



VIGNETTING REDUCTION IN MIMO OPTICAL WIRELESS SYSTEMS BASED ON AN ENRICHED APPROACH

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ABSTRACT

The vignetting effect reduces the performance of a multi-input multi-output (MIMO) wireless communication system. A gradual fall-off in illumination at the edges of a received image will occur due to the vignetting effect. In order to improve the performance of the pixelated MIMO optical wireless communication system the Non-DC-Biased spatial orthogonal frequency division multiplexing (OFDM) is adopted in the previous work to reduce the effect of vignetting for a pixelated system. However the performance is not up to the mark, so in this paper an improved asymmetrically clipped optical OFDM (IACO-OFDM) is proposed. This analysis shows that the vignetting effect causes attenuation as well as inter-carrier-interference (ICI) in the spatial frequency domain. The simulation result shows that the proposed IACO-OFDM is more robust vignetting than non-dc-biased spatial OFDM (NDC-OFDM), spatial dc biased optical OFDM (SDCO-OFDM) as well as spatial asymmetrically clipped optical OFDM (SACO-OFDM). The mathematical modelling is performed and verified by using the working platform of MATLAB 2014a.

Keywords: Optical OFDM, Spatial modulation, optical wireless communication, MIMO.

I. INTRODUCTION

Optical Wireless Communication (OWC) systems can be used as an alternative to radio frequency systems for short range indoor communications [1]. OWC has several appealing attributes including low cost, high security, unlicensed bandwidth and simplicity [2, 8]. Multiple-input multiple-output (MIMO) OWC systems have the potential to provide higher data rates than their single-input single-output counterparts. However, research has shown that non-imaging MIMO systems provide little diversity gain [9]. The use of imaging [10] rather than non-imaging systems may provide a solution to this problem. One form of MIMO imaging scheme is a pixelated system, where the transmitter transmits a series of pixelated images, and a lens along with an array of photo detecting elements reproduces the images at the receiver. Such systems have the potential to provide high data rate transmission by exploiting spatial diversity at a

large scale [13]. Pixelated MIMO imaging OWC systems have recently gained increasing attention [26]. Proof of concept experiments [12] has demonstrated the feasibility of pixelated MIMO communication. In a pixelated system, the transmitter consists of a 2-D array of optical transmitters which send information encoded as a sequence of images. LCDs and cameras are widely available in many handheld devices including laptops, tablet computers, personal digital assistants, and smart phones; and this creates a great opportunity for pixelated wireless communication [16, 17]. The distance and direction of such links can easily be controlled to preserve communication security and privacy. A possible outdoor application of a pixelated system is in intelligent transportation systems, where LED traffic lights or LED automobile headlights can be used to transmit driver assistance information, which can be decoded by a vehicle mounted with a camera [11, 27]. Some pixelated systems use 'spatial orthogonal frequency division

multiplexing (OFDM)' in the 2-D spatial domain. Compared to systems that encode data directly in the spatial domain, spatial OFDM based systems have the potential to be more resilient to spatial impairments [20]. A cyclic prefix (CP) and a cyclic postfix (CPo) can be appended around the borders of the spatial OFDM transmitted frames, to make them tolerant to linear misalignment within the range of CP and CPo [21]. Spatial asymmetrically clipped optical OFDM (SACO-OFDM) and spatial dc biased optical OFDM (SDCO-OFDM) are two forms of spatial OFDM that have been developed for MIMO imaging communication [14]. In practice, several factors limit the performance of a pixelated system. In previous work, the effects of linear misalignment channel noise and defocus blur [22] have been analysed, and ways to reduce the impact of these impairments discussed.

A pixelated system can also be impaired by 'vignetting' which is the gradual illumination fall-off from the centre to the corners of the received images [31]. This is because, depending on the spatial positions of the IM transmitter elements, there is a variation in the intensity received by the receiver imaging lens. The level of vignetting depends on the geometry of the lens optics, aperture settings, and other optical properties of the receiver [29]. The most prominent factors that contribute to vignetting in this type of imaging system are the 'cosine-fourth radiometric effect', and the blocking of the transmitted light by the receiver elements [28]. In current OWC systems, Light Emitting Diodes (LEDs) are used as transmitters to convert the modulated electrical signal to an optical signal. At the receiver, the optical signal is detected by photodiodes (PDs) and demodulated using digital signal processing techniques [37].

Thus, OWC using incoherent light sources as described can only be realized as an intensity modulation (IM) and direct detection (DD) system [38]. For IM/DD, standard digital modulation techniques are conceived, such as On-Off Keying (OOK), Pulse Position Modulation (PPM) and Pulse Amplitude Modulation (PAM) [39]. For high-speed data transmission, Inter symbol Interference (ISI) becomes an issue and computationally complex equalization techniques are required. In optical communications, OFDM can also be applied in the context of IM/DD systems [40]. Because the IM/DD system can only transmit real-valued signals, Optical OFDM (O-OFDM) needs to produce real-valued symbols. This can be achieved by imposing Hermitian symmetry on the information frame before the inverse fast Fourier transform (IFFT) operation during the signal generation phase. This comes at the expense of half of the spectral efficiency. In general, standard techniques to ensure

positive optical signals, which are required by LEDs, are DC-biased Optical OFDM (DCO-OFDM) and Asymmetrically Clipped Optical OFDM (ACO-OFDM) [41][42]. In the past work M. Rubaiyat H. Mondal *et al.* [46] have investigated the impact of vignetting on a spatial OFDM based pixelated system. They have showed that the vignetting effect introduces attenuation and ICI in the spatial frequency domain, resulting in bit errors. Two techniques were applied to reduce the effect of vignetting. Initially, the SDCO-OFDM approach was applied, which cause the system BER floor. The BER floor caused by means of the ICI contribution from the very large zeroth subcarrier. The BER floor were eliminated by leaving some of the lower unused spatial frequency subcarriers. Subsequently, SACO-OFDM was applied to estimate and equalize vignetting in the spatial domain, which provided improvement in the system BER performance.

Ultimately, it showed that for the parameter values considered equalized SACO-OFDM using 16-QAM has the same data rate as equalized SDCO-OFDM with 4-QAM, but was more optically power efficient. The main objective of a pixelated system is to enhance the image quality reproduced in the output. In case of the optical wireless communication, the pixelated MIMO system is used for the image transmission. In the pixelated MIMO system the spatial orthogonal frequency division multiplexing is applied. The spatial asymmetrically clipped optical OFDM (SACO-OFDM) and spatial dc biased optical OFDM (SDCO-OFDM) are used to remove the vignetting effect. Although, for an optical wireless communication system the spectral and power efficiency are the most important objective to improve. But still the spectral and power efficiency are not up to the mark by the existing method. Hence from our proposed method we can improve the spectral and power efficiency by using the non-dc-biased spatial OFDMA. The rest of the paper is organized as follows: the modelling of OSM-OFDM system is given in section 2. The model for proposed IACO-OFDM system is given in section 3. Experimental results and discussion is described in section 4 and in subsequent sections the conclusion and reference is given.

II. MODELLING OF OSM-OFDM SYSTEM

The main objective of a pixelated system is to enhance the image quality reproduced in the output. In case of the optical wireless communication, the pixelated MIMO system is used for the image transmission. In the pixelated MIMO system the spatial orthogonal frequency division multiplexing is applied. The spatial asymmetrically clipped optical OFDM (SACO-OFDM) and spatial dc biased optical OFDM (SDCO-OFDM) are used to remove

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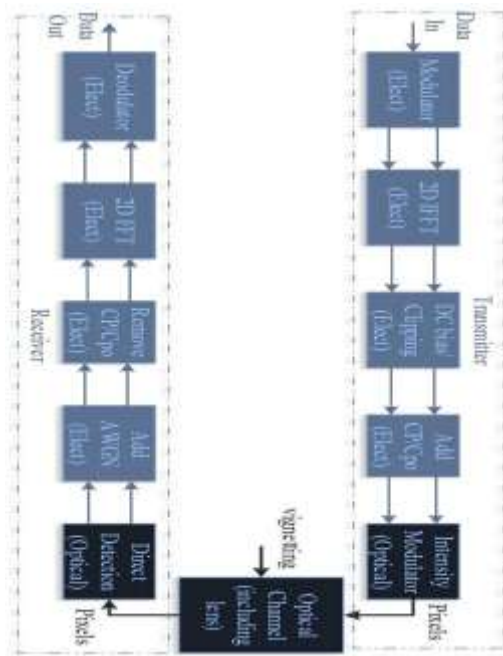


Figure 2: Optical OFDM system

Fig. 2 shows the system model of the conventional Optical Spatial Modulation (OSM) OFDM system. This system combines the basic OSM-OFDM [5] and traditional O-OFDM techniques [27].

In the first step of the modulation procedure, the input bit stream is reshaped and placed in an $N \times m$ matrix, $Q \times p$, where N is the number of OFDM subcarriers and $m = \log_2 M N_t$, the number of transmitters. This paper compares NDC-OFDM with OSM-OFDM when N_t is set to two. Under this assumption, bits in the first column of $Q \times p$ represent the index of transmitters. This means that when the bit in the first column is zero, the rest of the bits on the same row will be transmitted by the first LED and when it equals one, the rest of the bits will be conveyed by the second LED. Bits in the other columns of are mapped onto OFDM frames and they Each vector will be dealt with by the each row will be transformed to complex M-QAM symbols. For example, in fig 3, it can be seen that the first row of $Q \times p$ is

[1|01]. This means that [0 1] will be converted to a QAM symbol

SM mapping, two complex vectors, $X_1 \in \mathbb{C}^n$ and $X_2 \in \mathbb{C}^n$, are

obtained. Each vector passes through an O-OFDM modulator. In general, two standard techniques, ACO-OFDM and DCO-OFDM, are used to obtain positive and real-valued OFDM symbols, which are introduced and compared in [27] and [4]. In ACO-OFDM, $N/4$ QAM symbols are mapped onto half of the odd subcarriers of an OFDM frame. At the same time, the even subcarriers are set to zero. In DCO-OFDM, $N/2-1$ symbols are put into the first half of subcarriers and the DC subcarrier (the first subcarrier) is set to zero. Afterwards, for both ACO-OFDM and DCO-OFDM, Hermitian symmetry is applied on the rest of the OFDM frame. Thus, the two groups of QAM symbols from

$X_1 \in \mathbb{C}^n$ and $X_2 \in \mathbb{C}^n$ are transformed into real-valued OFDM symbols by the IFFT block. Finally, in order to get positive symbols, the negative values need to be set to zero in ACO-OFDM. In DCO-OFDM, before clipping, a DC-biased power is added to the bipolar OFDM symbols.

the main objective is to compare the performance of the conventional OSM-OFDM system with NDC-OFDM. Therefore, the same optical channel is used for all three schemes.

At the receiver, PDs convert optical signals to electrical signals. Additive white Gaussian noise (AWGN) is added to the signal due to ambient light and thermal noise in the transimpedance amplifier. Through the analog-to-digital conversion block, signals from each PD can be transferred to their corresponding vectors, $y_1 \in \mathbb{C}^k$ and $y_2 \in \mathbb{C}^k$

respective O-OFDM demodulator. As in conventional O-OFDM techniques, the received OFDM symbols are passed through a fast Fourier transform (FFT) operation which converts symbols to the frequency domain. In DCO-OFDM, $N/2-1$ symbols are obtained from the corresponding subcarriers and in ACO-

OFDM, $N/4$ symbols are obtained. The extracted symbols are $\in \mathbb{C}^n$.

transferred to two complex vectors, $Y_1 \in \mathbb{C}^n$ and $Y_2 \in \mathbb{C}^n$.

forcing (ZF) is used to reverse the impairments of the MIMO

channel to transform $Y \in \mathbb{C}^n$ and $\in \mathbb{C}^n$ into $Y' \in \mathbb{C}^n$ and $\in \mathbb{C}^n$.

1 2 1

respectively [5]. Afterwards, the SM detector compares the absolute values of the corresponding subcarriers from each channel to estimate the indices of the active

$$i = \arg \max_{i \in \{1, 2\}} |X_{i,n}|$$

As a result, the index of the estimated sub channel gives the bit information transmitted by the SM technique [5]. The bits from

the estimated indices are put into the first column of the output matrix, $Q' \in \mathbb{R}^{N \times p}$. This means that if $j \in \{1, 2\}$ is equal to one, the

corresponding bit is zero and if the result of the estimation is two, the bit is one. At the same time, the largest symbol in each comparison is chosen as the detected symbol,

$$X_{d,n} = \begin{cases} X_{1,n} & \text{if } j = 1 \\ X_{2,n} & \text{if } j = 2 \end{cases} \quad (2)$$

The detected QAM symbols are then decoded by the conventional Maximum Likelihood estimator. The result is

allocated to the other columns of $Q' \in \mathbb{R}^{N \times p}$. Finally, the output bit

stream is obtained by reshaping $Q' \in \mathbb{R}^{N \times p}$ into a serial bit stream.

The described SM detection algorithm is not the optimal one according to [11]. However, it has been selected in this work for its low computational complexity.

III. PROPOSED IACO-OFDM SYSTEM MODEL FOR VIGNETTING REDUCTION

The system model of IACO-OFDM is shown in Fig. 3. The input

bit stream is transformed into complex symbols,

$X \in \mathbb{C}^{N \times 1}$, $n = 1, \dots, N/2$ by an M-QAM modulator. As in

DCO-OFDM, $N/2$ QAM symbols are modulated onto the

first half of an OFDM frame, $X \in \mathbb{C}^{N \times 1}$, $k = 1, \dots, N/2$, and

Hermitian symmetry is imposed on the second half of the OFDM frame. After the N-IFFT operation, the complex

transmitters as follows,

$$\tilde{j} \in \{1, 2\} = \arg \max_{j \in \{1, 2\}} |X_{j,n}|, \quad i \in \{1, 2\}, \quad N \in \mathbb{N} \quad (1)$$

QAM

symbols become ' N ' real-valued OFDM samples, $x \in \mathbb{R}^N$, but they are still bipolar.

In IACO-OFDM, LEDs just send indisputably the estimation of $x(k)$ and the sign of the symbol is represented by the index of

the corresponding LED. As indicated by the working rule of OSM, stand out LED is activated during one symbol time. In the event that the transmitted symbol is positive, the first LED will be activated to send the symbol. In the event that the symbol is negative, its absolute value will be sent by the other LED. This rule constitutes the most critical contrast between the conventional OSOFDM and the IACO-OFDM. An extra distinction is that QAM symbols go through an OFDM modulator first and then pass through the SM mapping block in IACO-OFDM. In routine OSM-OFDM, the order is reversed.

As demonstrated in Fig. 3, after SM mapping, the converted optical signals, $L_1(k)$ and $L_2(k)$, will be transmitted by the corresponding LED over the optical MIMO channel H [27]. The

$N_t \times N_r$ optical channel matrix is

$$H = \begin{pmatrix} h_{11} & h_{12} & \dots & h_{1N_t} \\ h_{21} & h_{22} & \dots & h_{2N_t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_r1} & h_{N_r2} & \dots & h_{N_rN_t} \end{pmatrix} \rightarrow (3)$$

Where, $h_{N_r N_t}$ is the channel DC gain of a directed line-of-sight (LOS) link between the receiver N_r and the transmitter N_t . The transmitter N_t .

LOS link is considered in the system model, in light of the fact that the multipath components are significantly weaker and can thus be neglected. The channel gain can be calculated as follows [21]:

$$\frac{((\beta+1)A)}{2} \cos^2(\phi) \Gamma_s(\psi) \Gamma_c(\psi) \cos(\psi), \quad 0 \leq \psi \leq \Psi_c \rightarrow (4)$$

Where, $\beta = -\ln 2 / \ln(\cos(\Phi_{12}))$ and Φ_{12} is the transmitter semiangle. In addition, 'A' denotes the detector area of the PD and d is the distance between the receiver N_r and the transmitter N_t . The radiant angle and the incident angle are modelled respectively by φ and ψ .

$$y = Hs + w \quad (5)$$

Where, y is the N_r -dimensional received vector and s is the N_t -dimensional transmitted signal vector. In this paper, both N_r and N_t are set to two furthermore, w is the N_r -dimensional noise vector which is assumed to be real-valued AWGN.

Each PD converts the optical signal to an electrical signal. In this paper, it is assumed that the channel gain is known at the receiver. The ZF detection is used to recover the transmitted symbols as takes after,

$$g = H^{-1} y \quad (6)$$

Where, g is an N_t -dimensional vector which contains the estimated transmitted symbols and H^{-1} denotes the inverse of the channel matrix H . To estimate the indices of the active transmitters, the SM detector compares the values of the elements in g as follows,

$$I(k) = \arg\max(G(i, k)), i = 1, \dots, N \quad (7)$$

Where, G is the $N_t \times N$ equalized matrix which contains all

the estimated transmitted symbols and I is an N -dimensional vector which contains all the estimated indices. As specified,

there are two transmitters and two receivers. If $I(k)$ is equal to

one, this means that the symbol received at the time instant k is transmitted from the first LED. Accordingly this symbol is a positive-valued OFDM symbol. Unexpectedly, if the result of

$I(k)$ is two, a negative symbol is transmitted by LED2. As a result, the estimated OFDM symbols sequence is

$$x(k) = \begin{cases} \tilde{x}(k), & I(k) = 1 \\ -\tilde{x}(k), & I(k) = 2 \end{cases} \quad (8)$$

The optical filter gain T_s and the optical concentrator gain g_c depend on the properties of the receiver. Accordingly, optical MIMO signals can be obtained as,

In a perfect situation, if there is no AWGN, $x(k)$ ought to be the same as $\tilde{x}(k)$. In the wake of recovering the OFDM symbols, $x(k)$ is passed through the conventional OFDM demodulation block and the M-QAM demodulator in order to obtain the output bit stream.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The proposed NDC technique for the reduction of Vignetting of MIMO optical OFDM is implemented using MATLAB/Simulink with the following system configuration.

Processor: Intel i3 @ 3.07 GHz

(6) RAM: 2GB

Operating system: windows 8.1

MATLAB version: R2014a

The received constellations for the case of 4-QAM ACO-OFDM, 4-QAM DCO-OFDM, 4-QAM NDCO-OFDM and 4-QAM IACO-OFDM respectively, utilizing 256×256 subcarriers are indicated in fig. 5 shows. The impact of AWGN is overlooked to show the impact of vignetting. In Fig. 5(a), (b) and (c), the constellation points at the input to the transmitter 2-

D IFFT are shown as "+", and the received data-carrying constellation points are demonstrated as ".". It can be seen that the impact of vignetting is to change the amplitude and phase of the received constellation points reflecting the presence of both attenuation and ICI. The constellation points of DCO-OFDM, ACO-OFDM and NDC-OFDM also show the effect of clipping noise which is caused by the use of a moderate dc bias.

In the simulations the transmitted spatial OFDM signal was normalized to an optical power of unity. Vignetting is one and only of various impairments that can influence a pixelated optical wireless system using spatial OFDM. In this section we examine the impairments brought about by vignetting, linear misalignment, defocus blur and AWGN and the interaction between them. Linear misalignment was depicted in [13] and

[14] where it was demonstrated that the effect of linear misalignment depends both on whether the misalignment is within the length of the CP/CPo or not, and whether the misalignment is by an integral or fractional number of pixels. The main impact of integral misalignment within the CP/CPo length is a rotation of the received constellation points. This can be completely amended by an equalizer in the receiver without noise enhancement, and does not interact with other impairments. On the other hand misalignment by a fractional number of pixels has been shown to cause both attenuation and rotation of the subcarriers, even if the misalignment is within the CP/CPo length. High spatial frequency subcarriers experience much greater attenuation than lower frequency ones, so the noise enhancement is particularly pronounced for the high spatial frequency subcarriers. On the off chance that a little extent of the high frequency subcarriers is unused the attenuation gets to be negligible.

Defocus blur causes the signal from a solitary transmitted pixel to be spread over various of surrounding received pixels [16]. It has been demonstrated that for spatial OFDM systems, defocus blur causes an attenuation of the higher spatial frequency subcarriers. Like the attenuation caused by fractional misalignment, the attenuation can be remedied by an equalizer at the cost of noise enhancement. However for practical values of defocus blur the attenuation is significant for a larger proportion of high frequency subcarriers than for fractional misalignment.

In this paper, we have demonstrated that vignetting likewise causes attenuation of subcarriers, however that not at all like fractional misalignment and defocus blur, the attenuation is the same for all subcarriers, independent of spatial frequency. In light of the different underlying mechanisms, the three components of attenuation are independent and the overall attenuation for a given subcarrier can be calculated by multiplying the individual attenuation factors for fractional misalignment, defocus blur and vignetting. Vignetting, dissimilar to fractional misalignment and defocus blur also causes ICI which causes an additional noise-like term in the received subcarriers. This ICI noise is likewise upgraded by the equalizer, and in this way interacts with the attenuation caused by all the impairments.

V. CONCLUSION

The Improved Asymmetric Clipping MIMO optical OFDM is presented for the reduction of vignetting impact in pixelated system. The IACO-OFDM is embraced to reduce the effect of vignetting for a pixelated system. This analysis shows that the vignetting effect causes attenuation as well as inter-carrier-interference (ICI) in the spatial frequency domain. The simulation result

demonstrated that the proposed IACO technique is more robust vignetting than spatial the conventional DCO-OFDM, ACO-OFDM and NDC-OFDM. The implementation result proved that the proposed system has the highest performance by achieving the enhanced BER. Ultimately the proposed IACO technique is become a better choice for the reduction of vignetting in optical MIMO OFDM system. Grobe, and J. Li, "High-speed optical wireless demonstrators: Conclusions and future directions", *Journal of Light wave Technology*, Vol. 30, No. 13, pp. 2181–2187, Jul. 2012.

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