A New Hybrid PAPR Reduction Technique for OFDM based Visible Light Communication Systems

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Abstract:-Orthogonal frequency division multiplexing (OFDM) is used with visible light communication (VLC) systems to reduce the effects of inter-symbol interference (ISI) and to achieve communication with high speed of data transmission and huge bandwidth. However, OFDM based VLC systems suffer from high peak-to-average power ratios (PAPRs). This paper proposes a new hybrid PAPR reduction technique based on signal transformation combined with clipping. The Hadamard transform is used in the proposed technique due to its advantages in reducing the PAPR without affecting the bit error rate (BER) of VLC systems. The optimum clipping threshold at which we can simultaneously reduce the PAPR and improve the BER of VLC systems is also determined. In this paper we also propose a n ew OFDM structure based on using Discrete Cosine Transform (DCT) precoded before inverse fast Fourier transform (IFFT) stage to further improve the PAPR reduction capability and BER performance. The performance of the proposed technique in terms of complementary cumulative distribution function (CCDF) and the BER is simulated. The obtained results show that the proposed technique can simultaneously reduce the PAPR and achieve good BER performance when compared to the original OFDM based VLC system.

Key-Words: - OFDM, VLC systems, PAPR reduction, Hadamard transform, DCT precoding, clipping method.

1 Introduction

Visible light communications (VLC) is an emerging technology that uses the visible light spectrum to transmit information for indoor wireless communications [1], [2] and free from major outdoor environmental degradations such as rain, snow and building sway [3], [4]. VLC can provide illumination and communication simultaneously by way of light emitting diodes (LEDs). It offers low cost and energy efficient solution while ensuring high speed, large bandwidth and secure transmission [5]. VLC systems can be used in many applications such as the hospital and the airplane because it may slightly influence electronic devices [6]. VLC systems employ intensity modulation and direct detection (IM/DD) techniques which provide simple and low cost data transmission, thus only signal intensity information, not phase information is modulated [7], [8]. The main challenge in VLC is the limited modulation bandwidth of LED [1], [9]. White LEDs exhibits the low-pass filter characteristics so VLC channel appears as frequency-selectivity channel [8]. Because the

dispersion of the optical signal in indoor VLC caused by reflections from various sources inside a room, VLC systems suffer from multipath distortion which make inter-symbol interference (ISI) and as a results reduce the signal to noise ratio (SNR) [10], [11].

Orthogonal frequency division multiplexing (OFDM) has been considered for VLC because of its high speed data rates, huge spectral efficiency and more robustness against ISI and frequency selective fading [12], [13].IM/DD requires the electric signal to be real-valued and unipolar (positive-valued) [14]. The OFDM signals are generated by applying an inverse fast Fourier transform (IFFT) on the data stream at the transmitter and decoded using a fast Fourier transform (FFT) at the receiver [15]. Hermitian symmetry must be satisfied to obtain real value signal [16] and bipolar-to-unipolar module must be required [17]. DC bias is used to generate real positive signals in DC biased optical OFDM (DCO-OFDM) and it is inefficient in terms of the optical power because DCO-OFDM signal needs a large

DC bias [18]. In Asymmetrically Clipped Optical OFDM (ACO-OFDM) the signal is pre-clipped at zero or a positive bottom level [19], DCO-OFDM is less efficient in terms of the optical power than ACO-OFDM [20]. To achieve high spectral efficiencies high order quadratic amplitude modulation (QAM) has to be employed.

2 Problem Formulation

One of the main challenges that faces OFDM based VLC systems is the high peak-to-average power ratio (PAPR) that arises from high PAPR of OFDM signals and the limited dynamic range of LEDs devices. High PAPR deteriorates the VLC systems performance in terms of bit error rate (BER), so PAPR reduction is very important in OFDM based VLC systems [21], [22]. There are many techniques were proposed in literature to reduce the PAPR and to improve the power efficiency of RF communication systems [23-25]. However, since VLC differs from RF communication in many aspects such as; system constraint, baseband signal format and nonlinearity characteristic of front-end devices, it is not obvious how the PAPR is related to the illumination to communication conversion efficiency.

2.1 PAPR of OFDM based VLC

The PAPR of the continuous time OFDM signal is defined as the ratio of the maximum instantaneous power to the average power. The PAPR of discrete time VLC-OFDM signal $\hat{x}_n$ is defined as:

$$PAPR(dB) \triangleq 10\,log_{10}\,\frac{\max\limits_{0 \leq n \leq N} |\hat{x}_n|^2}{E[|\hat{x}_n|^2]} \qquad (1)$$

where E [·] denotes statistical expectation.

The Complementary Cumulative Distribution Function (CCDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques, it is defined as [26]:

$$CCDF = Prob(PAPR > PAPR_0) \qquad (2)$$

where $PAPR_0$ is the given threshold value. CCDF denotes the probability that the PAPR of a data block exceeds the threshold value.

3 Problem Solution

In this paper, we propose a hybrid technique to reduce the high PAPR of OFDM based VLC systems called Hadamard Transform Combined with Clipping (HTCC) technique. The effect of using HTCC technique on BER performance of VLC systems is also presented in this paper. High signal clipping ratio will introduce some deleterious side effects, such as the increase of BER and the growth of in-band radiation and out-of-band radiation. The authors in [27], [28] demonstrated that the Hadamard transform reduces the PAPR without increasing the system BER. Therefore, combining the clipping techniques with Hadamard transform as in the proposed technique will reduce the PAPR without increasing the BER performance. We also evaluate the optimum clipping threshold at which we can reduce the PAPR and simultaneously, improve the BER of VLC systems.

In this paper we also study the effect of using DCT precoding matrix to transform the transmitted data before being processed by IFFT stage. Then, the clipping is applied to further reduce the PAPR of the OFDM signal after the IFFT stage. The obtained results show that, the DCT precoding scheme can further improve the BER and PAPR performances of OFDM based VLC systems.

3.1 System Model

The system model of OFDM based VLC system treated in this paper is shown in Fig. 1. The original data is firstly processed by serial-to-parallel (S/P) and mapped onto *M*-level Quadrature Amplitude Modulation (QAM) constellation before being transformed by the Hadamard block which reduces the correlation of the input data sequences. Hermitian symmetry is imposed to obtain real value signal then, the real value signal goes through the inverse fast Fourier transform (IFFT). When applying IFFT, after the parallel-to-serial (P/S) operation, the Cyclic Prefix (CP) is added to elimin-
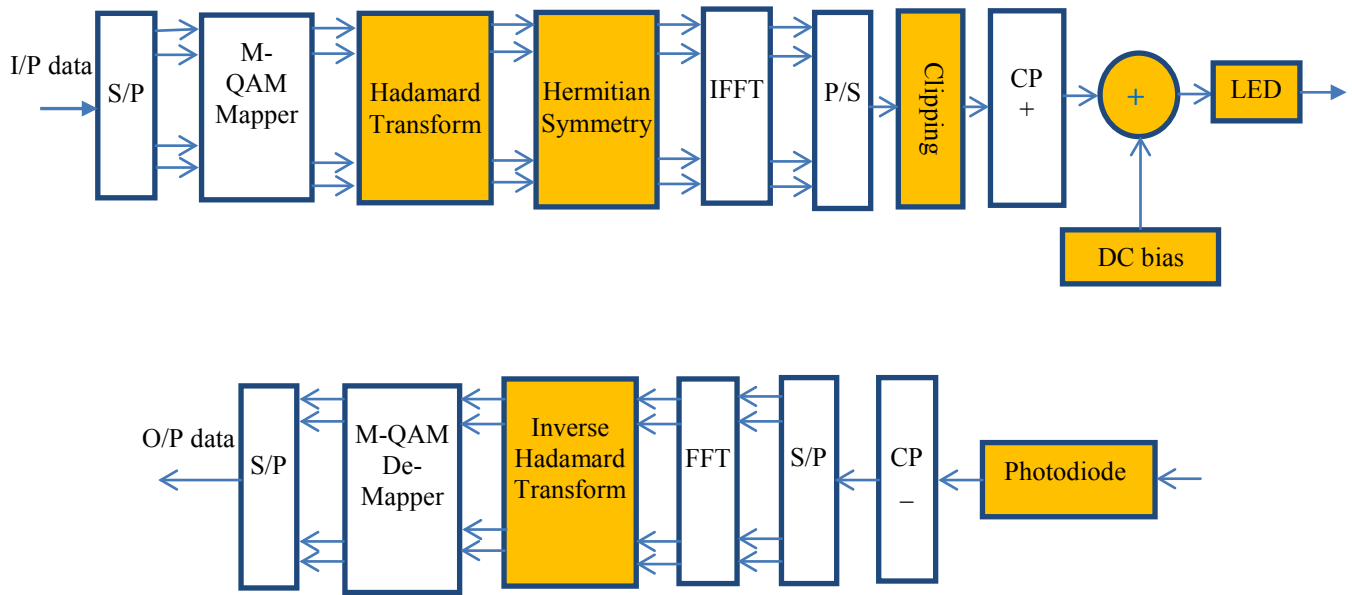
Haitham Freag, Emad S. Hassan,
Sami A. El-Dolil, Moawad I. Dessouky

Figure 1: OFDM based VLC system block diagram.

ate the inter-symbol interference. The OFDM signal enters the clipping block to reduce the PAPR. The OFDM time domain signal must be both real and positive, so DC biased is introduced. Intensity modulation (IM) is employed at the transmitter. The forward signal $y(t)$ drives the LED which in turn converts the magnitude of the input electric signals $y(t)$ into optical intensity. At the receiver side, direct detection (DD) is employed. The PIN Photo Detector (PD) converts the incoming optical power into the amplitude of an electrical signal. CP is removed, Inverse Hadamard transform is performed after the FFT and the M-QAM demodulation is performed. Finally, data signals are successfully received after the P/S conversion.

3.2 The Proposed Hybrid Hadamard Combined with Clipping Technique

3.2.1 Hadamard Transform

Hadamard transform is used to reduce the auto-correlation between the input data sequence and

the PAPR of the OFDM signal [15]. Let H_M be the Hadamard transform matrix of M orders, the elements of Hadamard matrix is 1 or -1, the second order of Hadamard matrix can be written as

$$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \tag{3}$$

The Hadamard matrix of M order can be given as:

$$H_M = \begin{bmatrix} H_{M/2} & H_{M/2} \\ H_{M/2} & -H_{M/2} \end{bmatrix} \tag{4}$$

where the matrix complementary of

$H_{M/2}$ is $-H_{M/2}$.

The data sequence after M-QAM is given by

$X = [X_1, X_2, X_3, \ldots, X_M]^T$, the new sequences $\hat{X}_M$ after the Hadamard transform can be represented as:

$$\hat{X}_M = H_M X_M \tag{5}$$

The signal $\hat{X}_M$ after N-point IFFT may be expressed as:

$$\hat{x}_M = IFFT(\hat{X}_M) = IFFT(H_M X_M) \tag{6}$$

3.2.2 The Proposed Clipping Method
The simple and effective technique to reduce PAPR is clipping algorithm. The clipping algorithm is that

the signal is limited to the set threshold when the peak of the input signal exceeds a certain threshold; otherwise, the signal passes through directly. Clipping operation can be represented as:

$$y_C = \begin{cases} -C & (\hat{x} < -C) \\ \hat{x} & (-C \leq \hat{x} \leq C) \\ C & (\hat{x} > C) \end{cases} \quad (7)$$

where $\hat{x}$ is the IFFT output signal which is real

value, C is the clipping threshold and y_C denotes the output signal after clipping block. In the clipping algorithm, the clipping ratio (CR) is a very important parameter, which is used to determine the clipping threshold C above. It is defined as

$$CR = 20 \log \frac{C}{\sqrt{\bar{P}}} \quad dB \quad (8)$$

where $\bar{P}$ is the average power of an OFDM symbol. Since about a half of the clipped samples are Negative real and the minimum value is $-C$ at least, we add bias of C to each OFDM sample to make the transmit signal be positive. With the above operations, the dynamic range of the amplitude can be suppressed to less than $2C$. Moreover, thanking to clipping without filtering the bias can be a constant for every OFDM symbol. Therefore, the receiver does not need to estimate the bias value in every OFDM symbol [28].

The steps of the proposed hybrid technique as shown in Fig. 1 can be summarized as follows:

Step 1: The sequence X from the QAM mapper is transformed by the Hadamard matrix as in Eq. (5).

Step 2: The transformed sequence is converted to time domain using IFFT as in Eq. (6).

Step 3: Set the CR and the OFDM symbol $\hat{x}_n$ enters the clipping block.

Step 4: Calculate the clipping level, C, using Eq. (8) and generate the sequence y_C by clipping $\hat{x}_n$ using Eq. (7).

Step 5: Finally add DC bias of C to each sample of OFDM symbols to make the transmitted signal positive.

3.3 The Proposed DCT Precoded OFDM based VLC System

The excellent energy compaction property of the DCT makes most of the signal energy concentrated in the first few samples, leaving the rest of samples close to zero [29]. If the DCT precoding is used prior to data transmission, it is expected that the ISI resulting from those small amplitude samples will be very small, leading to a lower BER performance.

As shown in Fig. 2, the main idea of this new technique is that the transmitted data is first transformed by the DCT matrix. Then, the transformed data are processed by the IFFT unit. In order to produce a real output from IFFT stage, the input of the IFFT must be a Hermitian symmetric structure.

DCT is a real transform which converts the modulated data, X_M into the new transform-domain signal using $K \times K$ DCT matrix F which is given as [30].

$$F_{n,m} = \begin{cases} \frac{1}{\sqrt{K}} & n = 0, \ 0 \leq m \leq K-1 \\ \sqrt{2/K} \cos\left[\frac{(2m+1)n\pi}{2K}\right] & 1 \leq n \leq K-1, \ 0 \leq m \leq K-1 \end{cases}$$
(9)

where n and m represent the row and column entries, respectively. The new sequences $\hat{X}_{M-DCT}$ after the DCT precoding matrix can be represented as:

$$\hat{X}_{M-DCT} = F X_M \quad (10)$$

Following the same steps as in section 3 and applying DCT precoding before IFFT stage, we can get a good PAPR reduction and good BER performance as shown in next section.

3.4 Simulation Results and Discussion

Simulation parameters are shown in Table 1. In the case of conventional OFDM based VLC system, bias values equal to the absolute value of the minimum value is added.
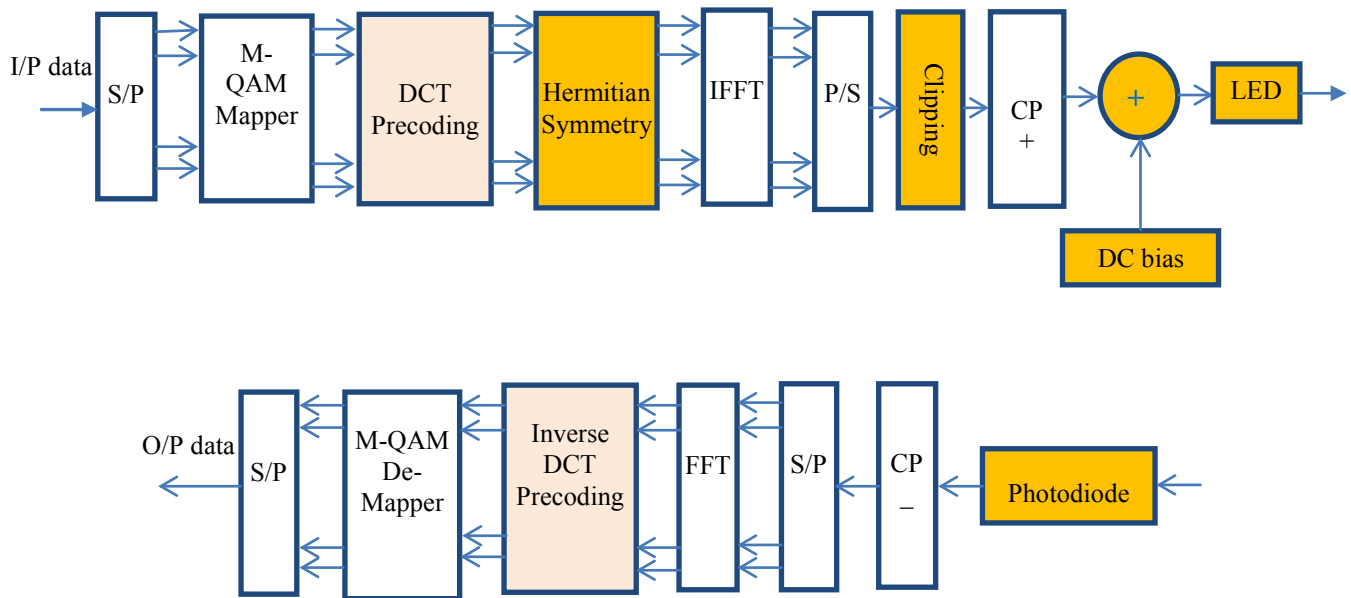
Figure 2: DCT pre-coded OFDM based VLC system block diagram.

Table 1: Simulation Parameters.

Modulation Type	4 QAM
OFDM symbols	10,000
No. of data subcarriers	48
FFT size	128
Guard interval	16 samples times
Total subcarriers	144
Channel Type	AWGN

3.4.1 Conventional FFT-OFDM based VLC Results

Figure 3 shows the CCDF performance comparison between the original OFDM based VLC system, the OFDM based VLC system with Hadamard transform only and with proposed technique using different clipping ratio. We can see that at CCDF=10-3, Compared with original system, about 0.5 dB PAPR reduction may be obtained using Hadamard transform. It is also clear that, as the CR value is smaller, the reduction effect of PAPR is better. For example, using the proposed technique, the PAPR of OFDM based VLC system can be improved by 6.5 dB, 7.5 dB, 8.2 dB and 9.2 dB with CR=1.8, 1.5, 1.3 and 1, respectively at CCDF = 10^{-3}.

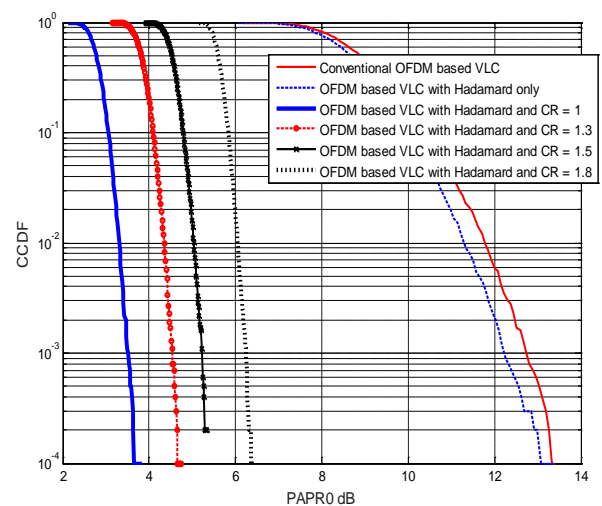The BER performance of the OFDM based VLC system with Hadamard transform only and with

proposed technique using different clipping ratio is shown in Fig. 4. The original OFDM based VLC system is included for comparison. At BER=10^{-3}, the system with Hadamard transform can achieve about 0.25 dB improvement. We also note that, the BER is improved by about 1 dB at a clipping ratio of 1.3 when comparing to the original system to satisfy BER of 10^{-3}. This improvement becomes 2 dB when the clipping ratio changed to 1.5 and 1.8.

Figure 3: The CCDF performance comparison between the original and the proposed OFDM based VLC system using different clipping ratio.

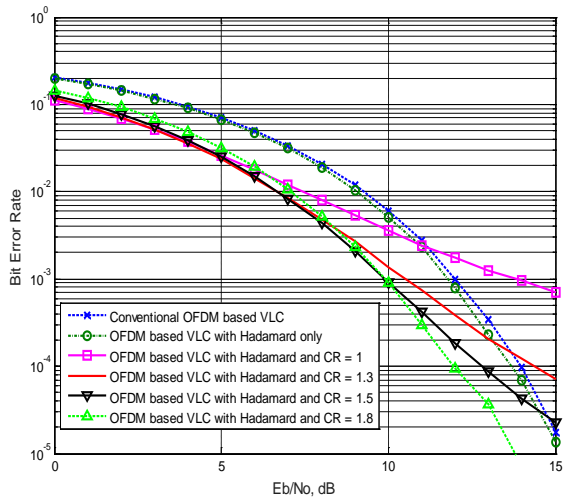**Figure 4:** BER performance of OFDM based VLC system with and without proposed technique.

Figure 5: The CCDF performance comparison between the original and the proposed OFDM based VLC system using DCT and different clipping ratio.

3.4.2 DCT Precoded OFDM based VLC Results

Figure 5 shows the CCDF performance comparison between the original and the proposed OFDM based VLC system using DCT precoding and different clipping ratio. We can see that at CCDF = 10^{-3}, compared with conventional system, about 2.8 dB PAPR reduction may be obtained when applying DCT precoding without clipping. It is also clear that, as the CR value is smaller, the reduction effect of PAPR is better. For example, using the proposed technique, the PAPR of OFDM based VLC system can be improved by 7 dB, 8 dB, 8.7 dB and 9.7 dB with CR = 1.8, 1.5, 1.3 and 1, respectively at CCDF = 10^{-3}.

Figure 6 presents the CCDF performance comparison between the conventional, the OFDM based VLC system with Hadamard transform and OFDM based VLC system with DCT precoding using clipping ratio of 1.8. We can see that at CCDF = 10-3, compared with conventional system, about 0.75 and 2.8 dB PAPR reduction may be obtained when applying Hadamard transform and DCT matrix transform, respectively without clipping. It is also clear that, the reduction effect of PAPR become better when applying clipping especially with smaller CR value.
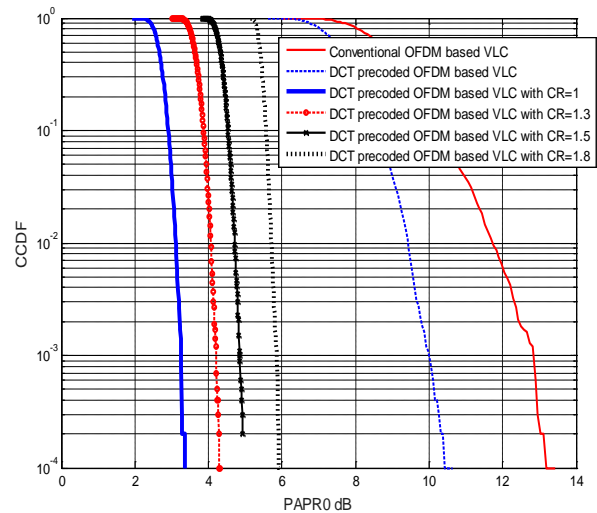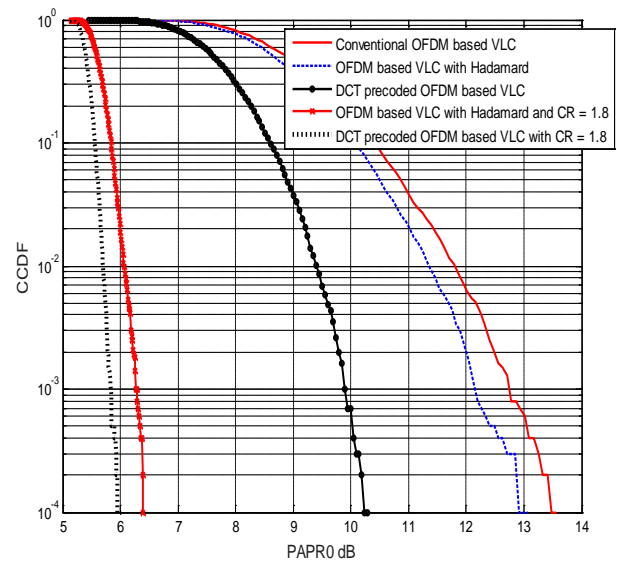

Figure 6: The CCDF performance comparison between the conventional and the proposed OFDM based VLC system and DCT VLC OFDM using clipping ratio = 1.8.

The BER performance of DCT-OFDM based VLC system with DCT precoding and different clipping ratio is shown in Fig. 7. The conventi-onal OFDM based VLC system is included for comparison. At BER = 10^{-3}, the system with DCT precoding can achieve about 1.25 dB improvement in SNR compared with conventi-onal system. We also note that, the BER is improved by about 2 dB at a clipping ratio of 1.3 when comparing to the conventional system. This improvement becomes 2.5 dB when the clipping ratio changed to 1.5 and 1.8.

Haitham Freag, Emad S. Hassan,
Sami A. El-Dolil, Moawad I. Dessouky

Figure 8 shows the performance comparison between the conventional, the OFDM based VLC system with Hadamard transform and OFDM based VLC system with DCT precoding using clipping ratio of 1.8. It is clear that, by replacing Hadamard transform block by DCT precoding block we can achieve further improvement in terms of BER.
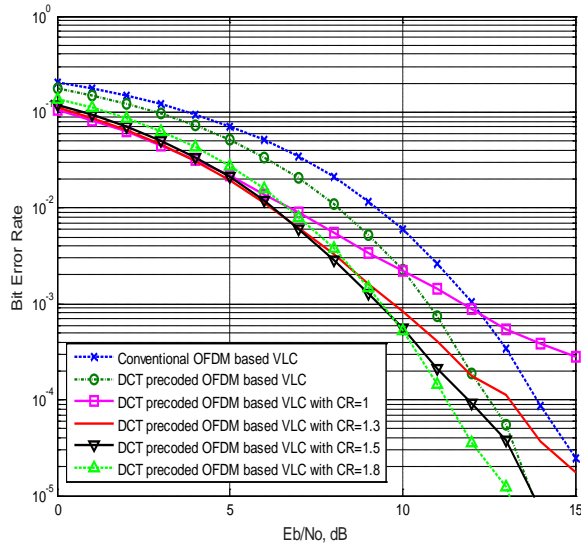

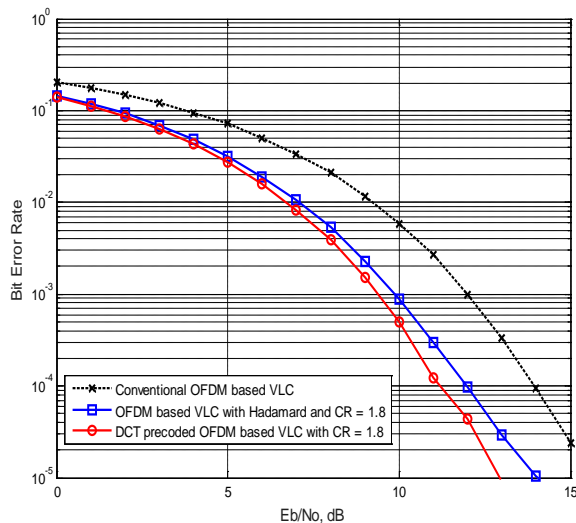**Figure 7:** BER performance of DCT OFDM based VLC system with and without proposed technique.

Figure 8: BER performance comparison of OFDM based VLC system with FFT and DCT using proposed technique.

4 Conclusion

This paper proposed new hybrid techniques to reduce the PAPR and improve the BER performance of OFDM based VLC systems. The proposed techniques combined the Hadamard transform or DCT matrix transform with clipping method. The optimum clipping threshold at which we can reduce the PAPR and simultaneously improve the BER of VLC systems was also evaluated. The performance of conventional OFDM based VLC system, the OFDM based VLC system with Hadamard transform only and with proposed techniques using different clipping ratio was evaluated and compared in terms of CCDF and BER. It was demonstrated that, the OFDM based VLC system with Hadamard transform combined with clipping technique has the lowest PAPR and good BER performance compared to conventional system. The CCDF and BER are further improved when replacing Hadamard transform block by DCT precoding block due to the excellent energy compaction property of the DCT transform.

References:

[1] Z. Ghassemlooy, W. Popoola, and S. Rajbhandari, Optical Wireless Communications: System and Channel Modelling with MATLAB, CRC Press, 2012.

[2] T. Komine and M. Nakagawa, "Fundamental analysis for visible-light communication system using led lights," IEEE Transactions on Consumer Electronics, vol. 50, no. 1, pp. 100–107, 2004.

[3] S. Randel, F. Breyer, S. C. Lee, and J. W. Walewski, "Advanced modulation schemes for short-range optical communications," IEEE Journal of Selected Topics in Quantum Electronics, vol. 16, no. 5, pp. 1280 –1289, 2010.

[4] T. Komine and M. Nakagawa, "Integrated system of white led visible light communication and power-line communication," IEEE Transactions on Consumer Electronics, vol. 49, no. 1, pp. 71–79, 2003.

[5] S. Arnon et al.: "Advanced Optical Wireless Communication Systems", Cambridge Uni. Press, July 2012.

[6] S. Haruyama "Visible light communication," IEICE Trans. Fundamentals, vol. J84-A, No. 12, pp. 1284–1291, Dec, 2003.

[7] L. Grobe, A. Paraskevopoulos, J. Hilt, D. Schulz, F. Lassak, F. Hartlieb, C. Kottke, V. Jungnickel, and K.-D. Langer, "High-speed visible light communication systems," IEEE Communications Magazine, vol. 51, no. 12, pp. 60–66, 2013.

[8] Hoa Le Minh, Dominic 0 Brien, Grahame Faulkner, Lubin Zeng, Kyungwoo Lee, and Daekwang Jung, "100-Mb/s NRZ Visible Light Communications Using a Postequalized White LED," IEEE Photonics Technology Letters, vol. 21, no. 15, pp. 1063-1065,2009.

[9] D. C. O'Brien, L. Zeng, H. Le-Minh, G. Faulkner, J. W. Walewski, and S. Randel, "Visible
light communications: challenges and possibilities," in IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, ser. ISBN: 978-1-4244-2644-7/08, Cannes, France, Sept. 2008.

[10] J. Armstrong, "OFDM for optical communications," J. Lightw. Technol., vol. 27, no. 3, pp. 189–204, Feb. 2009.

[11] O. Gonzalez, R. Perez-Jimenez, S. Rodriguez, J. Rabadan, and A. Ayala, "OFDM over indoor wireless optical channel," IEE Proc. Optoelectron., vol. 152, no. 4, pp. 199–204, Aug. 2005.

[12] S. Hranilovic, "On the design of bandwidth efficient signalling for indoor wireless optical channels," International Journal of Communication Systems, vol. 18, no. 3, pp . 205–228, 2005.

[13] J. Armstrong and A. J. Lowery, "Power efficient optical OFDM," Electronics Letters, vol. 42, no. 6, pp. 370– 372, 2006.

[14] Raed Mesleh, Hany Elgala, and Harald Haas, "LED Nonlinearity Mitigation Techniques in Optical Wireless OFDM Communication Systems," Journal of Optical Communications and Networking, vol. 4, no. 11, pp. 865, Oct. 2012.

[15] S. Dissanayake and J. Armstrong, "Comparison of ACO-OFDM, DCOOFDM and ADO-OFDM in IM/DD systems," J. Lightw. Technol., vol. 31, no. 7, pp. 1063– 1072, April 2013.

[16] Zhenhua Yu, Kai Ying, Robert J. Baxley and G. Tong Zhou, "PAPR Reduction for Bit-loaded OFDM in Visible Light Communications," IEEE Wireless Communications and Networking Conference, 334 – 339, March 2015.

[17] Zhenhua Yu, Robert J. Baxley, and G. Tong Zhou, "Impulses Injection for PAPR Visible Light OFDM Communications," in Proc. IEEE Global Conference on Signal Information Processing (GlobalSIP), Atlanta, GA, 2014, pp. 1–5.

[18] J. Armstrong and B. J. C. Schmidt, "Comparison of Asymmetrically Clipped Optical OFDM and DC-Biased Optical OFDM in AWGN," vol. 12, no. 5, pp. 343 – 345, May 2008.

[19] S. Dissanayake, K. Panta, and J. Armstrong, "A novel technique to simultaneously transmit ACO-OFDM and DCO-OFDM in IM/DD systems," Proc. of IEEE Global Telecommun. Conf., (GLOBECOM), pp. 782–786, Dec 2011.

[20] X. Li, et al., "On the Capacity of Intensity-Modulated Direct-Detection Systems and the Information Rate of ACO-OFDM for Indoor Optical Wireless Applications," IEEE Trans Commun, vol. 60, no. 3, March 2012.

[21] Zhenhua Yu, Robert J. Baxley, and G. Tong Zhou, "Distributions of upper PAPR and lower PAPR of OFDM signals in visible light communications," in Proc. IEEE Inti. Conference on Acoustics, Speech, and Signal Processing (ICASSP), Florence, Italy, 2014.

[22] Zhenhua Yu, Robert J. Baxley, and G. Tong Zhou, "Iterative Clipping for PAPR Reduction in Visible Light OFDM Communications," in Proc. IEEE Military Communications Conference (MILCOM), Baltimore, pp. 1—6, MD, 2014.

[23] S. H. Han and J. H. Lee, "An overview of peak-to average power ratio reduction techniques for multicarrier transmission," IEEE Wireless Communications, vol. 12, no. 2, pp. 56–65, Apr. 2005.

[24] J. Armstrong, "Peak-to-average power reduction for OFDM by repeated clipping and frequency domain filtering," Electronics Letters, vol. 38, no. 5, pp. 246, Feb. 2002.

[25] A. Aggarwal and T. H. Meng, "Minimizing the peak-to- average power ratio of OFDM signals using convex optimization," IEEE Transactions on Signal Processing, vol. 54, no. 8, pp. 3099–3110, Aug. 2006.

[26] Y. Nakamura, M. Saito, "Bit error rate of visible light OFDM signals by employing clipping method," Proc.IEICE General Confs, March, 2012.

[27] E.S. Hassan, S.E. El-Khamy, M.I. Dessouky, S.A. El-Dolil, F.E. Abd El-Samie, "Peak-to-average power ratio reduction in space–time block coded multi-input multi- output orthogonal frequency division multiplexing systems using a small overhead selective mapping scheme", The Institution of Engineering and Technology, Vol. 3, Iss. 10, pp. 1667–1674, 2009.

[28] M. Park, H. Jun, J. Cho, N. Cho, D. Hong, C. Kang, PAPR reduction in OFDM Transmission using Hadamard transform, IEEE Int. Conf. Commun. 1 (2000).

[29] E. S. Hassan, et al., "An Efficient Transceiver Scheme for SC-FDMA Systems Based on Discrete Wavelet Transform and Discrete Cosine Transform" *Wireless Personal Communications*, DOI 10.1007/s11277-015-2587-8, vol. 83, no. 4, pp. 3133-3155, 2015.

[30] Z. P. Wang, S. F. Chen, Y. Zhou, M. Chen, J. Tang, and L. Chen, "Combining discrete cosine transform with clipping for PAPR reduction in intensity-modulated OFDM systems," *Optoelectronics Letters*, vol. 10, no. 5, pp. 356–359, 2014.