DCT Precoded SLM Technique for PAPR Reduction in OFDM Systems

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Abstract — **High Peak to Average Power Ratio (PAPR) is still a most important challenge in Orthogonal Frequency Division Multiplexing (OFDM) system. In this paper, we propose a Discrete Cosine Transform (DCT) precoding based SLM technique for PAPR reduction in OFDM systems. This technique is based on precoding the constellation symbols with DCT precoder after the multiplication of phase rotation factor and before the Inverse Fast Fourier Transform (IFFT) in SLM-OFDM System. Simulation results show that our proposed technique can reduce the PAPR to about 5.5dB for N=64 and V=16 at clipping probability of 10^{-3}.**

Index Terms - **PAPR, OFDM, DCT Precoder, SLM**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission technique that has become the technology for next generation wireless and wireline digital communication systems because of its high speed data rates, high spectral efficiency, high quality service and robustness against narrow band interference and frequency selective fading [1].

OFDM thwarts Inter Symbol Interference (ISI) by inserting a Guard Interval (GI) using a Cyclic Prefix (CP) and moderates the frequency selectivity of the Multi Path (MP) channel with a simple equalizer. This leads to cheap hardware implementation and makes simpler the design of the receiver.

OFDM is widely adopted in various communication standards like Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), Digital Subscriber Lines (xDSL), Wireless Local Area Networks (WLAN), Wireless Metropolitan Area Networks (WMAN), Wireless Personal Area Networks (WPAN) and even in the beyond 3G Wide Area Networks (WAN) etc. Additionally, OFDM is a strong candidate for Wireless Asynchronous Transfer Mode (WATM).

However, among others, Peak to Average Power Ratio (PAPR) is still one of the major drawbacks in the transmitted OFDM signal [2]. Therefore, for zero distortion of the OFDM signal, the RF High Power Amplifier (HPA) must not only operate in its linear region but also with sufficient back-off. Thus, HPA with a large dynamic range are required for OFDM systems. These amplifiers are very expensive and are major cost component of the OFDM system. Thus, if we reduce the PAPR it not only means that we are reducing the cost of OFDM system and reducing the complexity of A/D and D/A converters, but also increasing the transmit power, thus, for same range improving received SNR, or for the same SNR improving range.

A large number of PAPR reduction techniques have been proposed in the literature. Among them, schemes like constellation shaping [3], coding schemes [4,5], phase optimization [6], nonlinear Companding transforms [7], Tone Reservation (TR) and Tone Injection (TI) [8,9], clipping and filtering [10], Partial Transmit Sequence (PTS) [11], Selected Mapping (SLM) [12,13,17] and precoding based techniques [14,18,19] are popular.

In [10] Wang and Tellambura proposed a soft clipping technique which preserves the phase and clips only the amplitude. They also put a lot of effort to characterize the performance and discover some properties to simplify the job. However, the PAPR gain is only estimated by simulations and is limited to a specific class of modulation technique.

In [11] Han and Lee proposed a PAPR reduction technique based on Partial Transmit Sequence technique in which they divide the frequency bins into sub blocks and then they multiply each sub-block with a constant phase shift. Choosing the appropriate phase shift values reduces PAPR. The most critical part of this technique is to find out the optimal phase value combination and in this regard they also proposed a simplified search method and evaluated the performance of the proposed technique.

In [12] Lim et.al, proposed a selected mapping (SLM) technique for PAPR reduction. In this technique, they multiply the constellation with a phase rotated sequence to reduce the PAPR.

In [13] Liang and Ouyang also proposed a low complexity an SLM technique in which they rotate the bins by one of the phase sequences and then select the sequence with lower PAPR for transmissions. The main emphasis of the paper is on method of generating the time domain results and IFFT is not performed on every possible phase rotation.

In [14] Enchang Sun et.al, presented a DCT based precoding technique for PAPR reduction in MSE-OFDM system and they claims through Simulations that DCT based precoding technique can considerably reduce the PAPR without rising the symbol error rate.

In [15] Han and Lee and in [16] Jiang and Wu presented an excellent survey of PAPR reduction techniques like

Clipping and filtering, Coding, PTS, SLM, Interleaving, TR, TI and ACE. In addition they also provide mathematical analysis of the distribution of PAPR in OFDM systems.

In [18] authors developed PSLM technique for PAPR reduction. In this technique Zadoff-Chu based precoder is applied after the multiplication of phase rotation factor and before the IFFT in the SLM-OFDM system. The proposed PSLM technique is signal independent and it does not require any complex optimization technique.

In [19] authors proposed Zero PAPR Zadoff-Chu precoder based technique for Single Carrier Frequency Division Multiple Access (SC-FDMA). This technique is efficient, signal independent, distortionless, it does not require any optimization algorithm and PAPR is completely eliminated.

In this paper, we present a new DCT precoder based SLM technique for PAPR reduction. In the proposed system we make use of DCT based precoder which is less complex then other precoders [14] after the multiplication of phase rotation factor and before the IFFT in the SLM-OFDM system. Our proposed DCT precoder based SLM technique is signal independent and it does not require any complex optimization technique either.

This paper is organized as follows: Section II describes the basics of the OFDM system and PAPR reduction, In Section III, we present the proposed system model for PAPR reduction, and Section IV presents computer simulation results and section V concludes the paper.

II. OFDM SYSTEM & PAPR REDUCTION

A. OFDM System

The OFDM system splits the high speed data stream into a number of parallel low data rate streams and these low rates data streams are transmitted simultaneously over a number of orthogonal subcarriers.

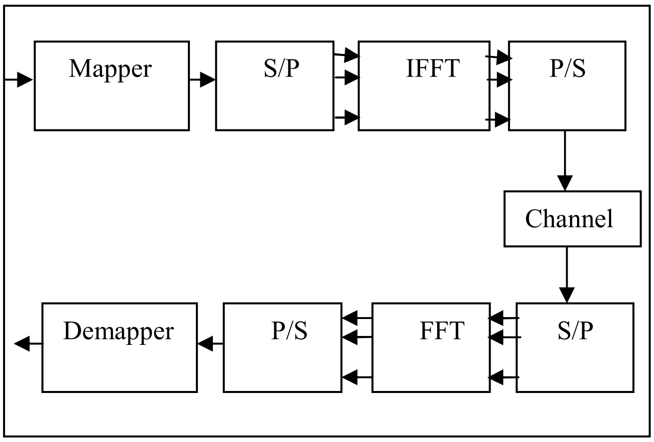

Figure 1. Block diagram of OFDM system

Fig. 1 illustrates the block diagram of an OFDM system. The baseband modulated symbols are passed through S/P converter which generates complex vector of size *N*. We can write the complex vector of size *N* as $X = [X_0, X_1, X_{2\ldots} X_{N-1}]^T$ and then X is then passed through the IFFT block. The complex baseband OFDM signal with *N* subcarriers can be written as

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \, . \, e^{j2\pi \frac{n}{N} k} \text{ , } n=0,\ 1,\ 2 \ldots N-1 \tag{1}$$

where $j=\sqrt{-1}$ and the PAPR of OFDM signal in (1) can be written as

$$PAPR = \frac{max|x_n|^2}{E[|x_n|^2]} \tag{2}$$

where *E* [.] denotes expectation and the Complementary Cumulative Distribution Function (CCDF) for an OFDM signal can be written as

$$P\ (PAPR > PAPR_0) = 1 - (1 - e^{-PAPRo})^{N} \tag{3}$$

where $PAPR_0$ is the clipping level and this equation can be read as the probability that the PAPR of a symbol block go over some clip level $PAPR_0$.

B. SLM Based OFDM System

The SLM is a PAPR reduction technique which is based on phase rotations. In SLM-OFDM system, a set of *V* different data blocks are formed at the transmitter representing the same information and a data block with minimum PAPR is selected for transmission [17].

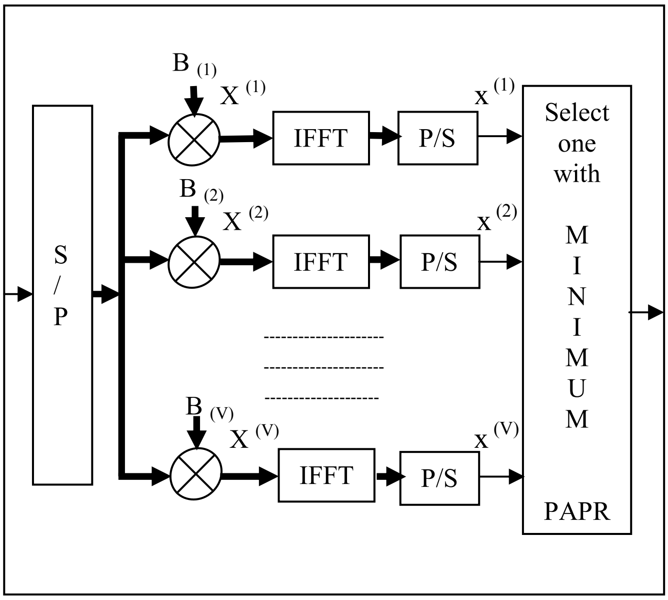

Figure 2. Block diagram of SLM based OFDM system.

Fig. 2 represents a block diagram of the SLM-OFDM system. Every data block is multiplied by *V* dissimilar phase sequences, each of length equal to *N*, $B^{(v)} = [b_{v,0}, b_{v,1}, \ldots, b_{v,N-1}]^T$, ($v$= 1, 2…$V$), which results in the changed data blocks. Now suppose the altered data block for the v^{th} phase sequence is given by $X^{(v)} = [\,X_0 b_{v,0},\ X_1 b_{v,1}, \ldots, X_{N-1} b_{v,N-1}]^T$, v=1, 2… V. Each X_n^v can be defined as

$$X_n^v = X_n b_{v,n} \quad , \quad (1 \leq v \leq V) \tag{4}$$

After applying SLM to *X*, the OFDM signal becomes as

$$x_n^{(v)} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k^v . e^{j2\pi \frac{n}{N} k} \text{ , } n=0,1,2,\ldots,N-1 \tag{5}$$

v = *1, 2… V.*

The PAPR of OFDM signal in (5) can be written as

$$PAPR = \frac{max\left|x_n^{(v)}\right|^2}{E\left[\left|x_n^{(v)}\right|^2\right]} \tag{6}$$

Amongst the tailored data blocks $X^{(v)}$, v = *1, 2… V,* the data block with the least PAPR is chooses for transmission and as a side information the information about selected phase sequence must be sanded to the receiver. At the receiving end, the operation is performed in the reverse order to recover the actual data block.

C. *DCT Precoder Based OFDM System*

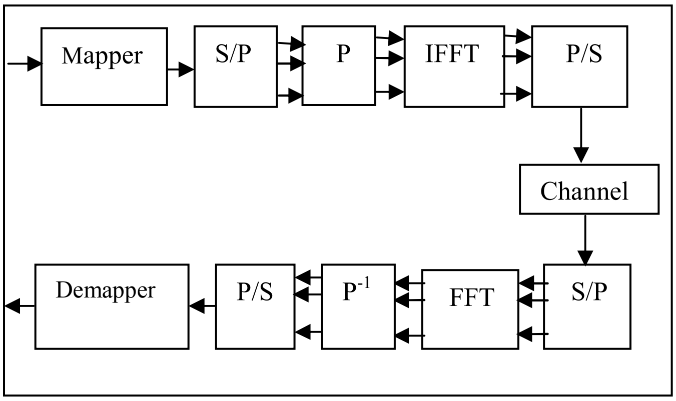

Figure 3. Block diagram of Precoding based OFDM system.

Fig. 3 shows a precoding based OFDM system. In this system a precoding matrix P of dimension N x N is constructed which is based on DCT. P is applied to constellations symbols before IFFT to reduce the PAPR. DCT matrix P of size N-by-N can be created by using equation (7)

$$D_{ij} = \begin{cases} \frac{1}{\sqrt{N}} & i = 0, \quad 0 \le j \le N-1 \\ \sqrt{\frac{2}{N}} cos \frac{\pi(2j+1)i}{2N} & 1 \le i \le N-1 \\ & 0 \le j \le N-1 \end{cases} \tag{7}$$

and DCT can be defined as

$$X_k = \sum_{n=0}^{N-1} x_n . cos\left[\frac{\pi}{N}\left(n + \frac{1}{2}\right)k\right] \tag{8}$$

where *k=0,1,...,N-1.* In precoding based OFDM system baseband modulated data is passed through S/P convertor which generates a complex vector of size N that can be written as $X = [X_0, X_1, X_2 \ldots X_{N-1}]^T$. Then precoding is applied to this complex vector which transforms this complex vector into new vector of length N that can be written as $Y=PX= [Y_0, Y1, Y2 \ldots Y_{N-1}]^T$, Where P is a DCT based precoding Matrix of size $M = N \times N$. With the use of reordering as given in equation (9)

$$k = mN + n \tag{9}$$

matrix P can be written as

$$P = \begin{bmatrix} p_{00} & p_{01} & \cdots & p_{0(N-1)} \\ p_{10} & p_{11} & \cdots & p_{1(N-1)} \\ \vdots & \vdots & \ddots & \vdots \\ p_{(N-1)0} & p_{(N-1)1} & \cdots & p_{(N-1)(N-1)} \end{bmatrix} \tag{10}$$

Accordingly, precoding X gives rise to Y as follows:

$$Y = PX \tag{12}$$

$$Y_m = \sum_{l=0}^{N-1} p_{m,l} X_n \qquad m = 0,1, \ldots N-1 \tag{13}$$

$p_{m,l}$ means l^{th} row and m^{th} column of precoder matrix. The complex baseband OFDM signal with N subcarriers can be written as

$$x_n = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} Y_m . e^{j2\pi\frac{n}{N}m}, \; n=0,1,2,...,N-1 \tag{14}$$

The PAPR of OFDM signal in (14) can be written as

$$PAPR = \frac{max|x_n|^2}{E[|x_n|^2]} \tag{15}$$

D. *Simulation Based Analysis*

We simulate and compare a few Precoding based OFDM systems in MATLAB®. To show the effect of precoding based OFDM systems we consider 4-QAM modulation with 10^5 random OFDM blocks.

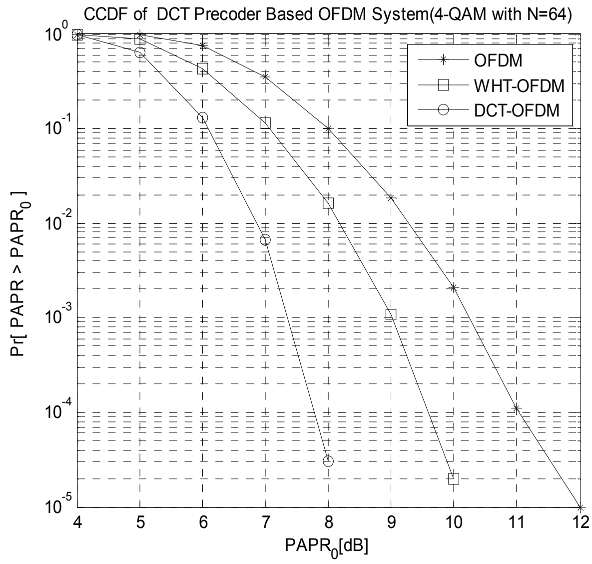

Figure 4. CCDF of OFDM Original, WHT Precoder Based OFDM System and DCT Precoder Based OFDM System, 4-QAM for N=64.

Fig. 4 shows the CCDF comparisons of DCT precoder based OFDM system, WHT precoder based OFDM system and OFDM Original System, for N = 64. At clip rate of 10^{-4} , the PAPR gain of 1dB is achieved when we compare WHT Precoder based OFDM system with OFDM Original System and PAPR gain of 2.5dB is achieved when we compare DCT Precoder based OFDM system with OFDM Original System.

III. Proposed Model

DCT Precoder Based SLM System

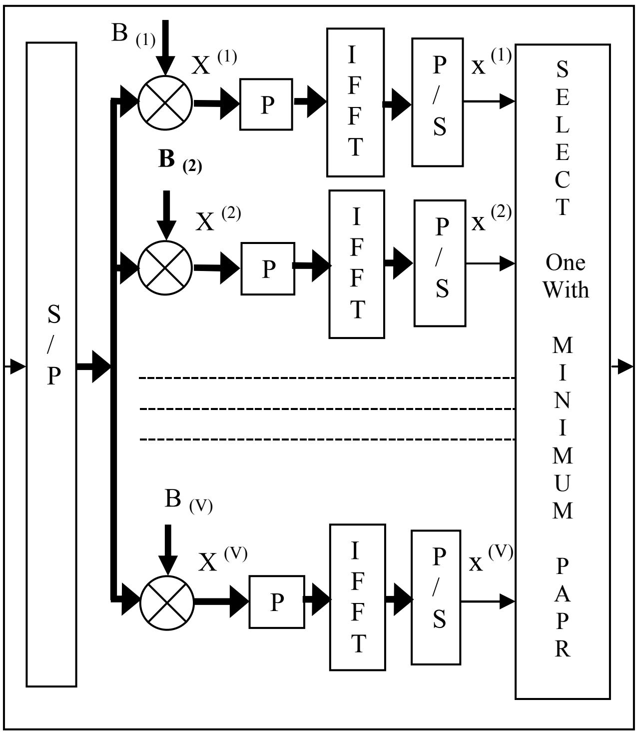

Figure 5.Block diagram of DCT Precoder based SLM-OFDM System.

The block diagram of the proposed DCT Precoder based SLM-OFDM system can be shown in fig. 5. Suppose data stream after Serial to parallel conversion is $X = [X_0, X_1, X_{2\ldots}\ X_{N-1}]^T$ and each data block is multiplied by V dissimilar phase sequences, each length equal to N, $B^{(v)} = [b_{v,0}, b_{v,1}, \ldots, b_{v,N-1}]^T$, ($v$= 1, 2…V), which results in the altered data blocks. Let us denote the altered data block for the v^{th} phase sequence is given by

$$X^{(v)} = [X_0 b_{v,0},\ X_1 b_{v,1}, \ldots, X_{N-1} b_{v,N-1}]^T \text{ , } v=1, 2, 3\ldots V.$$

Each X_n^v can be defined as

$$X_n^v = X_n b_{v,n} \quad , \quad (1 \le v \le V) \tag{16}$$

Now we pass the signal given in equation (13) through our DCT Precoder based precoder and the resultant signal can be written as

$$Y_m^v = \sum_{n=0}^{N-1} p_{m,n} X_n^v \qquad m = 0,1, \ldots N-1 \tag{17}$$

where $p_{m,n}$ means precoding matrix of n^{th} row & m^{th} column The signal in equation (14) after performing the IFFT can be written as

$$x_n^{(v)} = \frac{1}{\sqrt{N}} \sum_{m=0}^{N-1} Y_m^v . e^{j2\pi \frac{n}{N} m} \text{ , } n=0, 1, 2\ldots N\text{-}1 \tag{18}$$

where v = 1, 2… V and the PAPR of OFDM signal in (18) can be written as

$$PAPR = \frac{max \left| x_n^{(v)} \right|^2}{E[\left| x_n^{(v)} \right|^2]} \tag{19}$$

Precoding based SLM technique needs V IFFT operations and the information bits required as side information for each data block is $\lfloor log_2 V \rfloor$. Precoding based SLM technique is applicable for any number of subcarriers and all types of modulation techniques.

The PAPR reduction for Precoding based SLM technique depends on the number of phase sequences V and the output data with lowest PAPR is selected by the transmitter for transmissions.

IV. Simulation Results

Extensive simulations in MATLAB(R) have been performed in order to evaluate the performance of our proposed DCT precoder based SLM-OFDM system. We compared our results with OFDM original, SLM conventional and WHT precoder based OFDM systems for N=64, 256 & 512 with V=4 & 16. To show the effect of our proposed DCT Precoder based SLM-OFDM system we considered 4-QAM modulation technique with 10^4 random OFDM blocks and the clipping probability (Clip Rate of 10^{-3}) is used.

Figure 6 shows the CCDF comparisons of SLM-OFDM system, WHT precoder based SLM-OFDM system and our proposed DCT precoder based SLM-OFDM system with OFDM original system for N=64 and V=4.At clip rate of 10^{-3}, the PAPR gain of 2.2dB is achieved when we compare SLM-OFDM system with OFDM Original System, PAPR gain of 3dB is achieved when we compare WHT precoder based SLM-OFDM system with OFDM Original System and PAPR gain of 3.2dB is achieved when we compare our proposed DCT precoder based SLM-OFDM system with OFDM Original System.

Figure 7 shows the CCDF comparisons of SLM-OFDM system, WHT precoder based SLM-OFDM system and our proposed DCT precoder based SLM-OFDM system with OFDM original system for N=64 and V=16.At clip rate of 10^{-3}, the PAPR gain of 3.2dB is achieved when we compare SLM-OFDM system with OFDM Original System, PAPR gain of 3dB is achieved when we compare WHT precoder based SLM-OFDM system with OFDM Original System and PAPR gain of 4dB is achieved when we compare our proposed DCT precoder based SLM-OFDM system with OFDM Original System.

Figure 8 shows the CCDF comparisons of SLM-OFDM system, WHT precoder based SLM-OFDM system and our proposed DCT precoder based SLM-OFDM system with OFDM original system for N=256 and V=4. At clip rate of 10^{-3}, the PAPR gain of 2dB is achieved when we compare SLM-OFDM system with OFDM Original System, PAPR gain of 3dB is achieved when we compare WHT precoder based SLM-OFDM system with OFDM Original System and PAPR gain of 3dB is achieved when we compare our proposed DCT precoder based SLM-OFDM system with OFDM Original System.

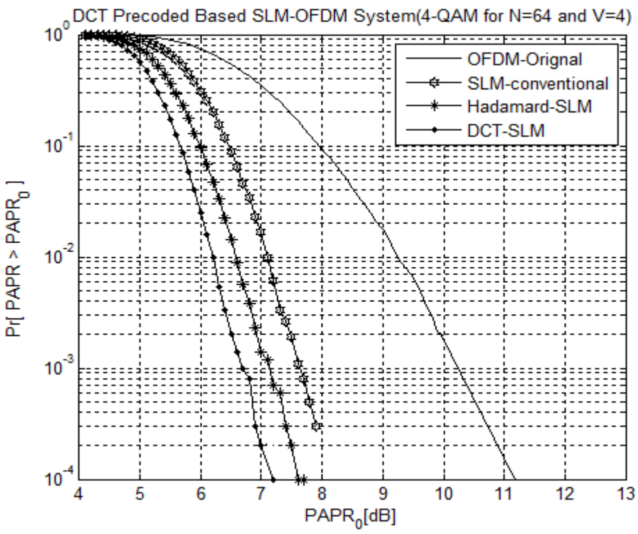

Figure 6. CCDF of the PAPR of OFDM Original, SLM Conventional, WHT Precoder based SLM-OFDM System & DCT Precoder based SLM-OFDM for N=64 & V=4.

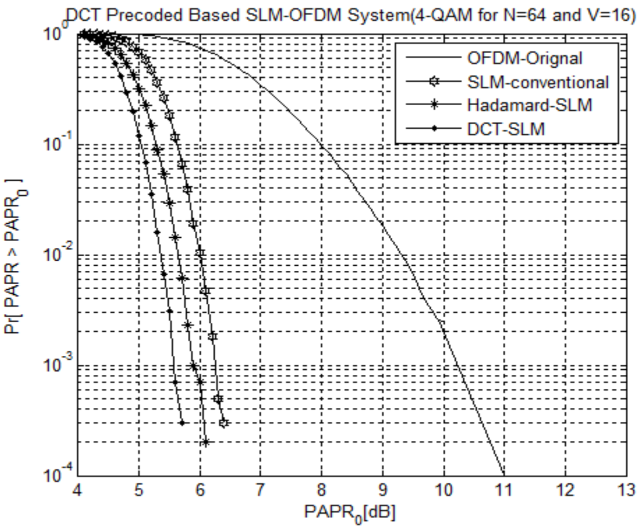

Figure 7. CCDF of the PAPR of OFDM Original, SLM Conventional, WHT Precoder based SLM-OFDM System & DCT Precoder based SLM-OFDM for N=64 & V=16.

Figure 9 shows the CCDF comparisons of SLM-OFDM system, WHT precoder based SLM-OFDM system and our proposed DCT precoder based SLM-OFDM system with OFDM original system for N=256 and V=16. At clip rate of 10^{-3}, the PAPR gain of 3dB is achieved when we compare SLM-OFDM system with OFDM Original System, PAPR gain of 3dB is achieved when we compare WHT precoder based SLM-OFDM system with OFDM Original System and PAPR gain of 3.9dB is achieved when we compare our proposed DCT precoder based SLM-OFDM system with OFDM Original System.

Figure 10 shows the CCDF comparisons of SLM-OFDM system, WHT precoder based SLM-OFDM system and our proposed DCT precoder based SLM-OFDM system with OFDM original system for N=256 and V=4. At clip rate of 10^{-3}, the PAPR gain of 2dB is achieved when we compare SLM-OFDM system with OFDM Original System, PAPR gain of 3dB is achieved when we compare WHT precoder based SLM-OFDM system with OFDM Original System and PAPR gain of 3dB is achieved when we compare our proposed DCT precoder based SLM-OFDM system with OFDM Original System.

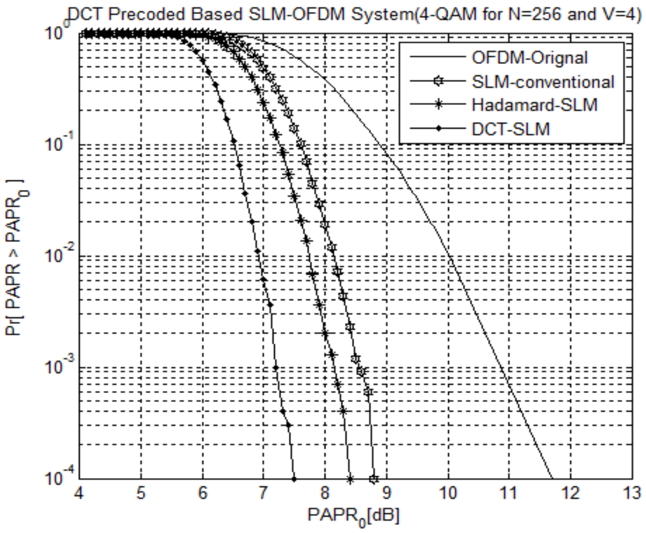

Figure 8. CCDF of the PAPR of OFDM Original, SLM Conventional, WHT Precoder based SLM-OFDM System and Zadoff-Chu Precoder based SLM-OFDM for N=256 and V=4.

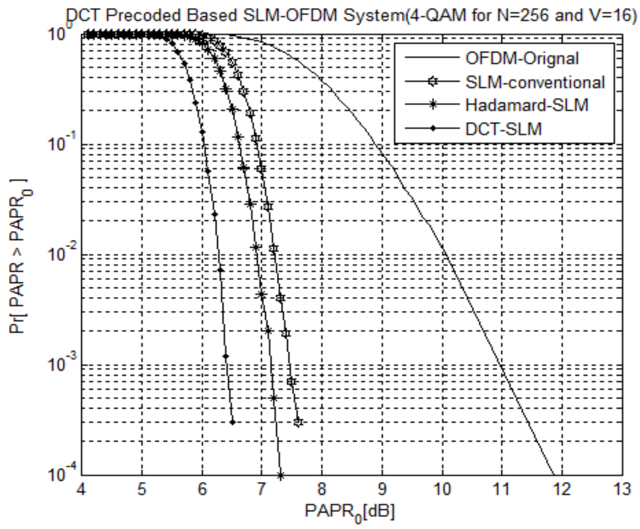

Figure 9. CCDF of the PAPR of OFDM Original, SLM Conventional, WHT Precoder based SLM-OFDM System and Zadoff-Chu Precoder based SLM-OFDM for N=256 and V=16.

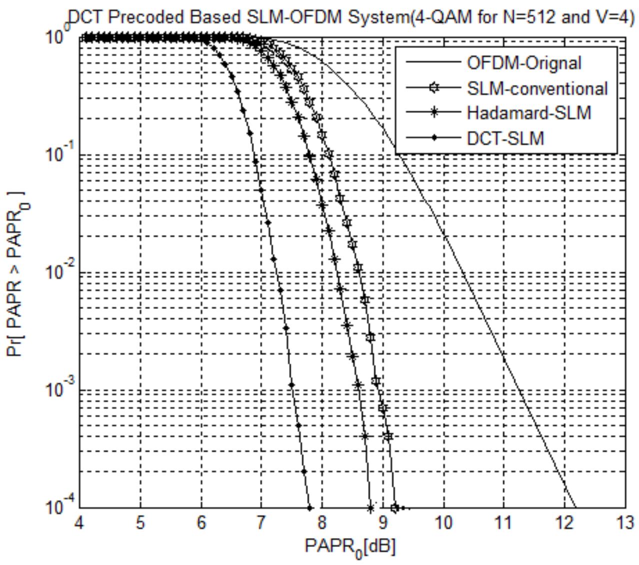

Figure 10. CCDF of the PAPR of OFDM Original, SLM Conventional, WHT Precoder based SLM-OFDM System and Zadoff-Chu Precoder based SLM-OFDM for N=512 and V=4.

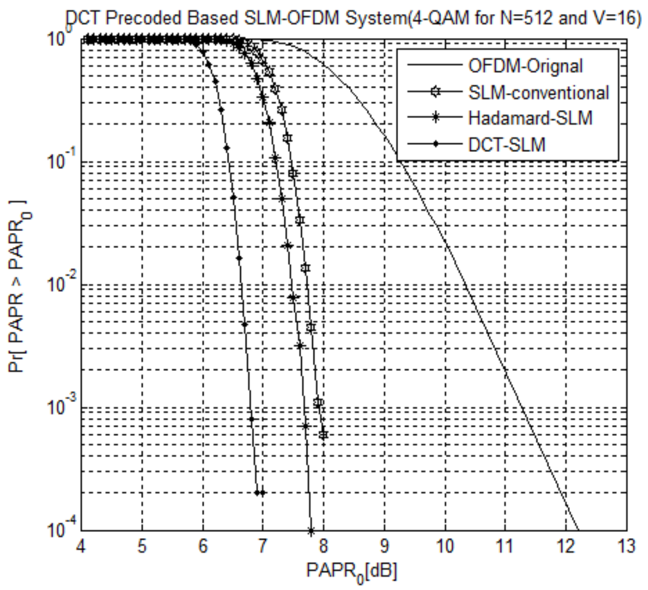

Figure 11. CCDF of the PAPR of OFDM Original, SLM Conventional, WHT Precoder based SLM-OFDM System and Zadoff-Chu Precoder based SLM-OFDM for N=512 and V=16.

Figure 11 shows the CCDF comparisons of SLM-OFDM system, WHT precoder based SLM-OFDM system and our proposed DCT precoder based SLM-OFDM system with OFDM original system for N=512 and V=16. At clip rate of 10^{-3}, the PAPR gain of 3.2dB is achieved when we compare SLM-OFDM system with OFDM Original System, PAPR gain of 3dB is achieved when we compare WHT precoder based SLM-OFDM system with OFDM Original System and PAPR gain of 4dB is achieved when we compare our proposed DCT precoder based SLM-OFDM system with OFDM Original System.

TABLE 1
PAPR Analysis of our proposed proposed DCT precoder based SLM technique with SLM conventional technique at clipping probability (Clip Rate of 10^{-3})

PAPR Reduction Technique	PAPR Gain in dB					
	N=64		N=256		N=512	
	V=4	V=16	V=4	V=16	V=4	V=16
DCT-SLM	3.2	4.0	3.0	3.9	3.2	4.0
SLM	2.2	3.2	2.0	3.0	2.0	3.2

Furthermore in Table 1, we compare our proposed DCT precoder based SLM technique with SLM conventional technique at clipping probability (Clip rate of 10^{-3}). It can be seen that our proposed technique shows 1dB better PAPR gain when we compare with SLM conventional. It is obvious in the table that PAPR gain of our proposed technique at V=4 and SLM conventional at V=16 is the same, the complexity of SLM is increases with increase in V. Hence, it is also concluded that our proposed DCT precoder based SLM technique reduces the computational complexity.

V. CONCLUSIONS

In this paper, we proposed a DCT precoder based SLM technique to reduce the high PAPR generated by multi carrier modulation in the OFDM system. At clip rate of 10^{-3}, $N = 64$ and $V = 16$, this technique can reduce PAPR up to about 5.5dB. Our proposed technique can reduce more PAPR if we increase the value of V, but with the increase in the value of V the computational complexity is also increased. Thus, the value of V should be chosen carefully. Additionally, this technique is efficient, signal independent, distortionless, it does not require any complex optimization.

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