



Coded DCO-OFDM Techniques in Intensity Modulation/Direct Detection (IM/DD) Systems

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Abstract

Optical wireless communications (OWC) are among the best alternative techniques for transmitting information-laden optical radiation across a free-space channel from one place to another. DC-biased optical OFDM (DCO-OFDM) is a technique that sacrifices the power efficiency to transmit unipolar OFDM signals. The primary drawback with DCO-OFDM is its clipping noise, which causes distortion and lowers the bit error rate (BER). Thus, in this paper, we show the performance of DCO with different coded techniques to improve the BER in additive white Gaussian noise (AWGN) for IM/DD systems. The experimental results show that the coded DCO-OFDM has the best performance. Furthermore, turbo coding has the best coding technique added to the DCO-OFDM system.

Keywords: OWC; IM/DD; DCO-OFDM

1. Introduction

The advent of advanced wireless applications has rapidly increased the demand for high data rate technologies such as computer networking and video conferencing, High-Definition TV (HDTV), and mobile video phones [1-3]. OWC is one of the most promising techniques to be used as an alternative to Radio Frequency (RF). It has many advantages over RF and can cover the most advanced applications. RF has various disadvantages, including a congested spectrum, a decreased data rate, and a high installation cost [4]. Compared to their RF equivalents, OWC systems have several distinct advantages. They are non-hazardous to human health, reasonably inexpensive, have a high level of security, are compact, have well-defined cell boundaries, and have no interference between channels [5, 6]. The optical radiation wavelength ranges from 100 nm up to 1mm. It contains ultraviolet (UV), visible light, and infrared (IR). In the past decade, the transmission of data using the visible light spectrum has been called visible light communication (VLC).

OWC is operable both indoors and outdoors. In an indoor OWC system based on IM/DD, the transmitted electrical signal modulates the optical signal's instantaneous power [7]. In intensity modulation, the optical source's instantaneous power is varied. The signal is modulated by the transmitted electrical signal [8]. Direct detection is used to recover the modulating signal [9]. Single carrier modulation (SCM) and multicarrier modulation (MCM) are two modulation schemes used in OWC. SCM is used for lower data rate applications. The advantages of SCM are immunity to non-linear distortion and energy efficiency. The main drawback of SCM is inter-symbol interference (ISI). So, multicarrier modulation (MCM) is applied. OFDM (orthogonal frequency division multiplexing) is a subclass of MCM systems in which data is transmitted over many subcarriers with a decreased data rate [10, 11]. The benefits of OFDM include fast transmission bit rates, efficient bandwidth

utilization, and resistance to ISI [11, 12]. Using OFDM with adaptive modulation in such channels increases the BER.

In IM/DD OWC systems, a typical bipolar and complex OFDM signal cannot be used for IM. Consequently, the optical OFDM signal must be both positive and real. In order to produce a real signal at the output of the IFFT, the subcarriers at the input of the IFFT must possess Hermitian symmetry. To make the resulting real signal positive, different techniques can be used. In indoor OWC based on IM/DD, asymmetrically clipped OFDM (ACO-OFDM) [13] signal and DC-clipped OFDM (DCO-OFDM) [14] are the most used approaches.

In this paper, We present a comparative study of coding techniques, including convolutional and turbo coding. Further, the code rates 1/2, 2/3, and 3/4 are applied for convolutional coding, and 1,3, and 6 iterations are applied for turbo coding. The rest of the paper is organized as follows. The conventional and coded DCO-OFDM are introduced in sections 2. Convolutional and turbo coding techniques are discussed in Section 3. The simulation results are presented in section 4. Finally, the conclusion is introduced in section 5.

2. Conventional DCO-OFDM and system model

Figure 1 shows the block diagram of DCO-OFDM system [16]. In DCO-OFDM system, Hermitian symmetry is applied to a block of $N/2 - 2$ complex valued Quadrature amplitude modulation (QAM) symbols, $[X_1, \dots, X_{N-2}]$. In order to make the output of the IFFT is a real valued signal as follows:

$$x_n = \text{ifft}\left(0, X_1, \dots, X_{\frac{N}{2}-1}, 0, X_{\frac{N}{2}-1}^*, \dots, X_1^*\right) \quad (1)$$

The After S/P, DC bias μ is added to the signal x_n to generate the biased signal, \bar{x}_n , as follows:

$$\bar{x}_n = x_n + \mu \quad n \in \{0, \dots, N-1\} \quad (2)$$

The DC bias μ is related to power of x_n according to the standard deviation, σ_x , of the signal x_n as follows.

$$\mu = \alpha \sigma_x \quad (3)$$

where the parameter α is a scaling factor and the DC bias μ can be expressed in decibel (dB) $10 \log_{10}(1 + \alpha^2)$ dB [15].

This DC bias causes power inefficiency. So, a moderate bias is added and the remaining negative values are clipped. Due to the dynamic range of the light emitting diode (LED), double-sided clipping must be performed as follows.

$$\hat{x}_{\text{even}} = \begin{cases} 0 & \bar{x}_n \leq 0 \\ \bar{x}_{\text{even}}[n] & 0 < \bar{x}_n < A \\ A & \bar{x}_n \geq A \end{cases} \quad n = 0, 1, \dots, N-1 \quad (4)$$

where A denotes the upper clipping level, and 0 denotes the lower clipping level.

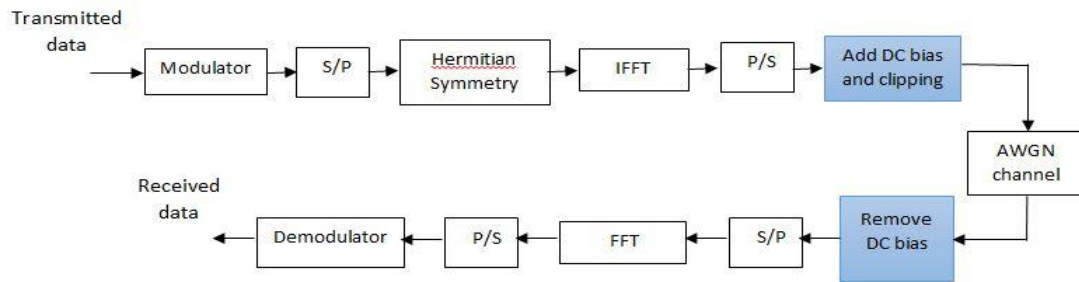


Figure 1: DCO-OFDM transmitter and receiver configuration

Finally, cyclic prefix is added after parallel to serial conversion to produce the transmitted DCO-OFDM signal.

3. Convolutional and turbo codes

A. Convolutional encoder

Convolution code is a type of forward error correction that is normally used in digital communication systems to improve the performance of BER. Convolutional codes generate redundant bit continuously. A (n, k, m) Convolutional encoder processes k bits at a time and produces n bit output for every k bits and m is the number of memory registers. Each input bit influences the output for L interval which L equals to $k(m-1)$ so L is called constraint length of the code.

A trellis diagram consists of a node and the branches representing the state of the encoder and the transition of state. There are 2^k branches entering each state and 2^k leaving each state. Convolutional encoder can be represented by state diagram. The state diagram is a four-state directed graph used to uniquely represent the input-output relation of convolutional encoder. Figure 2 shows the state diagram for a $(2, 1, 3)$ convolutional encoder, where the solid lines and dashed lines denote the data bits is zero and one, respectively. When the encoder is in state S_0 , and we input 1, the encoder output is 11 (dashed line).

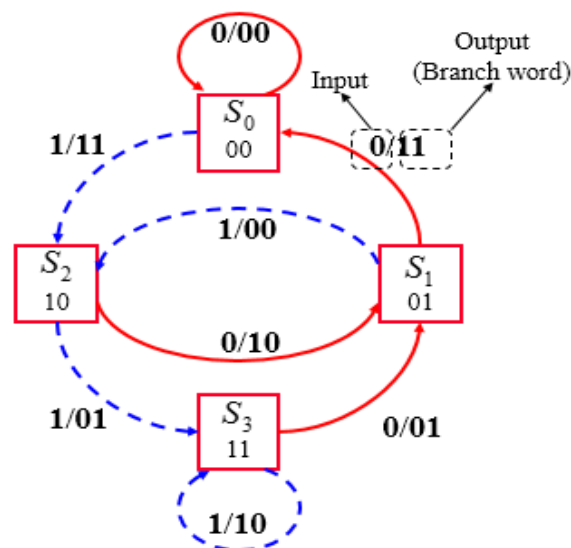


Figure 2: state diagram for $(2, 1, 3)$ convolutional encoder

The decoding of convolutional encoder is performed by Viterbi's maximum-likelihood. It is one of the best techniques yet evolved for digital communications where energy efficiency dominates in importance. The decoder structure is relatively simply for short constraint lengths, making decoding feasible at relatively high rates of up to 100 Mbit/s.

B. Turbo encoder

Turbo decoder developed for use in a variety of modern wireless application, see Figure 3. It uses an iterative decoding algorithm where the elementary convolutional codes use the maximum likelihood decoding algorithm. This iterative decoding achieves performance close to the theoretical limits and is a very efficient way to decode turbo codes.

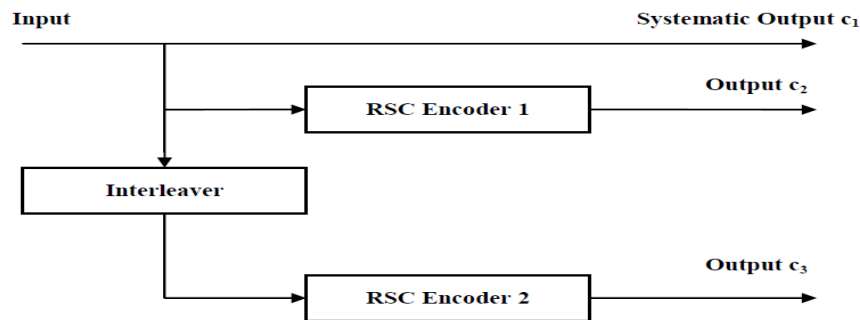


Figure 3: Rate 1/3 turbo encoder

Figure 4 shows the block diagram of coded DCO-OFDM system using convolutional or turbo coding techniques.

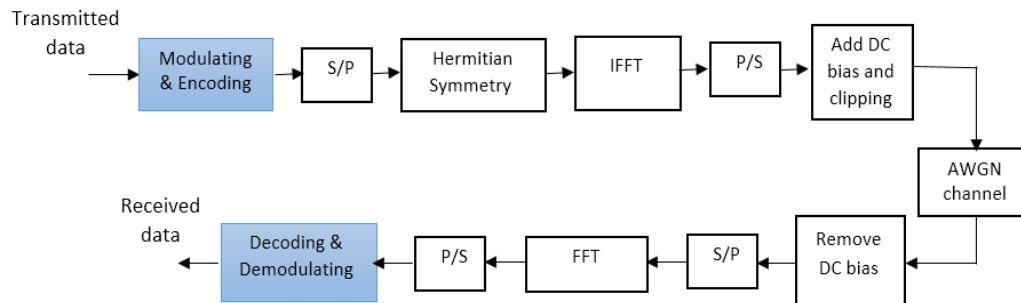


Figure 4: coded DCO-OFDM transmitter and receiver configuration

4. Simulation results

The experimental setting of this paper is as follows. we utilize 3dB/7dB DC bias for coded DCO. Further, we use 1/2, 2/3 & 3/4 as a code rate for Convolutional encoder. On the other hand, we utilize 2, 3, 6 iterations for turbo encoder. The size of IFFT/FFT is $N=1024$ and the cyclic prefix (CP) length is $N_{CP}=24$. Finally, we consider AWGN as a channel since it is the most common noise in OWC.

Figures 5 and 6 show the performance of our coding algorithm with 3dB/7dB DC bias compared to uncoded DCO-OFDM, where solid lines and dotted lines represent BER performance of coded and uncoded system. Moreover, for low E_b/N_0 , the BER of uncoded systems is clearly superior to that of coded systems. As the ratio of E_b/N_0 increase, coded systems reduce the BER significantly.

Furthermore, in convolutional coded system, 3/4 code rate outperforms 1/2 and 2/3 code rates. On the other hand, in turbo coded , 6 iterations improve BER performance over 1 and 3. Turbo-coded system perform better than convolutional-coded systems.

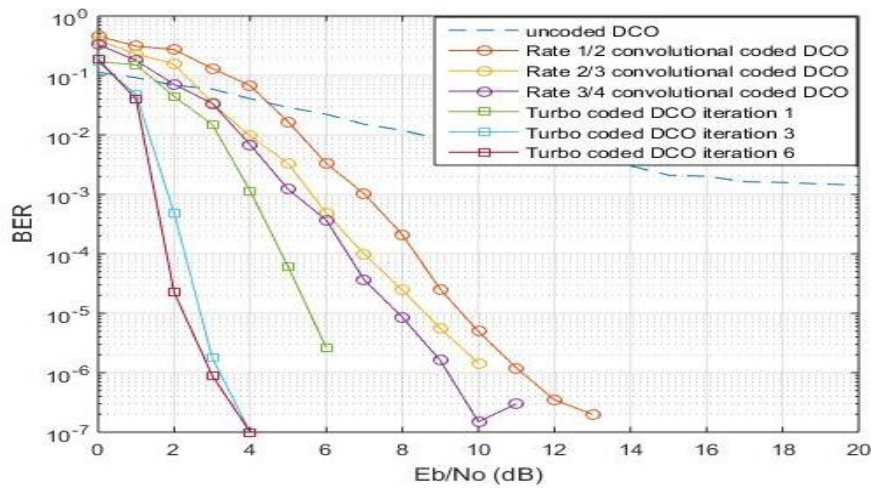


Figure 5: comparisons between uncoded and coded systems with 4QPSK and 3 dB bias in the AWGN channel

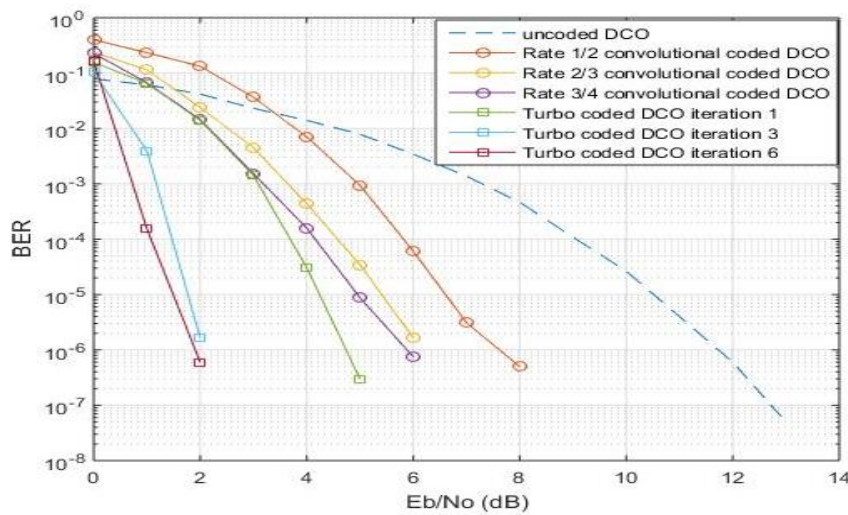


Figure 6: comparisons between uncoded and coded systems with 4QPSK and 7 dB bias in the AWGN channel

The performance of coded DCO-OFDM system with 7dB bias is better to those with 3dB bias, as shown in Figures 7 and 8. In contrast, the increased DC bias reduces power efficiency. Consequently, there is a control for the DC bias increase.

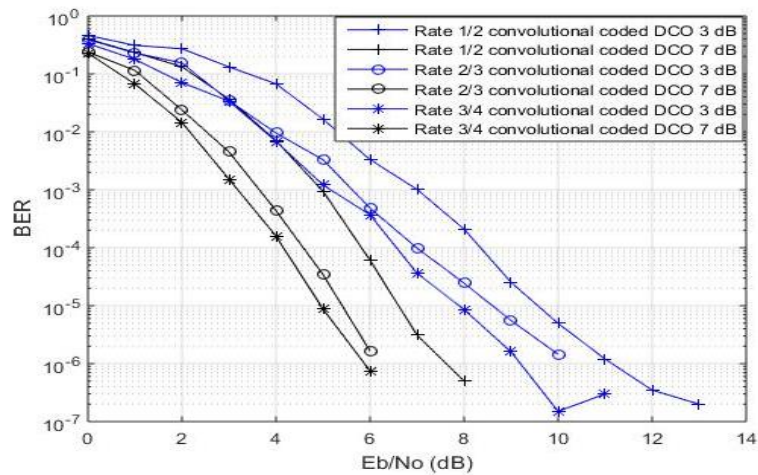


Figure 7: Performance of convolutional coded system with 3, 7 dB bias and 4QPSK in the AWGN channel

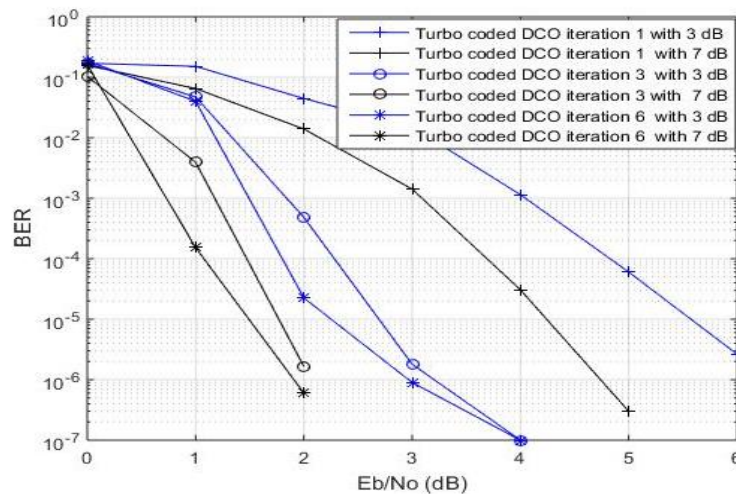


Figure 8: Performance of turbo encoded systems with 3, 7 dB bias and 4QPSK in the AWGN channel.

Tables 1 provide a comparison between uncoded and coded systems with a 3dB/7dB DC bias. In convolutional encoder, it is shown that a larger E_b/N_0 yields a significant performance advantage over a smaller E_b/N_0 . Tables 1 and 2 indicate the performance advantage of turbo-coded system with three and six iterations, respectively.

Table 1: Comparison between uncoded and coded systems

E_b/N_0	BER in uncoded DCO	Convolutional system			Turbo system		
		Code Rates			No. of iterations		
		1/2	2/3	3/4	1	3	6
3	0.0231	0.0366	0.0045	0.0015	0.0014	0	0
6	0.0034	6.0776×10^{-5}	1.6499×10^{-6}	7.4997×10^{-7}	0	0	0

5. Conclusion

The simulation results show that the BER of convolutional and turbo-coded system is lower than uncoded system when operating in an AWGN channel. The BER performance of convolutional and turbo-coded systems is better when they are operated with a greater DC bias. On the other hand, the performance is decreased under lower DC bias. Further, a rise in the DC bias results in a decrease in power efficiency. The performance of optical coded systems is typically superior to that of uncoded optical systems.

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