse response of the optical channel, and W is an AWGN that represents the sum of the receiver thermal noise and shot noise. It is important to note that the noise is added in electrical domain. Hence, the received signal Y can be negative as well as positive. So, unlike the transmitted signal, the received signal is bipolar instead of unipolar. The Cyclic Prefix (CP) is first removed and the linear convolution is converted to circular convolution as shown in Equation (2).

$$\tilde{Y} = \tilde{h} \odot \tilde{s} + \tilde{w} \tag{2}$$

where $\tilde{Y}$, $\tilde{h}$, $\tilde{s}$ and w are signals without the CP, and $\odot$

denotes circular convolution. To demodulate the signal, an N-point fast Fourier transform (FFT) is taken.

The photodiode converts the optical signal into electrical signal and then ADC operation will be performed. DC bias will be removed and serial to parallel conversion will be achieved. FFT will be carried out after that M-QAM demodulation. Finally, parallel to serial conversion is performed, and binary data will be received.

The information stream is first parsed into a block of complex data symbols denoted by x. The complex symbols are drawn from QAM constellations. These complex symbols are then mapped onto the vector as shown in Equation (3).

$$\{S_k\}_{k=0}^{N-1} = \left[0\{x_k\}_{k=1}^{\frac{N}{2}-1} 0\{x_k^*\}_{k=1}^{\frac{N}{2}-1}\right] \tag{3}$$

Where (*) denotes the complex conjugate. The Hermitian symmetry property of the vector S is needed to create a real output signal that is used to modulate the LED intensity. The OFDM modulator applies an N-point inverse fast Fourier transform (IFFT) on the vector S and adds a cyclic prefix (CP) creating the real-time signal S. The CP is needed to avoid inter-symbol interference (ISI) by converting the linear convolution with the channel into a circular one. The resulting time signal is used to modulate the intensity of LED. However, the intensity cannot be negative, and the bipolar time signal S must be converted to unipolar before modulating the LED intensity.

2.1. ACO-OFDM technique

In ACO-OFDM, only odd subcarriers are modulated. Since S contains data on the odd subcarriers only, the OFDM modulator produces a half-wave symmetry real-time signal S. The half-wave symmetry of S means that the same information in the first N/2 samples is repeated in the second half of the OFDM symbol. As a consequence, the negative part can be clipped without any loss of information. This clipping produces a unipolar signal. The inter modulation caused by clipping occurs only in the even subcarriers and does not affect the data-carrying odd subcarriers. However, it reduces the amplitude by a factor of two. The unipolar signal is then converted to an analog signal through the digital-to-analog converter (D/A) and used to modulate the intensity of LED.

At the receiver, the photodiode (PD) detects the transmitted intensity and the analog signal is converted back to digital. The ACO-OFDMOWC technique produces a half-wave symmetry time signal and allows clipping at the zero level, thus reducing DC power consumption by avoiding the need for a DC bias. These advantages are achieved at the expense of a major reduction in data rate as compared to DCO-OFDM systems (Figure 2).

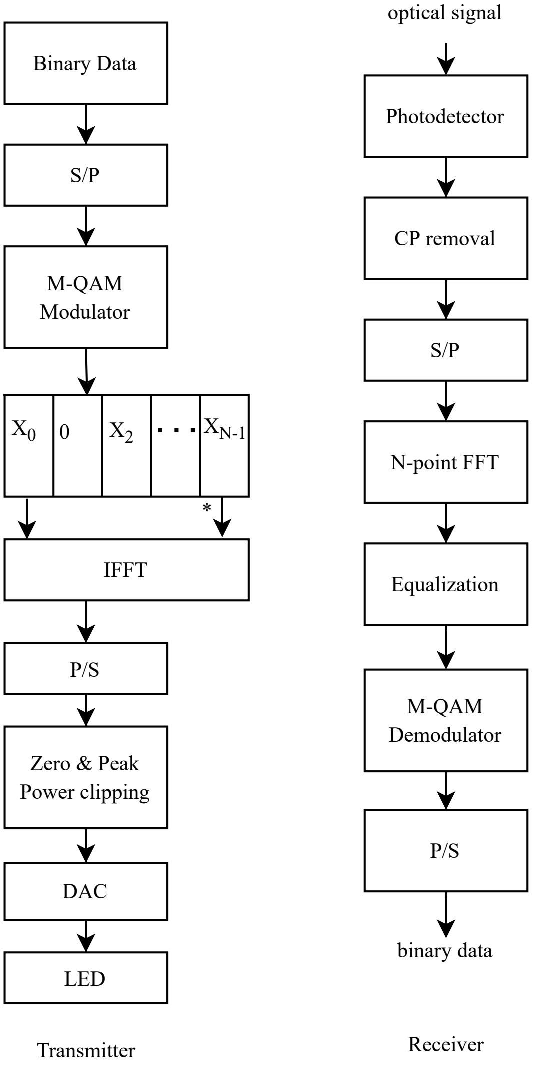

Figure 2. ACO-OFDM Transmitter and Receiver

2.2. DCO-OFDM technique

In DCO-OFDM the bipolar OFDM signal is converted to a unipolar signal by adding a DC bias. DCO-OFDM is a basic method of optical OFDM and is widely used due to its low complexity. Since only the non-negative signals can be transmitted, DCO-OFDM signals are derived by adding a DC bias to the bipolar OFDM signals. Hermitian symmetry is used to generate real signals for optical wireless communication systems at the transmitter. However, considering the peak power limit, the added DC bias cannot totally avoid zero clipping. In the meantime, adding the DC can introduce peak power clipping distortion. At the receiver, the DC bias needs to be removed first, and then the M-QAM data can be recovered and demodulated.

The DCO-OFDM technique assigns data to all odd and even subcarriers as in Equation (4).

$$S = \left[S_0, S_1, ...S_{\frac{N}{2}-1}, 0, S^*_{\frac{N}{2}-1}...S^*_1, S^*_2\right] \tag{4}$$

The DC-bias value depends on the LED characteristics, the OFDM signal envelope which depends on the considered modulation order, and the number of OFDM subcarriers can significantly affect system performance (Figure 3).

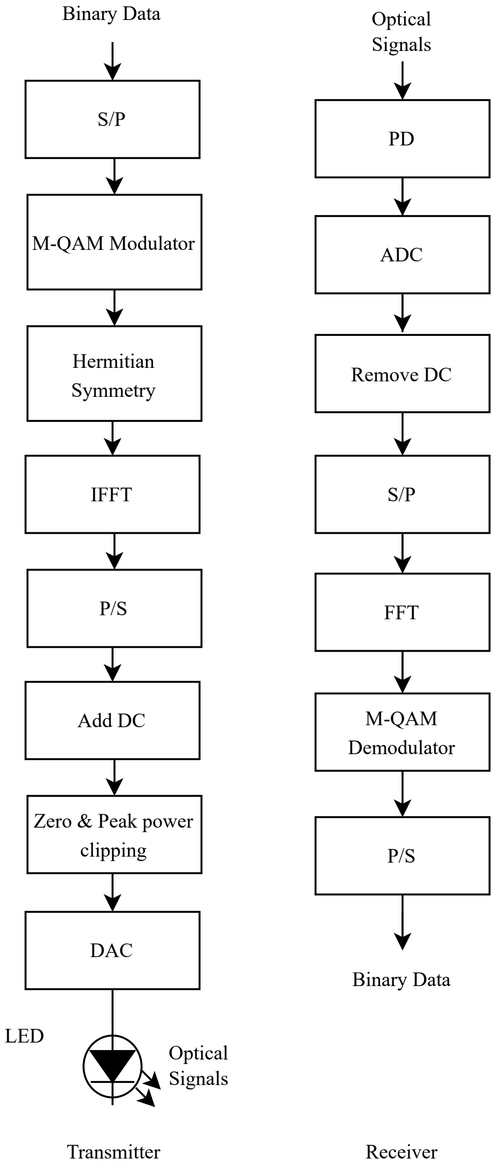

Figure 3. DCO-OFDM Transmitter and Receiver

3. Performance Comparision of ACO-OFDM and DCO-OFDM

The transceiver complexity comparison between ACO-OFDM and DCO-OFDM has been carried out. Table 1 shows the IFFT/FFT Computational Complexity of Transmitter and Receiver (Transceiver) of both ACO-OFDM and DCO-OFDM.

Table 1. IFFT/FFT Computational Complexity

	ACO-OFDM	DCO-OFDM
Transmitter	O(4Nlog$_2$(4N))	O(2Nlog$_2$(2N))
Receiver	O(4Nlog$_2$(4N))	O(2Nlog$_2$(2N))
Transceiver	O(8Nlog$_2$(4N))	O(4Nlog$_2$(2N))

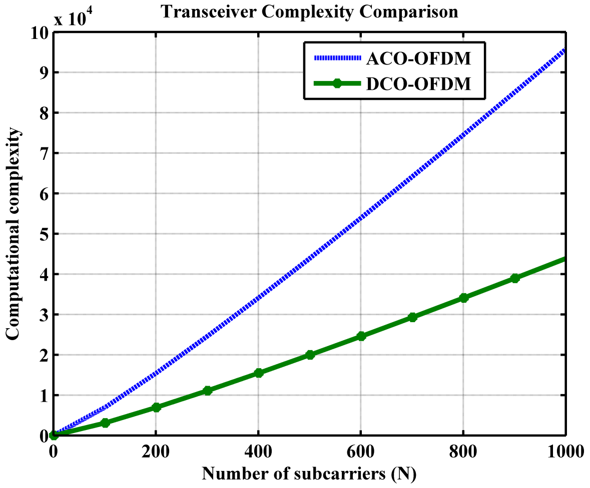

Figure 4. Transceiver Complexity of ACO-OFDM and DCO-OFDM

Figure 4 shows the transceiver complexity of ACO-OFDM and DCO-OFDM. From the simulation output curve, it can be seen that the computational complexity of ACO-OFDM is higher than the computational complexity of DCO-OFDM. Also, for number of subcarriers N=256, computational complexity for DCO-OFDM is approximately 0.9, and that of ACO-OFDM is 2. Similarly, for N=512, computational complexity for DCO-OFDM is approximately 2, and that of ACO-OFDM is 4.4. So, it can be concluded that the complexity for ACO-OFDM is at least twice than that of DCO-OFDM.

4. Conclusion

In this paper, transceiver complexity comparison between the most popular OFDM techniques used in VLC, namely ACO-OFDM and DCO-OFDM, was done. As mentioned in the literature, the BER performance of ACO-OFDM is better than DCO-OFDM; however, it was found that the transceiver complexity of ACO-OFDM is higher than the transceiver complexity of DCO-OFDM. It was found that the complexity for ACO-OFDM is at least twice than that of DCO-OFDM for different values of subcarriers. So, it can be concluded that ACO-OFDM is better in terms of BER performance, and DCO-OFDM is better in terms of transceiver complexity in VLC.

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