

DHT-based IM/DD optical OFDM system for power data transmission

Honghao Zhao^{1,a}, Jun Liu², Kai Liang², Yanping Zhang², Dan Yi², Changqing Zhong², Shuang Liu³

¹ State Grid Liaoning Electric Power Company Limited, Shenyang 110006, China

² State Grid Anshan Electric Power Supply Company, Anshan 114002, China

³ Liaoning Planning and Designing Institute of Post and Telecommunication Company Limited, Shenyang 110011, China

^aamengfb@163.com

Keywords: Power data transmission, Discrete Hartley transformation, IM/DD optical OFDM system.

Abstract. For achieve fast and reliable power data transmission, we propose a novel Intensity Modulation and Direct Detection (IM/DD) optical Orthogonal Frequency Division Multiplexing (OFDM) system. In this system, we utilize Discrete Hartley Transform (DHT) instead of Discrete Fourier Transform (DFT) which is used in traditional optical OFDM systems, in order to complete the signal demodulation and modulation procedures, thus leading to the orthogonality of data-carrying subcarriers. Simulation results show that the similar bit error rate performance can be achieved between the DHT-based optical OFDM system (BPSK, 4-Pulse Amplitude Modulation (PAM) and 8-PAM) and the DFT-based optical OFDM system (4-QAM, 16-QAM, 64-QAM).

Introduction

With the rapid development of modern information technology, human are entering into an era of high-speed information transmission, which puts forward a higher requirement for the carrier of the power data transmission. The emergence of the optical fiber communication significantly increases the rate of power data transmission. Since the Orthogonal Frequency Division Multiplexing (OFDM) has been widely applied in radio communication systems, the Optical OFDM which combines OFDM and optical communication technique has recently attracted great research interests all over the world. However, the channels of optical communication and radio communication are different, so there will be both opportunities and challenges by introducing the OFDM technology into optical fiber communication systems. On the one hand, we can take advantage of the existing wireless OFDM and digital signal processing technology, and on the other hand, the complex bipolar OFDM signal must be transmitted in the optical link [1-3].

To solve the aforementioned problem, the direct and coherent detection methods are proposed. Among which, the Intensity Modulation and Direct Detection (IM/DD) optical OFDM system has gained great attention due to the advantages of simple implantation, low cost and unnecessary locally-deployed oscillator laser in the receiver. In IM/DD optical OFDM systems, the Asymmetrically Clipped and Direct Current bias Optical (ACO and DCO) OFDM technologies are utilized to make OFDM signal unipolar [4-6]. In this paper, the DHT (IDHT) is employed to replace the Fast Fourier Transform (FFT) (IFFT) in traditional optical OFDM systems. Moreover, BPSK and M-PAM constellation mapping methods are utilized to generate real signals for optical transmission.

The remainder of this paper is organized as follows. We first introduce the ACO-OFDM power data transmission system based on DHT. Then, we demonstrate the simulation results and give some discussions. Finally, we conclude this paper.

ACO-OFDM power data transmission system based on DHT

Principle of Hartley transformation. Hartley transform is an effective real triangle transform in real-valued signal processing, during which, only the real operations are needed. More importantly, the Hartley transform and its inverse operation have the same real triangle transform, which is simpler than DFT. In DHT, the real value signal can be obtained by using one-dimensional constellation mapping such as BPSK and M-PAM, without the use of Hermitian symmetry, thus reducing the system complexity. Furthermore, all subcarriers are involved in the signal processing so that we can improve the utilization efficiency of subcarriers. Recently, DHT has gained attention in many scenarios in terms of power line communication and seismic wavefield modeling.

DHT and IDHT can be expressed by Eqs. (1) and (2).

$$H(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x(n) \left[\cos\left(\frac{2\pi}{N} nk\right) + \sin\left(\frac{2\pi}{N} nk\right) \right] \quad k = 0, 1, 2, \dots, N-1 \quad (1)$$

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} H(k) \left[\cos\left(\frac{2\pi}{N} nk\right) + \sin\left(\frac{2\pi}{N} nk\right) \right] \quad n = 0, 1, 2, \dots, N-1 \quad (2)$$

$cas(\cdot)$ can be defined as follows.

$$cas\left(\frac{2\pi}{N} nk\right) = \cos\left(\frac{2\pi}{N} nk\right) + \sin\left(\frac{2\pi}{N} nk\right) \quad (3)$$

According to Eqs. (1) and (2), the output signal of DHT $H(k)$ will be the real value signal if the input signal of DHT $x(n)$ is the real value signal, and each subcarrier is orthogonal to each other.

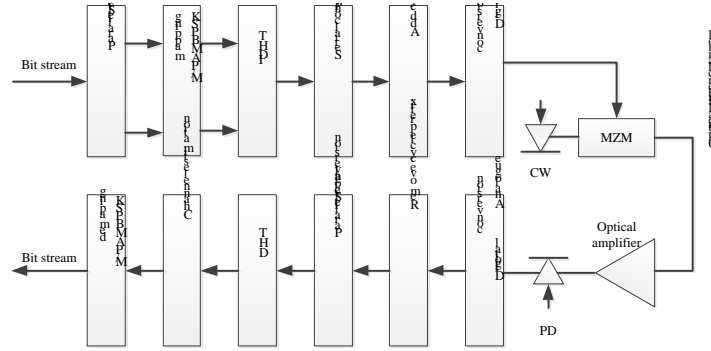


Figure 1. Schematic of DHT based OFDM system

Implementation of DHT-based optical OFDM system. As mentioned above, DHT is a real triangle transform where Hartley transform and its inverse operation are identical. The mirror symmetry of DHT guarantees the orthogonality between OFDM subcarriers. Thus, DHT can replace FFT for the modulation of the OFDM signal if the input signal is real-valued. The DHT does not utilize the Hermitian symmetry to generate the real value signal, which can simplify the transmission system and improve the transmission rate of power data. As in traditional OFDM systems, the DHT-based optical OFDM system also consists of series-to-parallel conversion, Cyclic Prefix (CP) adding, etc. Different from the traditional optical OFDM system, the DHT-based OFDM system utilizes DHT and IDHT instead of FFT and IFFT, meanwhile, BPSK and MPAM are employed to replace M-QAM. It should be noted that FFT carries information by phase, while DHT carries information by real triangle transform. Figure 1 shows the schematic of the DHT-based optical OFDM system.

DHT-based ACO-OFDM power data transmission system. The principle of the DHT-based ACO-OFDM power data transmission system can be described as follows. The odd subcarriers carry useful data, while even subcarriers are zero-padded. After performing IDHT, the truncation processing will be invoked, where the signal will be set to zero if it is less than zero, or the signal will remain unchanged if it is larger than zero. In the receiving side, the amplitude value of the signal becomes half of the useful signal after DHT. We can recover the transmitted signal correctly since the information is not lost.

Although the DHT- and DFT-based ACO-OFDM systems have the same procedure to implement the single-polarization, the useful subcarriers for them are $N/2$ and $N/4$, respectively. It can be seen that the DHT-based ACO-OFDM power data transmission system can improve the utilization efficiency of subcarriers without the use of Hermitian symmetry.

Simulation Results and discussions

In this paper, MATLAB 2015 software is utilized to build up the proposed systems, and the system performance is analyzed through an additive Gaussian white noise channel. In the DHT-based optical OFDM power data transmission system, the output symbols are real-valued signals after performing the BPSK mapping. Then, the resulting symbols are still real-valued signals after IDHT. Figures 2 (a) and 2(b) illustrate the input and output symbols before and after IDHT, respectively. The data symbols at different points of the proposed system can be seen in Fig. 3.

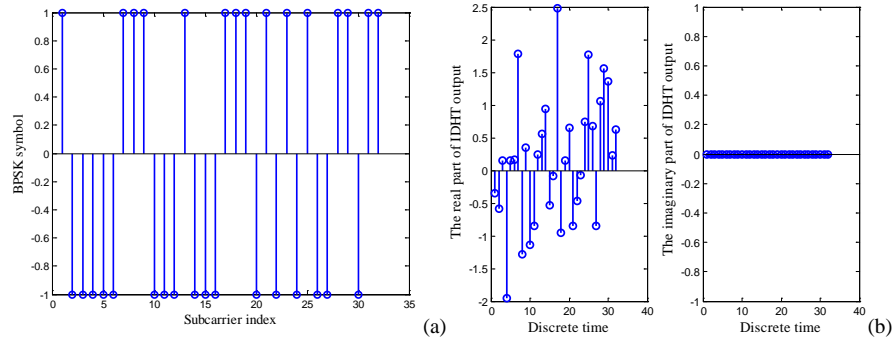
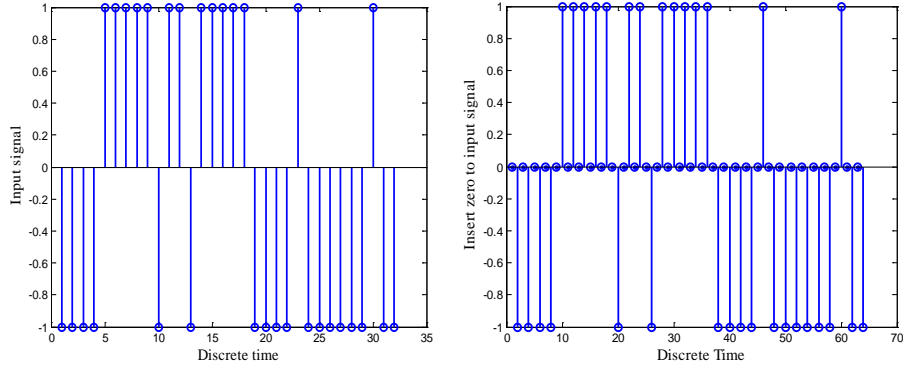
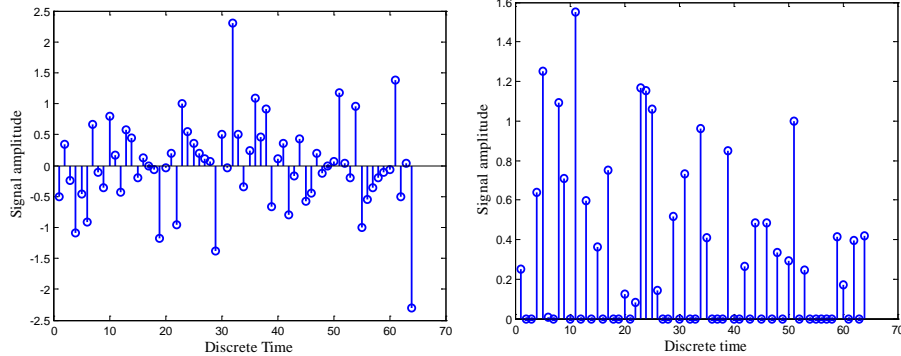


Figure 2. Input and output symbols before and after IDHT by using BPSK



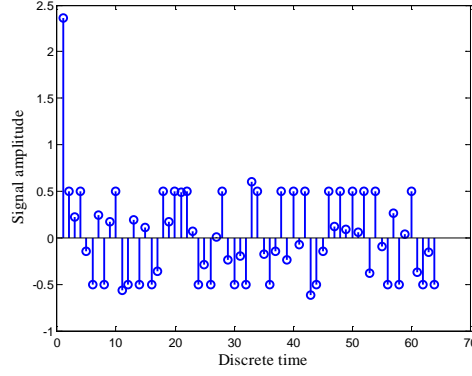
(a) Input signal $H(k)$ after BPSK mapping

(b) Signal $H_0(k)$ after inserting zero to $H(k)$



(c) Signal $x(n)$ after IDHT

(d) Signal $x_c(n)$ after clipping



(e) Received signal $H_c(k)$ after DHT

Figure 3. Data symbols at different points of the proposed system

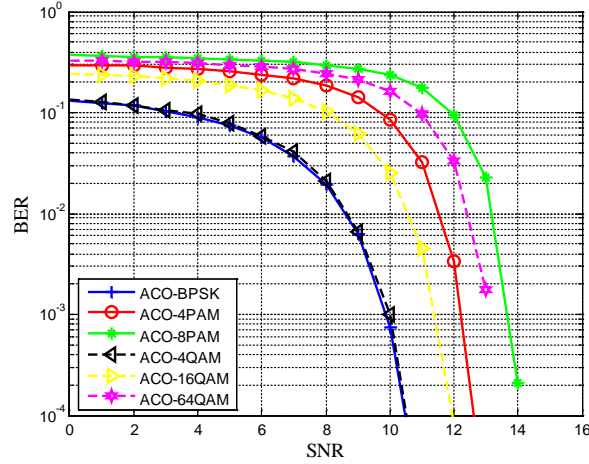


Figure 4. BER as a function of SNR with DHT based ACO-OFDM and DFT based ACO-OFDM

The measured Bit Error Rate (BER) as a function of Signal to Noise Ratio (SNR) with DHT- and DFT-based ACO-OFDM systems is shown in Fig. 4. We can see that the DHT-based ACO-OFDM system using BPSK, 4-PAM, 8-PAM exhibits almost the same BER performance when compared to the DFT-based ACO-OFDM system using 4-QAM, 16-QAM, and 64-QAM. Thus, the DHT-based OFDM power data transmission system can improve the spectrum efficiency and transmission rate with simple configuration. Therefore, it is a more promising solution by using DFT instead of DHT in optical OFDM systems.

Conclusions

In this paper, we have proposed a novel DHT-based optical OFDM power data transmission system. The real-valued signal has been obtained by using real constellation mapping, which can improve the subcarrier utilization efficiency. Furthermore, DHT can implement the single-polarization through ACO technique. Simulation results have shown that the DHT-based optical OFDM system has almost the same BER performance compared to the DFT-based optical OFDM system with the lower modulation level while being easily implemented.

References

- [1] X. Gong, L. Guo, J. Wu, Z. Ning. Design and performance investigation of LDPC-coded upstream transmission systems in IM/DD OFDM-PONs, *Optics Communications*, 2016, 380 (2016): 154-160.
- [2] M. F. Sanya, L. Djogbe, A. Vianou, C. Aupetit-Berthelemot. DC-Biased Optical OFDM for IM/DD Passive Optical Network Systems, *IEEE/OSA Journal of Optical Communications and Networking*, 2015, 7(4): 205-214.

- [3] X. Gong, Lei Guo, Y. Liu. Power-efficient schemes using directly modulated lasers for intensity modulation and direct detection OFDM-PONs, *Photonic Network Communications*, 2016, 31(2): 275-284.
- [4] J. Zhou, Y. Qiao. Low-PAPR Asymmetrically Clipped Optical OFDM for Intensity-Modulation/Direct-Detection Systems, *IEEE Photonics Journal*, 2015, 7(3): 7101608.
- [5] S. D. Dissanayake, J. Armstrong. Comparison of ACO-OFDM, DCO-OFDM and ADO-OFDM in IM/DD systems, *IEEE/OSA Journal of Lightwave Technology*, 2013, 31(7), 1063-1072.
- [6] X. Gong, Y. Peng, Y. Liu, H. Li. Novel Multi-Band DFT-Spread OFDM-PON Systems Based on Intensity Modulation and Direct Detection for Cloud Computing, *Photonic Network Communications*, 2016, 31(3): 550-558.