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Analysis of DHT-Spread ACO-OFDM Scheme Using Binary-PSK Modulation for PAPR Reduction

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***Abstract**: In conventional OFDM, the transmitted signals are bipolar and complex, but bipolar signals cannot be transmitted in an intensity modulated/direct detection (IM/DD) optical wireless system, because the intensity of light cannot be negative. OFDM signals designed for IM/DD systems must therefore be real and non-negative. There are several different forms of OFDM for IM/DD systems: asymmetrically clipped optical OFDM (ACO-OFDM), DC biased optical OFDM (DCO-OFDM), and other forms based on ACO-OFDM and DCO-OFDM. As we know that OFDM without clipping operation, ACO-OFDM has a higher PAPR due to the same peak power but lower average power caused by clipping operation. Therefore, it is much more essential for ACO-OFDM to decrease PAPR. There are various PAPR reduction techniques that use either DFT based and DHT based algorithms. The discrete Hartley transform (DHT) is an attractive alternative to the discrete Fourier transform (DFT) because of its real-valued computation and properties similar to those of the DFT. Another interesting property of the DHT is that the same kernel is used for both the transform and its inverse transform. Different from DFT-based ACO-OFDM, DHT-based ACO-OFDM does not need Hermitian Symmetry (HS), and the same algorithm can be applied to the multiplexing and demultiplexing processes. Consequently, since its introduction the DHT has found its way to many digital signal processing applications. In this paper, we propose a discrete Hartley transform (DHT)-spread technique using Binary-PSK modulation for peak-to-average power ratio (PAPR) reduction in a DHT-based asymmetrically clipped optical orthogonal frequency-division multiplexing (ACO-OFDM) system. DHT-S-OFDM by using Binary PSK (BPSK) modulation is shown to be more optically power efficient than conventional OFDM, ACO-OFDM and DHT-ACO-OFDM, for same bit rate/normalized bandwidths.*

***Keywords:** Discrete Hartley transform (DHT), DHT-spread technique, Binary-phase shift keying (PSK), asymmetrically clipped optical orthogonal frequency-division multiplexing (ACO-OFDM), peak-to-average power ratio (PAPR) reduction, intensity-modulated/direct-detection (IM/DD) systems*

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I. Introduction

In recent years, Orthogonal Frequency Division Multiplexing (OFDM) has emerged in optical transmission systems and access networks because of its high spectrum efficiency (SE) and robustness against inter-symbol interference (ISI) caused by a dispersive channel. Among the OFDM schemes, IM/DD technique is able to reduce the complexity and cost of the system [13]. So the brief structure of IM/DD optical OFDM is attractive for future cost-sensitive, short-range, and high speed optical communications such as discrete multi-tone (DMT) system, passive optical network (PONs), indoor optical wireless communications and interconnection in data centers [1],[13]. As we know, OFDM signal designed for IM/DD systems must be real value, because the intensity of light cannot carry phase information [13]. Recently, ACO-OFDM based on discrete Hartley transform (DHT) has been proposed for IM/DD system [12], [13].

DHT is a real trigonometric transform based on real values. It is different from DFT-based ACO-OFDM as DHT-based ACO-OFDM does not need Hermitian Symmetry (HS), and both the multiplexing and demultiplexing processes can be done by using the same algorithm. When DFT and DHT have the same size, 2-pulse-amplitude modulation (2-PAM) (M-PAM)-modulated DHT-based ACO-OFDM transmits the same number of bits and has the same bit-error ratio (BER) performance as QPSK (M^2-QAM)-modulated DFT-based ACO-OFDM [12]-[14] while by using Binary PSK modulation we obtain more effective results than 2-PAM modulation technique as PAPR is further reduced by around 2 dB than that of 2-PAM modulation which results about 9.7 and 6.2 dB lower than those of conventional DHT-based ACO-OFDM without DHT-spread technique for 2-pulse-amplitude modulation (2-PAM) and 4-PAM, respectively [1]. In this paper, a discrete Hartley transform (DHT)-spread technique for peak-to-average power ratio (PAPR) reduction in a DHT-based asymmetrically clipped optical orthogonal frequency-division multiplexing (ACO-OFDM) system by using Binary-PSK (BPSK) modulation is proposed.

II. Principle

The multiplexing/demultiplexing processes of the proposed OFDM scheme use the DHT algorithm. The N-point inverse DHT (IDHT) and DHT [14] are defined as:

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \text{cas}\left(\frac{2\pi kn}{N}\right), \qquad X_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x_n \text{cas}\left(\frac{2\pi kn}{N}\right) \tag{1}$$

where cas(.) = cos(.) + sin(.), n and k are from 0 to N-1, x_n is the time-domain OFDM sample, and X_k : frequency-domain input sample. As shown in (1), DHT is a real trigonometric transform with a self-inverse property [1]. Unlike the DFT-based IM/DD OFDM, DHT-based IM/DD OFDM does not need HS to generate real signal and the multiplexing and demultiplexing processes employ the same algorithm [1].

Table 1: Comparison between DHT-Based and DFT-Based O-OFDM for IM/DD Systems [12].

Optical OFDM type	N-order DHT-based		N-order DFT-based	
	DC-biased	ACO	DC-biased	ACO
Supported constellation	Real (BPSK, M-PAM)		Complex (m-QAM)	
Constell. size	$M=2^{log_4 L}$		$m=L$	
Hermitian symmetry	NOT required		Required	
Computational complexity [27]	P=(Nlog_2N-3N+4)/2 A=(3Nlog_2N-5N)/2+6 Self-inverse NO add. resources		P=(Nlog_2N-3N+4)/2 A=(3Nlog_2N-5N)/2+4 NOT self-inverse Resources for QAM*	
Subc. carrying info	N	N/2	N/2	N/4

As summarized in Table 1, the independent constellation symbols supported by an N-order FFT-based AC or DC-biased O-OFDM are N/4 and N/2, respectively. For DHT-based are N/2 and N, since the double of constellation symbols can be allocated. Therefore, in order to compare O-OFDM systems transmitting the same signal at the same bit rate, the input sequence of the DHT-based scheme is mapped into a real M-ary constellation that requires a lower value for M [12].

The block diagram of DHT-spread ACO-OFDM (DHT-S-ACO-OFDM) for IM/DD system is depicted in Fig. 1[1]. Unlike conventional ACO-OFDM, DHT-S-ACO-OFDM adds two *L*-point DHT modules in the transmitter and receiver as the red boxes show [1]. At transmitter, the data sequences are sent to the real constellation mapper [PAM mapper] after serial-to-parallel operation [1]. Then the generated M-PAM signals are sent to the *L*-point DHT to realize the DHT-spread operation [1].

At receiver, the inverse operations of transmitter are realized to recover the data sequences, mainly including analog-to-digital conversion (ADC), removal of CP, N-point DHT, channel estimation, L-point DHT and PAM demapper [1].

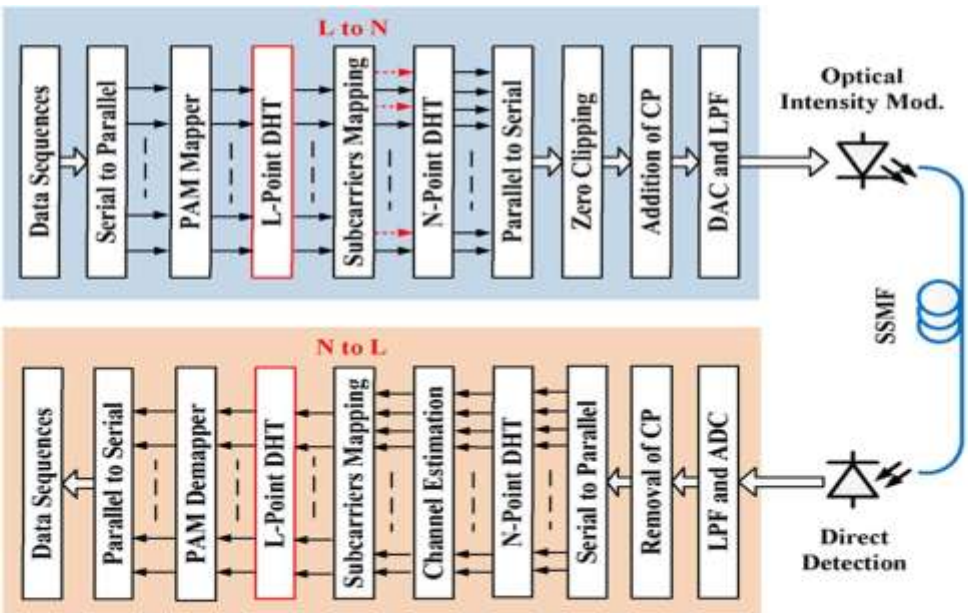

Fig. 1 Block diagram of DHT-spread ACO-OFDM for IM/DD system [1].

III. Performance Analysis

The PAPR, which is defined as the ratio between the maximum peak power and the average power of the discrete OFDM signal, can be expressed as [1]:

$$PAPR = 10\log_{10}\left(\frac{\text{Max}\{|S_i|^2\}}{E\{|S_i|^2\}}\right) \tag{2}$$

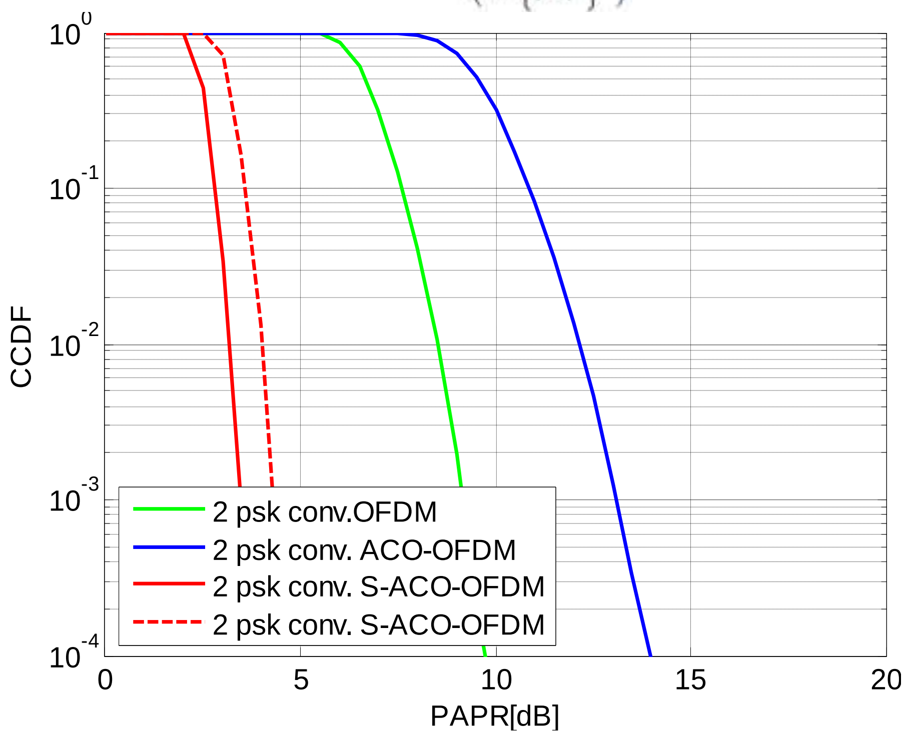

Fig. 2 Complementary cumulative distribution function (CCDF) curves of w/o clipping OFDM, conventional ACO-OFDM and DHT-S-ACO-OFDM using BPSK modulation.

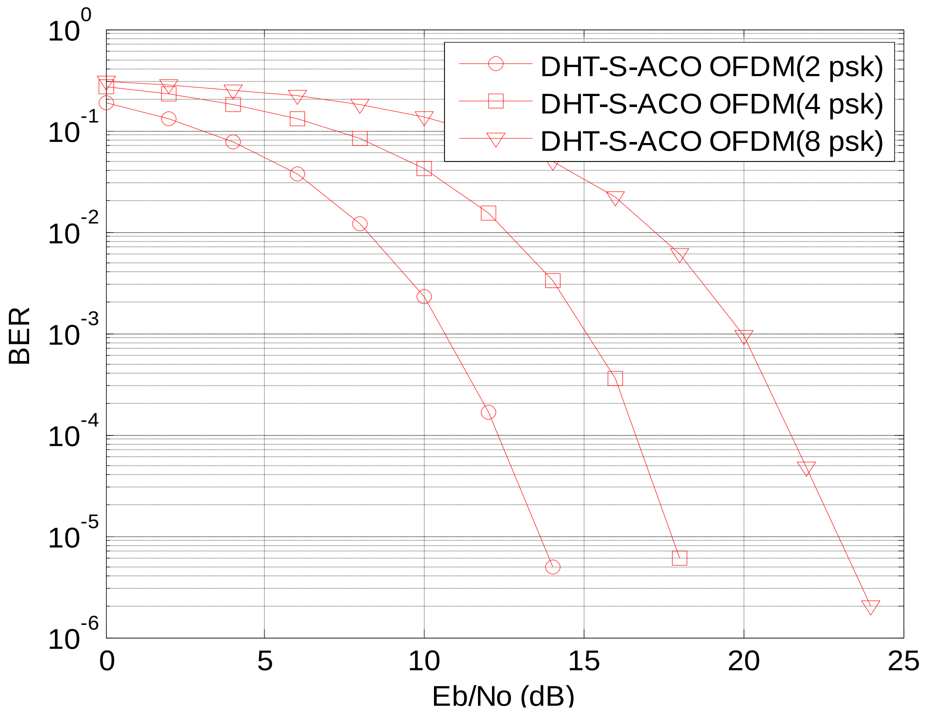

Fig. 3 Comparison of BER performance between conventional ACO-OFDM and DHT-S-ACO OFDM in AWGN channel.

Fig. 2 reveals the CCDF curves of PAPR for w/o clipping OFDM, conventional ACO-OFDM, and DHT-S-ACO-OFDM using Binary PSK modulation. In the simulation for CCDF curves, the number of subcarriers is set to 256 and the number of symbols for the probability of 10^{-4} is set to 10^{5}. The PAPR of DHT-S-ACO-OFDM is nearly 6 dB lower than conventional OFDM. When the DHT-spread technique is employed, the PAPR performance of ACO-OFDM is significantly improved.

Fig. 3 depicts BER performance of DHT-S-ACO-OFDM by using 2, 4 and 8 PSK modulation, where N is 256 in additive white Gaussian noise (AWGN) channel. When the same simulation parameters are adopted, BER curves of DHT-S-ACO-OFDM coincide to those of conventional ACO-OFDM.

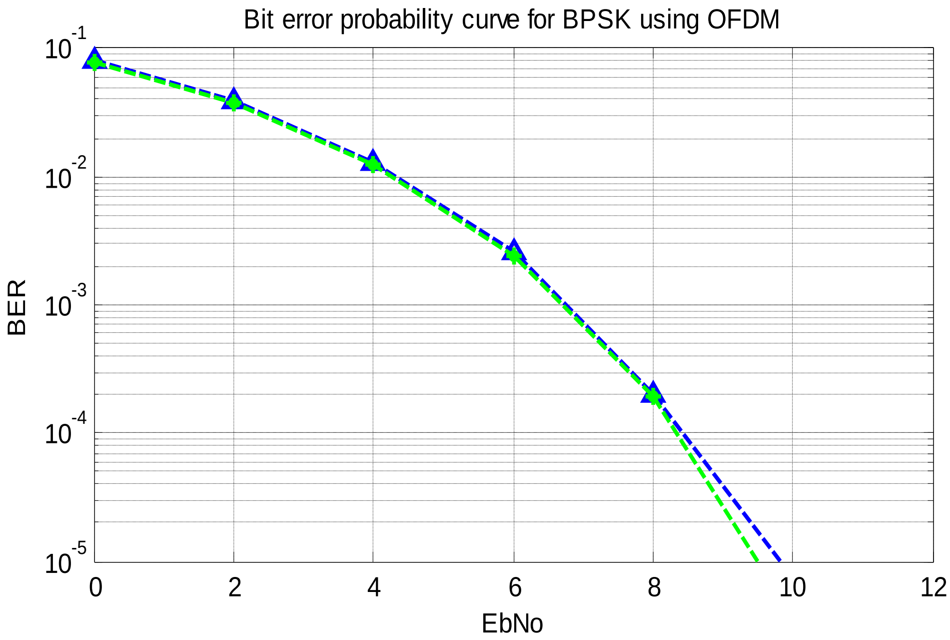

Fig. 4 Bit Error probability curve for OFDM system using BPSK modulation.

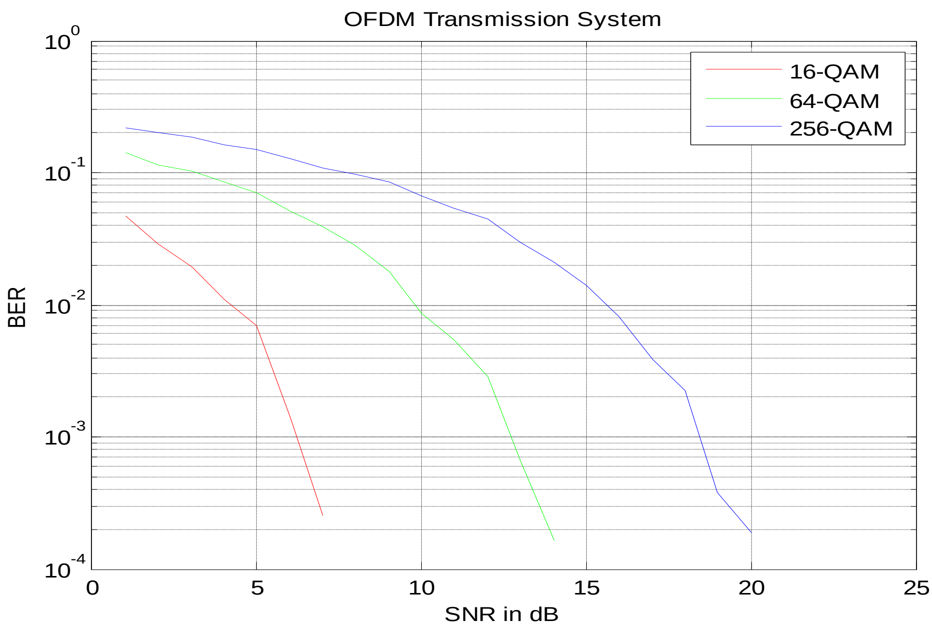

Fig. 5 Comparison of BER performance of OFDM system using 16-QAM, 64-QAM and 256-QAM in AWGN channel.

Fig. 4 depicts Bit Error probability curve for OFDM system using BPSK modulation and fig. 5 shows comparison of BER performance of OFDM system using 16-QAM, 64-QAM and 256-QAM in AWGN channel which shows 16-QAM is gives better performance than 64-QAM which in turn, is better than 256-QAM for the proposed OFDM scheme.

IV. Conclusions

In this paper, a discrete Hartley transform (DHT)-spread technique for peak-to-average power ratio (PAPR) reduction in a DHT-based asymmetrically clipped optical orthogonal frequency-division multiplexing (ACO-OFDM) system by using Binary-PSK (BPSK) modulation is proposed. By using Binary PSK modulation we obtain more effective results than 2-PAM modulation technique as PAPR is further reduced by around 2 dB than that of 2-PAM modulation with the same BER. The proposed scheme has better transmission performance than the conventional scheme due to its effective equalization and low PAPR. In conclusion, the proposed scheme is attractive to IM/DD systems due to its low PAPR and excellent transmission performance.

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