DCT Based Modified SLM Technique for PAPR Reduction in OFDM Transmission

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Abstract - Orthogonal Frequency Division Multiplexing (OFDM) is a promising multicarrier technique used in wireless transmission with high data rate and high bandwidth efficiency. One of the major drawbacks of OFDM transmission is high Peak to Average Power Ratio (PAPR).In this paper, a DCT based modified selective mapping technique is proposed to reduce the PAPR of the transmitted signal. This method combines Discrete Cosine Transform (DCT) with modified Selective Level Mapping (SLM), a variant of SLM that make use of the standard array of linear block codes. The proposed method can be realized in two ways- scheme 1 and 2. In scheme1 DCT is used before the IFFT block in Modified SLM and in scheme 2 DCT is used after the Modified SLM block. Simulation results shows that Scheme 1 is having better reduction performance than the scheme 2 and all the other methodologies discussed and realized in the paper.

Index Terms – CCDF, DCT, DCT SLM, Modified SLM, OFDM, PAPR, SLM.

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1 INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is one of the important multicarrier transmission techniques and is used in various wireless and wire-line systems because of its high data rates, high spectral efficiency, high quality of service and robustness against narrow band interference and frequency selective fading [1]. OFDM is a type of Frequency Division Multiple Access (FDMA) in the sense that multiple user access is achieved by sub-dividing the available bandwidth into multiple channels, which are then allocated to users. However OFDM uses the spectrum much more efficiently by spacing the channels more closely together. This is achieved by making all the carriers orthogonal to one `another, preventing interference between the adjacent carriers as shown in fig. 1.
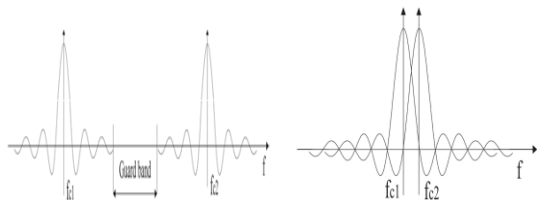

Fig. 1 Carrier spacing in FDM and OFDM

OFDM have got certain disadvantages also. One of the major disadvantages of OFDM is high PAPR associated with the transmitted signal. Large PAPR leads to both in-band distortion and out of band radiation. It also increases the complexity of the analog-to-digital and digital-to analog converter and reduces the efficiency of the Radio-Frequency (RF) power amplifier used. Therefore it is useful to reduce the PAPR of the OFDM system.

To reduce PAPR, many techniques have been proposed. This paper deals with the study of a hybrid model that combines two powerful PAPR reduction schemes such as DCT SLM [2] and Modified SLM [3, 4]. The former combines DCT with the conventional SLM technique and the latter is a modified version of conventional SLM which makes the use of standard array of linear block codes.[5] The combination of these two models can achieve higher PAPR reduction than each one.

The organization of paper is as follows. Section 2 describes about the PAPR problem and the various reduction techniques. A brief description about the existing methodologies that are taken in to consideration for formulating the new model is explained in section 3. Section 4 gives a brief description of the proposed methodology which is the hybrid model. The simulation results of the existing methodologies and the proposed methodology along with the comparison table is given in section 5. Finally the work is concluded in section 6.

2 PAPR (PEAK-TO-AVERAGE POWER RATIO)

The Peak to Average Power Ratio (PAPR) of OFDM is defined as the ratio between the maximum instantaneous power and the average power, defined by

$$\text{PAPR} = \frac{P_{peak}}{P_{average}} = \frac{\max|x(t)|^2}{E[\,|x(t)|]^2} \qquad (1)$$

where x(t) denotes an OFDM signal after IFFT, and E[.] denotes expectation.The complex baseband OFDM signal for N subcarriers can be represented as

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k \exp(j2\pi k \Delta f t) \qquad (2)$$

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where X_k is the data symbol carried by the kth subcarrier.

According to limit central theorem, when N is large, both the real and imaginary part of $s(t)$ are Gaussian distributed. The Cumulative Distribution Function (CDF) of the signal is:

$$F(z) = 1 - \exp(-z) \qquad (3)$$

If there are N subcarriers in an OFDM system, and all the sampling values are complete independence, the CDF of the system is given by the equation:

$$P(PAPR \le z) = (F(z))^N$$
$$= (1 - e^{-z})^N \qquad (4)$$

So in case of no over sampling, the Complementary Cumulative Distribution Function (CCDF), which is usually used as an important parameter to describe the PAPR of an OFDM system, is

$$P(PAPR > z) = 1 - (F(z))^N$$
$$= 1 - (1 - e^{-z})^N \qquad (5)$$

Several techniques have been proposed to reduce the PAPR. These techniques can mainly be categorized in to signal scrambling techniques and signal distortion techniques [6]. Signal scrambling techniques are all variations on how to scramble the codes to decrease the PAPR. Coding techniques can be used for signal scrambling [7]. However with the increase in the number of carriers the overhead associated with exhaustive search of the best code would increase exponentially. More practical solutions of the signal scrambling techniques are block-coding, Selective Level Mapping (SLM) and Partial Transmit Sequences (PTS) [8].

The signal distortion techniques introduce both In-band and Out-of-band interference and complexity to the system. The signal distortion techniques reduce high peaks directly by distorting the signal prior to amplification. Clipping the OFDM signal before amplification is the simplest method to limit PAPR. However clipping may cause large Out-Of Band (OOB) and in-band interference, which results in the system performance degradation.[9,10] Basic requirement of practical PAPR reduction techniques include the compatibility with the family of existing modulation schemes, high spectral efficiency and low complexity.

SLM is one of the probabilistic techniques adopted to reduce the PAPR of the OFDM signal. It is called Probabilistic technique as the probability of occurrence of high PAPR is reduced by modifying the signal [8]. Hence it can achieve PAPR reduction without distorting the signal and will not cause any loss of data. The main disadvantage of SLM is that the complexity is high. Now there are many extension schemes for reducing the complexity of SLM [11-14].

3 EXISTING METHODOLOGY

The existing methodology discussed here includes Selective

Level Mapping (SLM), Discrete Cosine Transform (DCT) SLM and modified SLM. The DCT SLM uses DCT for pre-coding the input before SLM block as well as can be used after SLM block. Modified SLM is a hybrid approach that uses the standard array of linear block codes. Each of the existing methodologies is discussed as follows.

3.1 SLM (Selective Level Mapping)

The SLM technique was first described by Bauml *et al.*[8]. In the SLM, from a number of copies that represent the same information, one with lowest PAPR is chosen for transmission.
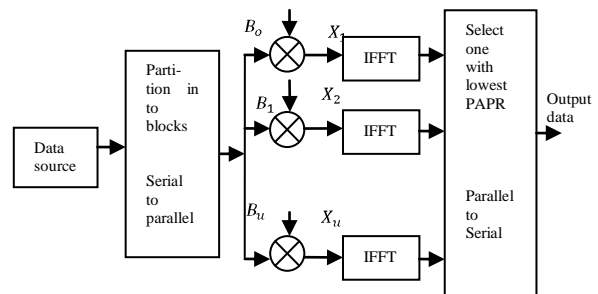

Fig. 4 SLM block diagram

Fig.2 shows the block diagram of the SLM technique. X is the OFDM data block, B_u is the phase vectors and X_u is the modified data vectors in the frequency domain. So the time domain signal,

$$X_U(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{k=N-1} X_k\, B_{u,k}\, e^{j2\pi K \Delta f t} \qquad (6)$$
$$0 \le t \le NT$$

where $u = 1,2\ldots U$, and N is length of X, also the number of sub-carriers.

Among the modified data blocks, the one with the lowest PAPR is selected for transmission. The amount of PAPR reduction for SLM depends on the number of phase sequences U and the design of the phase sequences.

Construction of OFDM frames representing the same information is by defining D distinct vectors:

$$\bar{B}^{(d)} = [B_1{}^{(d)},\ B_2{}^{(d)}, \ldots\ldots B_u{}^{(d)}] \qquad (7)$$

where $B_n{}^{(d)} = e^{j\varphi_n{}^{(d)}}$ is the rotation factor, n=0, 1,…,u. $\varphi_n{}^{(d)}$ is homogeneously distributed in $[0,2\pi]$. After modulating the vectors to N sub-carriers separately, each OFDM frame represents the same information. Then all D frames are transformed in to the time-domain using the IFFT and the one with the lowest PAPR is selected for transmission.

The block diagram of OFDM transmitter with SLM is shown in fig 2. To recover the data exactly, the receiver has to know which vectors of the D vectors is used .therefore it is necessary to transmit the number D of the vector as side information to the receiver.

As a result of selecting the sequence to transmit after IFFT, SLM technique needs D IFFT operations for each OFDM frame. It makes the system complicated. In addition, it's a difficulty in SLM that how to transmit side information.

3.2 DCT SLM

The idea to use the DCT transform is to re-duce the auto-correlation of the input sequence to reduce the peak to average power problem and it requires no side information to be transmitted to the receiver. Though SLM can obtain better PAPR by modifying the OFDM signal without distortion, its complexity is high. DCT SLM is an efficient PAPR reduction technique based on joint SLM and DCT matrix transform is proposed.

The main idea of the DCT SLM is to use a combination of two appropriate methods. One is the DCT matrix transform technique and the other is the SLM technique. The transmitter block is showed in fig 3. We call this scheme is scheme 1. In the transmit end, the data stream is firstly transformed by DCT matrix, then the transformed data is processed by the SLM unit. If data block passed by DCT matrix before IFFT, the autocorrelation coefficients of IFFT input is reduced, then the PAPR of OFDM signal could be reduced.
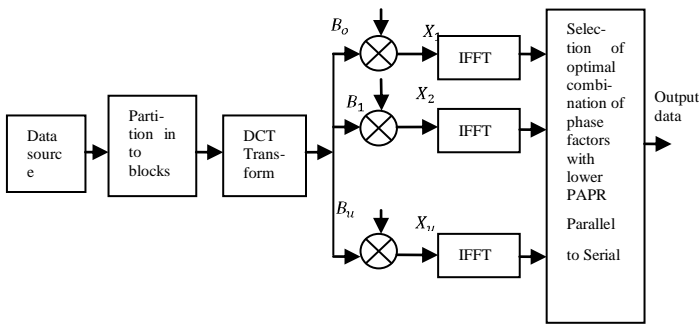

Fig.3 DCT before SLM

Also we use DCT matrix after SLM to further reduce the PAPR of signal. We call this scheme as scheme 2. In this fashion, the autocorrelation of the signal, which has been processed by SLM, is reduced by DCT matrix transform. The PAPR of fine output signal is further reduced. The block of transmitter is showed in fig 4.
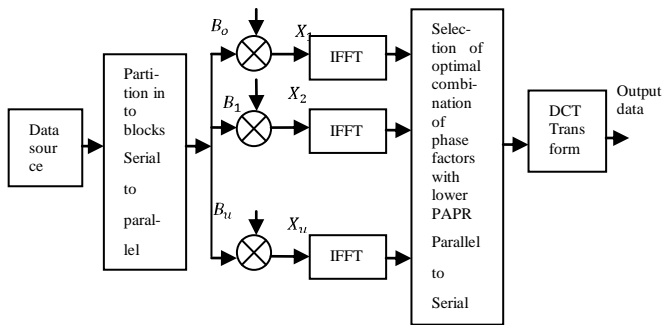

Fig.4 DCT after SLM

3.3 Modified SLM

The main purpose of the modified SLM technique is to re-duce PAPR and IFFT block. There is only one IFFT block at transmitter if the sequence which is the lowest PAPR can be found out by a decision algorithm before IFFT. The block diagram for modified SLM is given in fig.5.
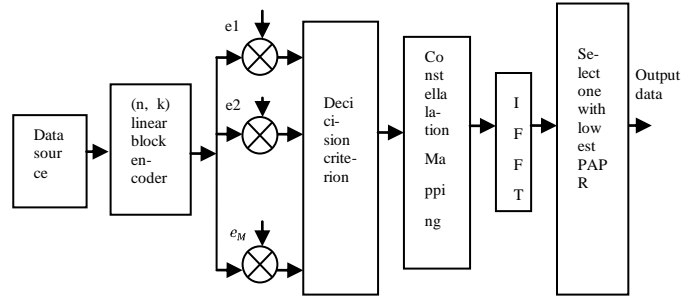

Fig.5 Modified SLM

The algorithm for modified SLM is as follows:

Step 1: A binary information source is divided into blocks of 4 bits.

Step 2: Each information block is encoded into a codeword c by a [7, 4] hamming encoder.

Step 3: A control bit added to codeword c to create an extended hamming code of 8 bits.

Step 4: Calculate the error table and coset leader, 16 in number

Step 5: Sixteen vectors are constructed as c+e1, c+e2, c+ e3..........etc

Step 6: For each scrambled codeword calculate the value of
$Z = U^2 + V^2 + W^2$

Step 7: Scrambled codeword with the minimum Z is selected and then Transformed to OFDM signal by constellation mapping and IFFT.

4 PROPOSED METHODOLOGY

The main idea of the proposed scheme is to use a combination of two appropriate methods described earlier. One is the DCT matrix transform technique and the other is the SLM technique. The transmitter block is showed in figure. We call this scheme is scheme 1. In the transmit end, the data stream is firstly transformed by DCT matrix, then the transformed data is processed by the modified SLM unit. If data block passed by DCT matrix before IFFT, the autocorrelation coefficients of IFFT input is reduced, then the PAPR of OFDM signal could be reduced.
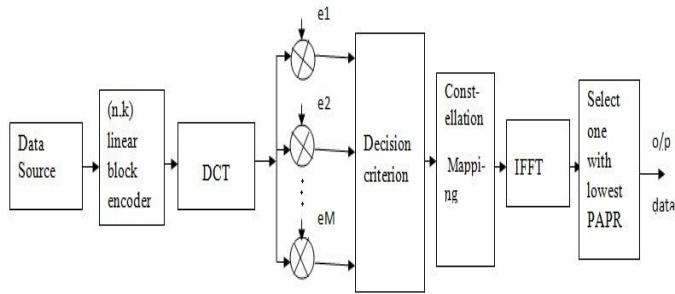
Fig. 6 DCT before modified SLM

In another approach, we use DCT matrix after modified SLM to further reduce the PAPR of signal. We call this scheme as scheme 2. In his fashion, the autocorrelation of the signal, which has been processed by SLM, is reduced by DCT.
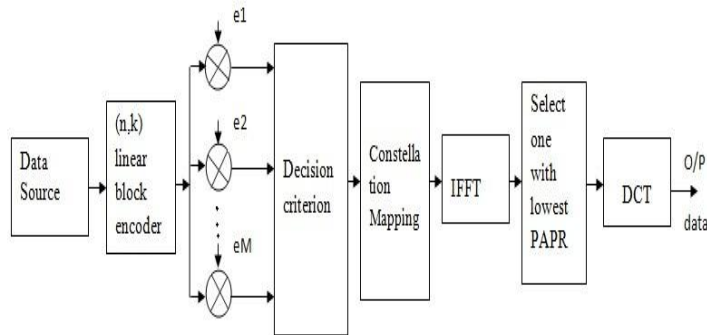

Fig 7 DCT after modified SLM

5 SIMULATION RESULTS

In this section the results of the simulations done using MATLAB are discussed and compared. The PAPR reduction performances of various existing methodologies as well as the proposed methodology are evaluated using the Complementary Cumulative Distribution Function (CCDF) of the PAPR of the output signal. Fig.8 represents the normal OFDM signal with 64,256 and 1024 subcarriers. We can see from the result that as the numbers of subcarriers increase the PAPR of the output signal increases, so we go for reduction methods.
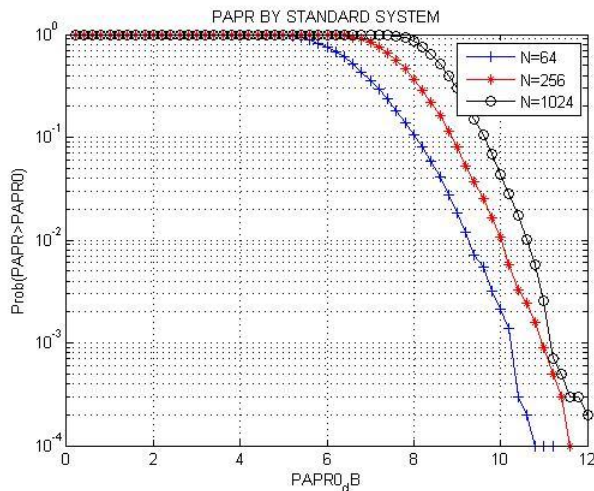

Fig 8 PAPR of basic OFDM system

For a 256 sub carrier system we can see that the PAPR of the Signal is about 11.8 db in a normal OFDM system which uses no reduction methods.By using reduction methods we can reduce the PAPR from 11.8 db to lower values.Fig.9 represents the PAPR reduction performance using SLM method. As the number of blocks representing the same information, D increases we can see that the PAPR of the signal comes down.

Further reduction in PAPR can be achieved by using DCT SLM. Fig.10 shows the PAPR reduction performance when DCT is used before IFFT and fig.11 shows the same when DCT is used after IFFT. We can infer that DCT used before the SLM block achieve good reduction performance compared to reduction performance of the other scheme.
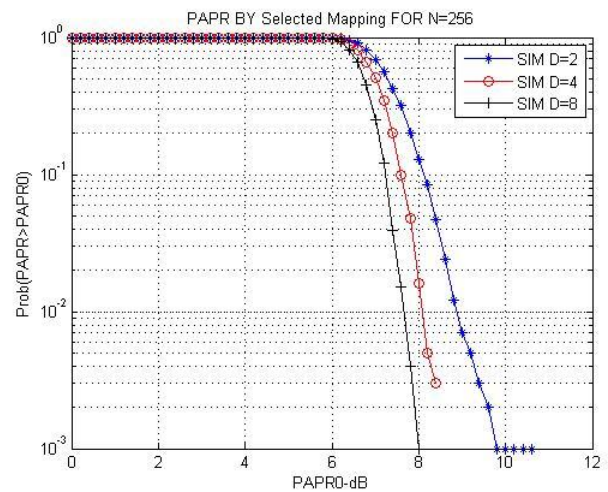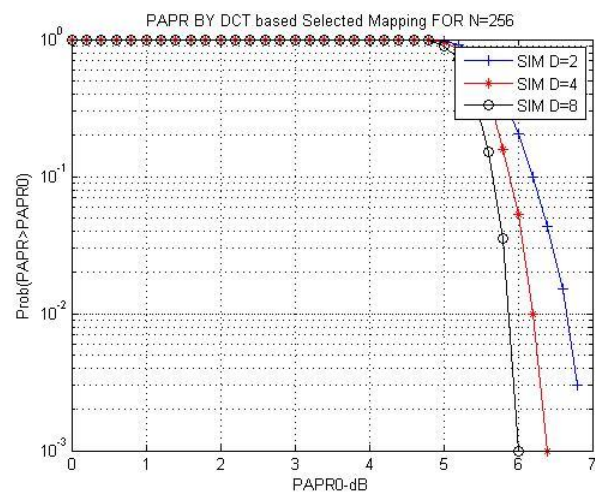

Fig 9 PAPR of conventional SLM system

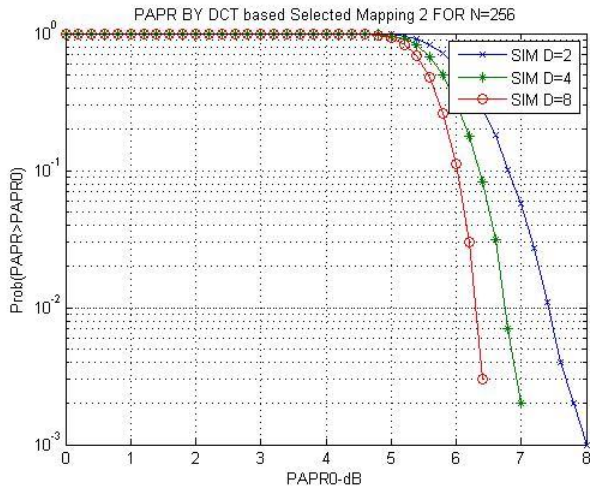Fig.10 PAPR of DCT SLM system-scheme 1
(DCT before SLM)
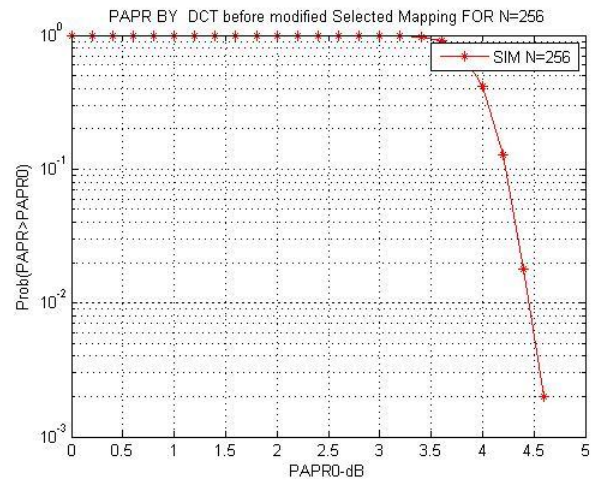
Fig.11 PAPR of DCT SLM system-scheme 2
(DCT after SLM)

Fig.12 represents the output of Modified SLM in which the PAPR of the signal got reduced further reduced. Modified SLM reduces the complexity of the SLM architecture by decreasing the number of IFFT blocks used as well as it reduces the PAPR to a fair amount which is about 5.8 db for a 256 subcarrier system.Thus we can see that almost 6 db got reduced from the normal OFDM by using modified SLM.
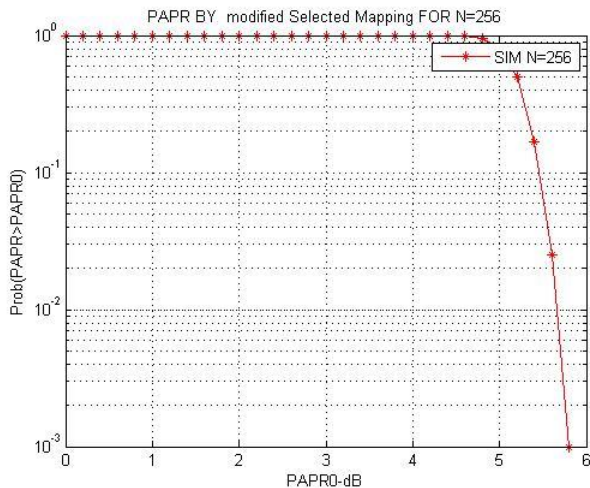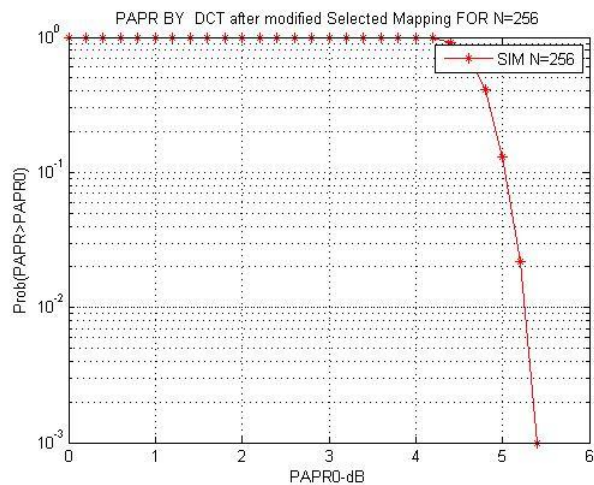

Fig.12 PAPR of Modified SLM system

Fig 13 and 14 represents the output of the proposed methodology. Fig.14 shows the simulation result for inputs processed by DCT block before the IFFT in Modified SLM which is cited as scheme 1 and the output of the scheme 2 in which the DCT is used after modified SLM is shown in fig.14.As we have seen above in the case of DCT SLM, here also DCT used before modified SLM performs better than the other scheme which uses DCT after the modified SLM block.

Fig.13 PAPR of DCT based Modified SLM -scheme1
(DCT used beforeIFFT in SLM)

Fig.14 PAPR of DCT Modified SLM system scheme2
(DCT used after SLM)

Table.1 gives a brief overview of the PAPR reduction performance of the various existing methodologies cited in this paper. N represents the number of subcarriers and D represents the number of blocks representing the same information. The factor D comes in to play only for SLM and DCT SLM. In modified SLM there are no blocks representing same information, instead a standard array of code words is formed. Simulation results are for N=256 and D=2, 4 and 8.

TABLE 1
Comparison of Various Methods of PAPR Reduction

Methodology	N=256 and	N=256 and	N=256 and

	D=2	D=4	D=8
Basic System (No D here)	11.8	11.8	11.8
Conventional SLM	9.8	9	7.9
DCT SLM (scheme1-DCT before SLM)	6.8	6.6	6
DCT SLM (scheme2-DCT after SLM)	7.8	7.6	6.5
Modified SLM (no D here)	5.8	5.8	5.8
DCT-Modified SLM Scheme 1-DCT before IFFT in Modified SLM (no D here)	4.6	4.6	4.6
DCT-Modified SLM Scheme 2-DCT after Modified SLM (no D here)	5.3	5.3	5.3

6 CONCLUSION

The paper presents an efficient method to reduce the PAPR of the OFDM signal.The new model combines the features of DCT SLM as well as that of modified SLM to produce further reduction in the PAPR of the signal than they perform individually.From the above results it is evident that in DCT SLM with 8 blocks representing the same information, the PAPR got reduced to 6 db ,reducing almost 5.8 db from the normal OFDM system which can be improved further by increasing the number of blocks that represents the same information,sacrificing the complexity of the architecture.As such trade off exists in DCT SLM we cannot go on increasing the number of blocks that represent the same information, but the usage of DCT in SLM architecture improves the PAPR as we can see that ,almost 1.9 db got reduced in DCT SLM with D=8 than conventional SLM with D=8. Therefore it is exploited in modified SLM, which itself perform abot 6 db reduction from normal OFDM. Therefore when DCT is used, it is evident from the results that about 7.2 db got reduced than the normal OFDm system and about 1.2 db than the modified SLM .Further modifications can be done to improve the reduction performance of this hybrid model using Discrete Wavelet Transform (DWT) [14] instead of using the conventional IFFT.and by adopting new modulation schemes like $\pi/4$-shifted DQPSK modulation. [13]

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