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A Novel Low Complexity GA Based PTS Method for PAPR Reduction in OFDM Systems

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Abstract

OFDM is a widely accepted scheme for high data rate applications in wireless medium. Unfortunately, higher peak to average power ratio (PAPR) is a serious problem associated with it especially when system has non linearity in its characteristic as nonlinearity creates harmonic distortion. To reduce PAPR, use of multiple signal representation technique such as Partial Transmit Sequence is one of the most favored methods. However, the use of conventional PTS technique requires excessive searches in order to find optimal phase sequence out of all permissible combinations, leading to sharp increment in computational complexity. Using optimization method such as genetic algorithm (GA) can reduce the number of searches and in turn the computation complexity too. Paper aims to reduce the cumbersome process of phase selection by making use of the similarity pattern in the phase vectors. Theoretical analysis shows that computational complexity is significantly reduced with the help of this proposed novel technique. We have also demonstrated that PAPR values are similar to conventional PTS i.e. PAPR reduction capability remains same but at reduced complexity.

Keywords: *OFDM, PAPR, PTS, Phase vector, GA, CCRR*

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier transmission method that divides a wideband channel into larger set of narrow parallel sub-channels; thus uses multiple-carriers for high rate data transmission. Due to narrow channel B.W, there is a greater tolerance to multipath fading as narrow channel experiences flat fading. Narrow channel shows higher resistance towards inter-symbol interference (ISI) (Cho *et al*.,2010) and use of cyclic prefix helps out in combating deficiency produced due to delay spread such as inter carrier interference (ICI) (Ren *et al*.,2016; Wang *et al*.,2016). Moreover, efficient utilization of the spectrum due to orthogonal subcarriers makes OFDM a widely used technique. The bandwidth efficiency and reliability of the transmission system are further enhanced when MIMO-OFDM techniques are combined.

At the OFDM transmitter, high peak-to-average power ratio (PAPR) may be generated by addition of independently transmitted subcarriers. When an OFDM signal with such high peaks is processed through a device with nonlinear characteristics *e.g.* a High Power Amplifier (HPA), leads to harmonic distortion and spectral re-growth causing in and out of band interference. Thus, HPA present at the OFDM transmitter needs to have a large input back off to keep the operations in the linear region which limits its efficiency. There are various methods detailed in literature (Rahmatallah and Mohan, 2013) for PAPR reduction such as clipping (Ali *et al*.,2017), employing forward error correction codes (Ghassemi and Gulliver, 2010), tone injection (Hou *et al*,2017), tone reservation (TR)

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(Hagras *et al*, 2016), companding (Mazahir and Sheikh,2016), pre-distortion and DFT-spreading (Chen, *et al*, 2016), Active constellation extension (Wang *et al*,2016), which are used for the sake of reducing the PAPR in the OFDM systems. Multiple signal representation techniques are one of the most widely used out of these above mentioned methods since multiple signal representation perform PAPR reduction without producing any distortion. It can be implemented with the help of selected mapping (SLM) (Bauml, *et al*, 1996; Yang *et al*, 2014; Taspinar and Yildirim,2015) and partial transmit sequences (PTS) (Cimini and Sollenberger, 2000;Chen, 2010). Out of these two techniques PTS is preferred due to its low computational complexity than SLM. In case of the conventional PTS scheme, input data is divided into independent sub-blocks. The Inverse Fast Fourier Transforms (IFFT) of all these sub blocks are then obtained and multiplied by various combinations from a set of phase rotation vectors. Following this, they are optimally combined to form an OFDM signal with lower peaks or PAPR. However, with the use of the PTS scheme, there is an added complexity of searching for the optimal phase sequence that generates least PAPR and this complexity increases with the number of sub-blocks. Also, to ensure that the OFDM signal is recovered correctly at the receiver, additional information about optimal phase sequence (side information) is to be sent along with the data which burdens the bandwidth as an overhead.

In this paper, we will deal with the issue of complexity in PTS. In recent times several low complexity PTS techniques have been suggested some them are as follows.

Han and Lee (2004) suggested the use of gradient descent search method for reducing the complexity; Yang *et al*. (2006) used a preset threshold for calculating final PTS candidate thus reducing searches. Varahram *et al*. (2010) suggested use of dummy sequence insertion method for reducing the complexity; Wang *et al*. (2010) considered artificial bee colony optimization for reduction in searches and complexity. Yang *et al*. (2011) suggested cyclic shifting and recursive method for PTS generation; Hou *et al*. (2011) exploited correlation between the candidates for complexity reduction. Taspinar *et al*. (2011) used parallel tabu search method for achieving same goal. Cho *et al*. (2012) used optimized search method for reducing searches and computational complexity; Ku (2014) suggested use of cost function based on sub-block sample power to estimate the PTS signal and extended it for MIMO systems. Ye *et al*. (2014) used segmentation method in place of PTS to create disjoint blocks for achieving better PAPR reduction at lower complexity. Lee *et al*. (2016) suggested improvement on selection of samples for power calculation and used rotating samples of IFFT block. Cho *et al*. (2017) used time domain sample for PAPR calculation based on some pre- defined metric. Joo *et al*. (2017) used method of additional phase offset on each phase sequence of PTS to avoid SI at reduced complexity.

Some of these methods (Varahram *et al*. ,2010; Hou *et al*., 2011; Cho *et al*., 2012) consider a preset threshold value of PAPR while searching for optimal phase sequence thus lowering down the computational complexity. However, consideration of threshold leads to sub-optimal sequences. Moreover, most of these techniques give a significant reduction in multiplicative operations while the reduction in the number of computations for additive operations is not as significant. The proposed scheme in this paper leads to significant reduction in both aspects of computational complexity by utilizing the similarity index of the candidate signals to sequentially obtain one from the other. Using GA based PTS (Kaur and Singh, 2016; Wang *et al*. ,2014; Liang *et al*., 2009; Luo *et al*.,2015; Wang *et al*.,2012) can further reduce the number of searches which will further lower down the complex additions and multiplication contributing to the complexity of the overall system.

2. Peak to Average Power Ratio and Multiple Signal Representation Technique

Being a multicarrier system OFDM is highly prone to large variations in time domain OOFDM signal leading to high peak to average power ratio. Peak to average power ratio is the ration peak power of the OFDM signal to the average power of the carrier. PAPR for an OFDM signal x is given by equation. 1.

$$PAPR(x) = \frac{\max\limits_{0 \le n \le N-1} |x_n|^2}{E\{|x_n|^2\}} \tag{1}$$

Where N is the number of subcarrier and $E\{.\}$ represents the expectation operator and $x = \lfloor x_0 \ x_1 \ .....x_{N-1} \rfloor$.

When PAPR is on the higher side it creates distortion when it passes through a device with nonlinear chraterstics, such as high power amplifier. Multiple signal representation techniques are one of the widely employed distortion-less technique for PAPR reduction, where data is subdivided in to sub blocks and phase shifted using different combinations of phase vector, thus generating several OFDM symbols for same data set and the one with the minimum power value will be used for transmission. Selective mapping and partial transmit sequence techniques are two such techniques. Partial transmit technique requires less number of complex arithmetic so used widely for many applications. *Figure 1* shows various functional blocks of a PTS system

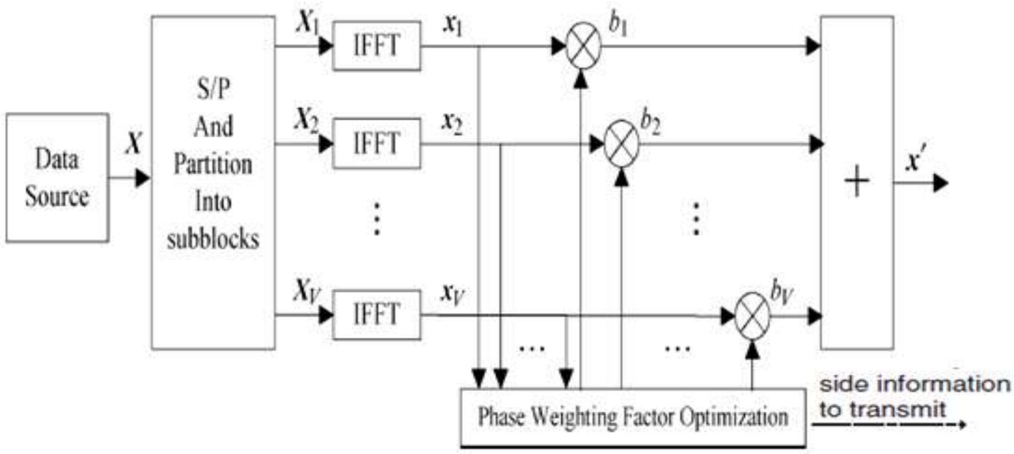

Figure 1. Functional Blocks of PTS

The data sequence X is subdivided in to V sub blocks of equal length N. Then sub blocks are multiplied with unique phase vector b^v. Resulting in to multiple OFDM candidates for different phase combination, each of them is given by the equation (2).

$$x^m = \sum_{v=0}^{V-1} b_m^v . x_v \tag{2}$$

Where $x_v = IFFT[X_v]$, with W phase weights total number of phase weights which need to be analyzed are W^{V-1}, as for the first sub-block the phase factor is usually selected as 1.

The optimum phase factor is the one which produces minimum PAPR of candidate signal x' as given by equation (3)

$$\left[\tilde{b}_1, \ldots\ldots\ldots \tilde{b}_V\right] = \underset{[b_1 \ldots\ldots b_V]}{\arg\min} \left(\max_{n=0,1\ldots.N-1} \left| \sum_{v=1}^{V} b_v x_v[n] \right| \right) \tag{3}$$

2.1. Computational Complexity Calculations

For Conventional PTS with V no. of sub-blocks and W phase weights, there are W^{V-1} possible PTS candidates, the candidate signa having least signal peak and minimum PAPR will be chosen as candidate for transmission. Computational complexity in terms of additions and multiplication for PTS will be given as follows equation (4, 5):

For N-point IFFT operations (N-subcarrier OFDM):

$$\text{Complex additions } N\log_2 N$$
$$\text{Multiplications } (N/2).\log_2 N \tag{4}$$

If an oversampling factor of L is used, then in the above equation N will be replaced by N.L and it will be N.L point IFFT.

In generation of PTS candidates additional $N \times W^{V-1} \times (V-1)$ multiplications and additions will be required. *A factor of L will be included for oversampling factor L.*

So, Overall complex additions = $V.N\log_2 N + N \times W^{V-1} \times (V-1)$

$$\text{Overall complex additions} = V.(N/2).\log_2 N + N \times W^{V-1} \times (V-1) \tag{5}$$

Whenever a new low complexity PTS scheme is suggested the following parameter is evaluated for measuring its effectiveness of the scheme (equation.6).

The Computational Complexity Reduction Ratio (CCRR) *value is a measure of reduction in computational complexity in the proposed scheme as compared the conventional PTS scheme, CCRR is evaluated using following expression:*

$$CCRR = \left\{ 1 - \frac{no.\ of\ computations\ in\ proposed\ scheme}{no.\ of\ computations\ in\ conventional\ PTS} \right\} \times 100 \tag{6}$$

Higher the value of CCRR better will be the scheme in terms of complexity involved.

2.2. Genetic Algorithm based PTS

Searching for the phase combination out of W^{V-1}combinations which generates least PAPR is a complex issue when both W and V values are on the higher side. Treating it as optimization problem we can get the required value of PAPR in less number of searches thus lowering down the complexity too. Here a GA-based PTS scheme is considered. Genetic algorithm (GA) (*Figure. 2*) is primarily based on the mechanism of natural selection where a candidate is chosen based on is fitness index calculated on a set of parameters. It presumes that optimal solution of a problem which requires finding a solution from a large set of values. These parameters chromosome and may represented in form of a binary string. GA - PTS scheme uses chromosomes represented in binary string.

For phase weights $W = 4$, $\{1, j, -j+1\}$, number of bits required to represent each weight will be $\lceil \log_2 W \rceil$ *i.e.* 2. So 00, 10, 01 and 11 will be representing $1, j, -1, -j$ respectively. But since the PAPR has to be reduced we will use the fitness function as (eq.7):

$$fitness \quad function = \frac{1}{PAPR(x)} \tag{7}$$

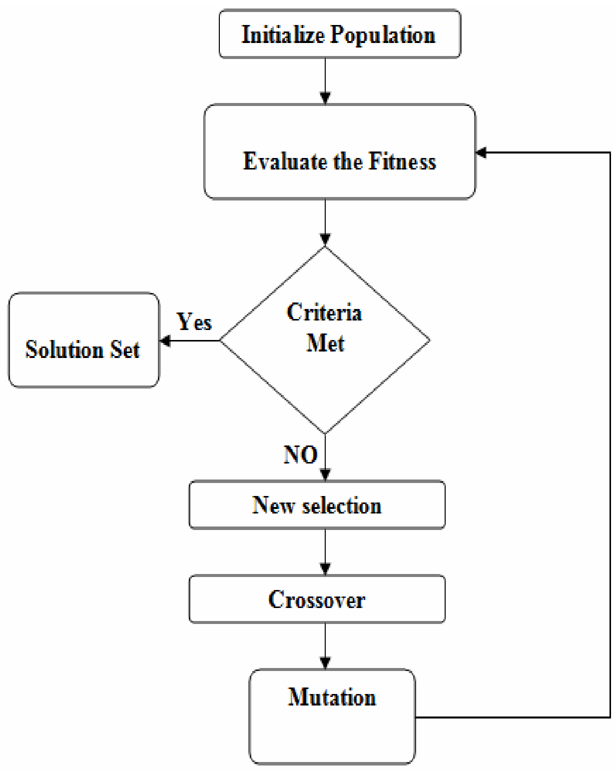

Figure 2. Genetic Algorithm Flow chart

3. Proposed Novel Low Complexity GA based PTS Scheme and its Analysis

The scheme primarily exploits the similarity in the multiple PTS candidates and then devises a method where the difference between the two candidates is used to generate one candidate from other

In this scheme we consider *W=2 i.e {+1,-1}*. It is assumed that the phase weight for the first sub-block 1 is always constant at +1. Therefore, it remains unchanged in all possible candidates. Taking the case of sub-blocks, *V=4* and *W=2*, the following candidate signals are to be obtained (equation.8):

$$\begin{gathered} T_1 + T_2 + T_3 + T_4 \\ T_1 + T_2 + T_3 - T_4 \\ T_1 + T_2 - T_3 + T_4 \\ T_1 + T_2 - T_3 - T_4 \\ T_1 - T_2 + T_3 + T_4 \\ T_1 - T_2 + T_3 - T_4 \\ T_1 - T_2 - T_3 + T_4 \\ T_1 - T_2 - T_3 - T_4 \end{gathered} \tag{8}$$

The number of computations required, according to the above equations, for varying values of *V* is shown in *Table 1*.

Here in calculations we have not considered the computations due to IFFT operations as it will remain same for any scheme so not affects CCRR. Factors of *N.L* will also get neutralized while calculating CCRR.

Table 1. Number of Computations Required in Conventional PTS for W=2

No. of computations for W=2		
No. of sub-blocks	**Additions**	**Multiplications**
V=4	24	24
V=5	64	64
V=6	160	160
V=7	384	384
V=8	896	896

By simple observation, it can be inferred that the signals do not differ significantly. They can be arranged in such an order that they differ by only one phase factor (equation 9):

$$S_1=T_1 + T_2 + T_3 + T_4$$
$$S_2=T_1 + T_2 + T_3 - T_4$$
$$S_3=T_1 + T_2 - T_3 - T_4$$
$$S_4=T_1 + T_2 - T_3 + T_4$$
$$S_5=T_1 - T_2 - T_3 + T_4$$
$$S_6=T_1 - T_2 - T_3 - T_4$$
$$S_7=T_1 - T_2 + T_3 - T_4$$
$$S_8=T_1 - T_2 + T_3 + T_4 \quad (9)$$

By using simple mathematics, it can be determined that successive candidate signals arranged in the above order, differ only by certain fixed signals called difference signals:

$D_2 = -2T_2$ Multiplications = 1
$D3 = -2T_3$ Multiplications = 1
$D4 = -2T_4$ Multiplications = 1

In the proposed scheme, instead of computing each and every signal, we make use of these pre-calculated difference variables D_2, D_3 and D_4 to obtain the candidates signals by ensuring that there is only one change of phase factors between two successive candidate signals. To begin with, the first candidate signal is calculated such (equation. 10):

$$S_1 = A = T_1 + T_2 + T_3 + T_4 \quad (10)$$

Number of Additions = 3, Number of Multiplications = 3

Now, subsequent signals are calculated, one from another, as they differ by only one term and the addition of a difference signal to the current candidate signal gives the next candidate signal and generation of each of them require just (eq.11): *1 addition and 0 multiplications*

$$S_2 = A + D_4$$
$$S_3 = S_2 + D_3$$
$$S_4 = S_3 - D_4$$
$$S_5 = S_4 + D_2$$
$$S_6 = S_5 + D_4$$
$$S_7 = S_6 - D_3$$
$$S_8 = S_7 - D_4 \quad (11)$$

Therefore, overall additions=10 while the multiplications are = 6.
V=4, the *CCRR* calculated is (equation12):

$$CCRR_+ = \left\{1 - \frac{10}{24}\right\} \times 100 = 58.33\%$$
$$CCRR_\times = \left\{1 - \frac{6}{24}\right\} \times 100 = 75\% \quad (12)$$

Here $CCRR_+$ and $CCRR_x$ represent complexity reduction due to proposed scheme with respect to conventional PTS scheme in terms of addition and multiplication respectively.

Similarly, for *V=5*, we have the following difference signals:

$D_2 = -2T_2$ Number of Multiplications = 1
$D_3 = -2T_3$ Number of Multiplications = 1
$D_4 = -2T_4$ Number of Multiplications = 1
$D_5 = -2T_5$ Number of Multiplications = 1

Subsequently, the following candidate signals are obtained sequentially with the phase vectors following the simple rule that there is only one change of phase factors between two successive candidate signals (equation.13)

$$S_1 = A = T_1 + T_2 + T_3 + T_4 + T_5 \quad (13)$$

Number of Additions = 4, Number of Multiplications = 4

Rest of the candidates are calculated as follows (equation.14) with each of them require

Additions = 1, Multiplications = 0

$$S_2 = A + D_5 = T_1 + T_2 + T_3 + T_4 - T_5$$
$$S_3 = S_2 + D_4$$
$$S_4 = S_3 - D_{55}$$
$$S_5 = S_4 + D_3$$
$$S_6 = S_5 + D_5$$
$$S_7 = S_6 - D_4$$
$$S_8 = S_7 - D_5$$
$$S_9 = S_8 + D_2$$
$$S_{10} = S_9 + D_5$$
$$S_{11} = S_{10} + D_4$$
$$S_{12} = S_{11} - D_5$$
$$S_{13} = S_{12} - D_3$$
$$S_{14} = S_{13} + D_5$$

$$S_{15} = S_{14} - D_4$$
$$S_{16} = S_{15} - D_5 \quad (14)$$

Here, overall additions=19 and overall multiplications=8.

Hence, for *V=5* we have

$$CCRR_{+} = \left\{1 - \frac{19}{64}\right\} \times 100 = 70.31\%$$

$$CCRR_{\times} = \left\{1 - \frac{8}{64}\right\} \times 100 = 87.5\%$$

The same method is applied for *V=6*. So, we have the following difference signals and subsequent candidate signals, as obtained from the difference signals:

$D_2 = -2T_2$ Number of Multiplications = 1

$D_3 = -2T_3$ Number of Multiplications = 1

$D_4 = -2T_4$ Number of Multiplications = 1

$D_5 = -2T_5$ Number of Multiplications = 1

$D_6 = -2T_6$ Number of Multiplications = 1

$$S_1 = A = T_1 + T_2 + T_3 + T_4 + T_5 + T_6$$

Additions = 5, Multiplications = 5, rest of the candidates are calculated as follows (eq.15) in similar fashion with each require 1 addition only.

$$S_2 = S_1 + D_6$$
$$S_3 = S_2 + D_5$$
$$\ldots..$$
$$\ldots\ldots\ldots$$
$$S_{31} = S_{30} - D_5$$
$$S_{32} = S_{31} - D_6 \quad (15)$$

Here, overall additions=36 and overall multiplications=10.

Hence, for *V=6* we have

$$CCRR_{+} = \left\{1 - \frac{36}{160}\right\} \times 100 = 77.5\%$$

$$CCRR_{\times} = \left\{1 - \frac{10}{160}\right\} \times 100 = 93.75\%$$

These values can be calculated for any value of *V* when *W=2*.

It can be inferred that the in proposed scheme the complex computations can be determined using equation 16:

$$Complex additions = L.N.(W^{V-1} - 1) + L.N(V-1)$$
$$Complex\ additions = 2.L.N(V-1) \quad (16)$$

Where *L and N do not affect in calculation of CCRR so can be dropped while calculating CCRR.*

Table 2 shows the values of *CCRR* for varying values of *V* when *W=2*.

Table 2. CCRR Values for Varying Values of V when W=2

CCRR for W=2		
sub-blocks size	**$CCRR_+$**	**$CCRR_X$**
V=4	58.33%	75%
V=5	70.31%	87.5%
V=6	77.5%	93.75%
V=7	82.03%	96.87%
V=8	85.04%	98.4%

4. Result Analysis and Comparison with other Low Complexity PTS Schemes

The scheme proposed here reduces computational complexity as indicated by CCRR for complex additions as well as multiplications, with keeping the number of candidate signal unchanged. The proposed scheme reduces CCRR for addition and multiplication in almost similar manner unlike other proposed methods in past where only CCRR for multiplications is of more concern.

When CCRR is compared with what evaluated in (Cho *et al.*, 2012) the CCRR× achieved is just 50% when compared with the value 98.4% we achieved, in (Joo *et al.*, 2017) CCRR values are in the range of 40% for V=4.

In (Han and Lee ,2004) CCRR× value of 85% is achieved for the sub-block size *V*=8 which is much less than 98.4 % achieved in our scheme for similar block size.

Similarly, in (Ye *et al*., 2014), (Wang *et al*., 2010), (Taspinar *et al*., 2011), and (Lee *et al*. ,2016) maximum reduction of 98% is achieved for the higher block size like *V=16* which is bit complex to implement than *V*=8 for similar values of CCRR since for higher value of *V* the computations increases sharply.

For PAPR performance simulation 10000 OFDM symbols are used with 128 subcarriers, for QAM mapping. For 2 phase weights and 16 block size32768 searches are required for optimum PTS. In GA-PTS the required searches are just 64×16=1024 searches only, resulting in further low computations.

Above all while implementing the proposed scheme for the sake of the reducing computational complexity the PAPR reduction capability of PTS remains intact as shown in the *Figure.3* as all the CCDF (complementary cumulative distribution function) are overlapping. The PAPR values are in the range of 4-6 dB which is ideal for 4-G practical implementation.

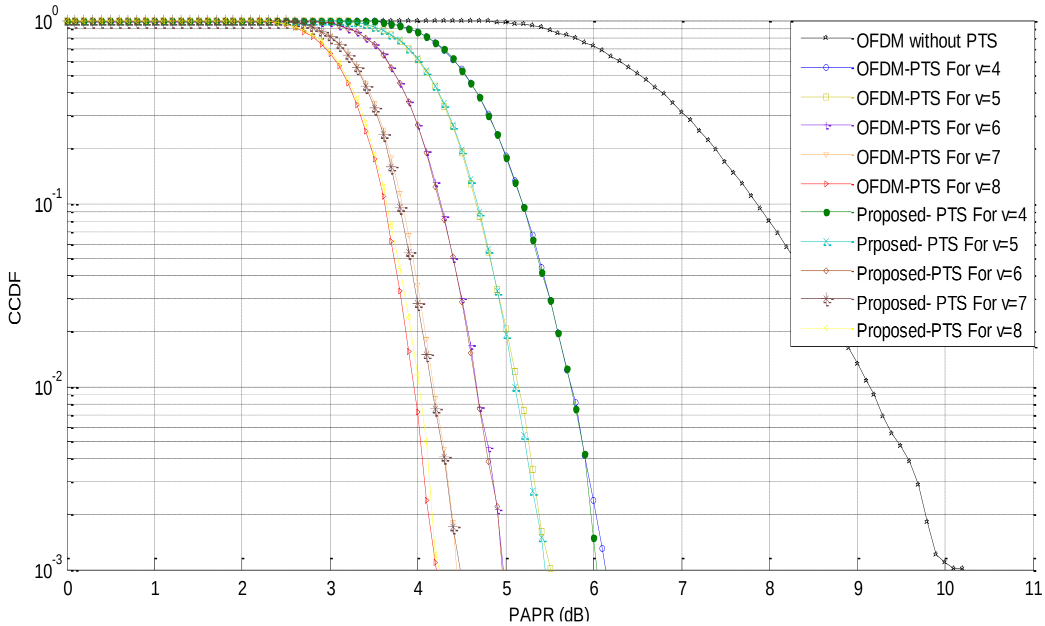

Figure 3. PAPR Performance Comparison of without PTS, Conventional -PTS and Proposed PTS Scheme

5. Conclusion

Being most preferred method for high rate transmission OFDM suffers from high PAPR issues and PTS is the most effective solution for it. Proposed scheme offers encouraging reduction as far as computational complexity is concerned in PTS technique. The reduction in complex multiplication is as high as 98.4% and in complex additions almost 85 % which would lead to an effective PTS with low complexity without degrading PAPR performance.

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