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# Various Indoor OFDM Optical Wireless Communication Systems and Performance Characteristics

**Babysen .R[1], Manikandan .P[2], G. K. D. Prasanna Venkatesan[3]**

[1]ME Communication System, PGP College of Engineering and Technology, Namakkal, India

[2]Assistant Professor, Department of ECE, PGP College of Engineering and Technology, Namakkal, India

[3]VicePrincipal, HOD, Department of ECE, PGP College of Engineering and Technology, Namakkal, India

**Abstract:** ***In this paper, the performance of indoor OFDM (Orthogonal Frequency Division Multiplexing) optical wireless communication systems in the presence of LED clipping distortions is analysed. The Orthogonal frequency division multiplexing (OFDM) is used in many wired and wireless broadband communication systems because of its resilience in the presence of signal dispersion or multipath distortion. OFDM has not been used in practical optical communication systems because the bipolar waveform cannot be used in intensity-modulated systems. A novel unipolar form of OFDM, asymmetrically clipped optical OFDM (ACO-OFDM), has recently been developed. In the case of an AWGN channel, we compare ACO-OFDM and other modulation schemes. An ACO-OFDM (asymmetrically clipped optical OFDM) system produces half-wave symmetry time signal at the output section of the OFDM modulator by special assignment of subcarriers. Therefore, bipolar-unipolar conversion is obtained by clipping the signal at the zero level. The other technique, called DCO-OFDM (DC-biased optical OFDM), assigns data to all possible subcarriers to increase the data rate. The performance can be analysed by considering average electrical OFDM signal versus BER,DC power consumption versus transmitted optical power characteristics.***

**Keywords:** Optical wireless communication, intensity modulation, direct detection, OFDM, ACO, DC-biased, LED nonlinearity.

## 1. Introduction

Orthogonal Frequency Division multiplexing (OFDM) uses a large number of parallel narrow-band subcarriers instead of a single wide-band carrier to transport information .In wireless communication short range-communication is one of the most important field. Now days a large scale of research and developments are **progressing** with the incremental improvement in technology. The major drawback for most of the short- range radio frequency (RF) technologies is the limited data rate.So interest in optical wireless (OW) technology for RF in short- range communications has gained new momentum. Also, there are certain locations where the use of radio frequencies is not-advised, such as in hospitals and installations containing navigation equipment as in airplanes.

OFDM is an FDM modulation technique for transmitting large amounts of digital data over a radio wave. FDM scheme used as a digital multi-carrier modulation method. The primary advantage of OFDM over a single carrier scheme is its ability to cope with severe channel conditions. The low symbol rate makes the use of a guard interval between symbols affordable. Thus it is possible to eliminate Inter Symbol Interference (ISI). It is a form of distortion of a signal in which one symbol interferes with subsequent symbols.

There are two different Optical Wireless (OW) OFDM techniques, namely ACO-OFDM (Asymmetrically Clipped OFDM) and DCO-OFDM(DC Biased Optical OFDM). Here the performance of indoor OFDM optical wireless communication systems in the presence of LED clipping distortions is analysed. ACO-OFDM produces half wave symmetry time signal at the OFDM modulator output. For performing such function it assigns special subcarriers. So the signal is usually clipped at the zero level and achieves bipolar-unipolar conversion. In DCO-OFDM it assigns data to all possible subcarriers and increases the data rate. The performance can be analysed through by considering a practical LED model and a plot of OFDM signal power vs BER (Bit Error Rate). Here for better simulation we can use Monte Carlo Simulation techniques.

## 2. Optical Wireless OFDM Techniques

In optical wireless communication OFDM is a method of encoding digital data on multiple carrier frequencies. OFDM is essentially identical to coded OFDM (COFDM) and discrete multi-tone modulation (DMT).

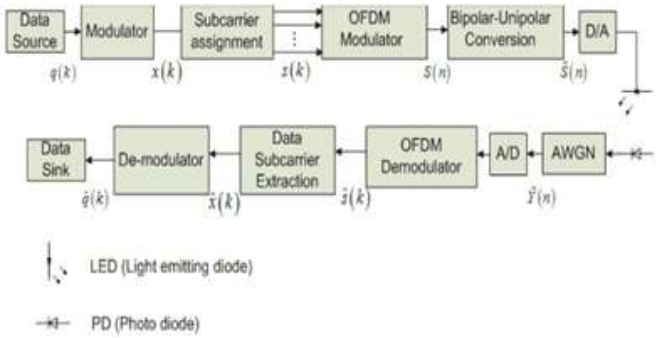


**Figure 1:** Indoor OW OFDM system model

A general system model of indoor OW OFDM systems is shown in fig.1.The data stream 'q' is first passed into a


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block of complex data symbols denoted by x. The complex symbols are the results of QAM modulation. These complex symbols are then mapped onto the following vector,

$$S= [x(k)\ 0\ x*\ (N-k)\ ,\ k = 1,2,..,N/2-1] \quad ...(1)$$

where $(\bullet)*$ shows the complex conjugate. The Hermitian symmetry property of the vector s(k) is used to create a real output signal, which is used to modulate the LED intensity. The OFDM modulator applies an N-point inverse fast Fourier transform (IFFT)and adds a cyclic prefix creating the real time signal S. Cyclic prefix is used to avoid ICI (inter-carrier interference ) and IBI (inter-block interference).The intensity of LED is modulated by the resulting time signal. The intensity can't be negative and the bipolar signal is converted to unipolar before modulating the LED intensity.

Based on the bipolar-unipolar conversion process, two OW OFDM techniques are reported, namely ACO- OFDM (asymmetrically-clipped optical OFDM) and DCO- OFDM (DC-biased optical OFDM).

### A. ACO-OFDM Technique

In ACO-OFDM, only odd subcarriers are modulated and produce shalf wave symmetry time signal at the OFDM modulator output. The signal is usually clipping at the zero level and performs bipolar to unipolar conversion. The first and the N/2 subcarriers are set to zeros to ensure that the output consists of only real values. So the achieved data rate for ACO-OFDM system is given by

$$R^{ACO} = (\frac{N/4-1}{N+N_g})\text{B log2M bits/s} \quad ....(2)$$

Where B denotes the bandwidth, Ng denotes the number of guard subcarriers used in the Cyclic prefix, and M is the modulation order. The OFDM modulator output produces a half-wave symmetry real time signal S. An example of S assuming N = 16 is shown in Fig. 2. 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. The negative part can be clipped without any severe loss of information. This level of clipping produces a unipolar signal. The unipolar signal is then converted to an analog signal through the digital-to-analog converter (D/A). This analog signal is used to modulate the intensity of an LED. At the receiver end the analog signal is converted back to digital and a PD (photodiode) detects the transmitted intensity level. The received signal before the analog-to-digital convertion (A/D) is given by

$$Y = h \otimes S + w \quad ......(3)$$

where h =[ h(0) h(1) ⋯ h(L−1) ]T is the L-path impulse response of the optical channel. w is an AWGN that represents the sum of the receiver thermal noise and shot noise. The noise power is represented by $\sigma_n^2$.Here noise added is in the electrical domain. So the received signal Y can be negative as well as positive. But here the received signal is bipolar instead of unipolar. Then the cyclic prefix is first removed and the linear convolution is converted to circular convolution. Then for demodulating the signal an N-point fast Fourier transform (FFT) is used.

$$y = H\ s + w \quad ....(4)$$

where H is an N × N diagonal matrix whose diagonal elements are the N-point FFT of h and ˆ w is the N-point FFT of w.The odd subcarriers are extracted from ˆ y to produce the following equation.A zero-forcing (ZF) equalizer is used to mitigate the effect of the channel.

$$yo = Ho\ so + wo \quad ..... (5)$$

### B. DCO-OFDM technique

The second technique assigns data to all odd and even subcarriers. Hence, the achieved data rate for DCO-OFDM system is given by,

$$R^{DCO} = (\frac{N/2-1}{N+N_g})\text{B log2M bits/s} \quad .....(6)$$

The OFDM modulator is applied to s producing the real time signal. An example of S for N=16 is shown in Fig.2. Here half wave symmetry signals can't be achieved and a DC bias is needed to convert the bipolar signal to a unipolar signal before modulating the LED intensity. After adding the DC bias ,all the remaining negative values are clipped. The DC bias value depends on the LED characteristics.

DCO-OFDM and ACO-OFDM are compared in terms of electrical power requirement to achieve a target BER of 10−3 and the corresponding spectral efficiency.In DCO-OFDM and ACO-OFDM, K is given as follows:

$$K = Q(\lambda bottom) - Q(\lambda top)$$

Here, Q(·) stands for the complementary cumulative distribution function (CCDF) of a standard normal distribution with zero mean and unity variance.

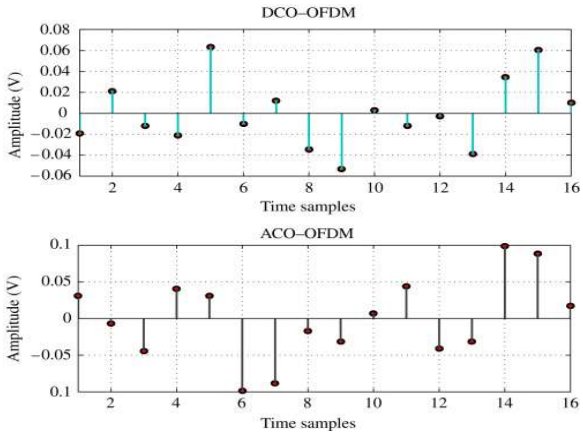


**Figure 2:** The output OFDM time signals for ACO-OFDM, and DC-bias OFDM systems for N = 16.

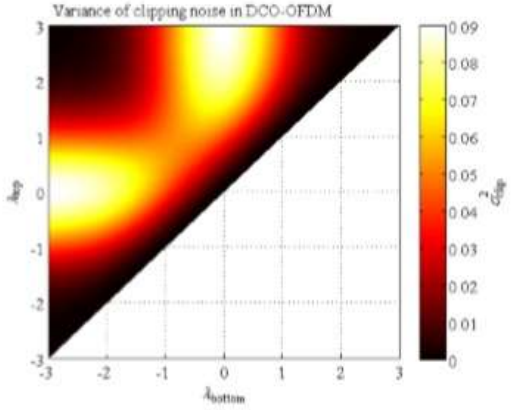


**Figure 3:** Clipping noise variance, σ2clip, in DCO-OFDM as a function of the normalized clipping levels


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## 3. Performance Analysis

### A. Analytical Treatment

The OFDM signal shows high peak-to average-power-ratio (PAPER). So a careful adjustment of the OFDM signal envelope is needed to control distortion levels. The LED is biased to insure minimum distortion.

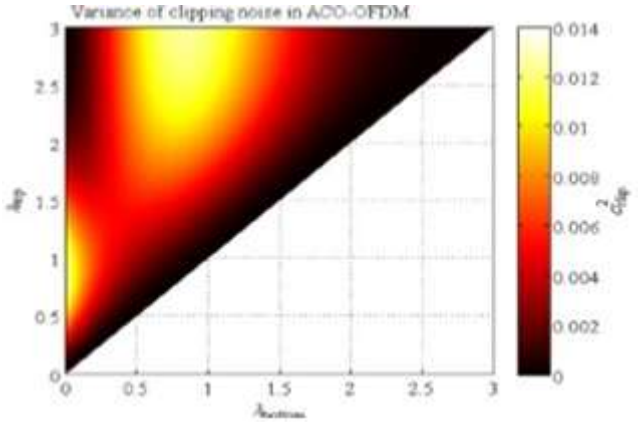


**Figure 4:** Clipping noise variance, σ2clip, in ACO-OFDM as a function of the normalized clipping levels.

The performance of optical OFDM techniques can be analysed with the help of certain parameters like SNR, BER , signal power. An OFDM signal is the sum of N independent sub channels. For large values of N, the ensemble average of sub carriers can be accurately modelled by central limit theorem with zero mean and variance. Thereby, the probability that at any given time instance ,S takes the value of z is given by

$$p(S = z) = p(z) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{z^2}{2\sigma^2}\right) \ldots\ldots(7)$$

In ACO-OFDM, the negative part of the signal is clipped and the LED is biased at the value of $c_l$. The signal peaks larger than the value of $c_u$ are also clipped which produces a clipping distortion power given by

$$\sigma^2_{clip} = \int_{c_u}^{\infty} (z - c_u)^2 \, p(z) \, dz \ldots\ldots(8)$$

For DCO-OFDM system, signal levels above $c_u$and below$c_l$ are clipped producing a clipping noise power given by

$$\sigma^2_{clip} = \int_{c_u}^{\infty} (z - c_u)^2 \, p(z)dz + \int_{-\infty}^{c_l} (z - c_{l)^2} p(z)dz$$

### B. Simulation results

The performances of ACO-OFDM an DCO-OFDM systems in the presence of LED clipping distortion are analysed analytically and through Monte Carlo simulations. Here an LED model is considering for the better analysis. An OSRAM white LED is considered in this paper. ACO OFDM requires less DC power since it needs biasing. In DCO OFDM DC bias shifts the signal to higher values. In the simulation results the x-axis represents the average electrical OFDM signal power before modulating the LED, while the y-axis represents the BER for different modulation orders in the figurers 5 and 6. The average transmitted optical power is denoted in fig.7 and 8.ACO OFDM transmitted signal power increases with increasing the input electrical power. But in DCO OFDM the transmitted average optical power starts to decay with increasing the input OFDM signal power.

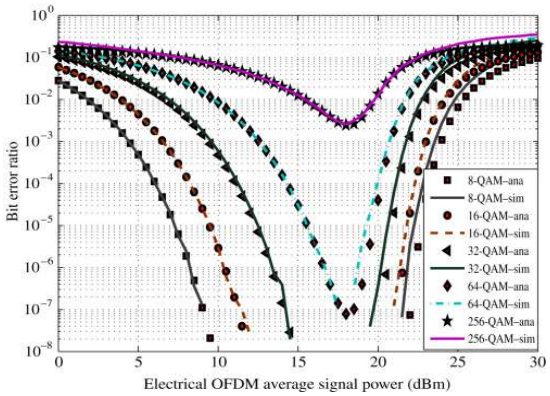


**Figure 5:** ACO-OFDM BER performance for different QAM modulation orders

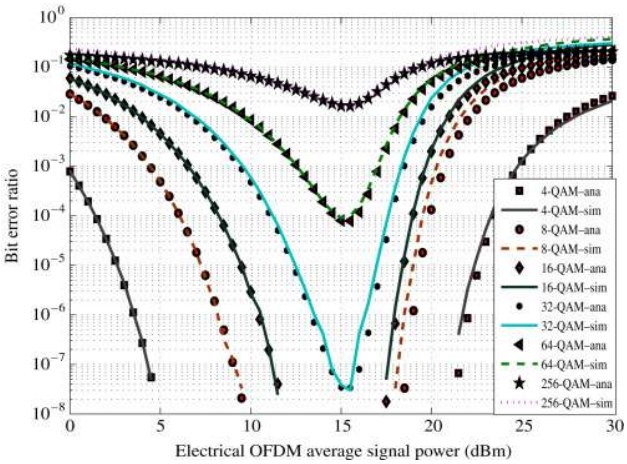


**Figure 6:** DCO-OFDM BER performance for different QAM modulation orders

The optimum value for ACO-OFDM system appears at larger signal power as compared to DCO-OFDM system for the same modulation order. This is because ACO OFDM utilizes larger LED dynamic range as compared to DCO OFDM. ACO-OFDM with 64-QAM modulation order achieves a data rate of about 29.77 Mbps while DC-bias OFDM system achieves a data rate of 59.65 Mbps for the same modulation order. The analysis in this paper allows a simple method to optimize system parameters for OFDM optical wireless transmission techniques.

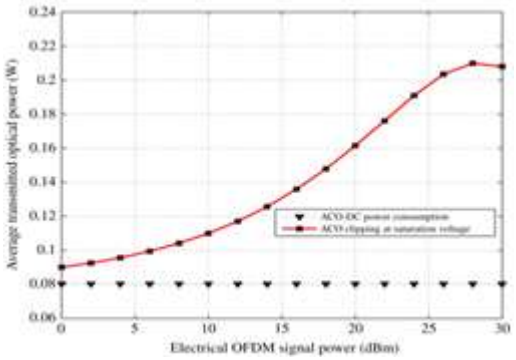


**Figure 7:** ACO-OFDM DC power consumption and the average output optical power for different input OFDM electrical signal power.


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A larger input signal leads to larger clipping distortion and more loss in transmitted optical power. Here consider DCO system which uses a bias point b = 0.625 V which corresponds to the recommended bias point for this LED from the manufacturer. But this might not be the optimum bias point for communication.

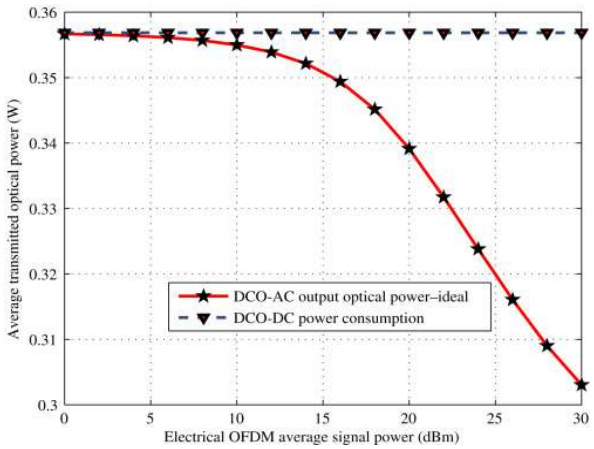


Figure 8: DCO-OFDM DC power consumption and the average output optical power for different input OFDM electrical signal powers

The BER for the 16-QAM DCO system with different bias points are shown in fig. 9. It is also shown that b = 0.525 V bias point performs slightly better than the considered b = 0.625 V bias point and with reduced DC power consumption. It shows the DCO-OFDM optimum bias point analysis. 16-QAM constellation is considered and the BER vs. electrical OFDM signal power is calculated for different bias points.

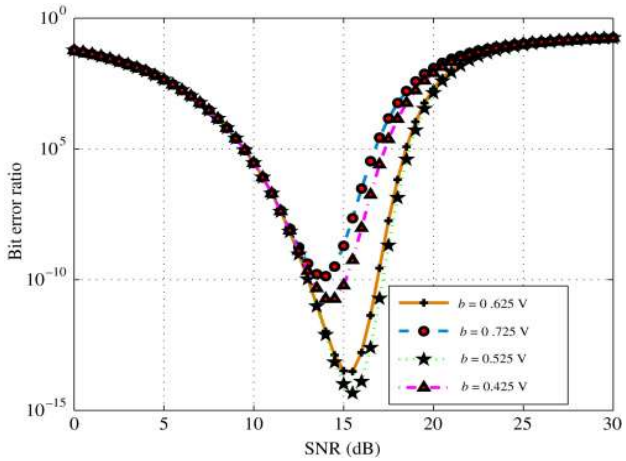


**Figure 9:** DCO-OFDM optimum bias point analysis. 16-QAM constellation is considered and then BER vs. electrical OFDM signal power is calculated for different bias points.

## 4. Conclusions

Both the indoor OFDM techniques are considered and their performances are analysed in the presence of LED clipping distortion. In ACO OFDM the distortion increases with increasing the modulation order. But it is more significant in DCO OFDM as compared to ACO OFDM. AWGN noise dominates at low SNR values and clipping distortion dominates at large SNR values. So during the system design care should be taken in LED clipping level and order of modulation.

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## Author Profile

**Babysen. R** received his B. Tech. degree in Electronics and Communication from IHRD College of Engineering Kottarakkara, Kollam, Kerala affiliated to CUSAT India, in 2010, persuing M.E. degree in Communication Systems from PGP college of Engineering and Technology Anna University, Chennai, India, in 2012-14, was an Assistant technician on contract in BSNL Kanjiramkulam during 2010-2012.

**Dr. G. K. D. Prasanna Venkatesan**, Completed Ph.D from College of Engineering, Anna University, Chennai, India. He is presently Working as Vice-Principal, Professor & Head of Department of Electronics and Communication Engineering at PGP College of Engineering and Technology. Namakkal, Tamilnadu, India. His research interest includes Wireless Sensor Networks, 4G Wireless Networks, Cloud .Computing, adhoc Network, etc.

**Mr. P. Manikandan** completed his ME from Sathyabhama University, India. He is presently working as Assistant Professor in PGP College of Engineering and technology Namakkal. His research work includes Signal Processing, Wireless Communication Networks. He had already published 10 journals in Signal Processing and Wireless domain.


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