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A Novel 2D ASCO-OFDM Scheme In Wireless Communication

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Abstract
The asymmetrically and symmetrically clipping optical OFDM (ASCO-OFDM) in two dimensional (2D) intensity modulation direct detection (IM/DD) is a novel technique in optical wireless communication (OWC). In 2D ASCO-OFDM the asymmetrically clipping optical OFDM (ACO-OFDM) symbols and the symmetrically clipping optical (SCO)-OFDM symbols are mapped into odd columns of transmitted matrices respectively. The spectral efficiency of 2D ASCO-OFDM is twice as much as that of 2D ACO-OFDM and other conventional 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 have high bit rate, and it exhibit better performance.
Keywords- *ASCO-OFDM, ACO-OFDM, SCO-OFDM, Optical Wireless Communication, PAPR.*

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 in [8]. 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 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, 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.

System Model

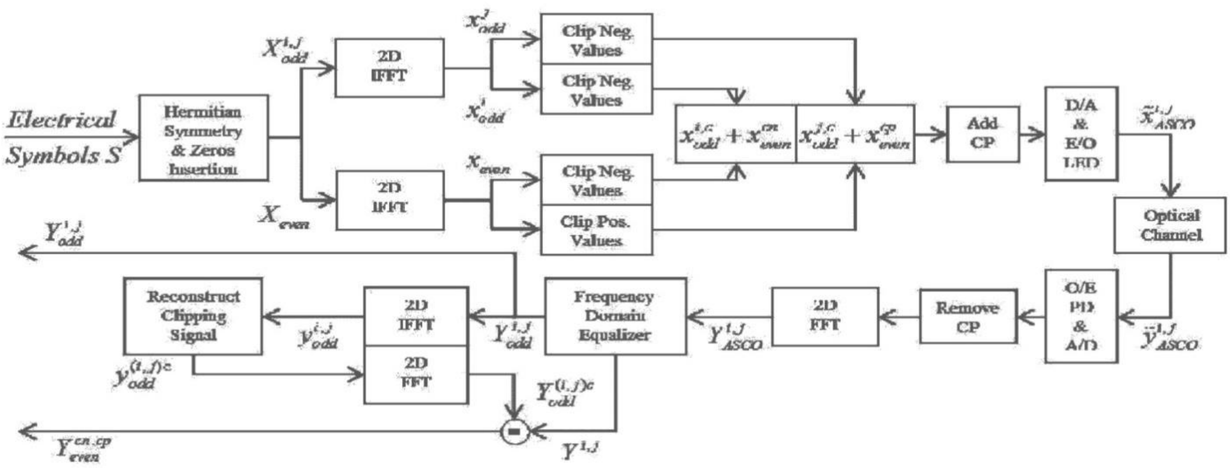

Fig 1. 2D ASCO-OFDM

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} have to be clipped to zeroes to yield $x^{i,c}_{odd}$ and $x^{j,c}_{odd}$. We use c to indicate the clipped signal in this paper. $x_{odd}^{i,c}$ and $x_{odd}^{j,c}$ are two independent signals, which are given by

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

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

They are transmitted in two consecutive sub-blocks, i and j. If an OFDM signal is converted from only even columns, such a X_{even}, the elements in the matrix x_{even} have the property that $s_{m,n} = s_{m,N2/2+n}$. 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; clip the positive elements to zeroes and turn the sign of negative elements to positive. Then, we have x_{even}^{cn} and x_{even}^{cp}, which are respectively given by

$$x_{even}^{cn} = 0.5\left(x_{even} + \left|x_{even}\right|\right)$$

$$x_{even}^{cp} = 0.5\left(-x_{even} + \left|x_{even}\right|\right)$$

These two signal matrices, x_{even}^{cn} and x_{even}^{cp} will be added to $x_{odd}^{i,c}$ and $x_{odd}^{j,c}$ respectively as follows:

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

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

The transmitted signal x_{ASCO}^{i} and x_{ASCO}^{j} with cyclic prefix (CP) is denoted as $\tilde{x}_{ASCO}^{i}$ and $\tilde{x}_{ASCO}^{j}$. And they are transmitted through the optical channel. The ASCO-OFDM receiver is shown in figure 3. Thus, a transmitted ASCO-OFDM signal consists of two parts of signals, x_{ASCO}^{i} and x_{ASCO}^{j} . CPs are attached to x_{ASCO}^{i} and x_{ASCO}^{j} to mitigate the effect of misalignment, which are denoted by $\tilde{x}_{ASCO}^{i}$ and $\tilde{x}_{ASCO}^{j}$. After removing the CP, the arrival signals, y_{ASCO}^{i} and y_{ASCO}^{j} , can be respectively given by

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

$$= (x_{odd}^{i,c} + x_{even}^{cn}) \otimes h(n) + w^{i}(n)$$

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

$$= (x_{odd}^{j,c} + x_{even}^{cp}) \otimes h(n) + w^{j}(n)$$

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

$$Y_{odd}^{i} = 0.5\widehat{x}_{odd}^{i}$$

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

$$Y_{odd}^{j} = 0.5\widehat{x}_{odd}^{j}$$

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

Channel Capacity

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 modulated into the intensity of optical carriers, which means the transmitted signal must be real and non-negative. Moreover, the average optical power of the transmitted signal must be limited due to the eye safety regulation.. If the transmitted optical signal is

$$y(n) = x(n) \otimes h(n) + w(n)$$

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

$$I(x, y) = h(y) - h(w)$$

$$= -\int_{\infty}^{-\infty} f(y)\log_2 f(y)dy - 0.5\log_2 2\pi 2\sigma_n^2$$

$h(y)$ 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_{ASCO}^{i} by convolution the PDF of x_{ASCO}^{i} and Gaussian distribution,

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

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

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

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

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

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

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

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

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

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

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 2. 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.

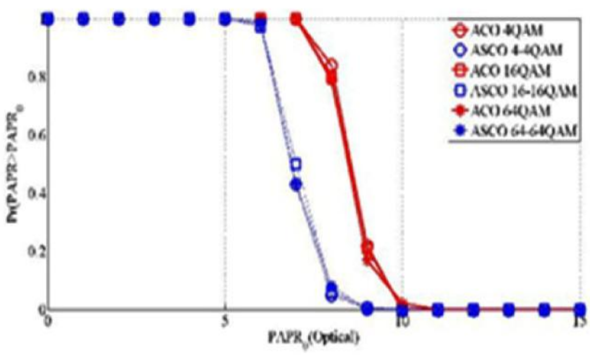

Fig 2. PAPR (OPTICAL POWER) Comparisons Of 2D ASCO-OFDM And 2D ACO-OFDM

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 dashed curves represent 2D ASCO-OFDM system.

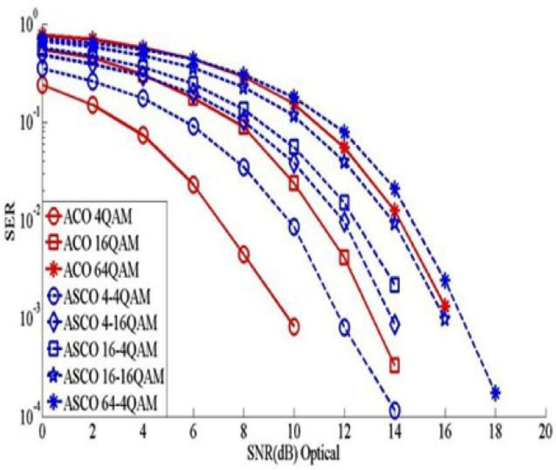

Fig 3. Ser Comparisons Of 2D ASCO-OFDM And 2D ACO-OFDM With Different Constellation Combination

Conclusion

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 improvement can be considered as the future scope.

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