

# Comparison of ACO-OFDM and DCO-OFDM in IM/DD Systems

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**Abstract**— In this paper the two Optical Wireless orthogonal frequency division multiplexing (OFDM) techniques in intensity modulated/direct detection (IM/DD) optical systems are compared. These are asymmetrically clipped optical OFDM (ACO-OFDM) and DC biased optical OFDM (DCO-OFDM). The comparison is done by the analysis of BER versus SNR of ACO-OFDM and DCO-OFDM for intensity-modulated direct-detection systems. DCO-OFDM is less efficient in terms of optical power than ACO-OFDM for lower SNR value. But for higher SNR values it is power efficient. This is because the DC bias used in DCO-OFDM is inefficient in terms of optical power, while the use of only half of the subcarriers to carry data in ACO-OFDM is inefficient in terms of bandwidth.

**Keywords**—ACO-OFDM, DCO-OFDM, IM/DD, optical systems.

## I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) allows high-speed data transmission across a dispersive channel, so is used in many new and emerging high-speed wired and wireless communication systems. However, OFDM is not used in commercial optical communication systems [1]. This is because OFDM signals are bipolar, while in optical systems that use intensity modulation (IM), only unipolar signals can be transmitted. Despite the many advantages of OFDM, and its widespread use in wireless communications, OFDM has only recently been applied to optical communications. This is partly because of the recent demand for increased data rates across dispersive optical media and partly because developments in digital signal processing (DSP) technology make processing at optical data rates feasible. However another important obstacle has been the fundamental differences between conventional OFDM systems and conventional optical systems. In typical (nonoptical) OFDM systems, the information is carried on the electrical field and the signal can have both positive and

negative values (bipolar). At the receiver a local oscillator and coherent detector is used. In contrast in a typical intensity-modulated direct-detection optical system, the information is carried on the intensity of the optical signal and therefore can only be positive (unipolar). There is no laser at the receiver acting as a local oscillator and direct detection rather coherent detection is used. OFDM is now increasingly being considered as a modulation technique for optical wireless systems. Many optical wireless systems use intensity modulated/direct detection (IM/DD). In IM/DD systems the transmitted electrical signal is modulated onto the intensity of the optical carrier. Therefore, only real and non-negative signals can be transmitted.

Optical OFDM Using Intensity Modulation have many optical modes that are present at the receiver result in optical wireless systems being linear in intensity. So, for optical wireless systems and other systems where many modes are received, the OFDM signal must be represented as intensity. This means that the modulating signal must be both real and positive, whereas baseband OFDM signals are generally complex and bipolar. A real baseband OFDM signal can be generated by constraining the input signal  $X$  to have Hermitian symmetry. Two forms of unipolar OFDM have been used in this paper. They are DC-biased optical OFDM (DCO-OFDM) as in [2] and asymmetrically clipped OFDM (ACO-OFDM) from [4]. In DCO-OFDM the signal is made positive by adding a DC bias. Because OFDM signals have a very high peak-to average power ratio, a very high bias would be required to eliminate all negative peaks. Instead, a moderate bias is normally used and the remaining negative peaks are clipped, resulting in clipping noise. Normally in DCO-OFDM both even and odd subcarriers are modulated and clipping noise affects all subcarriers. In ACO-OFDM, data is carried only on the odd subcarriers.

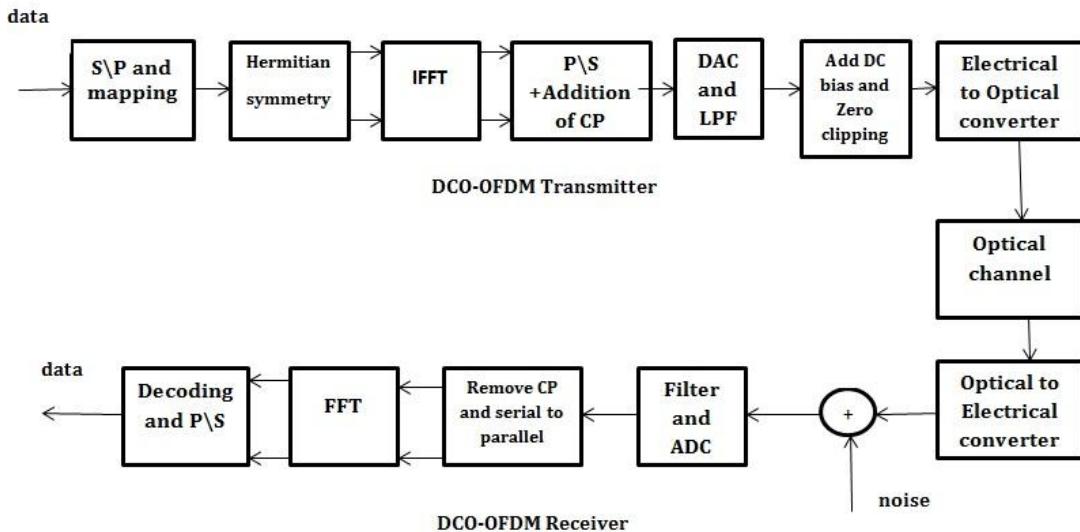


Figure 1: DCO-OFDM system

The resulting bipolar signal at the output of the IFFT is clipped at zero to give a non-negative signal [3]. The resulting clipping noise in ACO-OFDM affects only the unused even subcarriers and no clipping noise is present in the data carrying odd subcarriers.

## II. DESCRIPTION OF OFDM SCHEMES

Two forms of unipolar OFDM have been used in this paper. DC-biased optical OFDM (DCO-OFDM) and asymmetrically clipped OFDM (ACO-OFDM). They are described below.

### A. DCO-OFDM

A DCO-OFDM system is shown in figure 1. In DCO-OFDM all the subcarriers carry data symbols. The complex data signal, is input into the inverse fast Fourier transform (IFFT). The input signal is constrained to have Hermitian symmetry. Because of the Hermitian symmetry of the input, the output signal of the IFFT is real not complex. Signal is then converted from parallel to serial (P/S), a cyclic prefix (CP) is appended, the resulting signal is digital to analog (D/A) converted and low pass filtered resulting in  $x(t)$ . In this paper, an ideal low pass filter (LPF) is assumed.

For large subcarriers, the signal can be modeled as a Gaussian random variable. Next a suitable DC bias is added and then the remaining negative peaks are clipped. Because OFDM signals have a very high peak-to-average power ratio, so a very high bias is required to eliminate all negative peaks. If a large DC bias is used, the optical energy per-bit to single sided noise power spectral density, becomes very large, thereby making the scheme inefficient in terms of optical power. Instead, a moderate bias is normally used, and the

remaining negative peaks are clipped, resulting in clipping noise. In typical DCO-OFDM systems both odd and even subcarriers carry data symbols and the clipping noise affects all the subcarriers. Any negative peak which remains after the addition of DC bias level is clipped at zero. The clipped signal is then input to an optical modulator. Here an ideal optical modulator is used; therefore the intensity of the output optical signal is directly proportional to the input electrical current. The resulting signal is transmitted across a flat channel. Shot noise which affects the signal is modeled as additive white Gaussian noise (AWGN), is added in the electrical domain. At the receiver, the received signal is first converted from an optical signal to an electrical signal using a photodiode. The processing after this point is the same as a conventional OFDM receiver. i.e. the output of photodiode is then filtered and the resulting signal is then analog to digital converted. Then the appended cyclic prefix is removed and the signal is converted from serial to parallel. The signal is given as the input of FFT. Then it is decoded and converted from parallel to serial and finally data signal is retained.

### B. ACO-OFDM

In ACO-OFDM, only the odd subcarriers carry data symbols, while the even subcarriers form a bias signal which ensures that the transmitted OFDM signal meets the non-negativity requirement. Figure 2 shows an ACO-OFDM system. The input signal to the IFFT consists of only odd components. Also, the elements of the vector have Hermitian symmetry. The front-end of the ACO-OFDM transmitter is similar to a DCO-OFDM transmitter where is first serialized and a CP is appended to it. Then signal is D/A converted and sent across an ideal LPF. As negative samples cannot be transmitted in an IM/DD system, signal is clipped at zero

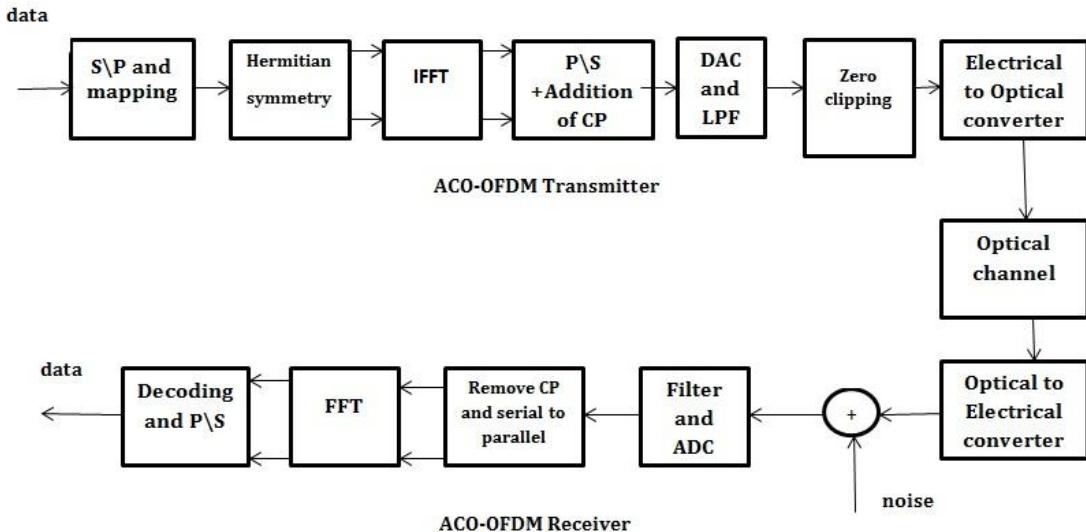


Figure 2: ACO-OFDM system

which results in the ACO-OFDM signal. As a result of the anti-symmetry of signal, clipping does not result in any loss of information. The ACO-OFDM signal is then given as input to an ideal optical modulator and the resulting signal transmitted across a at AWGN channel. The processing in the receiver is similar to a DCO-OFDM receiver, except that in ACO-OFDM only the odd subcarriers are demodulated, as only they carry the data symbols.

### III. EXPERIMENTAL RESULTS

The comparison of ACO-OFDM and DCO-OFDM are discussed here.

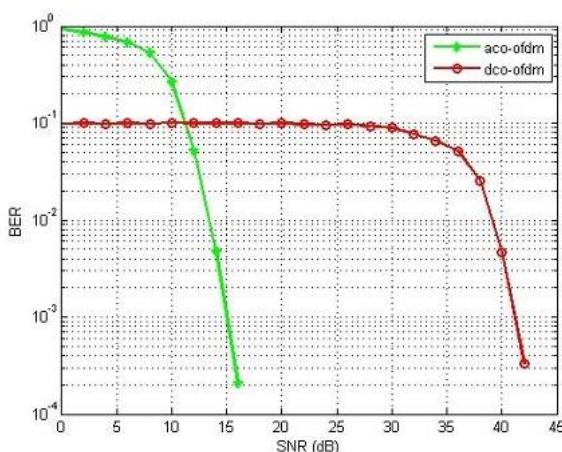


Figure 3: BER versus SNR for ACO-OFDM and DCO-OFDM

The graph of bit error rate (BER) versus SNR is used for the performance analysis. Bit error rate (BER) of a communication system is defined as the ratio of number of error bits and total number of bits transmitted during a specific period. It is the likelihood that a single error bit will occur within received bits, independent of rate of transmission. The bit error rate or bit error ratio (BER) is the number of bit errors divided by the total number of

transferred bits during a studied time interval. BER has been measured by comparing the transmitted signal with the received signal and computing the error count over the total number of bits. For any given modulation, the BER is normally expressed in terms of signal to noise ratio (SNR). SNR is defined as the ratio between signal power to noise power and it is normally expressed in decibel (dB).

The figure 3 shows the BER versus SNR graph for ACO-OFDM and DCO-OFDM. From the figure it can be observed that there is a clear difference between two OFDMs in terms of BER and SNR. In the initial stage BER for ACO-OFDM is higher than DCO-OFDM. As SNR value increases the BER will decrease suddenly for ACO-OFDM and in DCO-OFDM when SNR value increases the BER will be constant up to 30dB and then it will decrease. But for larger SNR the value of BER for DCO-OFDM is less. Because a larger DC-bias is used in DCO-OFDM, the nonlinear distortion is mitigated, but more power is sacrificed. Since there is no DC-bias for ACO-OFDM, it has significant advantages in terms of power efficiency. i.e. DCO-OFDM is less efficient in terms of average optical power in lower SNR values but for larger values it is power efficient. This is because the DC bias used in DCO-OFDM is inefficient in terms of optical power, while the use of only half of the subcarriers to carry data in ACO-OFDM is inefficient in terms of bandwidth.

### IV. CONCLUSION

In this paper two forms of orthogonal frequency division multiplexing (OFDM) in intensity modulated/direct detection (IM/DD) optical systems are compared. They are asymmetrically clipped optical OFDM (ACO-OFDM), DC biased optical OFDM (DCO-OFDM). The comparison is done by the analysis of BER versus SNR of ACO-OFDM and DCO-OFDM for intensity-modulated direct-detection systems. DCO-OFDM is less efficient in terms of optical power than ACO-OFDM for lower SNR value. But for higher SNR values it is power efficient.

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