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Asymmetrically And Symmetrically Clipping Optical OFDM Channel Capacity In Wireless Communication

Sreya Manoj, Vishnu Prabha N Kaimal

ECE dept, nehru college of engineering, kerala, india,

Abstract*— In this paper, we compare the asymmetrically and symmetrically clipping optical (ASCO)-OFDM and asymmetrically clipping optical (ACO)-OFDM in two dimensional (2D) intensity modulation direct detection (IM/DD) optical wireless communication (OWC). In 2D ASCO-OFDM the asymmetrically clipping optical (ACO)-OFDM symbols and the symmetrically clipping optical (SCO-OFDM symbols are mapped into odd columns of transmitted matrices respectively. In 2D asymmetrically clipped optical scheme only the asymmetrically clipped optical (ACO) symbols in the odd columns are modulated. In IM/DD optical wireless systems, the information data is modulated into the intensity of optical carriers. Thus only real and non-negative values can be used to realize the intensity modulation. Then we apply an inverse fast fourier transform (IFFT) to convert block of Hermitian symmetry complex symbols. For the non-negative requirement of the transmitted optical signals, the symbol clipping is performed The spectral efficiency of 2D ASCO-OFDM is twice as much as that of 2D ACO-OFDM. Comparing with different constellation, 2D ASCO-OFDM reduces the Peak-to-Average power ratio (PAPR) by 2dB. Moreover the SER performance of 2D ASCO and 2D ACO are compared for same bit rate, and it exhibit better performance for 2D ASCO.

***Index Terms*—ACO-OFDM, ASCO-OFDM, OWC, PAPR, SCO-OFDM .**

I. INTRODUCTION

Optical wireless communication (OWC) has been widely studied in recent decade because it can be an effective alternative to radio frequency communication (RFC) for indoor wireless applications. Intensity modulation and direct detection (IM/DD) can be simply implemented into optical wireless systems. The information stream is modulated into the intensity of optical carriers, and the optical signals are transmitted by LED emitters. The intensity variation of optical signal will be detected by a photodiode and the received optical signals are converted to electrical signals for decoding. However, most experiments are developed over single-input single-output (SISO) systems. In the meantime, the two dimensional (2D) optical wireless system, which is a form of multiple-input multiple-output (MIMO), also has been studied and they are getting more and more attentions.

OFDM is capable of combating the inter symbol interference (ISI) caused by multipath transmission. As we adopt IM/DD to realize the transmission and reception, the optical signals must be real and non-negative. In order to obtain real signals, blocks of complex symbols in the frequency domain must be constraint to Hermitian symmetry. Then two modulation schemes, asymmetrically clipping optical (ACO)-OFDM and DC biased optical (DCO)-OFDM, have been adopted to make the real signals non-negative in one dimensional (1D) optical systems. Also, these two techniques have been investigated in 2D optical wireless systems. By adding an appropriate DC bias to remove the negative values, 2D DCO-OFDM has been described. However, it has been shown that DCO-OFDM is not optical power efficient, and the performance highly depends on the DC bias level in 1D OWC. ACO-OFDM is much more optical power efficient than DCO-OFDM, but it requires twice bandwidth as much as DCO-OFDM does. Additionally, the ACO-OFDM transmitted signals inherently have a large PAPR.

ASCO-OFDM is a novel clipping OFDM modulation scheme. We first map ACO-OFDM symbols onto the odd subcarriers, and SCO-OFDM symbols are mapped onto the even subcarriers. The property of SCO-OFDM has been derived. A transmitted ASCO-OFDM signal is the sum of an ACO-OFDM signal and a SCO-OFDM signal. Since the clipping noises fall onto the even subcarriers without distorting the odd subcarriers, we can directly detect the symbols on the odd subcarriers to recover ACO-OFDM symbols. After subtracting the estimated ACO-OFDM clipping noise from even subcarriers, we finally obtain the SCO-OFDM symbols. This scheme, ASCO-OFDM, not only improves the bandwidth

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efficiency but also reduces the PAPR of transmitted optical signals. The probability density function (PDF) of ASCO-OFDM signals, which is the convolution of the PDFs of ACO-OFDM signals and SCO-OFDM signals. Mathematically,

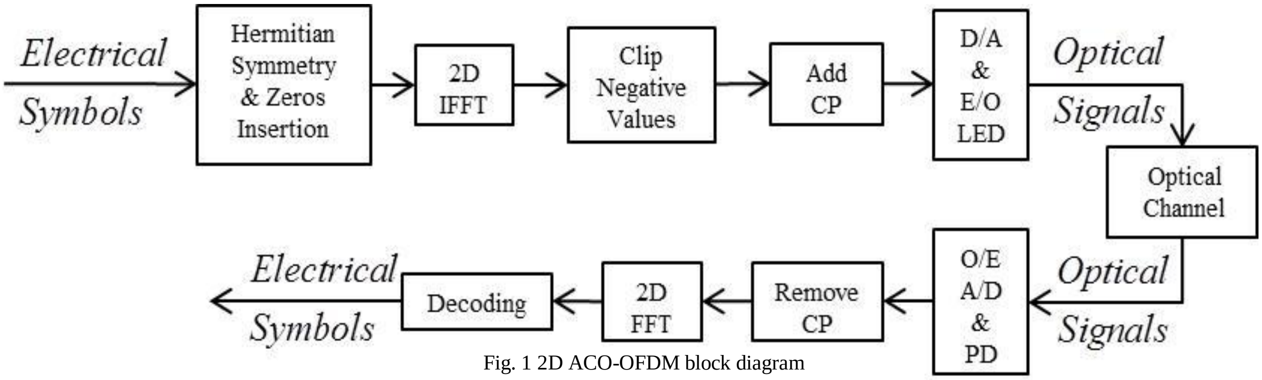

Fig. 1 2D ACO-OFDM block diagram

these two signals follow the same distribution, called clipped Gaussian distribution. We found that the mean of an ASCO-OFDM signal is twice as large as that of an ACO-OFDM signal while the peak value is not doubled. In this paper, we apply ASCO-OFDM into 2D optical systems to improve the performances in terms of the bandwidth efficiency, PAPR and SER.

II. SYSTEM MODEL AND ASSUMPTIONS

A. 2D ACO-OFDM

The block diagram of a 2D ACO-OFDM system is shown in fig.1. Blocks of electrical symbols drawn from constellations, such as 4-QAM, 16-QAM, and 64-QAM, are input to the system. Conventionally, the symbols are mapped into a signal vector in 1D optical wireless system. In the 2D case, the input

symbols are mapped into N1xN2 signal matrix as follows:

$$S_{N1\times N2} = \begin{bmatrix} S_{00} & S_{01} & . & . & S_{0,N2-1} \\ S_{10} & S_{11} & . & . & S_{1,N2-1} \\ & . & & & \\ . & . & . & . & . \\ & . & & & \\ . & . & . & . & . \\ S_{N1-1,0} & S_{N2-1,1} & . & . & S_{N1-1,N2-1} \end{bmatrix}$$

where N1 and N2 are even numbers. This matrix is taken by a 2D IFFT to transform it into the time domain to yield s_{N1XN2}

$$s_{N1XN2} = \begin{bmatrix} s_{01} & s_{01} & . & . & s_{0,N2-1} \\ s_{10} & s_{11} & . & . & s_{1,N2-1} \\ . & . & . & . & \\ . & . & . & . & \\ s_{N1-1,0} & s_{N2-1,1} & . & . & s_{N1-1,N2-1} \end{bmatrix}$$

In this paper, the upper cases represent frequency domain symbols and the lower cases represent time domain signals. In order to ensure each value in the matrix real, the elements in matrix S must have 2D Hermitian symmetry constraint, which is defined as follows:

$$S(k1, k2) = S^*(N1 - 1 - k1, N2 - 1 - k2)$$

The elements $S_{0,N}$ in the first row and the elements $S_{0,M}$ in the first column are set to be zeroes. Another element $S_{N1/2,N2/2}$, which is corresponding to $S_{0,0}$, has to be zero as well. Then, symbols are put onto the odd columns (odd rows) and zeroes are set to the rest even columns (even rows). Since the transmitted optical signals are 2D frames, we can use either odd columns or odd rows to carry symbols. If symbols are on the odd columns, the elements in s have the property that

$$s_{m,n} = -s_{m,N2/2+n}\,.$$

Similarly, if symbols are on the odd rows, the elements in s have the property that

$$s_{m,n} = -s_{N1/2+m,n}\,.$$

In order to obtain the non-negative signals, the negative values in $s_{N1\times N2}$ should be clipped to zeroes because $s_{m,n}$ is real but bipolar. A frame of transmitted signal is given by

$$x_{m,n} = 0.5\left(s_{m,n} + \left|s_{m,n}\right|\right)$$

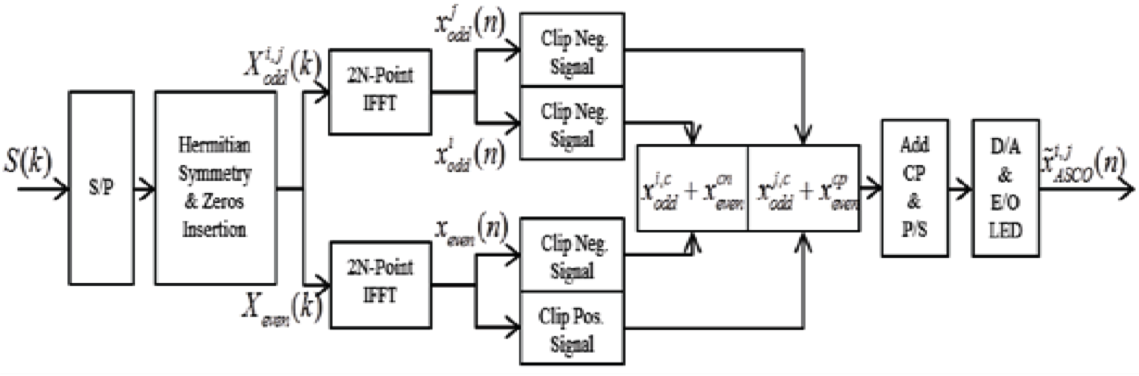

Fig. 2 2D ASCO-OFDM transmitter block diagram

In 2D optical signal transmission, the cyclic prefix (CP) is added to both columns and rows of $x_{m,n}$ to mitigate the effect of misalignment, which is denoted by $\widehat{x}_{m,n}$. The intensity of each pixel in the transmitted frame is modulated by a corresponding element in $\widehat{x}_{m,n}$. In this paper, we assume that a short range optical path as a flat fading channel so that $\left|h_{m,n}\right|$ is the same for any coordinate point. The noise $w_{m,n}$ consists of shot noise and thermal noise, which can be approximated as additive white Gaussian noise (AWGN). After removing the CP and transforming the arrival signal into the frequency domain,

A. 2D ASCO-OFDM TRANSMITTER

In this subsection, we describe the block diagram of 2D ASCO-OFDM optical wireless system, which is presented in Fig. 2. The input symbols are parsed into three parts, then they are mapped into three N1 × N2.

matrices, X^{i}_{odd} , X^{j}_{odd} and X_{even} . The symbols are put onto the odd columns and the even columns respectively. Which are shown as follows:

$$X_{odd} = \begin{bmatrix} 0 & 0 & 0 & . & . & . & 0 & 0 \\ 0 & S_{11} & 0 & . & . & . & 0 & S_{1,N2-1} \\ 0 & S_{21} & 0 & . & . & . & 0 & S_{2,N2-1} \\ . & . & . & . & . & . & . & . \\ 0 & & 0 & . & . & . & 0 & S_{N1-1,N2-1} \end{bmatrix}$$

$$X_{even} = \begin{bmatrix} 0 & 0 & 0 & . & . & . & 0 & 0 \\ 0 & 0 & S_{13} & . & . & . & S_{1,N2-1} & 0 \\ 0 & 0 & S_{23} & . & . & . & S_{2,N2-2} & 0 \\ 0 & 0 & . & . & . & . & . & 0 \\ 0 & 0 & S_{N1-1,3} & . & . & . & S_{N1-2,N2-2} & 0 \end{bmatrix}$$

i and j represent two consecutive time slots. X^{i}_{odd} , X^{j}_{odd} and X_{even} are constraint to 2D Hermitian symmetry, so they can be transformed by a 2D IFFT to obtain real but bipolar matrices x^{i}_{odd} , x^{j}_{odd} and x_{even} . In order to make these matrices real and unipolar, all the negative elements of xi odd and x^{i}_{odd}

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

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

They are transmitted in two consecutive sub-blocks, i and j. If an OFDM signal is converted from only even columns, such as X_{even} , the elements in the matrix x_{even} have the property that

$s_{m,n} = s_{m,N2/2+n}$.

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Thus, half of the information in x_{even} is lost due to clipping. In order to make all the information in x_{even} transmitted, we generate two different clipped signal matrices for x_{even}. Clip the negative elements to zeroes and keep the positive elements, and clip the positive elements to zeroes and turn the sign of negative elements to positive. Then, we have x^{cn}_{even} and x^{cp}_{even}, which are respectively given by

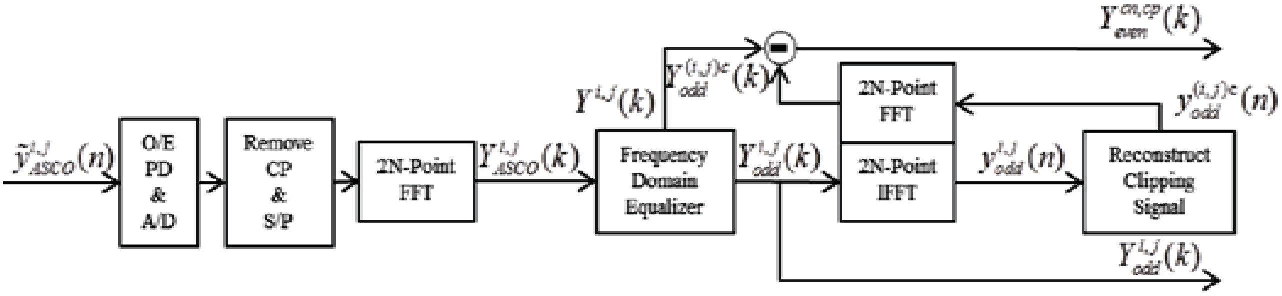

Fig. 3 2D ASCO-OFDM receiver

$$x^{i}_{ASCO} = x^{i,c}_{odd} + x^{cn}_{even}$$

$$x^{j}_{ASCO} = x^{j,c}_{odd} + x^{cp}_{even}$$

The transmitted signal x^{i}_{ASCO} and x^{j}_{ASCO} with cyclic prefix (CP) is denoted as $\tilde{x}^{i}_{ASCO}$ and $\tilde{x}^{j}_{ASCO}$. And they are transmitted through the optical channel.

B. 2D ASCO-OFDM RECEIVER

The ASCO-OFDM receiver is shown in Fig 3. Thus, a transmitted ASCO-OFDM signal consists of two parts of signals, x^{i}_{ASCO} and x^{j}_{ASCO}. CPs are attached to x^{i}_{ASCO} and x^{j}_{ASCO} to mitigate the effect of misalignment, which are denoted by $\tilde{x}^{i}_{ASCO}$ and $\tilde{x}^{j}_{ASCO}$. After removing the CP, the arrival signals, y^{i}_{ASCO} and y^{j}_{ASCO}, can be respectively given by

$$\begin{aligned} y^{i}_{ASCO} &= x^{i}_{ASCO}(n) \otimes h(n) + w^{i}(n) \\ &= (x^{i,c}_{odd} + x^{cn}_{even}) \otimes h(n) + w^{i}(n) \\ y^{j}_{ASCO} &= x^{j}_{ASCO}(n) \otimes h(n) + w^{j}(n) \\ &= (x^{j,c}_{odd} + x^{cp}_{even}) \otimes h(n) + w^{j}(n) \end{aligned}$$

After equalization, in the absence of noise, the symbols located on the odd columns and even columns are respectively shown as,

$$Y^{i}_{odd} = 0.5\hat{x}^{i}_{odd}$$

$$Y^{i}_{even} = 0.5\left(\left|\hat{x}^{i}_{odd}\right| + \hat{x}_{even} + \left|\hat{x}_{even}\right|\right)$$

$$Y^{j}_{odd} = 0.5\hat{x}^{j}_{odd}$$

$$Y^{j}_{even} = 0.5\left(\left|\hat{x}^{j}_{odd}\right| - \hat{x}_{even} + \left|\hat{x}_{even}\right|\right)$$

III. CHANNEL CAPACITY CALCULATION

Channel capacity of OFDM is defined as the maximum mutual information between input and output of the channel. In optical wireless communication, the information is The optical channel is considered as a flat channel, thus we assume $h(n)$=1. The combination of all noise $w(n)$ is approximately modeled as additive white Gaussian noise. In order to accurately calculate capacity, cyclic prefix is not considered. Then the channel capacity is given by

$$C = \max I(x, y)$$

Where $I(x, y)$ is the mutual information, which is given by

$$\begin{aligned} I(x, y) &= h(y) - h(w) \\ &= -\int_{\infty}^{-\infty} f(y)\log_2 f(y)dy - 0.5\log_2 2\pi 2\sigma_n^2 \end{aligned}$$

$h(y)$ and $h(w)$ are the differential entropy of received signals and Gaussian noise respectively. $f(y)$ is the distribution of transmitted signals plus noise. To calculate the channel capacity of ASCO-OFDM, we derive the distribution of y^{i}_{ASCO} by convolution the PDF of x^{i}_{ASCO} and Gaussian distribution,

$$f_{y^{i}_{ASCO}}(y) = \int_{\infty}^{-\infty} f_{x^{i}_{ASCO}}(\chi) f(y-\chi)d\chi$$

$$= \frac{\sqrt{2}}{4\pi\sqrt{D+\sigma_n^2}} \exp\left(\frac{-y^2}{2(D+\sigma_n^2} \right)$$

$$. \int_{\frac{-y\sqrt{D}}{\sigma_n\sqrt{2\left(D+\sigma_n^2\right)}}}^{\infty} \exp(-m^2)$$

$$.\left[erf\left(\frac{\sigma_A \sigma_n m}{\sigma_S\sqrt{D+\sigma_n^2}} + \frac{y\sigma_A\sqrt{2D}}{2\sigma_S(D+\sigma_n^2)} \right)\right]$$

$$+ erf(\frac{\sigma_s \sigma_n m}{\sigma_A\sqrt{D+\sigma_n^2}} + \frac{y\sigma_S\sqrt{2D}}{2\sigma_A(D+\sigma_n^2)})dm$$

$$+ \frac{1}{4\sqrt{2\pi(\sigma_A^2+\sigma_n^2)}} \exp(\frac{-y^2}{2\sigma_A^2+\sigma_n^2})$$

$$.\{1 - Q(\frac{-y\sigma_A}{\sigma_n\sqrt{2(\sigma_A^2+\sigma_n^2)}})]$$

$$+ \frac{1}{4\sqrt{2\pi(\sigma_S^2+\sigma_n^2}} \exp(\frac{-y^2}{2(\sigma_S^2+\sigma_n^2)})$$

$$.[1 - Q(\frac{-y\sigma_S}{\sigma_n\sqrt{2(\sigma_S^2+\sigma_n^2)}})]$$

$$+ \frac{1}{4\sqrt{2\pi\sigma_n}} \exp(\frac{-y^2}{2\sigma_n^2})$$

IV. SIMULATION RESULT

In this section, we compare the performances between 2D ASCO-OFDM and 2D ACO-OFDM in terms of Peak-to-average power ratio (PAPR), average bit rate, and symbol error rate (SER). The average optical power of transmitted signals is defined as E{x(n_1, n_2)}.

A. Peak-to-average Power Ratio (PAPR)

The intensity of each pixel is plotted against the 2D coordinate n_1 and n_2. The intensity of each pixel is plotted against the 2D coordinate n_1 and n_2. The original symbols are drawn from 4QAM and they are converted by a 2D IFFT into the time domain. Since the output of 2D IFFT follows Gaussian distribution with mean zero and variance σ, the PDF of an ACO- OFDM signal follows clipped Gaussian distribution with mean σ/2π and variance $\sigma^2/2$ The PAPR performances of 2D ASCO-OFDM and 2D ACO-OFDM with different constellations are compared in Fig 5. The red solid curves represent the PAPR of ACO-OFDM and the blue dashed curves represent the PAPR of ASCO-OFDM. We use circle, square and star to represent the ACO-OFDM signals modulated by 4QAM, 16QAM, and 64QAM respectively. For ASCO-OFDM, since ACO-OFDM signals and SCO-OFDM signals are independent, they can be modulated by different constellations. In order to fairly compare the PAPR between two transmitted signals, the same constellation is applied onto odd and even subcarriers for 2D ASCO-OFDM. We notice that the PAPR of 2D ASC OFDM is 2dB less than that of 2D ACO-OFDM.

B. Symbol Error Rate(SER)

The symbol error rate(SER) vs. SNR for 2D ASCO-OFDM and 2D ACO-OFDM in shown in Fig.8. The solid curve represent 2D ACO-OFDM system and the dahed curves represent 2D ASCO-OFDM system.

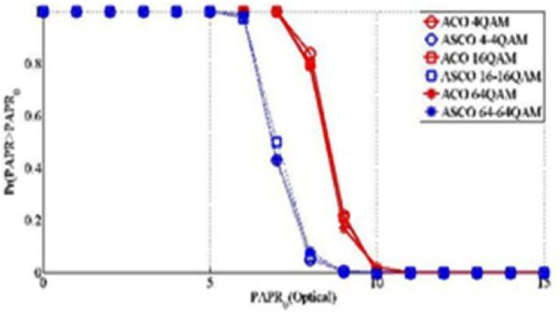

Fig. 4 PAPR (OPTICAL POWER) Comparisons Of 2D ASCO-OFDM And 2D ACO-OFDM

C. Channel Capacity

The channel capacity between ASCO-OFDM and ACO-OFDM are compared. ASCO_OFDM can be used from 0dB SNR case while ACO_OFDM with certain constellation combinations does not work in small SNR cases.

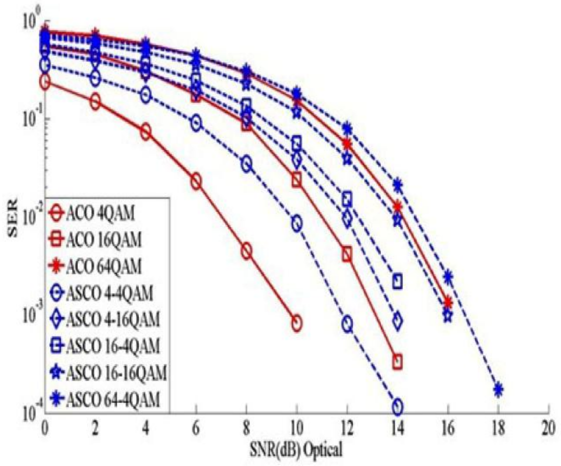

Fig. 5. Ser Comparisons Of 2D ASCO-OFDM And 2D ACO-OFDM With Different Constellation Combination.

V. CONCLUSION

Thus in this paper, the ASCO-OFDM scheme is extend into 2D IM/DD optical wireless systems. It improves the spectral efficiency because both odd columns and even columns are used to carry symbols while only odd columns are modulated in the 2D ACO-OFDM scheme. Since the odd columns and the even columns of 2D ASCO-OFDM can be separately detected, different constellation combinations are taken for modulation. By applying smaller constellations, 2D ASCO-OFDM can achieve better SER performance than 2D ACO-OFDM in the same bit rate case. Moreover, the 2D ASCO-OFDM is more power efficient because its PAPR performance is 2dB lower than that of 2D ACO-OFDM. Consequently, ASCO-OFDM is an attractive choice for 2D IM/DD optical wireless systems. The channel capacity is calculated. The channel capacity improvement can be considered as the future scope and also both frequency domain equalization and time domain equalization can be considered to reduce the interference.

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