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PAPR analysis of OFDM system using AI based multiple signal representation methods

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Abstract

OFDM (orthogonal frequency division multiplexing) is widely used in 4th generation applications owing to its robustness in fading environments. The major issues with OFDM systems is the high PAPR (peak-to-average power ratio) of the transmitted signals, it leads to in and out of band distortion. SLM (selective mapping) and PTS (partial transmit sequence) are two key methods for PAPR reduction. Both the methods require exhaustive searching of phase factors to optimize the PAPR, these searches lead to high computational complexity. This paper discusses using optimization based PAPR reduction methods which an be used with PTS for the reduction of computational complexity and search space. In this paper we have analyzed PTS and SLM with particle swarm optimization (PSO), Artificial Bee Colony (ABC) and differential evolution (DE). PAPR and BER (bit error rate) comparison is done for both the cases.

Keywords: *ABC, DE, PAPR, PTS, PSO*

1. Introduction

Orthogonal frequency division multiplexing (OFDM) [1, 2] is a multicarrier transmission method which plays an important role in achieving high data rate in 4th generation applications. In OFDM available bandwidth is divided in to narrow band channels and each of the channels carry a subcarrier leading to a multicarrier system. OFDM has gained its popularity owing to its superlative performance in the fading environments. Use of guard band and cyclic prefix in OFDM works well against menace of inter symbol interference (ISI) and inter-carrier interference (ICI) [3]. However OFDM is largely affected by problem of high peak to average power ratio (PAPR) [4]. When OFDM signal is transmitted where each of the subcarrier is different modulated by different symbols it might lead to high peaks in domain when a number of subcarriers align in same phase. These high peaks lead to high power, when such OFDM signal are fed to high power amplifiers (HPA) which are employed for downlink purpose, causes harmonic distortion and intermodulation. This is due to nonlinear characteristics of HPA. To make sure that HPA works in the linear region large back-off is required, this reduces efficiency of HPA.

There are numerous methods detailed in literature [4] for PAPR reduction, such as clipping where signal is clipped off beyond a certain signal level [5], using forward error correction codes [6, 7] for generating combination with lower PAPR, tone injection (TI) [8, 9], tone reservation (TR) [10, 11] where additional data block and power reduction carriers are used for PAPR reduction, companding reduces PAPR by compressing the higher peaks at the transmitter [12, 13], pre-distortion and DFT-spreading are some of the pre-coding [14] method for PAPR reduction, active constellation extension [15, 16] uses extension of existing constellation without affecting actual data. All of the above mention methods are either result in to distortion or requires high power transmission. Multiple signal representation method such as selected mapping (SLM) [17, 18] and partial transmit sequences (PTS) [19-21] are most sought choices for PAPR reduction as the resultant signal does not have any distortion. SLM performs better in terms of PAPR reduction but PTS is preferred over it owing to less computational complexity. In conventional PTS input data set is subdivided in to uncorrelated sub-blocks, after processing theses sub-blocks through Inverse Fast Fourier Transforms (IFFT) each of them is multiplied by a phase factor and finally they are summed up to generate OFDM candidate,

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however the candidate signal with least PAPR is transmitted. To find optimum phase set excessive searches are require leading to high computational complexity. In this paper, we have taken up the issue of large number of searches involved in PTS [22]. Since reduction in number of searches will lead to lower computational complexity [23]. By using optimization techniques number of required searches can be reduced. Some of the excessively used methods are Genetic Algorithm (GA) [24, 25], Particle Swarm Optimization (PSO) [26], Artificial Bee Colony (ABC) [27, 28], Biogeography Based Optimization (BBO) [29] and differential evolution (DE) [30].

2. Peak to Average Power Ratio in OFDM Systems

An OFDM signal with *N*-subcarrier is represented as

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k .\exp\left(\frac{j.2.\pi.k.n}{N}\right) \tag{1}$$

where N is the number of sub carriers i.e ($k=0,1....N-1$) and X_k is the symbol modulating the k^{th} subcarrier. IFFT sum in OFDM may results in to large envelope peaks in time domain. This results in 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 as:

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

where $|x_n|$ the magnitude and E is representing the expectation operator. To evaluate PAPR reduction performance of a method complementary cumulative function is used as a performance index. CCDF represents the probability that signal level will remain above a particular level, power level in case of PAPR. CDF can be represented as

$$CCDF = \Pr(PAPR > PAPR_0) \tag{3}$$

3. Multiple Signal Representation Methods

In such method same set of data is represented by a set of OFDM candidate signals which are generated with the help of different phase sets. The candidate with least PAPR is transmitted. The two widely used methods are SLM and PTS.

3.1. SLM

Selected mapping [19-22] scheme is shown in Figure 1. The input symbols are multiplied with a set of phase vectors and after IFFT block multiple OFDM signal candidates representing the same data set are produced then one with the least PAPR is chosen for final transmission. This also requires transmission of side information for error free recovery of OFDM symbols.

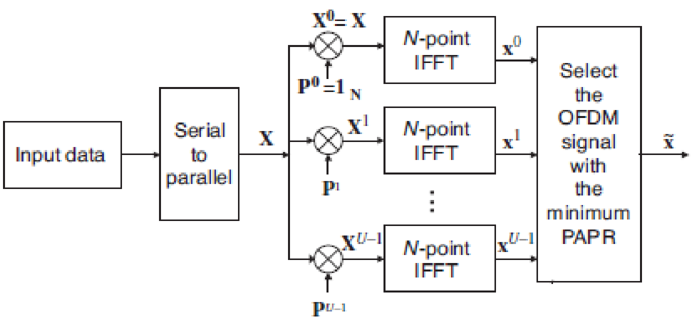

Figure 1. OFDM system with SLM technique

Every data block is multiplied by *U* phase sequences, with each block of equal size *N*, the phase factor $P^{(u)} = \left[p_{u,0}, p_{u,1}, \dots, p_{u,N-1}\right]^T$, where *u* = *1,2…U,* and $P_{u,v} = e^{j\phi u,v}$ and $\phi_{u,v} \in [0,2\pi)$ for *v* = 0,1….*N-1.* This resultant signal is:

$$X_n^u = X_n P_{u,n} \tag{4}$$

after taking its IFFT the various OFDM sequence get generated among which $\tilde{x} = x^{\tilde{u}}$, with lowest PAPR is selected for transmission.

$$\tilde{u} = \underset{u=1,2,\dots,U}{\arg\min}\left(\max\left|x^{u[n]}\right|\right) \tag{5}$$

3.2. PTS

Figure 2 shows typical PTS scheme. The data sequence X is split 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 (6):

$$x^m = \sum_{v=0}^{V-1} b_m^v . x_v \tag{6}$$

where $x_v = IFFT[X_v]$, with *Jz*phase weights total number of phase weights which need to be analyzed are J^{V-1}, as for the first sub block the phase factor is usually chosen as 1. The optimum phase factor is the one which produces minimum PAPR of candidate signal *x'* as given by (7):

$$\left[\widetilde{b_1}, \dots, \widetilde{b_v}\right] = \underset{[b_1,\dots\dots\dots.b_v]}{\arg\min}\left(\max_{n=0,1\dots N-1}\left|\sum_{v=1}^{V} b_v x_v[n]\right|\right) \tag{7}$$

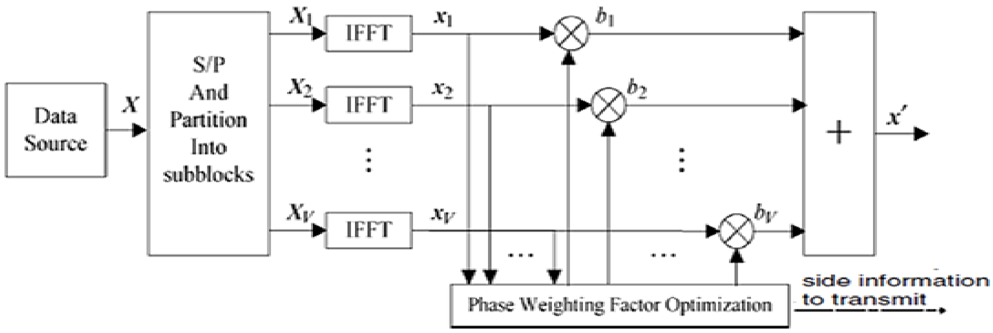

Figure 2. OFDM systems using PTS

3.3. Complex Computations in PTS

For *V* sub-blocks and *J*-phase weights, J^{V-1} possible phase combination is searched and analysed which results in to same number of PTS candidates are generated. For *N*-point IFFT operations (*N*-subcarrier OFDM):

$$\text{Complex addition: } N\log_2 N \text{ and multiplications } (N/2).\log_2 N \tag{8}$$

for an oversampling factor of R, Factor of N will be replaced by N.R. In generation of PTS candidates additional $N \times J^{V-1} \times (V-1)$ multiplications and additions will be required. So,

$$\begin{aligned}&\text{Overall complex additions} = R.V.N\log_2 N + R.N \times J^{V-1} \times (V-1)\\&\text{Overall complex mulitplications} = R.V.(N/2)\log_2 N + R.N \times J^{V-1} \times (V-1)\end{aligned} \tag{9}$$

If we can reduce the number of searches from J^{V-1}, the number of computations required will also reduce. Optimization methods can be used to serve the purpose.

4. Multiple Optimization Methods based PTS

Using optimization methods, we can put a cap on the searches required and thus overall computational complexity of PTS systems. In this paper we used ABC, PSO, DE and GA method for reduction of number of searches.

4.1. Particle Swarm Optimization Algorithm (PSO)-PTS

The method labels the population as swarm and each individual is called a particle. The typical flowchart for the algorithm is shown in Figure 3. PSO-PTS technique is implemented by changing phase factor combination b_v which used as position vector. Each PTS candidate x is considered as a particle with position vector, b_v $(v=0,1....V-1)$ along with the velocity vector is changed is changed to get a new solution or PTS candidate. A true solution is the one which using b_v achieves desired relation between and local and global objective of the algorithm. pbest and gbest are PAPR values for a set of b_v. The iterations end when both the variable achieves the pre-decided PAPR threshold. The new velocity for ith particle is given by:

$$z_i(t+1) = w.z_i(t) + a_1.c_1.\left({b_v}^{pbest}(t) - b_v(t)\right) + a_2.c_2\left({b_v}^{gbest}(t) - b_v(t)\right) \tag{10}$$

where a_1 and a_2 are acceleration factors and c_1, c_2 are uniformly distributed $r.v$ in [0,1] and z is representing the velocity.New position will be:

$$b_{i,v}(t+1) = b_{i,v}(t) + z_i(t+1) \tag{11}$$

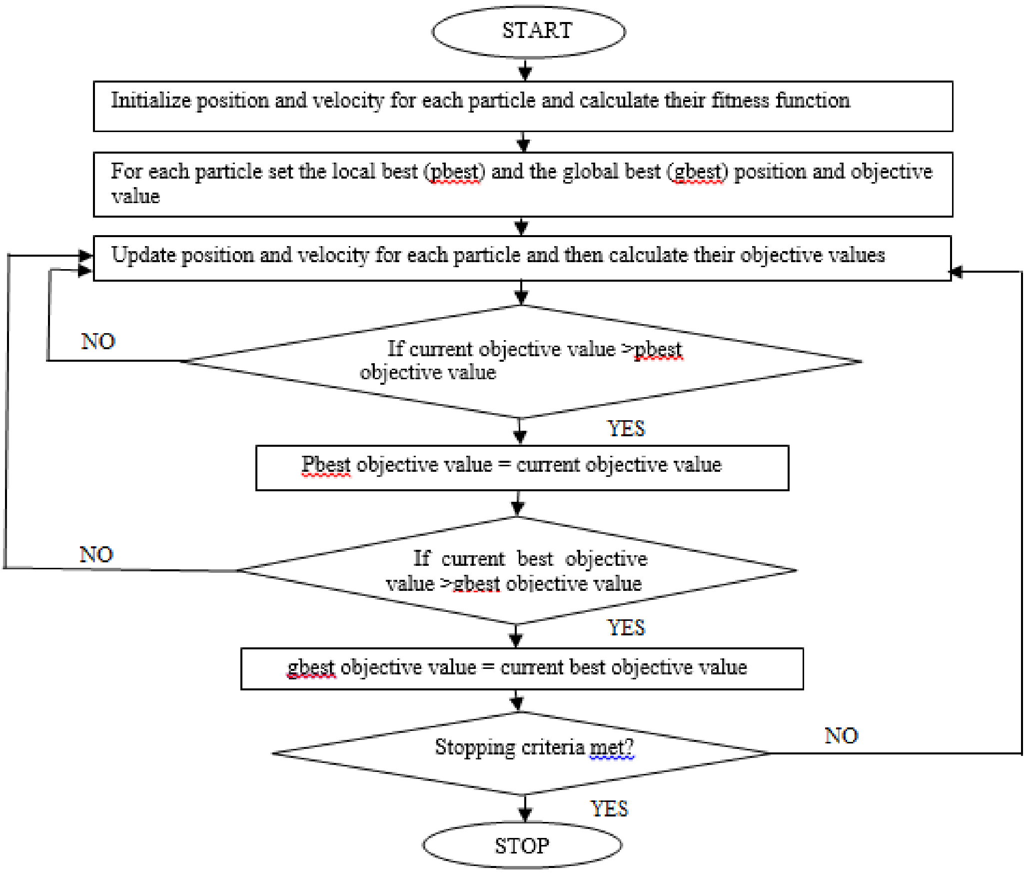

Figure 3. Flowchart for PSO algorithm

4.2. Particle Artificial Bee Colony (ABC)-PTS

The algorithm contains three dissimilar groups of bees: “employed bees”, “onlooker bees” and “scout bees”. The different sources here are member of solution space and nectar represents fitness. According to this algorithm initially a randomly distributed population is generated which represent the employed bees. The employed bees execute various operations with the neighborhood values in seeking the best value. If the solution in the vicinity is healthier than the initially received one, the new solution is allocated in place of the first one. When the entire search process of the employed bee is concluded, they distribute this information with the next set of bees i.e. “onlooker bees. The employed bee turns towards the food source. The goal is to discover a phase vector with extreme fitness value; the fitness function is given by:

$$fit(x_j) = 1/1 + f(x_j) \tag{10}$$

where x_j is the solution primed in continuous space and then transformed into discrete phase vector space. Also, $f(x_j)$ represents the PAPR value. Whenever fitness is high, PAPR has a low value. A corresponding fitness value of the phase vectors are calculated, if the old value is lower than the new value, then the bee memorizes the new phase value. The new phase vector is chosen by:

$$x_j = x_j + a_j(x_j - x_p) \tag{11}$$

where α_j is a random number generated in the range [-1,1], and x_p is the solution within the neighborhood of x_j the fitness value is then pooled by the onlooker bees, when the work of employed bees is finished. Onlooker bees move towards new food sources, based on the knowledge provided to them by employed bees, through a formula:

$$S_j = fit(x_j) \Big/ \sum_{j=1} fit(x_j) \tag{12}$$

the onlooker bee demeanors a search in the neighborhood of the food source chosen by (12) till the threshold value. ABC-PTS implementation is shown in Figure 4.

Finally, when the onlooker bees accomplish their task, the employed bees transform to scout bees, in order to seek new food sources randomly, by the following formula:

$$x_j = \min(x_j) + rand(0{,}1) * (\max(x_j) - \min(x_j)) \tag{16}$$

where, rand (0,1) is the random number with a uniform distribution.

4.3. Differential Evolution (DE)-PTS

The DE technique twitches with an initial solution set. The DE process usually three chief processes: initialization, mutation operation, crossover operation, and selection operation. DE is implemented as per following block diagram shown in Figure 5.

5. Simulations and Results

The simulations has been carried out in MATLAB for N=128 for V=8 sub blocks and 4 phase weights $\{1, j, -1, -j\}$. Mapping scheme used is BPSK, 1000 OFDM symbols have been used for simulations. Rayligh fading channel is used with 4 taps for BER calculations. Figure 6 (a) shows PAPR reduction capabilities of PTS, ABC-PTS and PSO-PTS in terms of CCDF. It clearly shows that ABC and PSO-PTS performs better than conventional one. The PAPR values for ABC-PTS are in the range of 4-7 dB where as for PSO-PTS value may go up to 9 dB as compared to >10 dB for PTS. Figure 6 (b) compares the PAPR reduction performance of SLM, ABC-SLM and PSO-SLM. Again, the CCDF curves are plotted it implies that, the PAPR values for ABC-SLM are in the range of 4-6.8 dB where as for PSO-SLM value may go up to 7.8 dB as compared to 9.4 dB for SLM.

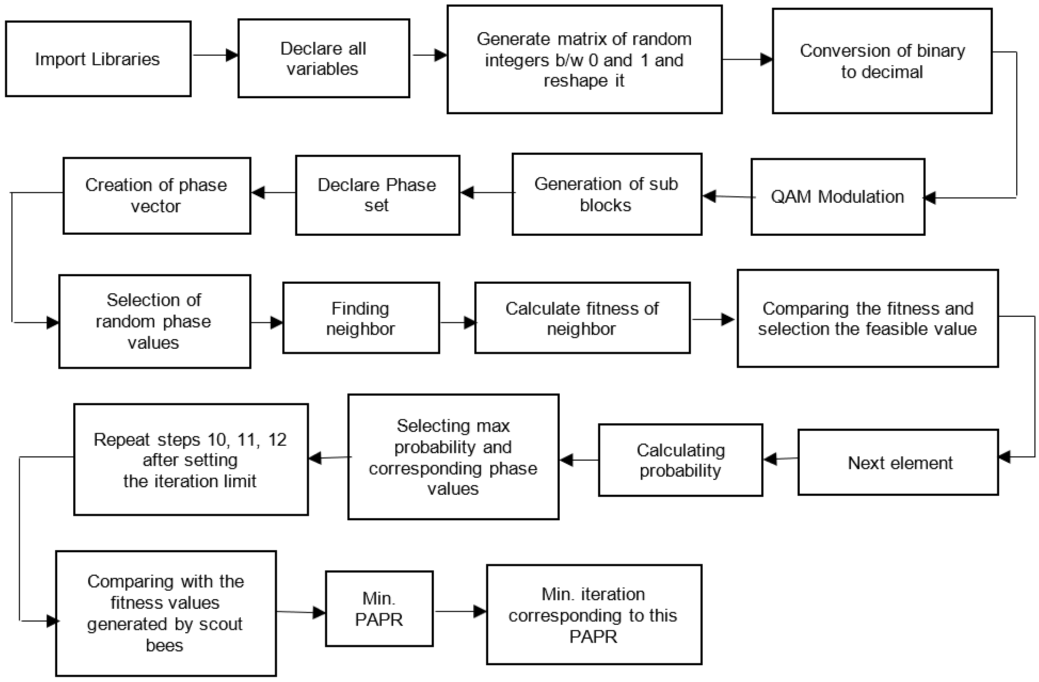

Figure 4. Implementing ABC-PTS algorithm

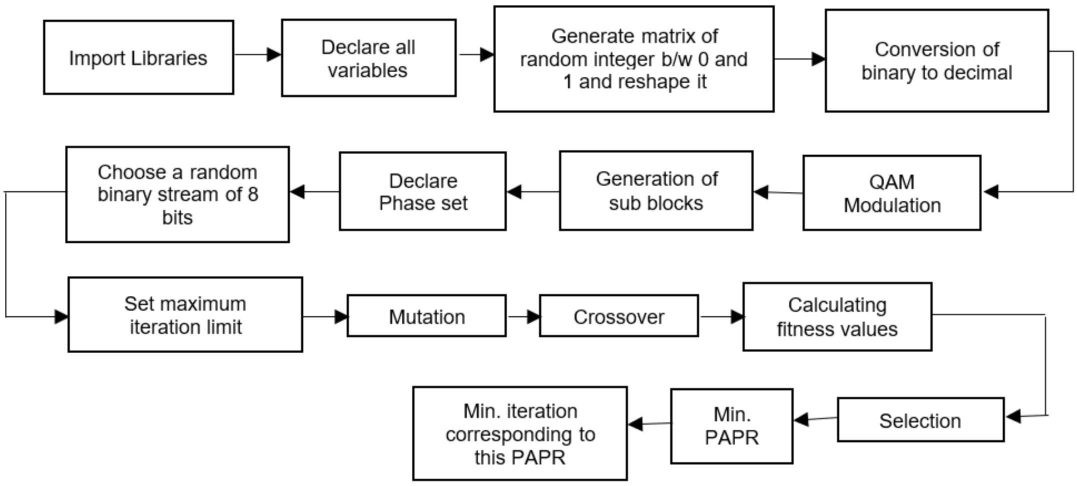

Figure 5. Implementing DE algorithm

Figures 7 (a) and (b) shows BER performance of ABC and PSO in SLM and PTS OFDM systems BER curves show similar performance and trend SLM and PTS however ABC results in to better BER value than PSO. Overall, we can say that PAPR performances of the optimization-based methods are good enough in practical scenarios. Table 1 summarizes the result of above study for PTS it clearly shows that for lower number of iterations similar PAPR performance can be achieved. This will lead to reduction in complexity.

Reduction in iterations will reduce the number of complex additions and multiplications e.g.: For 4 sub-blocks and 4 phase weights number of complex multiplications will be = $4^{(4-1)}\times 3=192$. Similarly, number of complex multiplications will be = 192. However, theses values will reduce to 18 and 99 for ABC and DE based PTS methods. However, for similar complexity PAPR reduction in PSO PTS is better.

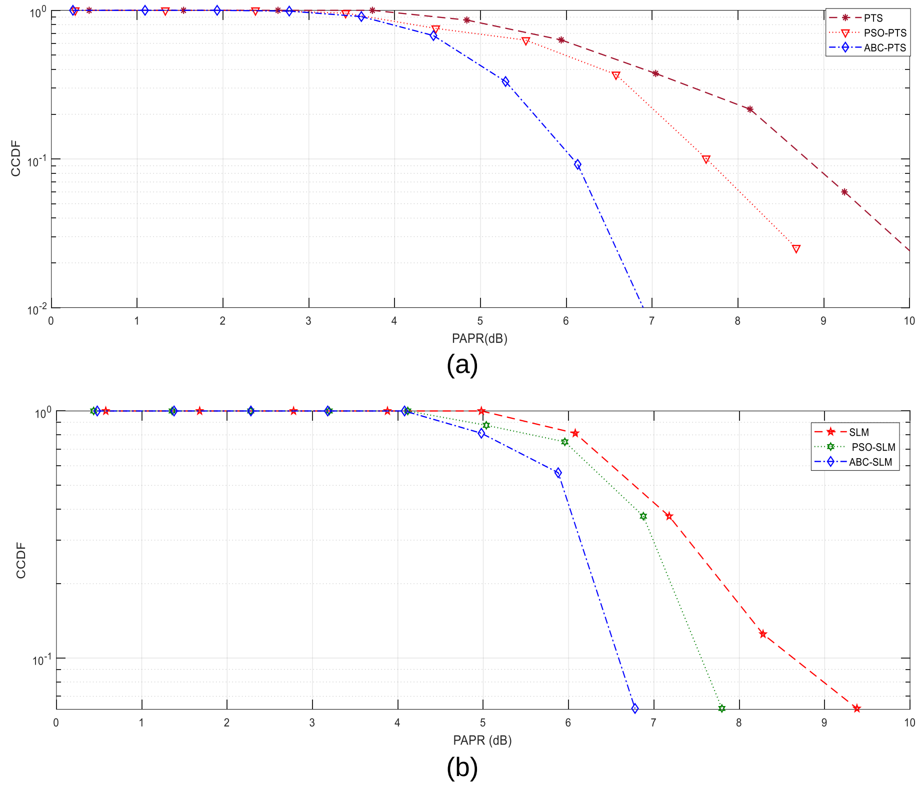

Figure 6. CCDF curves for (a) PTS, ABC-PTS and PSO-PTS and (b) SLM, ABC-SLM and PSO-SLM

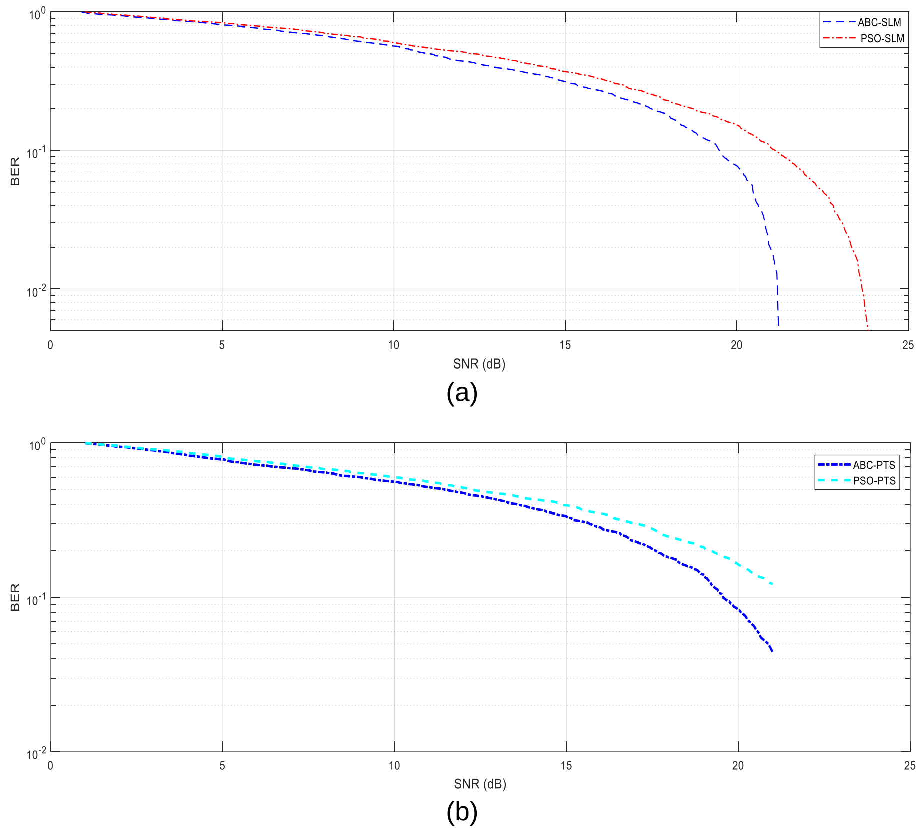

Figure 7. BER comparison of (a) ABC-SLM and PSO-SLM and (b) ABC-PTS and PSO-PTS

Table 1. PAPR and Iterations for Various Optimization Methods

Methods	PAPR	Iterations
PTS	9.554	64
ABC-PTS	7.6752	6
DE-PTS	7.0307	33
PSO-PTS	8.9185	64

6. Conclusion

High PAPR is on of the major challenges 4th generation OFDM based systems are facing, PTS and SLM are the most sought distortionless methods for PAPR reduction. But both the methods require excessive searches to find the optimum signal for transmission. Using AI based optimization techniques we can achieve similar PAPR reduction at reduced searches this directly impacts the number of computations required in both the methods. In this paper PSO, ABC and DE methods are used, but the analysis can be further carried out for other methods such as biogeography, differential evolution and other optimization methods.

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