PAPR Reduction for OFDM System using DCT Based Modified PTS Technique

S. SUJATHA, R.JAYSHRI and P. DANANJAYAN
Department of ECE
Pondicherry Engineering College
Pondicherry, India
sujatha.s@cmrit.ac.in, Jayaravikumar.cl@gmail.com, pdananjayan@pec.edu

Abstract: - Though the OFDM provides high data rate due to its high spectral efficiency, it has high PAPR which results in performance degradation and high out of band radiation due to nonlinearity of the high power amplifier. Partial Transmit sequence is one of the distortions-less PAPR reduction techniques which obtain the minimum PAPR signal by multiplying suitable phase factors with sub-sequenced subcarriers. In order to reduce PAPR even more, autocorrelation among data should be less. So DCT is applied along with PTS technique which has the property of reduction of autocorrelation. In the proposed method DCT is applied before PTS technique and after the PTS technique. The simulation results show that DCT preceding PTS technique has better performance compared to DCT succeeding PTS technique. The analysis of the both the proposed method is carried out with different subcarriers and sub-blocks are discussed.

Key-Words: - OFDM, PAPR, IFFT, DCT, IDCT, Modified PTS.

1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) [1] is a parallel data transmission scheme which is capable of providing high speed transmission by employing orthogonal set of subcarriers. Here the input serial data stream is converted into parallel data symbols and each data symbol is modulated using an orthogonal subcarrier. Because of this, the wideband spectrum is broken into many narrowband spectrums, each carrying a data symbol. This conversion permits the use of simpler equalization technique at the receiver to retrieve the transmitted data symbols. By adopting parallel data transmission, the frequency selective fading which may occur over many data symbols is reduced to single sub-carriers resulting in reduced distortion.

OFDM system processes the input serial data bits into parallel data bits using serial to parallel converter. Then IFFT of parallel data bits are carried out which is used to produce 'N' number of parallel orthogonal subcarriers. The orthogonal subcarriers are used to overcome the crosstalk between the sub channels. OFDM makes use of IFFT [2] block which reduces the system complexity appreciably. Without IFFT blocks, bank of modulators and demodulators are used for producing the number of subcarriers which makes the system more complex and expensive. After IFFT operation, parallel to serial conversion of orthogonal subcarrier is done. Since the spectra of OFDM signal are not strictly band limited, guard interval is used to mitigate the multipath effects which lead to spreading of energy of signal from one sub-channel into other adjacent sub-channels. The guard interval is a cyclic extension, in which each OFDM symbol is preceded by a periodic extension of the signal itself. It should be greater than channel impulse response or multipath delay. It is added to serially converted orthogonal subcarriers to overcome the Inter-carrier Interference (ICI) and for receiver carrier synchronisation.

OFDM system has many advantages like high spectral efficiency because bandwidth required for OFDM is less compared to single carrier systems. It mitigates several effects of channel conditions like selective fading and ISI due to its parallel data transmission. It requires simple equalization technique at the receiver side because the frequency response over each individual sub-band is relatively flat. Even though it has many advantages for transmission criteria, it has several degrading issues like sensitive to Doppler shift because of parallel data streams, sensitive to frequency synchronisation at the receiver side, peak to average power problem at transmitter side. Among the disadvantages of OFDM system, PAPR problem is of major issue because it requires very efficient High Power Amplifiers (HPA) and Digital to Analog Converter (DAC) to resolve it. Many PAPR reduction techniques[3] are proposed for OFDM system, which are broadly categorized into two techniques, *viz* signal distortion techniques and signal distortionless techniques.

The clipping and filtering technique [3, 4] is one of the nonlinear process which is of signal distortion PAPR reduction technique type. In this technique, the signal power level above the operating point of HPA is clipped before the amplification process. Filtering technique is then applied to reduce the spectral splatter caused by clipping of OFDM signal. It reduces the crest factor of OFDM signals using realistic linear amplifiers but has a main disadvantage of peak regrowth. This technique has the probability of clipping of the information bits leads to poor BER performance. In the coding PAPR reduction technique[3,5,6], from all the codewords generated, the particular codeword with reduced PAPR is selected for further processing and it gives good BER at the receiver side. In this technique, there is a tradeoff between coding rate and PAPR reduction level. This method has a disadvantage of high computation complexity. The signal distortionless technique is comprised of two methods, Selected Mapping (SLM) and Partial Transmit Sequence (PTS). In SLM [3,7] method, the parallel data sequences are multiplied with different phase factors and IFFT operation is carried out individually to all parallel data sequences. After this the set of signals with minimum PAPR is selected for transmission. This method requires $\log_2^v$ number of data bits for transmitting the side information of phase factors where 'v' is number of phase factors used. Increasing the number of phase factors reduces PAPR of the OFDM signals appreciably. The disadvantages of this method are high hardware complexity, computation complexity increases with increase in number of phase factors. In PTS technique [3,8], the parallel data sequences are separated into several subsequence's and IFFT operation is done individually to every partitioned subsequence's. After this different combination of phase factors are multiplied with those IFFT transformed data. The set of signals with minimum PAPR is selected for transmission. Here also $\log_2^v$ number of data bits for transmitting the side information of phase factors is required. Here the hardware complexity decreases by using only IFFT blocks equal to number of phase factors employed. Modified PTS technique is a kind of PTS technique which employs neighbourhood searching algorithm instead of exhaustive search of minimum PAPR signals. This PTS technique reduces PAPR efficiently but even more PAPR can be reduced by reducing the autocorrelation between data sequences. Discrete cosine transform is a transform which has the major advantages of reduction of autocorrelation and signal energy compaction. So the proposed work combines the DCT with modified PTS technique for reduction of PAPR.

2. Characteristics Of OFDM Signal

Orthogonal Frequency Division Multiplexing is the combination of orthogonal frequency modulation and frequency multiplexing of orthogonal subcarriers. Let us consider 'n' data symbols, where $X=\{x_k, k=0,1,\ldots\ldots.n-1\}$. Each data symbols are frequency modulated using subcarriers of frequency f_k where $k=0,1,\ldots.n-1$. The subcarriers are orthogonal to each other, which mitigates crosstalk between the subbands. The subcarriers are placed at equal intervals and subcarrier spacing is equal to $1/T_s$ where T_s is symbol period. Therefore, subcarrier frequency $f_k = k\Delta f$ where $\Delta f=1/NT_s$. The IFFT applied OFDM signal is represented by following equation (1),

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t}, \quad 0 \le t \le NT_s \qquad (1)$$

Here input data bits are statistically independent and identically distributed (i.i.d). The real and imaginary parts of *x(t)* are statistically uncorrelated and orthogonal.

3. Peak To Average Power Ratio

The OFDM has a main drawback of Peak to Average Power Ratio(PAPR) which requires very efficient and expensive HPA and DAC for processing. PAPR is defined as the ratio of maximum squared peak value of OFDM signals to squared average of all OFDM signals employed. PAPR is a measure of the amount of power greater than the average power. PAPR is mainly derived from the term called Crest Factor(CF). CF is equal to square root of PAPR of the OFDM signals. The CF is given by the equation (2),

$$CF = \frac{|x_{peak}|}{x_{rms}} \qquad (2)$$

Therefore PAPR of the OFDM signal is given by the equation (3),

$$PAPR = \frac{\max\left[|x(t)|\right]^2}{E\left[|x(t)|\right]^2} \qquad (3)$$

The PAPR value is usually measured in decibels because PAPR is a unit less quantity. The PAPR in dB is given by the equation (4) and (5)

$$PAPR(dB) = 10\log_{10}(PAPR) \qquad (4)$$

$$P\{PAPR > PAPR_0\} = 1-[1-e^{-PAPR_0}]^N \qquad (5)$$

4. Complementary Cumulative Distribution Function

The nature of OFDM signals is of Rayleigh distribution and they are statistically uncorrelated. The probability density function for the OFDM signals are given by

$$fx_n = 2xe^{-x^2} \qquad (6)$$

where n={0,1,…..N-1}. Here 'N' is the total number of subcarriers. From the equation (5) the maximum of x_n is equivalent to the crest factor. So the Cumulative Distribution Function for the PAPR is given by,

$$CDF = \Pr\{x_{\max} < x\} \qquad (7)$$

$$CDF = (1-e^{-x})^N \qquad (8)$$

The Complementary cumulative Distribution Function (CCDF) [10] is given by equation (10),

$$CCDF = 1 - CDF \qquad (9)$$

$$CCDF = 1-(1-e^{-x})^N \qquad (10)$$

With the help of CCDF plot, it is possible to know that how many OFDM signals have PAPR that are above certain clipping level.

5. PARTIAL TRANSMIT SEQUENCE

Partial transmit sequence algorithm [10] is a signal distortionless technique which reduces the PAPR by improving the PAPR statistics of OFDM signal. In this algorithm, modulated data sequence is divided into several sub-sequences. For every individual sub-sequences the IFFT operation is carried out then its multiplied with different combinations of phase factors. Initially data block is considered as vector of $X=[x_1, x_2,\ldots xn]^T$. Then X is partitioned into 'm' number of disjoint sets $\{X_m, m=1,2,\ldots M\}$. Here it is assumed that each group consist of contiguous sets of subcarrier and are of equal size. The objective is to optimally combine the 'm' group.

$$X^{'} = \sum_{m=1}^{M} b_m X_m \tag{11}$$

where $\{b_{m,} m=1,2,\ldots.M\}$ are weighting factors and are assumed to be pure rotations. Here X_m is the partial transmit sequence. The increase in the number of phase factor decreases PAPR of the OFDM signal but in turn increases the hardware complexity.

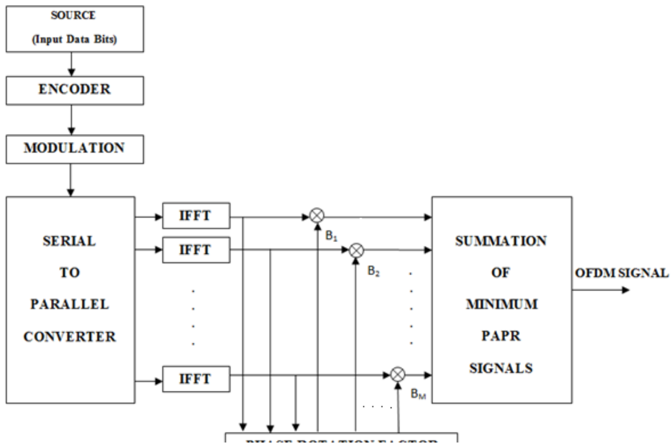

Fig. 1 Block diagram of OFDM system with PTS technique

6. MODIFIED PTS TECHNIQUE

In the modified PTS technique[11], the neighbourhood search is employed as a searching algorithm to find the phase factor, and then set a threshold to reduce the computational complexity and get a suboptimum. The algorithm sets an initial solution $s_0$and then searches the better solutions at the neighborhood of $s_0$iteratively. If there is such a solution s', $s_0$is replaced ass'. A local optimum $s'$is got when there is not a better solution in its neighborhood. The neighborhood search algorithm has follow features:

a) The algorithm is easy to achieve.

b) The performance depends on the initial solution and the neighborhood function.

c) Part optimization.

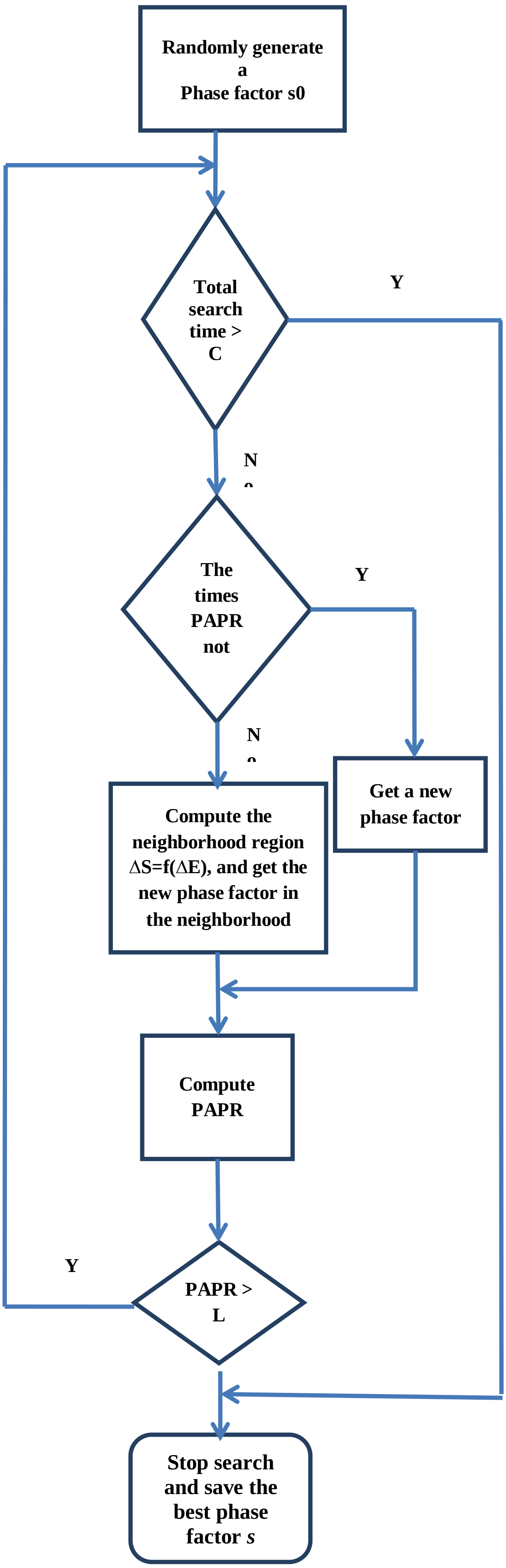

Fig. 2 Flow chart of modified PTS algorithm

7. Discrete Cosine Transform

The Discrete Cosine Transform of a signal produces the cosine function of the signal which is of real and evenly symmetric. DCT extends N data points to 2N points due to mirror extension of data sequences. Therefore DCT will be twice the length of data sequences of DFT method. There are four types of DCT, they are DCT-I, DCT-II, DCT-III and DCT-IV. In these four types, DCT-I method has orthogonal property because inverse of DCT-I is obtained by multiplying 2/N-1 to DCT-I. The main properties of DCT are signal energy compaction and reduction of autocorrelation among data sequences. The representation of DCT is given in equation (12),

$$A[k] = a[k] \sum_{n=0}^{N-1} a[n] \cos\frac{\pi(2n+1)k}{2N} \quad (12)$$

For k = 0,1 . . . N- 1 , the inverse DCT is defined as,

$$A[k] = \frac{1}{\sqrt{N}} \qquad for\ k = 0; \qquad (13)$$

$$= \sqrt{\frac{2}{N}} \qquad for\ k = 1,2, \dots \dots . N-1$$

The basis sequences of the 1D DCT are real, discrete-time sinusoids defined by:

$$C_N[N,K] = \frac{\pi(2n+1)k}{2N} \qquad (14)$$

The DCT basis consists of the following N real sequences,

$$C_N[N,0], C_N[N,1], \ldots\ldots\ldots.. C_N[N,n-1]$$

$$A_N = C_N \alpha \quad (15)$$

where A and α are both the vector with Nx1 and C_N is a DCT transform matrix with N x N. The row (or column) of the DCT matrix C_N are orthogonal matrix vectors. Then we can use this property of the DCT matrix and reduce the peak power of OFDM signals. The main requirement of OFDM signals is to reduce the similarity between the signals to reduce the PAPR of the OFDM signals which will be provided by DCT.

8. DCT With Modified PTS Technique

A. DCT Preceding Modified PTS Technique

The first proposed work is that of using Discrete Cosine Transform preceding the modified Partial Transmit Sequence is shown in Fig.3. The application of DCT preceding modified PTS reduces the autocorrelation of conventionally digital modulated data bits. Because of this reduction, the similarity among phases of data gets reduced. PTS is a data scrambling technique which uses different combination of phase factor to reduce the autocorrelation between data. This proposed work is simulated which shows reduction in PAPR compared to conventional modified PTS technique.

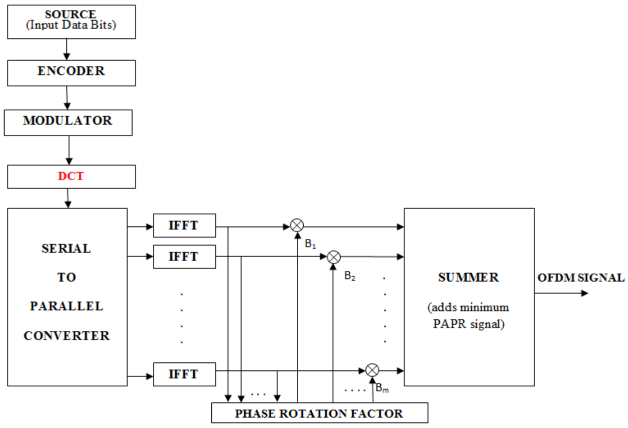

Fig. 3 Block diagram of OFDM system with DCT preceding modified PTS technique

The mathematical analysis of DCT before PTS is done by first computation of DCT followed by IFFT of divided subsequences. The DCT of modulated data is given by,

$$C_N = \frac{1}{2}[a_0 + -1^k a_0] + \sum_{i=1}^{n-2} \left(a_i \cos \frac{\pi k i}{n-2} \right) \quad (16)$$

The IFFT of partially divided DCT data is given by,

$$x(t) = \sum_{j=1}^{m} \sum_{i=1}^{\frac{n}{m}} \left(C_N \, \mathrm{e} \frac{j2\pi u i}{n} \right) \quad (17)$$

where

a is the phase modulated data bits

N is the length of data sequence

K = 0, 1, ...N-1

C_N is the Discrete Cosine Transformed data sequence

u is the number of subcarriers

n is total number of data sequence

m is the total number of phase factor used

B. DCT Succeeding Modified PTS Technique

The second proposed work is of DCT succeeding modified PTS technique is shown in Fig.4. The conventionally modulated data bits are converted into parallel streams. The paralleled converted data bits are applied to data scrambling technique PTS technique which reduces the similarity between data by rotating with 'm' number of phase factors. The signals with minimum PAPR are added using summer and the output is given to DCT block. The DCT reduces the autocorrelation between the summed OFDM signal. The simulation result shows that the DCT succeeding modified PTS reduces PAPR compared to conventional PAPR. But DCT preceeding modified PTS technique shows better performance compared to DCT succeeding modified PTS. This is because DCT succeeding modified PTS reduces only autocorrelation between minimum PAPR signals where as in the DCT preceeding PTS reduces the autocorrelation between each of the conventionally digital modulated data bits.

The mathematical analysis of DCT succeeding modified PTS technique is obtained by first computation of IFFT of divided subsequences followed by DCT. The DCT of modulated data is given by,

$$x(t) = \sum_{j=1}^{\text{潩}} \sum_{i=1}^{\frac{n}{m}} \left(a_N \, e \frac{j2\pi ui}{n} \right) \qquad (18)$$

The DCT of orthogonal signal is given by,

$$C_N \frac{1}{2}[x(0) + -1^k x(1) \sum_{i=1}^{u-2} \left(x(u) \cos \frac{\pi k i}{u-2} \right) \qquad (19)$$

where a is the phase modulated data bits N is the length of data sequence

K = 0, 1, ...N-1

C_N is the Discrete Cosine Transformed data sequence

u is the number of subcarriers

n is total number of data sequence m is the total number of phase factor used

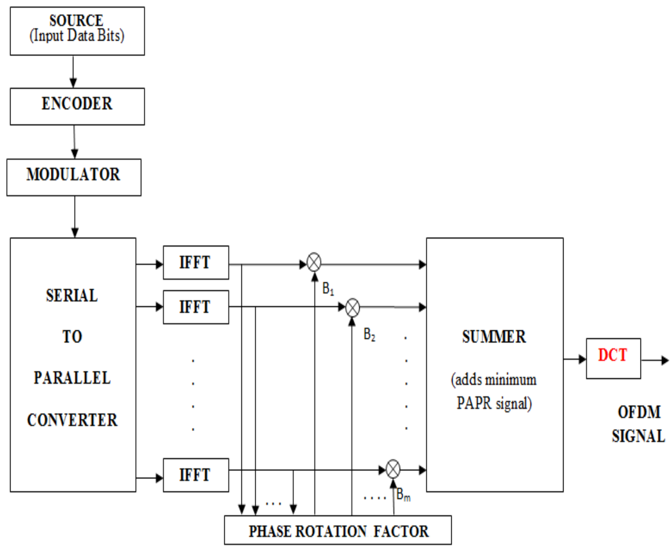

Fig.4 Block diagram of OFDM system with DCT succeeding modified PTS technique

9. SIMULATION RESULTS

The proposed work of DCT preceding modified PTS technique and DCT succeeding modified PTS technique in OFDM system are simulated using MATLAB software. The parameters used for simulation are discussed in below Table 1,

Table 1. Simulation parameters

Parameter	Type/Value
Number of subcarrier	64, 128,256, 512, 1024
Modulation scheme	4-QAM
Number of Phase Rotation Factor	2, 4, 8, 16
Number of combinations of Phase Factors	16

The OFDM system is designed by using modified PTS technique in order to reduce PAPR. The application of first order DCT which introduces orthogonality is used before and after PTS are simulated. The CCDF curve is plotted to find the number of PAPR of the signals greater than clipping level of power amplifier.

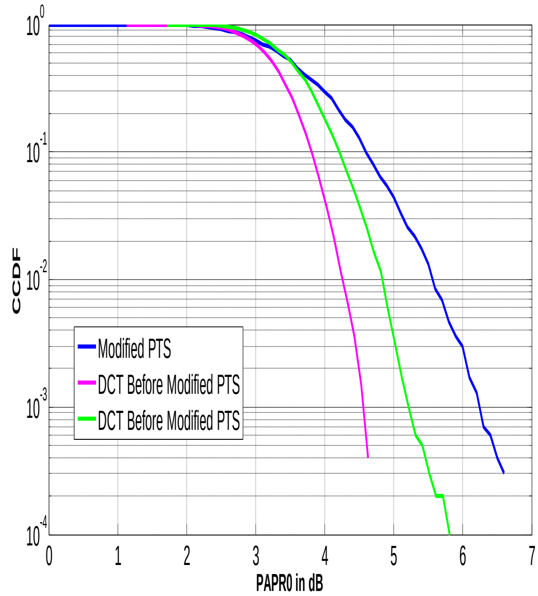

Fig. 5 CCDF performance of OFDM system with DCT preceding modified PTS technique with 64 subcarrier and 4 phase factors

The Fig. 5 shows comparison among modified PTS, DCT preceding modified PTS technique and DCT succeeding modified PTS technique. The proposed work DCT preceding modified PTS efficiently reduces PAPR effectively compared to other proposed and conventional schemes. The proposed work DCT succeeding modified PTS technique also shows reduction in PAPR compared to conventional modified PTS but not efficient as DCT preceding modified PTS technique. The DCT preceding modified PTS shows 26.93% PAPR reduction compared to conventional modified PTS. The DCT succeeding modified PTS shows 15.96% PAPR reduction compared to conventional modified PTS technique. Whereas the DCT preceding modified PTS shows nearly 13.05% PAPR reduction compared to DCT succeeding modified PTS. In DCT preceding modified PTS technique, the autocorrelation between every modulated data bits are reduced so that PAPR is get reduced. In DCT succeeding modified PTS technique, the autocorrelation between processed OFDM signals are get reduced so that PAPR is reduced.

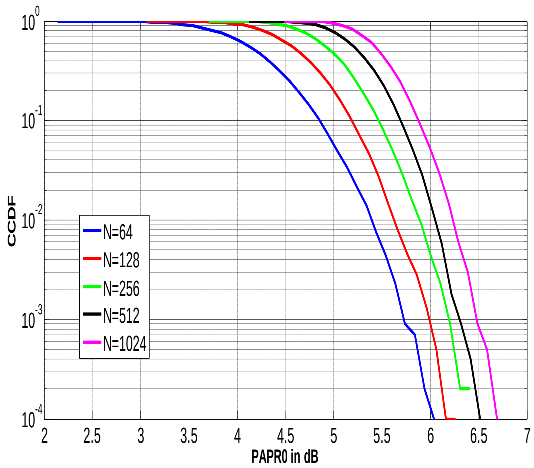

Fig. 6 CCDF performance of OFDM system with DCT preceding modified PTS technique using 4-QAM scheme and 2 phase factors

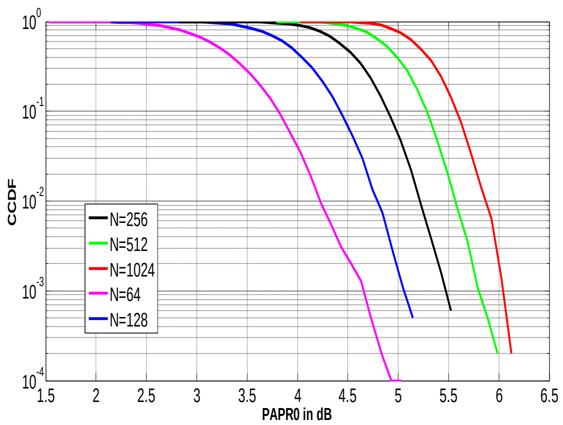

Fig. 7 CCDF performance of OFDM system by DCT preceding modified PTS technique using 4-QAM scheme and 4 phase factors

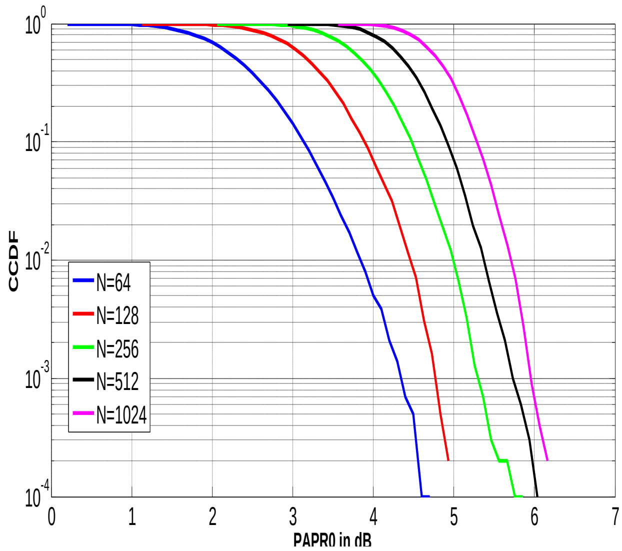

Fig. 8 CCDF performance of OFDM system by DCT preceding modified PTS technique using 4-QAM scheme and 8 phase factors

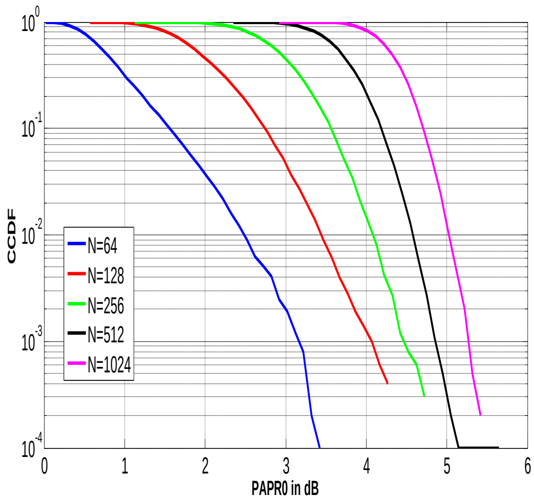

Fig. 9 CCDF performance of OFDM system with DCT preceding modified PTS technique using 4-QAM scheme and 16 phase factors

Table 2 PAPR reduction by DCT preceding modified PTS

Number of Subcarriers	PAPR in dB (CCDF at 10^{-3})			
	m=2	m=4	m=8	m=16
64	5.73	4.63	4.29	3.12
128	5.96	5.04	4.74	4.067
256	6.205	5.42	5.25	4.423
512	6.317	5.78	5.735	4.84
1024	6.489	6.024	5.964	5.32

The Fig 6, Fig 7, Fig 8 & Fig. 9 show the comparison of OFDM system with DCT preceding modified PTS technique for different subcarriers using different phase factors and 4-QAM scheme. In various subblocks, using 64 subcarriers showing better performance compared to other subcarriers because increase in number of subcarriers leads to more loss of orthogonality which increases the value of PAPR. It is observed that increases in number of subblocks reduces the PAPR but increases the complexity of the system. The table 2 shows the PAPR value at CCDF 10^{-3} for different number of subcarriers and different number of sub-blocks. Using 64 subcarriers in DCT preceding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 19.19%, 25.13% and 45.59% PAPR reduction compared to 2 sub-blocks. Using 128 subcarriers in DCT preceding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 15.43%, 20.46% and 31.87% PAPR reduction compared to 2 sub-blocks. Using 256 subcarriers in DCT preceding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 12.65%, 15.39% and 28.71% PAPR reduction compared to 2 sub-blocks. Using 512 subcarriers in DCT preceding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 8.5%, 9.217% and 23.38% PAPR reduction compared to 2 sub-blocks. Using 1024 subcarriers in DCT preceding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 7.16%, 8.09% and 18.01% PAPR reduction compared to 2 sub-blocks. From the percentage analysis of PAPR shows that less number of subcarriers with more number of sub-blocks shows better performance.

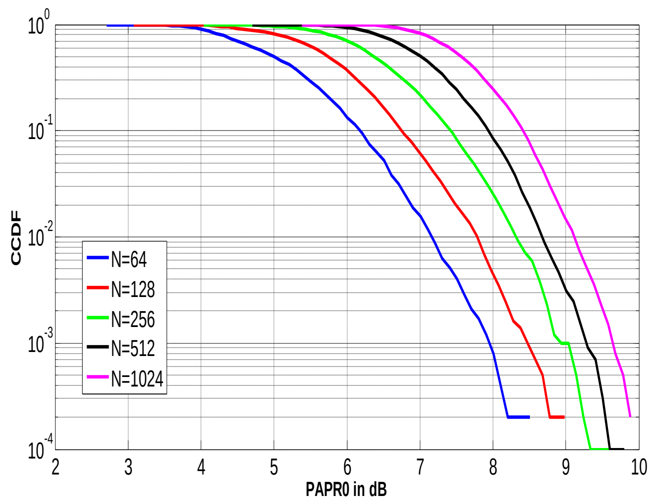

Fig. 10 CCDF performance of OFDM system by DCT succeeding modified PTS technique using 4-QAM scheme and 2 phase factors

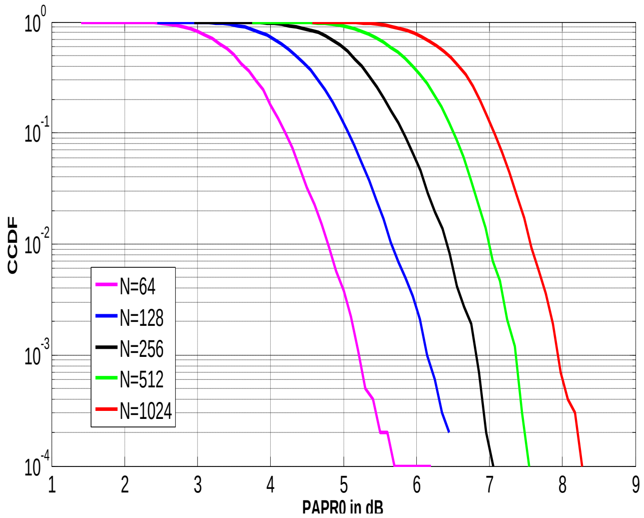

Fig. 11 CCDF performance of OFDM system by DCT succeeding modified PTS technique using 4-QAM scheme and 4 phase factors

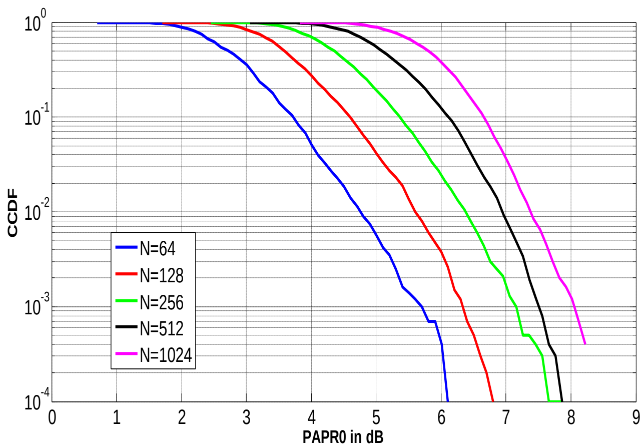

Fig. 12 CCDF performance of OFDM system by DCT succeeding modified PTS technique using 4-QAM scheme and 8 phase factors

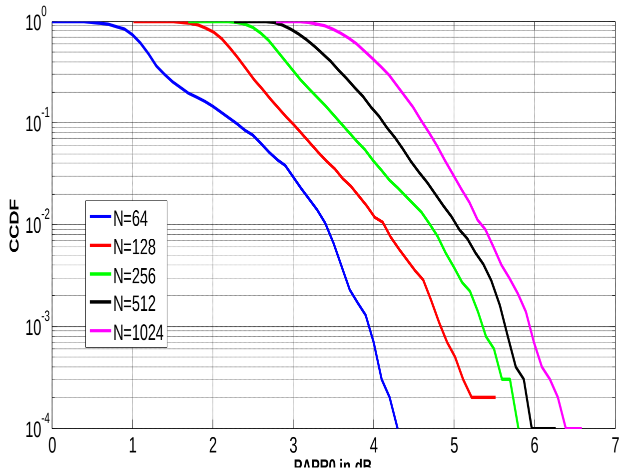

Fig. 13 CCDF performance of OFDM system by DCT succeeding modified PTS technique using 4-QAM scheme and 16 phase factors

Table 3 PAPR reduction by DCT succeeding modified PTS

Number of Subcarriers	PAPR in dB (CCDF at 10^{-3})			
	m=2	m=4	m=8	m=16
64	7.91	5.20	5.1	3.9
128	8.48	6.15	6.30	4.81
256	8.94	6.85	7.15	5.29
512	9.30	7.35	7.56	5.66
1024	9.68	7.97	8.02	5.88

The Fig 10, Fig 11, Fig 12 and Fig. 13 shows the comparison of OFDM system with DCT succeeding modified PTS technique for different subcarriers using different phase factors and 4-QAM scheme. In various subblocks, using 64 subcarriers showing better performance compared to other subcarriers because increase in number of subcarriers leads to more loss of orthogonality which increases the value of PAPR. It is observed that increases in number of subblocks reduces the PAPR but increases the complexity of the system. The table 3 shows the PAPR value at CCDF 10^{-3} for different number of subcarriers and different number of sub-blocks. Using 64 subcarriers in DCT succeeding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 34.26%, 35.52% and 50.69% PAPR reduction compared to 2 sub-blocks. Using 128 subcarriers in DCT succeeding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 27.47%, 25.70% and 43.27% PAPR reduction compared to 2 sub-blocks. Using 256 subcarriers in DCT succeeding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 23.37%, 20.02% and 40.82% PAPR reduction compared to 2 sub-blocks. Using 512 subcarriers in DCT succeeding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 20.96%, 18.7% and 39.13% PAPR reduction compared to 2 sub-blocks. Using 1024 subcarriers in DCT succeeding modified PTS technique the comparison of four, eight and sixteen sub-blocks shows 17.66%, 17.14% and 38.25% PAPR reduction compared to 2 sub-blocks. From the percentage analysis of PAPR shows that less number of subcarriers with more number of sub-blocks shows better performance. The DCT preceding modified PTS with different sub-blocks and different number of subcarriers in all combinations shows better performance compare in DCT succeeding modified PTS technique.

10. CONCLUSION

OFDM is an orthogonal modulation and multiplexing scheme which is used mainly to overcome the problem of selective fading effects. In spite of its many advantages it has a main drawback of PAPR problem. Many PAPR reduction techniques are present in which signal distortion less technique reduces PAPR efficiently. PTS is one of those technique which has less hardware complexity comparatively. In the proposed work, characteristics of DCT is utilized in PTS technique to reduce the PAPR further. The proposed work uses DCT before and after PTS in order to reduce PAPR. The modified PTS technique which has less computational complexity compared to conventional PTS is combined with DCT to reduce PAPR with different number of subcarriers and subblocks. The proposed work is simulated with MATLAB 2010a which shows reduction in PAPR compared to conventional schemes. In the proposed work application of DCT preceding the modified PTS technique shows more PAPR reduction compared to application of DCT succeeding the modified PTS techniques. In DCT preceding the modified PTS techniques, the autocorrelation between every modulated data bits are reduced whereas in DCT succeeding the modified PTS techniques, the autocorrelation between processed OFDM signals are reduced. Because of the application of DCT in PTS techniques increases the hardware complexity of the OFDM system. Increase in number of subblocks increases the complexity of the system.

REFERENCES

[1] Yiyan Wu and William Y. Zou, " Orthogonal Frequency Division Multiplexing: A Multi-Carrier Modulation Scheme," IEEE Transactions on Consumer Electronics, vol. 41, no. 3, pp. 392-399, August 1995.

[2] S. B. Weinstein and Paul M. Ebert, " Data Transmission by Frequency Division Multiplexing using the Discrete Fourier Transform," *IEEE Transactions on Communication Technology*, vol. 19, no. 5, pp. 628-634, October 1971.

[3] Tao Jiang and Yiyan Wu, " An Overview: Peak to Average Power Ratio Reduction Techniques for OFDM Signals," *IEEE Transactions on Broadcasting*, vol. 54, no. 2, pp. 257-268, June 2008.

[4] Xiaodong Li and Leonard J. Cimini, "Effects of Clipping and Filtering on the Performance of OFDM," *IEEE Communications Letters*, vol. 2, no. 5, pp. 131-133, May 1998.

[5] William Y. Zou and Yiyan Wu, " COFDM: An Overview," *IEEE Transactions on Broadcasting*, vol. 41, no. 1, pp 1-8, March 1995

[6] Jones A. E. , Wilkinson T. A. and Barton S. K., "Block Coding Scheme for Reduction of peak to mean envelope power ratio of multicarrier transmission scheme," vol. 30, issue 25, pp. 2098-2099, August 2002.

[7] R.W. Bauml, R.F.H. Fischer and J.B. HuberJ. Wang, "Reducing the Peak-to-Average Power Ratio of Multicarrier Modulation by Selected Mapping," *IEEE Electronic Letters*, vol. 32, no. 22, pp. 2056-2057, October 1996.

[8] S.H. Muller and J.B. Huber, "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences", *IEEE Electronics Letters*, vol. 33 no. 5, pp. 368-369, February 1997.

[9] Parneet Kaur, Ravinder Singh, "Complementary Cumulative Distribution Function for Performance Analysis of OFDM Signals", *IOSR Journal of Electronics and Communication Engineering (IOSRJECE)*, ISSN : 2278-2834, vol 2, Issue 5, pp 05-07, Sep-Oct 2012.

[10] S.H. Muller and J.B. Huber, "OFDM with reduced peak-to-average power ratio by optimum combination of partial transmit sequences", *IEEE Electronics*

Letters, vol. 33 no. 5, pp. 368-369, February 1997.

[11] Tian Ya-fei, Ding Rong-hua, Yao Xiao-an and Tang Hai-wei, "PAPR Reduction of OFDM Signals using Modified Partial Transmit Sequences," *Proceedings of 2nd International Conference on Image and Signal Processing*, pp. 1-4, October 2009.

[12] N. Ahmed, T. Natarajan and K. R. Rao, "Discrete Cosine Transform", *IEEE Transactions on Computers*, pp. 90-93, January 1974.C. J. Kaufman, Rocky Mountain Research Lab., Boulder, CO, private communication, May 1995.

[13] [13] Osama A. Omer and Ahmed Abdel-Reheem, "Adaptive Hybrid PAPR Reduction in OFDM System", *International Journal of Future Computer and Communication*, Vol. 2, No. 3, pp. 188-191, June 2013

[14] P. Mukunthan and P. Dananjayan, "PAPR reduction based on a Modified PTS with Interleaving and Pulse Shaping method for STBC MIMO-OFDM System*", Third International Conference on Computing, Communication and Networking Technologies*, pp. 1-6, July 2012.

[15] P. Mukunthan and P. Dananjayan, "Modified PTS with FECs for PAPR Reduction in MIMO-OFDM system with Different Subcarriers*", International Symposium on Humanities, Science and Engineering Research*, pp. 89-94, 2011.

[16] Naofal Al-Dhahir, Hlaing Minn, and Shilpa Satish, "Optimum DCT-Based Multicarrier Transceivers for Frequency-Selective Channels", *IEEE Transactions on Communications*, Vol. 54, No. 5, pp. 911-921, May 2006.

[17] Sara Mlng, T.Mata, P.Boonsrimuang and H.Kobayashi, "Interleaved Partitioning PTS with New Phase Factors for PAPR Reduction in OFDM Systems", *Proceedings of 8th International Conference on Electrical Engineering, Thailand*, pp. 361-364, May 2011.

[18] Xinchun Wu, Zhigang Mao, Jin xiang Wang, Bin Zho, "A Novel PTS Technique with Combinative Optimization in Real Part and Imaginary Part for PAPR Reduction in OFDM Systems", *Proceedings of Third International Conference on Next Generation Mobile Applications, Services and Technologies, Cardiff, Wales, UK*, pp. 215-218, September 2009.

[19] D.Phetsomphou, S.Yoshizawa and Y. Miyanaga, "A Partial Transmit Sequence Technique for PAPR Reduction in MIMO-OFDM Systems", *Proceedings of 10th International Symposium on Communications and Information Technologies, Tokyo, Japan*, pp. 672-676, October 2010.

[20] S.Sujatha and P.Dananjayan"PAPR Reduction Techniques In OFDM Systems Using DCT And IDCT", ***Journal of Theoretical and Applied Information Technology***, 30 June 2014 -- Vol. 74. No. 3 – 2014.