An Improved Scheme Asymmetrically and Symmetrically Clipped DC-Biased Optical (ASDCO)-OFDM for Wireless IM/DD Optical System

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***Abstract*—In this paper, a modified system built on (ASCO)-OFDM, that can be utilized in IM/DD wireless optical system is designed and analyzed. At the transmitter the modified ASDCO-OFDM scheme uses the fact of nullifying the mean dc-bias of subcarriers generated after the Hermitian symmetry and removal of interference at the receiver with the help of equalizer. By utilizing this modified scheme both odd and even subcarriers are modulated to convey the input signal. The modulations of subcarriers that are odd are performed by ACO-OFDM whereas modulations of subcarriers that are even are performed by SCO-OFDM which is a novel modulation scheme. ACO-OFDM and SCO-OFDM causes asymmetrically clipping noise and symmetrically clipping noise in the generated system. These interferences can be assessed and expelled at the receiver using zero forcing equalizer. Therefore, this scheme helps in accomplishing superior efficiency in terms of Symbol Error Rate(SER) and Optical power as compared to ASCO-OFDM.**

Keywords—ASCO-OFDM; ASDCO-OFDM; IM/DD; SER; Optical power.

I. INTRODUCTION

Optical wireless systems with intensity modulation directdetection (IM/DD) can be efficient substitute to wirelesssystems. Radio Frequencies (RF) are used for transmission ofdata at high speed in an indoor environment.They are the mostwidely studied areas in current scenario [1-3]. Optical WirelessCommunication (OWC) in comparison to RF communicationoffers inexhaustible transmission bandwidth. An economicalspatial diversity is reached with a large space detector andshort carrier wavelengths[4]. Multipath distortion occurs thatis brought on by reflection from dividers or household items,which sorely disturbs the characteristics of transmission of anoptical signal. In RF communication, to battle inter-symbol interference(ISI) caused by multipath propagation, a promisingmodulation technique that has been widely adapted is commonlyknown as Orthogonal Frequency Division Multiplexing(OFDM)[5]. An asymmetrically clipped optical OFDM (ACO-OFDM)[6,7] and DC-biased optical OFDM (DCO-OFDM)[8] are the two different techniques of OFDM that has been effectivelyutilized in IM/DD OWC. An asymmetrically clippedDC-biased optical OFDM (ADO-OFDM) [9] has been buildup in conjunction with the methods of the aforementionedprocedures and it is a lot economical in case of optical powerand bandwidth. Additionally, polar-OFDM and a hybrid modelof ACO-OFDM are the perfect examples of OFDM systemsthat are spectrally economical[10,11].

The information carrying datastream is allowed to bemodulated into the intensity of optical carriers, in opticalwireless systems. Thus, to perceive the intensity modulationsolely real and positive values may be used. With a specificend goal to achieve a signal that is real and to translate blocksof Hermitian symmetry complex symbols an Inverse FastFourier Transform (IFFT) must be applied. Two conventionaltechniques that are adopted in a large extent, for the positivedemand of the transmitted optical signals are clipping andaddition of DC bias.In DCO-OFDM, to abolish the non-positive values we have to add some DC bias within thetransmitted signal. However, the DC bias level strongly ensures the performance of DCO-OFDM [12]. The negative valueswhich are left should be fixed to zero, if the negative peak isnot exceeded by the added DC bias, then all subcarriers areplagued by noise caused due to clipping. The DCO-OFDM inthe case of optical power becomes inefficacious, if the negativepeak is smaller than the DC bias. DCO-OFDM is bandwidthefficient in light of the fact that even subcarriers as well asodd subcarriers are utilized to convey information. In ACO-OFDM,only positive value will remain as all the non-positivevalues are fixed to zero. In [13], it is given that on the evensubcarriers all the clipping noise falls without manipulating theinformation on the subcarriers and it does not affect the data ofthe odd subcarriers. This reduces the amplitude of the actualsymbols to half by applying the clipping approach. Thus,to carry information in ACO-OFDM solely odd subcarriersare used. ACO OFDM is efficient in case of optical powercompared to DCO-OFDM, but its information measure isdouble that of DCO-OFDM. A grouping scheme known asADO-OFDM has been created, to maintain the benefits andavoid shortcomings of the aforementioned optical systems. Ingeneral, the even and the odd subcarriers are modulated byDCO-OFDM and ACO-OFDM symbols respectively. ACO-OFDMand DCO-OFDM produces some non-positive valueswhich are discretely clipped to zero. Then, by using a LED[14,15] the totality of the two left over positive signals iscommunicated. By sensing the information conveyed withthe help of odd subcarriers, ACO-OFDM symbols can beeffortlessly recuperated. On receiving the ACO-OFDM signalsone can easily predict the ACO-OFDM clipping noise atthe transmitter end by adding a reasonable DC bias. Aninsignificant clipping noise is produced related to the desiredsignal by DCO-OFDM. Finally,the symbols of DCO-OFDMare magnificently regained by deducting the expected clippingnoise of ACO-OFDM signal from the obtained DCO-OFDMsignals.

A modest and straight methodology is the addition of DCbias at the transmitter, however it ends up in a huge left-overof optical power [11]. A hybrid ACO-OFDM whichis completely spectrally competent optical system has been proposed by M. Kavehrad and B. Ranjha. Hybrid ACO-OFDMis more power efficient than ADO-OFDM, even when deprivedof using the DC bias. Our suggested system and the model ofthe hybrid ACO-OFDM follow similar concepts. ACO-OFDMsymbols are being carried by the odd subcarriers used forthe hybrid ACO-OFDM and also for our suggested system.The dissimilarities are that even subcarriers are mapped to theQAM symbols while in event of the hybrid ACO-OFDM totransmit PAM-DMT symbols it makes use of the even subcarriersimaginary parts. We have certainty that our suggestedmodel will be superior to the hybrid model of ACO-OFDMdue to the fact that the PAM symbols are much greater thanthe average power of QAM symbols within the same level ofconstellation case.

Until now, for attaining real signals the restriction of Hermitiansymmetry is generally imposed on the signal vector.Though, to produce real unipolar signals without the restrictionof Hermitian symmetry alternative scheme was provided alsoknown as polar-OFDM (P-OFDM) by T.D.C. Little and H.Elgala. The QAM symbols are mapped only to the evensubcarriers. The half wave even symmetry is obtained bythe signal vectors that are complex after the IFFT operation.At that point, to obtain exponential signal from the complexform the authors applied the Cartesian-polar operation [11].The phase values and amplitude of different samples arecommunicated. The reverse operation is used by T.D.C. Littleand H. Elgala to recuperate the initial complex symbols atthe receiver end. There are some differences in the designingconcepts of our anticipated system and P-OFDM. The use ofHermitian symmetry restriction plays a vital role. Authors haveused more DC-bias in the configuration of aforementionedtechniques which leads huge wastage of optical power.TheASDCO-OFDM construction details are given in section III.

In this paper, we have used a different methodology, whichis an improved version of ASCO-OFDM[16]. This modifiedASDCO scheme uses the fact of nullifying the mean dc-biasof subcarriers generated after the Hermitian symmetry. At thesame time we are using even subcarriers to transmit (SCO)-OFDM symbols and odd subcarriers to transmit symbols of(ACO)-OFDM. ACO-OFDM symbol fulfills this condition of$x(n) = -x(n+N)$ that comprises of odd subcarriers [13,17] and$x(n) = x(n+N)$ for symbol which is regenerated solely from thesubcarriers that are even, if we assume the signal length to be2N. In the first and second half subsequent to clipping, similarnon positive values are eliminated. Therefore the positivesignals are referred to as symmetrical clipping optical-OFDMsignals. Since the ACO-OFDM symbols falls on top of theeven subcarriers, they are not influenced by the clipping noiseof the SCO-OFDM. By utilizing a similar process in ADO-OFDM,we can retrieve symbols of ACO-OFDM by bringingout the information on the odd subcarriers. Similarly, theclipping noise of ACO-OFDM can be precisely assessed fromthe recuperated ACO-OFDM signals. The clipping noise ofthe ACO-OFDM, the SCO-OFDM, and the various noisesbrings about the contortion of data on the even subcarriers.In section II we examine the subtle elements of reproducingSCO-OFDM. In terms of symbol error rate (SER) and alsooptical power, this methodology of ours unveils superior performances,as there is absence of DC bias from all subcarriers.In addition, to boost the SER execution [18] the existingmethod [19] can be applied.

This paper is sorted as follows: Apart from the section I, InSection II A, the arrangement of ASCO-OFDM is quicklylooked into. In Section II B, we introduce the improvedASDCO-OFDM framework in detail. In Section III the examinationof power/bit and the average Bitrate/Normalized Bandwidthsfor ASDCO-OFDM and ASCO-OFDM is introduced.Performance evaluations and simulation outcomes betweenASCO-OFDM and improved ASDCO-OFDM are given inSection IV. Lastly, the conclusion of the work in Section V.

II. System Model

A. Survey of asymmetrically and symmetrically clipping optical(ASCO)-OFDM

The ASCO-OFDM's block diagram is displayed in Fig 1.(ASCO)-OFDM system input is a block which is separatedinto 3 parts out of which two of the signal vectors are oflengths $(N/2)\,x\,1$ and $(N/2-1)\,x\,1$ respectively. Thus totalnumber of complex data symbols are of length $(3N/2-1)x1$.Likewise, we have to form the IFFTs input to satisfy theHermitian symmetry, so as to get a real signal.To form X_{odd}^{i} and X_{odd}^{j} signal vectors of length $2N\,x\,1$,two signal vectors of length $(N/2\,x\,1)$ are united with signalvectors which are conjugate to them in series and in the evensubcarriers we inject some zeroes, which are given by:

$$X_{odd}^{i}=\left[0,S_0^i,0,S_1^i,0,\dots,0,S_{\frac{N}{2}}^i,0,S_{\frac{N}{2}}^{i*},0,\dots,S_1^{i*},0,S_0^{i*}\right]^T \quad (1)$$

$$X_{odd}^{j}=\left[0,S_0^j,0,S_1^j,0,\dots,0,S_{\frac{N}{2}}^j,0,S_{\frac{N}{2}}^{j*},0,\dots,S_1^{j*},0,S_0^{j*}\right]^T \quad (2)$$

The X_{even} signal vector of length $(N/2-1)\,x\,1$ ischaracterized correspondingly with zeroes embedded in thesubcarriers that are odd to frame the signal in this way:

$$X_{even}=\begin{bmatrix}0,0,S_0,0,S_1,\dots,S_{\frac{N}{2}-1},0,0,0,S_{\frac{N}{2}-1},\\ \dots,S_1,0,S_0,0\end{bmatrix}^T \quad (3)$$

Hermitian symmetry is the important constraint for X_{odd}^{i},X_{odd}^{j} and X_{even} signal vectors. In order to yield signalvectorsx_{odd}^{j}, x_{odd}^{i} and x_{even} that are real bipolar, both $X_{odd}^{i,j}$and X_{even} are subjected to $2N$ point Inverse Fast FourierTransform. Zero clipping operation is performed for the non-positive values in x_{odd}^{j} and x_{odd}^{i} to produce $x_{odd}^{j,c}$ and $x_{odd}^{i,c}$ respectively. The non-positive values in the x_{even} and thepositive values in the x_{even} are clipped to attain a value ofzero to yield x_{even}^{cn} and x_{even}^{cp}.To transmit these clipped signalswe add $x_{odd}^{j,c}$ with x_{even}^{cp} and $x_{odd}^{i,c}$ with x_{even}^{cn} and than weconcatenate these two blocks of signal matrix one after the. $x_{ASCO}^{i,j}$ is the signal that's need to be transmittedwhich is the sum of cyclic prefix(CP) and these clipped signal.

A multipath propagation channel can also be used to modelan indoor optical wireless channel [20]. Optical channel'simpulse response is specified by c(n) = [c(0), c(1), … , c(l)],cyclic prefix's length is decided by the amount of channelcoefficients and is depicted by l. The received optical signal's intensity is sensed by an active photodiode at the receiver theoptical channels convolution with the optical signal plus somenoise gives $y_{ASCO}^{i,j}(n)$:

$$y_{ASCO}^{i,j}(n)=w(n)+h(n)\otimes x_{ASCO}^{i,j}(n) \quad (4)$$

Thermal noise with the combination of shot noise is representedby $w(n)$.This combination can also be estimated asAWGN.

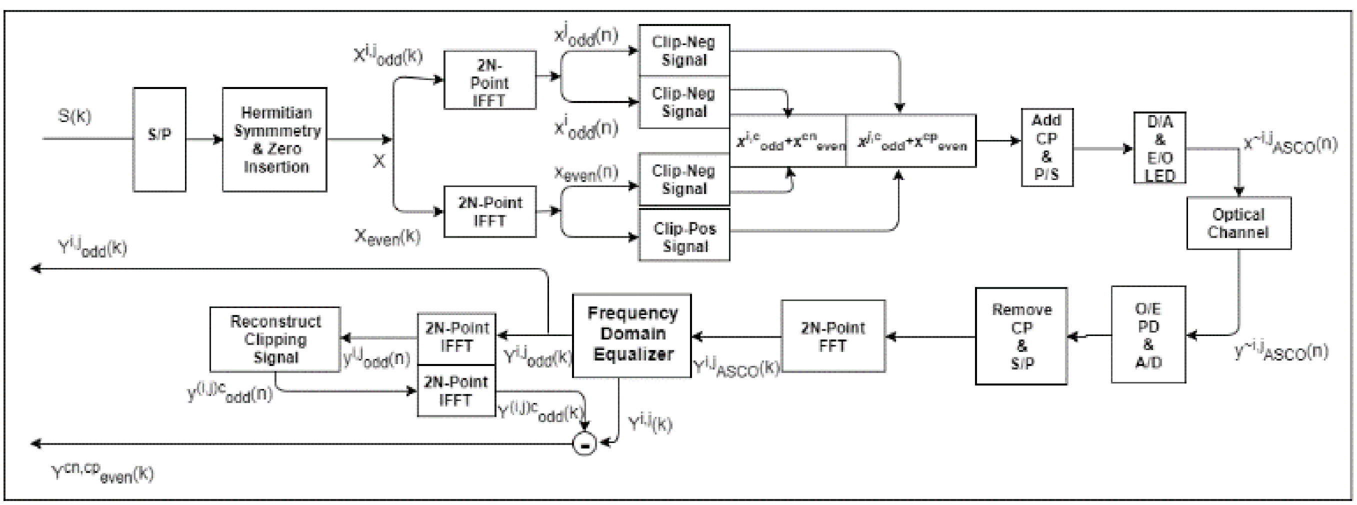

Fig. 1. Transmitter and Receiver Configuration of ASCO-OFDM

At the receiver end the channel state information (CSI)can be assumed to be well known. $Y_{ASCO}^{i,j}(k)$is operatedby frequency domain equalizer, which is an output of $2N$point FFT. By mining the odd components of Y,x_{odd}^{ij} canbe recovered.By transforming $Y_{odd}^{ij}(k)$ into time domain, areconstructing clipping signal block reconstruct a referencesignal $y_{odd}^{(i,j)c}(k)$. Finally $Y_{even}^{cn,cp}$ is obtained by subtracting$Y^{i,j}$ (k)from the time domain version of reference signal.

B. Improved novel scheme (ASDCO)-OFDM.

The improved ASDCO-OFDM's block diagram is displayedin Fig 2. Suppose the input to the system isa set of symbols consisting of complex data given by$S = [S_0, S_1, S_2, \dots, S_{N-2}]^T$. Quadrature amplitude modulationtechnique is used to modulate these complex data symbolsusing combination of 4QAM,16QAM or 64QAM. Since anovel transmission scheme is utilized by improved ASCO-OFDMframework. The input to the system is a block whichis separated into 3 parts out of which two of the signal vectorsare of lengths $(N/2)\ x\ 1$ and $(N/2\ -\ 1)\ x\ 1$ respectively, thustotal number of complex data symbols are of length $(3N/2\ -1)x1$.Likewise, we have to form the IFFTs input to satisfy theHermitian symmetry to get a real signal given by:

$$X_H = \left[0, S_0, S_1, \ldots, S_{N/2}, 0, S_{N/2}, \ldots, S_1, S_0\right]^T \qquad (5)$$

After performing the Hermitian Symmetry and Zero Insertionoperation, we introduce a block which calculate the meandc-bias of the signal X_H given by $X_{DC-bias}$ and then wesubtract $X_{DC-bias}$ from X_H to yield X, this block nullifies thedc bias of subcarriers generated after the Hermitian Symmetrygiven by:

$$X = X_H - X_{DC-bias} \qquad (6)$$

To form X^i_{odd} and X^j_{odd} signal vectors of length $2N\ x\ 1$, twosignal vectors of length $(N/2\ x\ 1)$ are united with signalvectors which are conjugate to them in series and in the evensubcarriers we inject some zeroes, which are given by:

$$X^i_{odd} = \left[0, S^i_0, 0, S^i_1, 0, \ldots, 0, S^i_{\frac{N}{2}}, 0, S^{i*}_{\frac{N}{2}}, 0, \ldots, S^{i*}_1, 0, S^{i*}_0\right]^T (7)$$

$$X^j_{odd} = \left[0, S^j_0, 0, S^j_0, 0, \ldots, 0, S^j_{\frac{N}{2}}, 0, S^{j*}_{\frac{N}{2}}, 0, \ldots, S^{j*}_1, 0, S^{j*}_0\right]^T (8)$$

The X_{even} signal vector of length (N/2- 1) x 1 is characterizedcorrespondingly with zeroes embedded in subcarriers that areodd to frame the signal in this way:

$$X_{even} = \left[\begin{matrix} 0, 0, S_0, 0, S_1, \ldots, S_{\frac{N}{2}-1}, 0, 0, 0, S_{\frac{N}{2}-1}, \\ \ldots, S_1, 0, S_0, 0 \end{matrix}\right]^T (9)$$

The Hermitian symmetry constrain is applied to each ofthe three signal vectors X_{even}, X^j_{odd}, X^i_{odd}.2N-point IFFToperation must be performed to provide signal vectors x_{even},x^i_{odd} and x^j_{odd} which are bipolar and real. Zero clippingoperation is performed for all the non-positive values in x^j_{odd} and x^i_{odd} to produce $x^{j,c}_{odd}$ and $x^{i,c}_{odd}$ to confirm the positiveprerequisite of the transmitted signal given by:

$$x^{j,c}_{odd} = 0.5\left(\left|x^j_{odd}\right| + x^j_{odd}\right) \qquad (10)$$

$$x^{i,c}_{odd} = 0.5\left(\left|x^i_{odd}\right| + x^i_{odd}\right) \qquad (11)$$

The relation of $x_{even}(n) = x_{even}(n+N)$ is formed, as eachspecimen in x_{even} is changed over from even subcarriers. Halfof the data conveyed in x_{even} is lost, by clipping the non-positive values. In this manner, for transferring the data in x_{even} two signal vectors are produced x^{cp}_{even} and x^{cn}_{even}. Everynegative estimation of x_{even} are cut to zero is represented byx^{cn}_{even}. Every single positive estimation of X_{even} are cut tozero represented by x^{cp}_{even} and the left over values which areless than zero are swung to positive. They are correspondinglygiven by:

$$x^{cn}_{even} = 0.5(|x_{even}| + x_{even}) \qquad (12)$$

$$x^{cp}_{even} = 0.5(|x_{even}| - x_{even}) \qquad (13)$$

At that point, we build a signal to convey the informationwhich comprises of sequential sub-blocks, x^i_{ASDCO} andx^j_{ASDCO} which are given by:

$$x^i_{ASDCO} = x^{cn}_{even} + x^{i,c}_{odd} = 0.5\left(\left|x^i_{odd}\right| + x^i_{odd} + |x_{even}| + x_{even}\right) \qquad (14)$$

$$x^j_{ASDCO} = x^{cp}_{even} + x^{j,c}_{odd} = 0.5\left(\left|x^j_{odd}\right| + x^j_{odd} + |x_{even}| - x_{even}\right) \qquad (15)$$

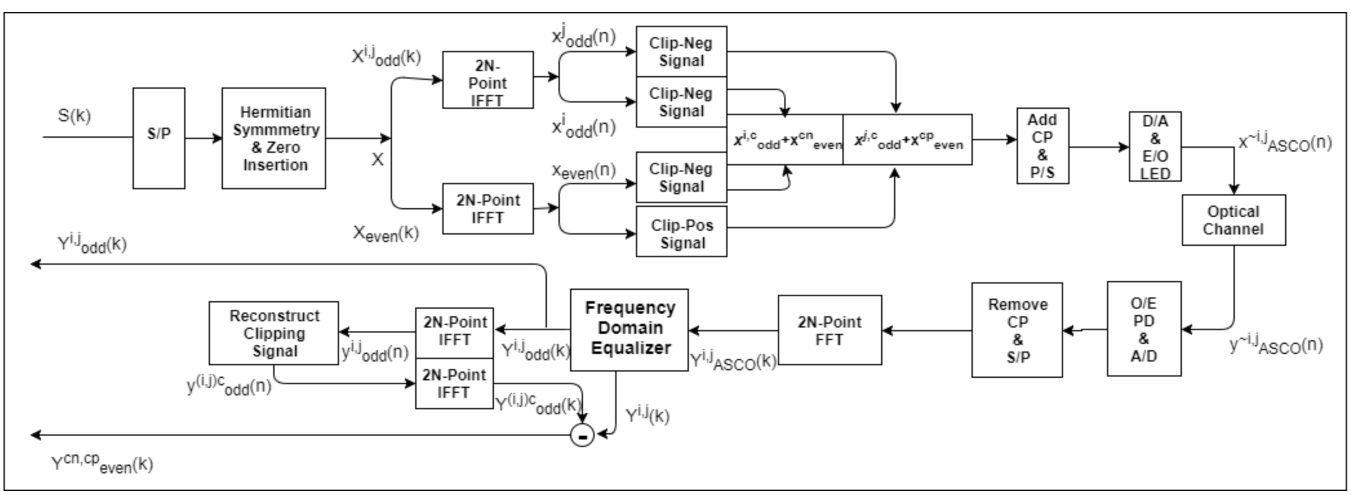

Fig. 2. Transmitter and Receiver Configuration of ASDCO-OFDM

When a cyclic prefix is attached to the transmitted signals, x^j_{ASDCO} and x^i_{ASDCO} they are signified by x^j_{ASDCO} and x^i_{ASDCO}. LED is used to convey these signal via an opticalchannel. The signals at the receiving end are as follows:

$$y^j_{ASDCO}(n) = w^j(n) + h(n) \otimes x^j_{ASDCO}(n) \quad (16)$$

$$y^i_{ASDCO}(n) = w^i_n(n) + h(n) \otimes x^i_{ASDCO}(n) \quad (17)$$

whereh(n) is optical channels impulse response,andadditive white Gaussian noise can be represented by $w^i(n)$or $w^j(n)$,which is the sum of all noise. The received signaly^j_{ASDCO} and y^i_{ASDCO} are one-to-one transmuted using 2N-pointFFT operation to produce Y^j_{ASDCO} and Y^i_{ASDCO} intothe frequency domain, after the removal of cyclic prefix.Atthat point,with the understanding of channel state informationa zero forcing equalizer is applied Y^j_{ASDCO} and Y^i_{ASDCO} toproduce:

$$Y^i = \Lambda^H Y^i_{ASDCO}\left(\Lambda^H\Lambda + \left(\frac{\alpha}{SNR}\right) I_{2N}\right)^{-1} \quad (18)$$

$$Y^j = \Lambda^H Y^j_{ASDCO}\left(\Lambda^H\Lambda + \left(\frac{\alpha}{SNR}\right) I_{2N}\right)^{-1} \quad (19)$$

Since, α= 0 for zero forcing equalizer:

$$Y^i = Y^i_{ASDCO}/\Lambda \quad (20)$$

$$Y^j = Y^j_{ASDCO}/\Lambda \quad (21)$$

where$2N \; x \; 2N$ diagonal matrix is represented by Λ and itsdiagonal is h(n)'s 2N-point FFT, and the Hermitian symmetry vector of Λ is given by Λ^H. Y^i and Y^j can likewise appearin the frequency domain given by:

$$Y^i = X^{cn}_{even} + X^{i,c}_{odd} = 0.5(|X^i_{odd}| + X^i_{odd} + |X_{even}| + X_{even}) \quad (22)$$

$$Y^j = X^{cp}_{even} + X^{j,c}_{odd} = 0.5(|X^j_{odd}| + X^j_{odd} + |X_{even}| - X_{even}) \quad (23)$$

If we take the 2N-point FFT of x^j_{odd} andx^i_{odd} we will getX^j_{odd} and X^i_{odd}. In a similar manner the other equivalentterms in equations 14,15,22,23 are defined. We must notethat on the subcarriers consisting of odd components of Y^j and $Y^i$the symbols $0.5X^j_{odd}$ and $0.5X^i_{odd}$ falls,and on theeven subcarriers of Y^j and Y^i, these additional symbols thatcomprises of the other terms, $0.5(X_{even} + |X^i_{odd}| + |X_{even}|)$and $0.5(-X_{even} + |X^j_{odd}| + |X_{even}|)$ falls, correspondingly.In this way, by removing the symbols ofY^j_{odd} and Y^i_{odd} thecomplex symbols can be effortlessly recuperated, and theyare the odd portion of $Y^j$and Y^i, because the even portionof Y^j and Y^i are only influenced by the clipping noisesthat are caused because of $x^{j,c}_{odd}$ and $x^{i,c}_{odd}$.With a specificgoal to precisely gauge the clipping noise, transformation ofY^i_{odd} and Y^j_{odd} into the time domain is done to produce realbipolar signal y^i_{odd} and y^j_{odd},correspondingly. The manner inwhich$x^{j,c}_{odd}$ and $x^{i,c}_{odd}$ are created in a similar way $y^{j,c}_{odd}$ and$y^{i,c}_{odd}$ are produced, respectively, then to produce $Y^{i,c}_{odd}$ and $Y^{j,c}_{odd}$ they are changed back to frequency domain. Contrasted withY^i_{odd} and Y^j_{odd}, $Y^{i,c}_{odd}$ and $Y^{j,c}_{odd}$ have a similar symbol on thesubcarriers that are odd, however the noise due to clippingshows up on the subcarriers that are even. In this way, Y^{cn}_{even} is obtained by deducting $Y^{i,c}_{odd}$ from Y^i and Y^{cp}_{even} is obtainedby subtracting $Y^{j,c}_{odd}$ from Y^j , which are as follows:

$$Y^{cn}_{even} = Y^i - Y^{i,c}_{odd} = 0.5(|X_{even}| + X_{even}) \quad (24)$$

$$Y^{cp}_{even} = Y^i - Y^{j,c}_{odd} = 0.5(|X_{even}| - X_{even}) \quad (25)$$

We take note of that $x_{even} = x^{cn}_{even} - x^{cp}_{even}$; subsequently, Y_{even} can be assessed as follows:

$$Y_{even} = Y^{cn}_{even} - Y^{cp}_{even} \quad (26)$$

III. Analysis of the Signal for ASCO-OFDM andModified ASDCO-OFDM

Under this segment, we initially examine the average Bitrate/Normalized Bandwidths of modified ASDCO-OFDM andASCO-OFDM. We can acquire the power(optical) per bit forboth systems through figuring the data bit and the transmittedsignal's overall optical power.

A. Analyzing the average Bitrate/Normalized Bandwidths

Complex symbols of length $2N - 2$ are modulated for bothASCO-OFDM and modified ASDCO-OFDM while the lengthof the spectrum is 2N;subsequently,for both the scheme$N/(N-1)$ represent the normalized bandwidth. For ASCO-OFDMand modified ASDCO-OFDM,all data conveyed isisolated into two continuous sub-blocks $x^i_{ASCO/ASDCO}$and$x^j_{ASCO/ASDCO}$,for the even subcarriers. In this way, the datain x_{even} is conveyed by the even elements is reduced to halfi.e.$x^i_{ASCO/ASDCO}$and$x^j_{ASCO/ASDCO}$ of one sub-block. As aresult, for both ASCO-OFDM and modified ASDCO-OFDM, for one sub-block the average bit rate can be achieved by:

$$R_{b,ASDCO-OFDM} = (0.5\log_2 C_{SCO} + \log_2 C_{ACO})/2 \quad (27)$$

and $((0.5\log_2 C_{SCO} + \log_2 C_{ACO})/2)/(N/(N-1))$ representthe normal bit rate/normalized bandwidth , where C_{ACO} andC_{SCO} are correspondingly characterized. In ASCO-OFDMand modified ASDCO-OFDM for both even and odd subcarrierswe apply different constellation, in Table I for both themodified schemes we look into the average Bitrate/NormalizedBandwidths.

TABLE I. ASDCO-OFDM Average Bitrate/Normalized Bandwidths with Different Constellation Combinations

Symbol	ASDCO-OFDM constellation size	B.R./N. B
P	Even subcarriers 4 QAM Odd subcarriers 4 QAM	1.5

Q	Even subcarriers 4 QAM Odd subcarriers 16 QAM	2.5
R	Even subcarriers 4 QAM Odd subcarriers 64 QAM	3.5
S	Even subcarriers 16 QAM Odd subcarriers 16 QAM	3
T	Even subcarriers 16 QAM Odd subcarriers 64 QAM	4
U	Even subcarriers 64 QAM Odd subcarriers 64 QAM	4.5

B. Analyzing the Optical power/bit

So as to discover the precise $P_{opt/bit}$, for ASCO andASDCO-OFDM, in the transmitted optical signal we add eachand every value, without the addition of cyclic prefix.

Two back to back sub-blocks are present in transmittedoptical signal i.e.$x^{i}_{ASCO/ASDCO}$ and$x^{j}_{ASCO/ASDCO}$, forboth ASCO and ASDCO OFDM techniques. Consequently,for both the transmitted ASCO and ASDCO OFDM signalthe aggregate optical power is given by:

$$P_{opt,ASDCO} = \sum_{n=0}^{2N-1} x^{i}_{ASDCO}(n) + x^{j}_{ASDCO}(n) \qquad (28)$$

The input block comprising of symbols that are complex for ASDCO-OFDM of length $3N/2-1$ are isolated in three sections. To produce $x^{j,c}_{odd}$ and $x^{i,c}_{odd}$ modulation of complex symbols contained in two blocks of length $N/2$are done by ACO-OFDM. To obtain x^{cn}_{even} and x^{cp}_{even}, modulation of complex symbols contained in one block of length $N/2-1$ is done by SCO-OFDM. Hence, for ASCO-OFDM and modified ASDCO-OFDM the total transmitted bits are given by:

$$T_{b,ASDCO-OFDM} = \left(\frac{N}{2}-1\right)\log_2 C_{SCO} + 2\left(\frac{N}{2}\right)\log_2 C_{ACO} (29)$$

TABLE II. COMPARISON OF POWER(OPTICAL) PER BIT OF ASCO-OFDMAND ASDCO-OFDM

Constellation Size	**ASCO-OFDM**	**ASDCO-OFDM**
Odd subcarriers 4-QAM Even subcarriers 4-QAM	2.2	.66
Odd subcarriers 16-QAM Even subcarriers 4-QAM	2.1	1.511
Odd subcarriers 64-QAM Even subcarriers 4-QAM	2.5	1.8
Odd subcarriers 16-QAM Even subcarriers 16-QAM	2.4	1.531
Odd subcarriers 64-QAM Even subcarriers 16-QAM	2.7	1.642
Odd subcarriers 64-QAM Even subcarriers 64-QAM	3.2	1.611

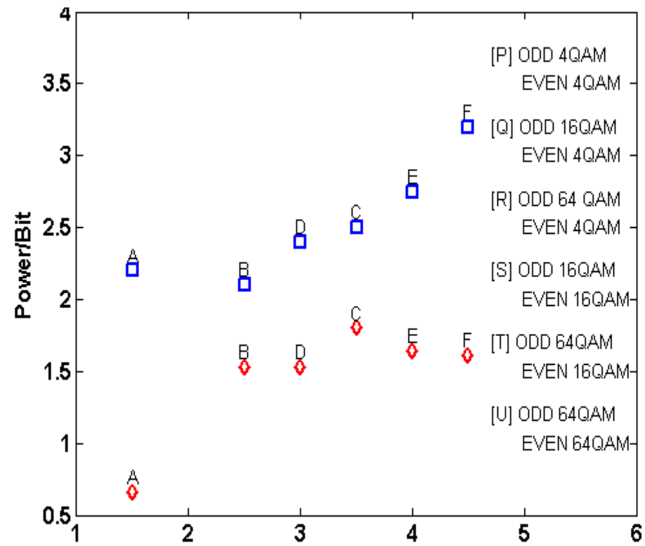

Fig. 3. Bit rate/Normalized Bandwidth versus

IV. SIMULATION RESULTS

Comparison of the outcomes of $P_{opt/bit}$ for ASCO andASDCO OFDM are shown in Figure 3. Combination ofsix constellation represented by P to U, which are given inTable II. They are operated on even and odd subcarriers oftwo systems. ASCO-OFDM is symbolized by squares, andmodified ASDCO-OFDM is symbolized by rhombus. 64 QAMsymbols are symbolized by rhombus F and square F on allsubcarriers for modified ASDCO-OFDM and ASCOOFDM respectively.

On the off chance that modulation of the two frameworksare done by a similar constellation combination. Bitrate/normalized bandwidth of ASDCO-OFDM and ASCO-OFDMsare comparable.

On the other hand, requirement ofoptical power in modified ASDCO-OFDM is less than ASCO-OFDMfor each bit because of mean DC-bias subtractionfrom the Hermitian symmetric signal after the modulation.Despite the similarity in the Bitrate/Normalized Bandwidthof ASDCO-OFDM, the efficiency of the optical power forgrouping of dissimilar constellation is more compared to thatof ASCO-OFDM. As a result, in terms of optical powerof ASCO-OFDM is less effective in comparison with modifiedASDCO-OFDM.

The SER comparison is illustrated in Figure 4 for ASCO-OFDMand modified ASDCO-OFDM when combination ofdifferent constellations areapplied to represent similar combinationof constellation we use the similar marker. ASCO-OFDMis denoted by a dashed curve whereas a solid curvedenotes modified ASDCO-OFDM. Likewise, some particularcomparison pairs ought to be explained. Looking at the dashed triangle curve to the solid rhombus curve, 16-4 QAM ASCO-OFDMhave similar symbol error rate performance as modifiedASDCO-OFDM with 16-16QAM, and the requirementof optical power for both the combination is more or lesssimilar as depicted in Figure 4.While accomplishing a similarBitrate/Normalized Bandwidth, ASDCO-OFDM beats ASCO-OFDMas far as the performance of SER and efficiency ofoptical is concerned, which is revealed for all constellationcombination. Lastly, we bring up that modified ASDCO-OFDM(solid curve) is superior to ASCO-OFDM (dashedcurve) in all view points since the performance of SER isbetter and the optical power per bit requirement is less.

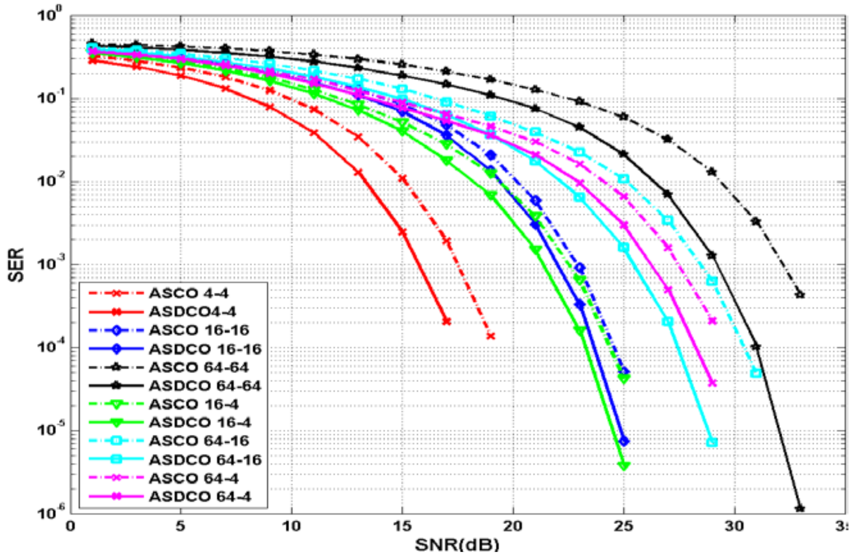

Fig. 4. Symbol error rate versus signal to noise ratio

V. Conclusion

In this paper, we suggest an improved methodology knownas ASDCO-OFDM which can be utilized in wireless opticalsystems. Mean dc-bias of subcarriers is subtracted fromthe Hermitian symmetric signal for power efficiency. Oddsubcarriers are modulated using ACO-OFDM whereas evensubcarriers are modulated using SCO-OFDM which is a novelmodulation scheme. To convey the symbols in case of SCO-OFDM,we efficaciously implement two successive sub-blockson the subcarriers that are even and is deprived of DC bias.Meanwhile the even part and the odd part of two frameworkscan be discretely distinguished,diverse combinations of constellationare taken into record for modulation. Contrastedwith ASCO-OFDM, our modified model exhibits excellentperformance in case of SER and the optical power requirementper bit is less. Thus, we can say that modified ASDCO-OFDMis an appealing decision for wireless optical system.

References

[1] Armstrong, Jean. "OFDM for optical communications."Journal of Lightwave Technology 27.3 (2009): 189-204.

[2] Acolatse, Kodzovi, Yeheskel Bar-Ness, and Sarah Kate Wilson. "Novel techniques of single-carrier frequency domain equalization for optical wireless communications." EURASIP Journal on Advances in Signal Processing(2011).

[3] Acolatse, Kodzovi, Yeheskel Bar-Ness, and Sarah Kate Wilson. "SCFDE with space-time coding for IM/DD optical wireless communication." IEEE Wireless Communications and Networking Conference (WCNC), (2011).

[4] Ghassemlooy, Zabih, W. Popoola, and S. Rajbhandari."Optical wireless communications: system and channel modelling with MATLAB." Boca Raton, FL: Taylor & Francis, (2013).

[5] Y Sun. "Bandwidth-efficient wireless OFDM". IEEE J.Sel. Areas Commun. 19(11), 22672278 (2001).

[6] Armstrong, Jean, et al. "Spc07-4: Performance of asymmetrically clipped optical ofdm in awgn for an intensity modulated direct detection system." Global Telecommunications conference GLOBECOM'06.IEEE,(2006).

[7] Wilson, Sarah Kate, and Jean Armstrong. "Digital modulation techniques for optical asymmetrically-clipped OFDM."IEEE Wireless Communications and Networking Conference, 2008. WCNC 2008,(2008).

[8] Gonzlez, Oswaldo, et al. "Adaptive OFDM system for communications over the indoor wireless optical channel." IEEE Proceedings-Optoelectronics 153.4 (2006): 139-144.

[9] Dissanayake, Sarangi Devasmitha, and Jean Armstrong." Comparison of aco-ofdm, dco-ofdm and ado-ofdm in im/dd systems." Journal of Lightwave Technology 31.7 (2013): 1063-1072.

[10] Elgala, Hany, and Thomas DC Little. "P-OFDM:spectrally efficient unipolar OFDM." Optical Fiber Communication Conference. Optical Society of America, (2014).

[11] Ranjha, Bilal, and Mohsen Kavehrad. "Hybrid asymmetrically clipped OFDM-based IM/DD optical wireless system." Journal of Optical Communications and Networking 6.4 (2014): 387-396.

[12] Armstrong, Jean, and Brendon JC Schmidt. "Comparison of asymmetrically clipped optical OFDM and DC-biased optical OFDM in AWGN." IEEE Communications Letters 12.5 (2008).

[13] Armstrong, Jean, and A. J. Lowery. "Power efficient optical OFDM." Electronics Letters 42.6 (2006): 370-372.

[14] Elgala, Hany, Raed Mesleh, and Harald Haas. "Indoor broadcasting via white LEDs and OFDM." IEEE Transactions on Consumer Electronics 55.3 (2009).

[15] Elgala, Hany, Raed Mesleh, and Harald Haas. "A study of LED nonlinearity effects on optical wireless transmission using OFDM." Wireless and Optical Communications Networks, 2009. WOCN'09. IFIP International Conference on. IEEE, (2009).

[16] Wu, Nan, and Yeheskel Bar-Ness, A novel powerefficient scheme asymmetrically and symmetrically clipping optical (ASCO)-OFDM for IM/DD optical systems. EURASIP Journal on Advances in Signal Processing (2015).

[17] Wilson, Sarah Kate, and Jean Armstrong. "Transmitter and receiver methods for improving asymmetricallyclipped optical OFDM." IEEE Transactions on Wireless Communications 8.9 (2009).

[18] Wu, N., and Y. Bar-Ness. "An improved performance decoding technique for asymmetrically and symmetrically clipped optical (ASCO)-OFDM." Appear in Asilomar Conference on Signals, Systems, and Computers. (2014).

[19] Katz, Eyal, Amir Laufer, and Yeheskel Bar-Ness. "A new improved-performance decoding technique for Asymmetrically-Clipped Optical-OFDM." Information Sciences and Systems (CISS), 2012 46th Annual Conference on. IEEE, (2012).

[20] Barros, Daniel JF, Sarah K. Wilson, and Joseph M. Kahn. "Comparison of orthogonal frequency-division multiplexing and pulse-amplitude modulation in indoor optical wireless links." IEEE Transactions on Communications 60.1 (2012): 153-16