Improved PTS Schemes for PAPR Reduction in OFDM Signals

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***Abstract*-One of the major drawbacks of orthogonal frequency division multiplexing (OFDM) is the high peak-to-average power ratio(PAPR) of the transmitted OFDM signal, which may result in signal distortion, loss of orthogonality in OFDM signals, etc. Hence it is the most concerned problem in OFDM systems, which has to be reduced. Among all the available PAPR reduction techniques, Partial Transmit Sequences (PTS) is one of the most attractive schemes to reduce the PAPR. But the conventional PTS scheme requires exhaustive search over all combinations of the phase factors which consequently increases the computational complexity to transmit the optimum signal with low PAPR. This paper proposes a new efficient PTS scheme which utilizes the correlation property among all available candidate signals generated in PTS to reduce the computational complexity. Also particle swarm optimization (PSO) based PTS are presented here which exploits heuristic to search the optimal combination of phase factors with low complexity. The numerical calculation and simulation results show that the proposed PTS approach can reduce the computational complexity while achieving the same PAPR reduction when compared to the conventional PTS scheme. The results also show that PSO based PTS provides more improved PAPR reduction performance.**

Index Terms- **Orthogonal frequency division multiplexing (OFDM), partial transmit sequence (PTS), peak-to-average power ratio (PAPR), particle swarm optimization (PSO).**

I. INTRODUCTION

New technologies and thereby new applications are emerging not only in wired environment but also in the wireless arena. The next generation systems are expected to provide a substantially high data rate to meet the requirements of future high performance multimedia applications. To provide such a high data rate with high spectral efficiency the promising modulation technique that is increasingly considered is Orthogonal Frequency Division Multiplexing (OFDM) [1]. The basic principle of OFDM is to split a high-rate data stream into number of lower rate streams that are transmitted simultaneously. OFDM has been proposed for terrestrial digital TV broadcasting (DVB-T), the IEEE 802.11a standard for wireless local area network (WLAN), the IEEE 802.16d standard for wireless metropolitan area networks (WMAN) and other high speed wireless networks over multipath channels [2].

However, the OFDM systems suffer from the drawback of a high peak-to-average power ratio (PAPR) of the transmitted signal. When passed through a non-linear device, such as a transmit power amplifier, the signal may suffer significant spectral spreading and in-band distortion [3].Thus it is highly desirable to reduce the peak power. The conventional solutions to the PAPR problem are to use a linear amplifier or to back-off the operating point of a non-linear amplifier; both approaches resulting in a significant power efficiency penalty. Other alternative solutions have been proposed among which one is to simply clip the OFDM signal before amplification [3], which reduces PAPR but signal suffers from some performance degradation. Another method is to use non-linear block coding [4], which suffers from small bandwidth penalty but the large look-up tables required for implementing this coding limit its use to applications with a small number of sub-channels. Companding technique [5] based on speech processing is another PAPR reduction method which has better BER performance than clipping method.

Selected Mapping (SLM) [6] and Partial transmit Sequence (PTS) [7] are other methods proposed to reduce the PAPR with a relatively small increase in redundancy. Among all these methods, PTS scheme is an efficient approach in which the input symbol sequence is partitioned into a number of disjoint subsequences.

However, the computational complexity of the conventional PTS schemes increases exponentially with the number of sub-blocks. It requires exhaustive search over all combinations of allowed phase factors. Therefore practically, it is not realizable for the large number of sub-blocks. To reduce the search complexity, some simplified search techniques have recently been proposed [8]–[10]. However, for all these search methods, either the computational complexity is still high, or the PAPR reduction performance is not good enough. In this paper, we present a novel approach to tackle the PAPR problem to reduce the computational complexity based on the correlation property between the available candidate signals. This scheme achieves the PAPR reduction similar to the conventional PTS scheme and reduces the computational complexity and time to large extent. Similarly, PSO based PTS [13], [14] is also introduced in this paper which results in further decrease in PAPR at low complexity.

This paper is further organized as follows: Section II describes the OFDM system and introduces the definition of PAPR of OFDM system and the principle of PTS scheme. Section III puts forth the proposed low complexity PTS scheme and PTS based PSO scheme. The computational complexity and PAPR performance of the proposed and PSO based PTS scheme are evaluated in Section IV and finally, the concluding remarks and future enhancements are given in section V.

II. OFDM SYSTEM AND PTS SCHEME

A. OFDM System

Let N subcarriers be used for parallel information transmission and let a block of N symbols, $A = \{A_r, r = 0,1,2, \ldots, N-1\}$ be formed with each symbol modulating one of a set of subcarriers, $\{k_r, r = 0,1,2, \ldots, N-1\}$. The N subcarriers are taken to be orthogonal. The complex envelope of the transmitted OFDM signal is given by

$$a(t) = \frac{1}{\sqrt{N}} \sum_{r=0}^{N-1} A_r exp(j2\pi k_r t) \quad (1)$$

Therefore, the PAPR of the OFDM signal sequence, defined as the ratio of the maximum divided by the average power of the signal in one symbol period is expressed as

$$PAPR = 10 \cdot log_{10} \frac{\max_{0 \le t \le NT} |a(t)|^2}{E[|a(t)|^2]} (\text{dB}), \quad (2)$$

where $|a(t)|$ returns the magnitude of $a(t)$ and $E[\cdot]$ denotes the expectation operation. Peak power occurs when the modulated symbols are added with the same phase.

B. Conventional PTS Scheme

In PTS scheme [7], only part of the data of varying sub-carrier with low PAPR is transmitted which covers all the information to be sent in the signal as a whole. The block diagram of the PTS scheme is shown in the Fig.1. As shown in the figure, the input data block A (frequency domain vector) is partitioned into M disjoint sub-blocks, which are represented by $\{A^{(m)}, m = 1,2, \ldots, M\}$ such that

$$A = \sum_{m=1}^{M} A^{(m)} \quad (3)$$

where $A^{(m)} = [A_0^{(m)}, A_1^{(m)}, \ldots, A_{M-1}^{(m)}]$ with $A_r{}^{(m)} = A_r$ or 0(0≤m≤M). Then, the sub-blocks $A^{(m)}$ are transformed into time-domain partial transmit sequences

$$a^{(m)} = \left[a_0^{(m)}, a_1^{(m)}, \ldots, a_{M-1}^{(m)}\right] = IFFT_{LN \times N}[A^{(m)}] \quad (4)$$

where L is the oversampling factor which is taken to be $L \ge 4$ to get $PAPR(a) \approx PAPR(x(t))$. Here, we adopt L=4 for our numerical simulation.

The above partial sequences are independently rotated by phase factors $b = \{b_m = e^{j\theta_m}, m = 1,2, \ldots, M\}$. The objective is to optimally combine the M sub-blocks to obtain the time-domain OFDM signals with the lowest PAPR

$$a' = \sum_{m=1}^{M} b_m a^{(m)} \quad (5)$$

Assuming that there are W phase angles to be allowed, thus b_m can have the possibility of W different values. Hence W^M combinations should be checked to obtain the minimum PAPR. Therefore, this conventional PTS scheme requires large computations to get an optimum candidate signal with low PAPR.

III. IMPROVED PTS SCHEMES

A. Proposed Reduced Complexity PTS Scheme

In this section, a new PTS scheme [12] is proposed which reduces the computational complexity by utilizing the correlation among the phase factors in each subset which are listed into multiple subsets table.

To start with the proposed method, first the phase factors in a phase set are defined. If W is the number of phase factors then for W=4 and $M = 2$, all phase factors can be listed as: $b_1 = \{1,1\}$, $b_2 = \{1,-1\}$, $b_3 = \{1, j\}$ and $b_4 = \{1, -j\}$ which denote real and imaginary in-phase and out-of-phase factors. Then the basis vector of these phase sets can be given as $B_1 = \{1, j\}$.

Accordingly, using the following rules all the phase weighting vectors can be listed on the table known as Rule Table:

a. The basis vectors of all phase weighting vectors should be found and kept in the first row (only one element in the adjacent basis vectors is different);
b. The phase weighting vectors have the same basis vector in each column;
c. Adjacent phase weighing vectors in the same column differ only by the sign of one element;
d. The last phase weighting vectors in one and the first phase weighting vectors in the next column have the same sign.

Now, knowing the phase factors, a fundamental combination can be created. All the other candidate signals can be derived from this combination. In this paper, we select the phase weighting vector $b = \{-1,1,-j,j\}$, that is $W = 4$. In Table I all the possible phase vectors for $M = 3$ and $W = 4$ are listed based on four Rules.

For example, let us take M=3 and $W = 4$ to search the optimum candidate signal using the four Rules. Then, let $a = \{a^1, a^2, a^3\}$ and let us set $b_{B1,1}$ ={1,1,1}. Thus,

$$a_{B1,1} = b_{B1,1,1}a^1 + b_{B1,1,2}a^2 + b_{B1,1,3}a^3 = sgn(b_{B1,1,1})a^1 + sgn(b_{B1,1,2})a^2 + sgn(b_{B1,1,3})a^3 \quad (6)$$

Here, $sgn\{\cdot\}$ is the sign function, $B_{i,j}$ is the j^{th} element of the basis vector B_i, and $B_{i,r,p}$ denotes the r^{th} phase weighting vector based on the vector B_i, where p represents this phase weighting vector applied to the p^{th} sub-block of the transmitted signal.

In order to reduce the computational complexity, Rule 3 is used to compute $a_{B1,2}$ from the first candidate signal $a_{B1,1}$ as

$$a_{B1,2} = a_{B1,1} - sgn(b_{B1,1,2}).2a^2, b_{B1,2,2} \neq b_{B1,1,2} \quad (7)$$

Similarly, $a_{B1,i+1}$ derived from the first weighted combination can be expressed as

$$a_{B1,i+1} = a_{B1,i} - sgn(b_{B1,i,p}).2a^p, b_{B1,i+1,p} \neq b_{B1,i,p} \quad (8)$$

where $a^p \in a$. Using this $a_{B1,3}$ and $a_{B1,4}$ can be calculated. Now, a new parameter $S_{i,j}$ is introduced to calculate $a_{B2,1}$ from $a_{B1,4}$ $(i.e. a_{B1,last})$. For $W = 4$,

$$S_{i,j} = \begin{cases} 1 & B_{i,j} = B_{i-1,j} \\ -j & B_{i,j} \neq B_{i-1,j}, B_{i,j} = 1 \\ j & B_{i,j} \neq B_{i-1,j}, B_{i,j} = j \end{cases} \quad (9)$$

From Rule 4 and equation (9)

$$a_{B2,1} = a_{B1,4} - sgn(b_{B1,4,3}).a^3 + sgn(b_{B1,4,3}).S_{2,3}a^3, b_{B2,3} \neq b_{B1,3} \quad (10)$$

Again using Rule 3, $a_{B2,i+1}$ can be expressed as

$$a_{B2,i+1} = a_{B2,i} - sgn(b_{B2,i,p}).2a^p, b_{B2,i+1,p} \neq b_{B2,i,p} \quad (11)$$

Similar to (10), $a_{B3,1}$ can be derived from $a_{B2,4}$,

$$a_{B3,1} = a_{B1,4} - sgn(b_{B2,4,2}).a^2 + sgn(b_{B2,4,2}).S_{3,2}a^2, b_{B3,2} \neq b_{B2,2} \quad (12)$$

In the same manner, we compute until $a_{B4,4}$ has been searched and the corresponding PAPR values are calculated. So by using the equations from (6) to (12), first and last candidate signals can be written as follows

$$a_{B1,1} = a^1 + a^2 + a^3 \quad (13.1)$$

$$a_{B4,4} = a^1 + ja^2 + a^3 \quad (13.2)$$

Then, candidate signal with the minimum PAPR is chosen as the optimized transmitted signal.

From the above example it can be concluded that the optimization search is done by using the above basis vectors and the updated $a^{(r)}$. While calculating $a_{Br,i+1}$ from $a_{Br,i}$ only the complex addition is needed. Eventually, the Rule Table can be updated by replacing $a_{Bi,r,p} = sgn(a_{Bi,r,p})$.

Generalization:

$$a_{B(r+1),1} = a_{Br,last} - b_{Br,last,p}a^p + b_{Br,last,p}.S_{(r+1),p}a^p \quad (14)$$

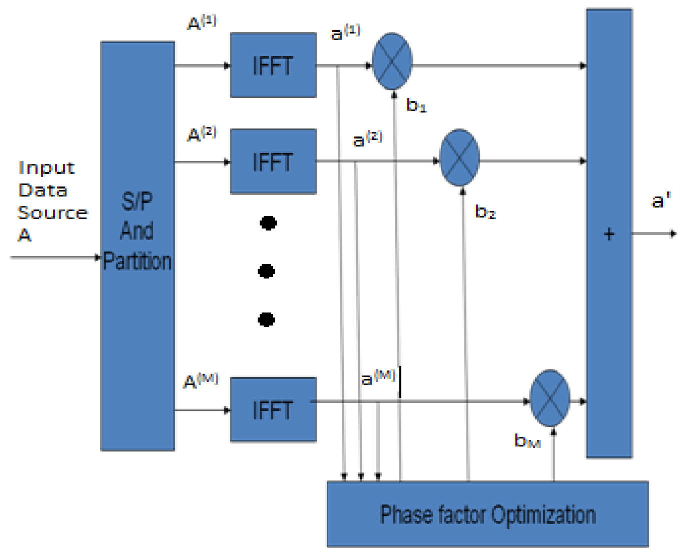


Figure 1: Block Diagram of the Partial Transmit Sequence Scheme

where $last = 2^{M-1}, a^p \in a^{r-1}$, $B_{(r+1),p} \neq B_{r,p}$.

And

$$a_{B(r+1),i+1} = a_{B(r+1),i} - b_{B(r+1),i,p}.2a^p \quad (15)$$

where $b_{B(r+1),i+1,p} \neq b_{B(r+1),i,p}$, $a^p \in a^{(r)}$.

This algorithm iterates until $a_{B(W/2)^{M-1},2^{M-1}}$ is obtained (in the above example until $a_{B4,4}$ is obtained).

Since the neighboring phase weighing vectors in Table I. vary in one bit only we can use the concept of gray code to derive all the phase weighting vectors and hence the candidate signals.

Finally, by taking the specific value of number of sub-blocks and phase factors, we can determine phase weighting vectors in advance thus, reducing the computational complexity in the transmitter and receiver. Further, utilizing the generalized equations in the proposed technique computational complexity is reduced, achieving the same PAPR reduction compared to the conventional PTS technique.

B. PSO Based PTS Scheme

PSO [13] technique is proposed to reduce the computational complexity of searching the optimum set of phase factors. The PSO is a randomized, population based optimization method. In PSO algorithm, each single solution is a particle in the search space. A swarm of these particles moves through the search space to find an optimal position. Each particle here is characterized by two parameters: position and velocity.

The flowchart of the PSO algorithm is shown in Fig.2. For a K-dimensional optimization, the position (phase weighting factor) and the velocity of the i^{th} particle can be represented as $b_i = \{b_{i,1}, b_{i,2}, \dots, b_{i,K}\}$ and $v_i = \{v_{i,1}, v_{i,2}, \dots, v_{i,K}\}$ respectively.

As shown in Fig.2 particles are initialized with a group of random position and velocity vectors and then searches for optima by updating generations.

Basis Vectors	B_1 = {1 1 1}	B_2 = {1 1 j}	B_3 = {1 j j}	B_4 = {1 j 1}
Phase Weighting Vectors	$b_{B1,1}$= {1 1 1}	$b_{B2,1}$= {1 1 -j}	$b_{B3,1}$= {1 j j}	$b_{B4,1}$= {1 j -1}
	$b_{B1,2}$= {1 -1 1}	$b_{B2,2}$= {1 -1 -j}	$b_{B3,2}$= {1 -j j}	$b_{B4,2}$= {1 -j -1}
	$b_{B1,3}$= {1 -1 -1}	$b_{B2,3}$= {1 -1 j}	$b_{B3,3}$= {1 -j -j}	$b_{B4,3}$= {1 -j 1}
	$b_{B1,4}$= {1 1 -1}	$b_{B2,4}$= {1 1 j}	$b_{B3,4}$= {1 j -j}	$b_{B4,4}$= {1 j 1}

TABLE I. PHASE WEIGHTING VECTOR

The global best (gbest) position denoted by $b^g = \{b_{i,1}, b_{i,2}, \dots, b_{i,K}\}$ represents the best particle found so far at time t in the entire swarm. After finding the two best values, the update of velocity and position for each particle are described by

$$v_i(t+1) = wv_i(t) + c_1 r_1 \left(b_i^p(t) - b_i(t)\right) + c_2 r_2 \left(b^g(t) - b_i(t)\right) \quad (16)$$

$$b_i(t+1) = b_i(t) + v_i(t+1), \quad (17)$$

where $v_i(t)$ is the velocity of the i^{th} particle and the $b_i(t)$ is current solution of the i^{th} particle at the time t. The c_1 and c_2 are the acceleration terms, r_1 and r_2 are two random variables with uniform distribution between [0,1] and w is the inertia weight which shows the effect of the previous velocity vector on the new position vector. According to the new velocities and locations calculated by (16) and (17), populations of particles are then moved and tend to cluster together from different directions. Thus the evaluation of each associate fitness of new population of the particles begins again. The algorithm runs through these processes iteratively until it stops. The current position can be modified by

$$w(t) = w_1 - \left(\frac{w_1 - w_2}{Maximum\ iteration}\right) \times Current\ iteration \quad (18)$$

where w_1 is the initial weight and w_2 is the final weight.

IV. ANALYTICAL AND SIMULATION RESULT

A. Computational Complexity Analysis

In the previous section, it has been shown how the proposed scheme reduced the computational complexity of obtaining the time domain signal. Here, in this section we analyze the computational complexity reduction by defining the term Computational Complexity Reduction Ratio (CCRR) of the proposed PTS scheme comparing with that of the conventional PTS scheme The CCRR is given by

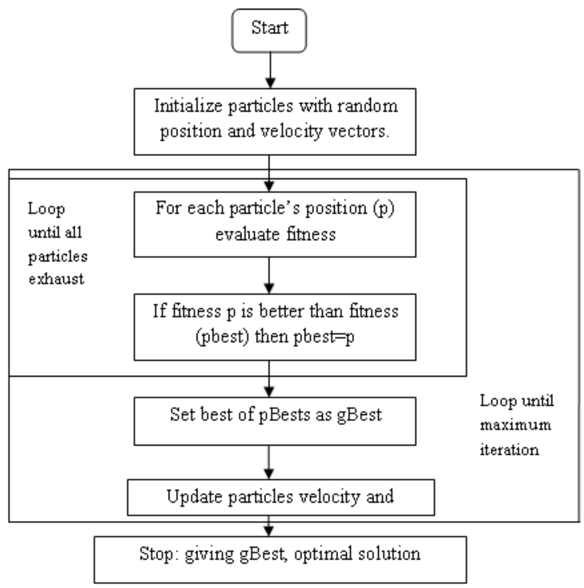


Figure 2: Flowchart of Particle Swarm Optimization

$$CCRR = \left(1 - \frac{\ }{C\ldots}\right. \quad (19)$$

From the dimension of the Table I. in section III i.e. $2^{M-1} \times W^{M-1}$, the number of complex multiplications is given by

$$n_{mul} = N.\left[\left(\frac{W}{2}\right)^{M-1} - 1\right] \tag{20}$$

And the number of multiplications required by the conventional PTS is given by

$$\beta_{mul} = N.\left[1.C_{M-1}^{1}\left(\frac{W}{2}-1\right)^{1} + \cdots + k.C_{M-1}^{r}\left(\frac{W}{2}-1\right)^{r} + \cdots + (M-1).C_{M-1}^{M-1}\left(\frac{W}{2}-1\right)^{M-1}\right].2^{M-1}$$
(21)

Table II gives CCRR of the proposed scheme over the conventional PTS OFDM scheme with typical values of M and W.

Computational complexity reduction ratio values enumerated on the Table II shows that the complexity is dramatically reduced by using the proposed method compared to the conventional PTS scheme. Thus, for M=2, M=4, and M=6 the number of complex multiplications of the proposed method is reduced to 33%, 8% and 2% of the conventional method respectively.

TABLE II.
COMPUTATIONAL COMPLEXITY REDUCTION RATIO

Comparison	CCRR %		
Phase Factors	W=4		
No. of Sub-blocks	M=2	M=4	M=6
No. of Complex Multiplication	67	92	98

B. *Simulation Results*

In order to demonstrate the performance of the proposed PTS scheme and compare it with the performance of conventional PTS and PSO based PTS scheme various simulation results are presented in this section. To compare the performance of conventional and proposed PTS scheme N=256 subcarriers are taken and QPSK modulation is employed. For the accurate estimation of the PAPR, the sampling rate needs to be increased by 4 times (L=4). 1000 random OFDM frames have been generated to produce the complementary cumulative distribution function (CCDF) of the PAPR. CCDF of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. In the performance comparison and analysis, the CCDF parameter is defined as

$$P(PAPR > z) = 1 - P(PAPR \leq z) = 1 - \left(1 - exp(-z)\right)^{N}$$
(22)

Here, taking z as $PAPR_o$, CCDF is given as

$$CCDF(Pr[PAPR > PAPR_o]) \tag{23}$$

Simulation results are shown in Fig.3, Fig.4 and Fig.5. In Fig.3 it can be seen from MATLAB simulation that the proposed PTS algorithm and the conventional PTS PAPR performance is almost in consistent, but the computational speed of proposed PTS scheme is greatly

Figure 4: CCDF's of original OFDM, conventional PTS, and PSO based PTS with 256 subcarriers, BPSK modulation, number of sub-blocks M=4 and oversampling factor L= 4

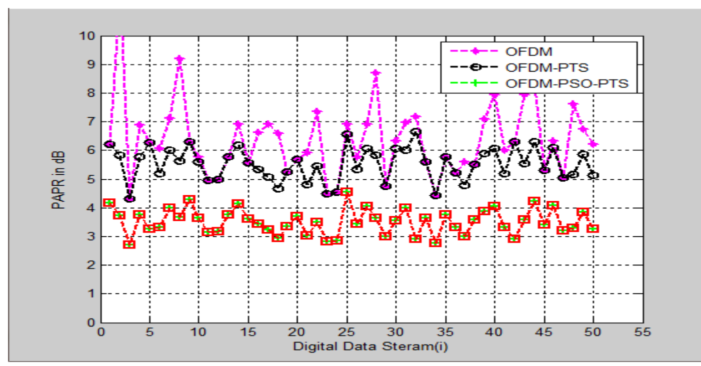
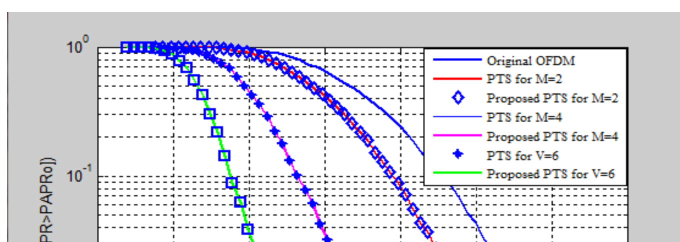


Figure 5: Comparison of PAPR plots between original OFDM, PTS and PSO based PTS



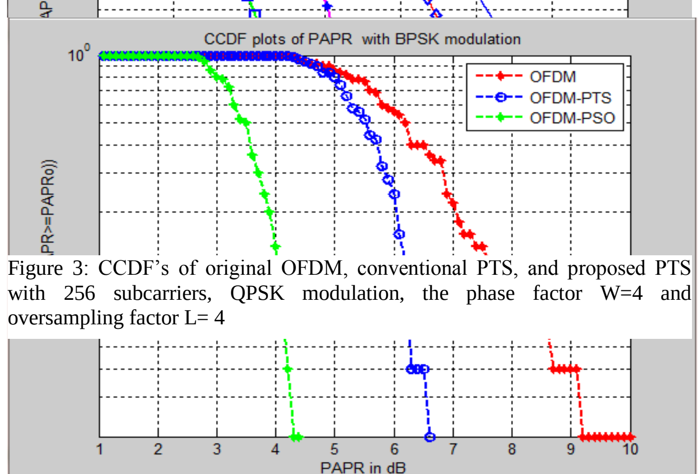


Figure 3: CCDF's of original OFDM, conventional PTS, and proposed PTS with 256 subcarriers, QPSK modulation, the phase factor W=4 and oversampling factor L= 4

reduced. The computation time for obtaining the OFDM signal using conventional PTS scheme is approximately 15.014633 seconds and using proposed PTS scheme is 5.146481seconds. CCDFs of PAPRs are computed for different number of sub-block i.e. for M=2, M=4 and M=6. It can be seen from Fig.3 that when $CCDF = Pr(PAPR > PAPRo) = 10^{-2}$, the PAPRo of the original OFDM is 9.59 dB, PTS with M=2 is 8.87dB, PTS with M=4 is 7.23dB and PTS with M=6 is 6.2dB. With proposed PTS scheme same reduction in PAPR is obtained as the number of sub-blocks is increased but CCRR % (shown in Table II.) is also increased as the number of sub-blocks is increased unlike conventional PTS. Thus proposed PTS gives same PAPR performance as conventional PTS but with much reduced complexity.

TABLE III. PERFORMANCE COMPARISON

Technique	Minimum PAPR(dB)	Maximum PAPR (dB)	Dynamic Range (dB)	Complexity	Speed	Performance
Original OFDM	3.4306	8.8606	5.4	Very Less	Fast	Poor
Conventional PTS	3.4306	7.1388	3.7	More	Slow	Good
Proposed PTS	3.4306	7.1388	3.7	Less	Fast	Good
PSO based PTS	2.2032	5.0140	2.8	Less	Fast	Very Good

Similarly, Fig.4 shows the comparison of PAPR performance of conventional scheme, proposed PTS scheme and PSO based PTS scheme. For the simulation of PSO based PTS total number of iteration is set to15, acceleration parameters are set to $c_1 = c_2 = 2$, initial weight w is set to 0.55, 256 particles are taken in the swarm and dimension of each particle is taken to be 4. BPSK modulation is used and OFDM symbols are generated with 52 bits per symbol. In Fig.4, when $CCDF = Pr(PAPR > PAPRo) = 10^{-1}$ the PAPRo of original OFDM is 7.9 dB, PTS (M=4) is 6.2 dB and PSO based PTS (M=4) is 4 dB. Hence we can say that PAPR reduction capability of PSO based PTS is best among the three since it uses social experiences of neighbor particles along with individual experience to find the best phase factor to minimize PAPR. Thus searching for the best phase factor takes less time of around 3 seconds which is less than that taken by conventional PTS and proposed PTS schemes.

Figure 5 illustrates the PAPR performance of original OFDM, PTS OFDM and the PSO based PTS OFDM which shows that PSO based PTS OFDM have signals with low PAPR. And Table III summarizes the performance of three PAPR reduction techniques.

V. CONCLUSION

OFDM is a very appealing technique for achieving high-bit-rate wireless data transmission. However, the potentially large PAPR has limited its application. PTS scheme reduces the PAPR to a great extent compared to other existing methods but its computational complexity is very high. Therefore, this paper proposes a novel reduced complexity PTS scheme which uses correlation among the candidate signals to derive the optimal OFDM signal with low PAPR while achieving the same PAPR reduction as the conventional PTS. Similarly, this paper also presents the PSO based PTS technique which uses social and individual experience to give the global best value of the phase factor in less time. Simulation results have shown that the PAPR of original OFDM is about 8 dB and after using PTS and proposed PTS algorithm it reduces to around 6-7 dB while the PSO based PTS reduces PAPR to around 4-5 dB. Thus we can conclude that proposed PTS and PSO based PTS techniques give good PAPR reduction performance with low complexity and less searching time.

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