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PAPR, SPECTRAL EFFICIENCY, BER AND SNR ANALYSIS OF OFDM : A NOVEL PARTIAL TRANSMIT SEQUENCE-PARTICLE SWARM OPTIMIZATION TECHNIQUE

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is a widely used multicarrier modulation (MCM) technique in the field of wireless communications, specifically designed to facilitate high-speed data transmission. The use of several subcarriers inside an OFDM system for the transmission of modulated symbols results in the generation of OFDM signals with a significant peak-to-average power ratio (PAPR). In this study, we propose a novel approach for mitigating the high PAPR in wireless communication systems (WCS). Our method utilizes a partial transmit sequence (PTS) strategy, which is enhanced by using an adaptive particle swarm optimization (PSO) algorithm. In this study, we present a description of an OFDM system employing the standard PTS technique in conjunction with PSO. To mitigate computational complexity, the suggested methodology efficiently explores the optimal amalgamation of phase rotation components. Experimental findings demonstrate that the computational complexity and PAPR have been greatly minimized by the suggested method.

KEYWORDS

BER, CCDF, computational complexity, communication, OFDM, PAPR, PTS, PSO, SNR.

1. INTRODUCTION

In nowadays days, the digital landscape is replete with wireless technologies that facilitate the seamless execution of daily tasks, hence enhancing the quality of life for individuals. The proliferation of wireless technology has led to a substantial increase in the population's awareness and proficient use of this technology. The increasing number of active users has led to a strong demand for services such as high-definition television, mobile video, high-speed internet, and video conferencing [1-4]. OFDM is widely recognized as a fundamental transmission strategy for multicarrier (MC) due to its ability to split the channel into sub-channels, enabling parallel data transfer with extended symbol lengths. This characteristic makes OFDM a highly efficient and straightforward option for wideband communication. The problem of estimating inter-symbol interference (ISI) is addressed, and a method is proposed to transform a specified frequency fading channel into a flat fading channel [5-6]. One of the MCM techniques often employed in wireless communications is OFDM [7]. The use of the OFDM technique is a common strategy in achieving high-speed transmission across frequency-selective fading channels [9]. OFDM signals commonly demonstrate amplitude variation in the time domain and possess a notable dynamic range, also known as PAPR, owing to their MC structure [8], as the PAPR of an OFDM signal is high, it undergoes clipping as it passes through a nonlinear high power amplifier (HPA). This

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results in a decrease in performance and leads to the generation of out-of-band (OoB) radiation and in-band distortion. Therefore, the use of expensive linear HPA with a wide dynamic range is important for OFDM transmitters [10]. An elevated PAPR has a detrimental effect on the efficiency of radio-frequency (RF) power amplifiers, resulting in increased costs. Numerous approaches have been developed to mitigate the disadvantages associated with high PAPR. In the context of OFDM systems, there exist many techniques aimed at reducing the PAPR. These methods encompass clipping, coding, non-linear companding, tone reservation (TR) and injection, selective mapping (SLM), and PTS [11]. Among the many ways, the PTS approach emerges as the most successful and distortion-free technique for minimizing PAPR in OFDM systems. One of the most effective techniques for reducing PAPR is PTS. One of the challenges associated with the PTS strategy is its significant computational burden in establishing the optimal phase factors. Additionally, the requirement to give an excessive amount of phase factors as side information to the receiver side poses another issue [12]. The optimal selection of phase factors was achieved by the application of several optimization approaches, including PSO, Simulated Annealing (SA), Genetic Algorithms (GA). These strategies were employed to overcome the restrictions associated with the use of PTS [13]. In the PTS technique, the input data block is divided into many distinct sub-blocks, each of which is independent. Prior to multiplying each related time signal with a phase rotation factor, an IFFT operation is performed on each independent sub-block. The objective of the PTS approach is to select appropriate phase factors in order to minimize the PAPR of the combined signal generated by all sub-blocks [14]. The complexity of conducting an exhaustive search for the optimal phase factors in the PTS technique increases fast due to the number of sub-blocks and phase rotation variables involved. Previous studies [15-17] have examined many suboptimal ways to minimize the search complexity in the context of PTS.

The PSO-PTS Scheme utilized in the OFDM system, as described in the work of Wen, Horng, et al. [18], utilizes heuristic techniques to determine the optimal combination of basic phase variables. This approach leads to a decrease in computational complexity, but with a little trade-off of increased PAPR. In their study, the researchers in reference [19] introduced an OFDM system that utilizes a sub-optimal PTS technique based on PSO to determine the ideal phase weighting factors. The results produced from this approach demonstrated good performance in terms of PAPR and computational complexity, while using only a limited number of iterations. Additionally, authors worked on the PTS-OFDM technique in [20], which provided a novel strategy for reducing computational complexity using PSO, with the approach's output coming close to being achieved but requiring the use of PAPR. The lower PAPR received, but the complexity load was still somewhat above average, in accordance with GA-PTS and partheno-crossover operator combination(PCGA)[21]. Additionally, the GA and Optimization algorithms in PTS-OFDM were analyzed, and the results indicated that while the GA reduced PAPR at the expense of computational complexity, the PSO approach achieved the vice versa[23]. The reader may read [24] for more details on another approach called fireworks algorithm (FWA) that outperformed the two techniques mentioned above. PSO and GA were suggested as some evolutionary PTS-based optimization techniques for lowering search numbers[22]. In order to solve the computationally challenging PAPR minimization problem in the PTS technique, a novel PSO-based approach is presented in this article. The suggested approach decreases PAPR with a better convergence rate and a reduced computational complexity.

The remaining of the article is arranged as follows. The OFDM transceiver model is described in Section 2. The PSO algorithm and PTS approach are described in Section 3. Section 4 summarizes the discussion and simulation outputs. Section 5 provides conclusions.

2. OFDM SYSTEM MODEL

All the telecommunications standards, such as those for WLANs, DTT, and DRT in much of the world, are based on OFDM, a Commonly employed modulation and multiplexing technology[25]. The literature has referred to OFDM in the past and present as MC, Multi-tone, and Fourier Transform. The idea of OFDM is to distribute the data to be broadcast among a lot of carriers that are all modulated at a low rate. By carefully deciding on their frequency spacing, the carriers are made orthogonal to one another[26]. The complete amount of spectrum bandwidth is divided into sub-bands using a multicarrier system like FDM so that many carriers can broadcast simultaneously. It creates a composite high speed communication system by combining a lot of low data rate carriers [27]. The carriers can be tightly spaced with overlapping and no ICI because of orthogonality. The need for greater data rate services, such as multimedia, audio, and data across wired and wireless lines, is rising along with communications technologies. To transport the vast quantity of data that conventional approaches cannot handle, new modulation methods are needed. High data rate, acceptable bit error rate(BER), and more latency must be provided by these methods[28]. One of them is OFDM. In Europe, OFDM has been utilized for large data rate wired networks like ADSL, DAB, and DVB.

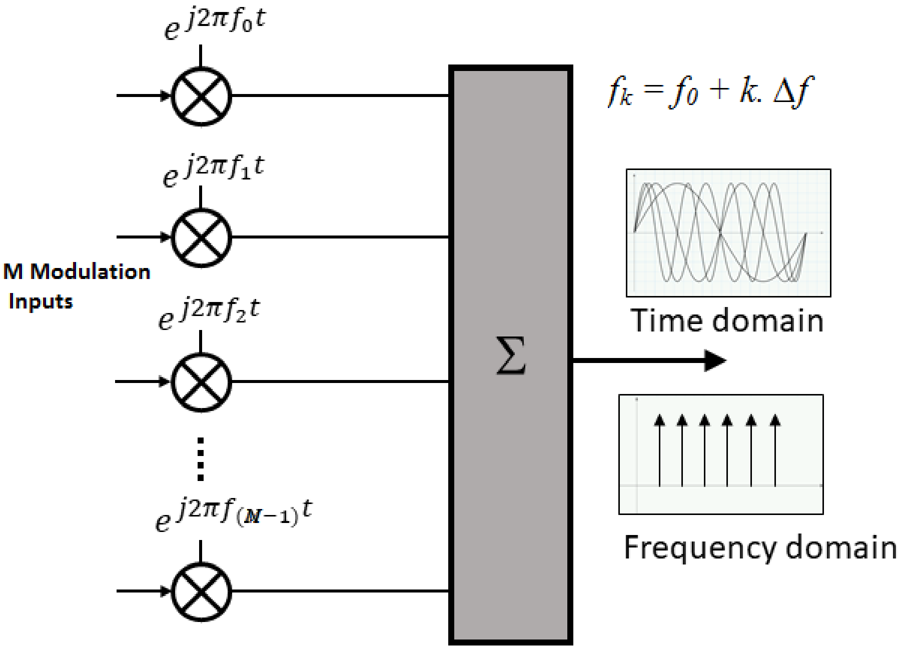

Figure 1. Signals of various frequencies are added via an OFDM modulator

An effective modulation scheme named OFDM is employed in current wireless communication systems, such as 5G. The development of a high-speed communication system involves the integration of FDM and QAM in the OFDM technique [29]. BPSK, QPSK, 16QAM, and 64QAM are a few of the various modulation types referred to as QAM. R. W. Chang was the first to suggest the fundamental idea of OFDM, realizing that band limited orthogonal signals might be mixed with substantial overlap while minimizing ICI. Using OFDM, we could create a network of subcarriers that work together to transfer data across several frequencies. These subcarriers must carry out orthogonal functions. For two functions to be termed orthogonal in mathematics, the integral of their product over the chosen time range must be zero[29]. In a broader sense, orthogonal functions can be formed of as statistically unconnected.

The signal representation is given by

$$s(t) = \sum_{k=0}^{M-1} c_n e^{j2\Pi f_k t} \tag{1}$$

$$\text{Here,} \quad f_k = f_0 + k.\,\Delta f \tag{2}$$

Figure 1 demonstrates how M subcarriers with identical spacing can be merged to create an array of parallel signals. QAM is used to modify each subcarrier. Although these modulated subcarriers can support separate baseband signals, they are often merged to offer the highest data throughput for a single stream of data. These subcarriers can be mathematically represented by utilizing a complex form that is compatible with the usage of QAM. A transmitter and receiver combine up the fundamental block diagram of OFDM system in Figure 2. At the transmitter side, the input bit stream enters into the system. Normally, this input bit stream is de-multiplexed into smaller bit streams that are given to each of the M-QAM modulators individually.

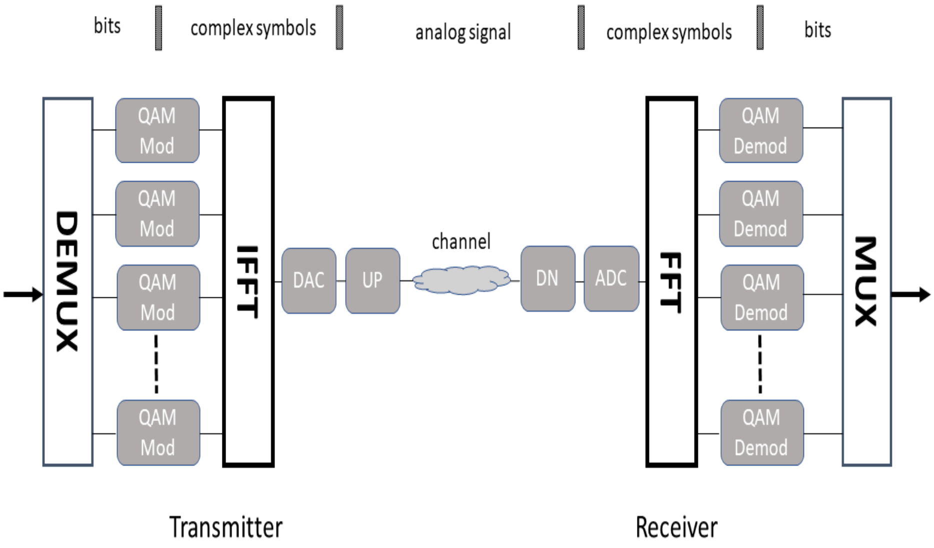

Figure 2. A basic OFDM system

The production of the time domain signal from the array of modulated subcarriers using the IFFT is a crucial factor that facilitates the implementation of OFDM. The digital OFDM signal obtained is subsequently applied to the DAC for conversion into an analogue waveform [30]. The baseband signal is frequently subjected to up-conversion to a higher frequency prior to its transmission across the channel. At the recipient, the process is reversed. The function of an analogue down-converter (DN) is to perform a frequency shift on the OFDM signal, bringing it back to the baseband. The ADC is responsible for converting the incoming signal into a digital representation prior to transmitting it to the FFT block. The FFT module performs a conversion of the input signal from the time domain to a collection of subcarriers in the frequency domain, which are then modulated using QAM. Upon the completion of QAM demodulation, the bit stream from each subcarrier is reproduced. Subsequently, the original single data stream is reconstructed by the process of multiplexing [31]. Figure 3 illustrates the temporal and spectral representation of an OFDM transmission signal.

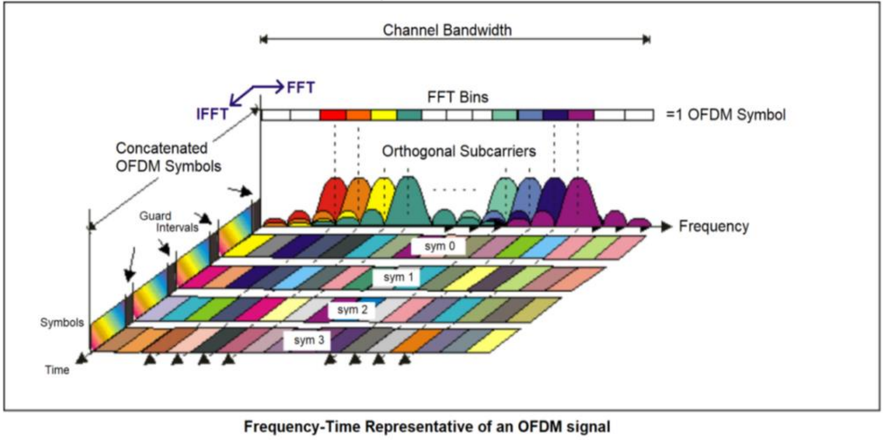

Figure 3. combined view of the OFDM signal in the time and frequency domains

Figure 3 illustrates the time plus frequency domain visualization of an OFDM signal. A set of OFDM subcarriers is represented by each symbol in the diagram and is transmitted along the channel. Through the application of a digital modulation technique, the initial binary sequence undergoes a conversion process resulting in a limited number of constellation points. The utilization of a serial to parallel (S/P) converter is employed in order to divide the baseband modulated symbols that have been successfully acquired into M-frames of identical length prior to performing an IFFT operation. The generation of the baseband OFDM signal involves the transmission of a sequence of baseband modulated symbols S_k via an IFFT block [32,35]. The discrete-time transmitted OFDM signal, consisting of M subcarriers, can be represented by n samples, given below:

$$s_n = \frac{1}{\sqrt{M}} \sum_{k=0}^{M-1} S_k e^{\frac{j2\Pi kn}{M}} ;0 \le n \le M-1 \tag{3}$$

The PAPR of the signals is the ratio of maximum power to average power and is generally expressed as:

$$PAPR = \frac{Max\left|s_n\right|^2}{E\left[\left|s_n\right|^2\right]} \tag{4}$$

$$PAPR_{dB} = 10\log_{10} \frac{Max\left|s_n\right|^2}{E\left[\left|s_n\right|^2\right]} \tag{5}$$

The efficiency of the PAPR minimization method is often examined using the complementary cumulative distribution function(CCDF). The CCDF may be defined as: "The probability that an OFDM signal's PAPR will exceed a threshold level. ρ"

$$CCDF = P(PAPR > \rho) = 1 - \left[1 - e^{-\rho}\right]^{M} \tag{6}$$

3. PTS AND PSO-PTS METHOD

In the PTS approach, the input sequence is partitioned into many subsequences. Subsequently, every subsequence of symbols undergoes an IFFT, and the resultant subsequences of signals are combined by multiplication with a set of distinct rotating vectors [11]. The signal sequence exhibiting the minimum PAPR is thereafter sent after evaluating the PAPR for each resulting sequence. When the number of subcarriers and the sequence of modulation increase, prioritizing the reduction of computational complexity is more important than minimizing redundancy.

The input data block, consisting of M symbols, is divided into N distinct sub-blocks using the PTS technique. The IFFT is subsequently performed on each sub-block individually and is multiplied by the corresponding complex phase factor $p^n = e^{i\theta_m}$. In order to mitigate the PAPR of the aggregate signal originating from all sub-blocks, appropriate phase factors are used. Figure 4 is a schematic diagram of the OFDM transmitter that incorporates the PTS technique. The input data stream, denoted as S, is partitioned into N distinct sub blocks, referred to as S_n. Each sub block undergoes an IFFT operation, and its associated weighted phase factor, p^n, is appropriately modified. The objective is to determine the set of phase factors p^n that minimizes the PAPR of the composite time-domain signals.

$$s = \sum_{n=1}^{N} p^n s_n \tag{7}$$

$$s = \sum_{n=1}^{N} p^n \ \mathrm{IFFT}\left[S_n\right] \tag{8}$$

$$s = \sum_{n=1}^{N} \tilde{p}^n \, x_n \tag{9}$$

The phase factors are selected to reduce the PAPR, which is expressed as follows:

$$\left[\tilde{p}^1, \tilde{p}^2, \ldots, \tilde{p}^n\right] = \arg\min\left[\max\left|\sum_{n=1}^{N} p^n s_n\right|\right] \tag{10}$$

The time-domain signal with the associated minimal PAPR is represented by:

$$s = \sum_{n=1}^{N} \tilde{p}^n s_n \tag{11}$$

It needs to be noted that choosing the best phase factors needs a thorough search of all possible combinations of phase factors, which increases computing complexity. In order to decrease the complexity of the search, a certain set of elements are limited by phase factor p^n. The best set of phase vectors should be found by searching 4^N sets of phase factors as the range of permitted phase factors is p={±1, ±j}. With more sub-blocks, the search complexity is obviously considerably more difficult.

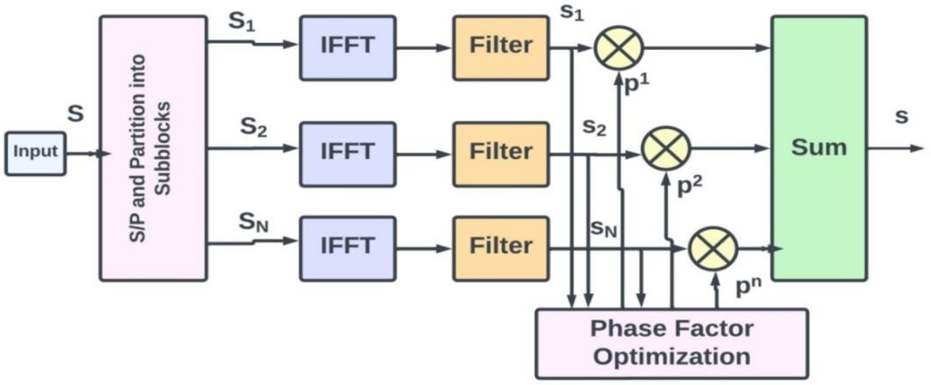

Figure 4. PTS method of OFDM PAPR minimization

PSO is a stochastic optimization approach that relies on the movement and behaviour of swarms. In PSO, the utilization of social interaction is employed as a means to tackle various challenges. The proposed method employs a collection of particles, referred to as agents, which navigate inside the search region with the objective of locating the most optimum solution. Every individual inside the swarm actively seeks the positional coordinates within the solution space that correspond to the most optimal solution they have generated thus far. The term commonly referred to as a personal best is denoted as pbest. The PSO algorithm also considers the global best (gbest) as a significant metric. The maximum value is determined by the particle next to it. In the initialization phase of the PSO algorithm, a random velocity is assigned to each possible solution within the population of randomized solutions. The transportation of potential solutions occurs inside the issue space in the form of particles. Particles have been shown to be associated with the most optimal result or highest degree of physical fitness seen thus far. Furthermore, the fitness value is also kept. The designated nomenclature for this particular value is "pbest". Another significant measure identified by the international iteration of the PSO algorithm is the collective best value attained by each particle inside the population, together with its corresponding location. The term used to refer to this number is often known as "gbest." The aforementioned is the worldwide manifestation of PSO. During each iteration, the particle modifies its velocity and moves closer to its personal best (pbest) and the global best (gbest) positions. The technique being referred to is commonly referred to as the local variant of PSO. In this approach, each individual particle in the swarm keeps note of the best solution it has seen, known as the neighbourhood best (nbest) or local best (lbest). This is achieved by considering a small topological neighbourhood of particles [33]. One of the strategies employed in evolutionary computing is the PSO algorithm. The primary objective was to demonstrate the stochastic locomotion patterns of a collective of avian organisms. An enhanced PSO algorithm is proposed in this study to minimize the high PAPR of an OFDM system using the PTS technique [34], while reducing computational complexity. A collection of factors can be seen as a specific point or place inside the extensive space of phase factors, where each value along a dimension corresponds to a distinct component. The suggested PSO technique use a primary set of solutions referred to as "particles" as the first starting point. Each particle is located at a specific position inside the N-dimensional space. To clarify, it may be said that every particle possesses an N-dimensional phase vector, whereby each component is selected from a set of phase factors. Particles traverse across space in search of the most favorable location, and their final positions are determined by the interplay of their interactions. Consequently, individuals seek out opportunities for optimization at both local and global levels. Ultimately, each individual particle achieves motion towards the optimal location. Particles possess the inherent potential to explore and, as a result, they engage in a search process to identify the most favorable sequence of phase factors.

Let $L_j = (l_{j1}, l_{j2},..., l_{jN})$ is the location/vector of the jth particle, $P_j = (p_{j1}, p_{j2},..., p_{jN})$ is the best place (p_{best}) found by the j^{th} particle and the best place discovered by all particles with the g_{best} index is shown. $V_j =(\vartheta_{j1},\vartheta_{j2},..,\vartheta_{jN})$ is used to denote the j^{th} particle's velocity (V). By using Eq.(12) and (13), particles move.

$$v_{jb}(k+1)=\omega\ v_{jb}(k)+Q_1+Q_2 \qquad (12)$$

Here , $Q_1 = a_1 r_{1b}(k)\left[p_{jb}(k)-l_{jb}(k)\right]$, and $Q_2 = a_2 r_{2b}(k)\left[p_{jb}(k)-l_{jb}(k)\right]$

$$l_{jb}(k+1)=l_{jb}(k)+v_{jb}(k+1) \qquad (13)$$

Here, k indicates the number of iterations and $b = 1, 2,..., N;$ ω stands for the inertia weight, which has a positive value in terms of a time-varying linear function. The right inertia weight establishes a balance between local and global exploration, which speeds up the algorithm's ability to locate the best response.

$$\omega = \text{Iteration Number/Max Iteration} \qquad (14)$$

The coefficients, a_1 and a_2, show how quickly each particle approaches its respective individual and global optimal places. When these accelerations are low, particles circle the target region without attempting to approach it, and when they are strong, particles travel toward the target area at fast speeds and may even pass through it. Two uniformly distributed random numbers in the range (0,1) are r_1 and r_2, respectively. The maximum velocity(V_{max}) sets a limit on the particle velocities. The greatest movement a particle can make in the search space is determined by this vector. The particles cannot be investigated outside of the semi-optimal regions if the V_{max} is low. Particles may go through the optimal solution if V_{max} is high. The difference in particle positions at the two points determines the velocity. The new particle velocity is determined by applying Eq. (12). The prior velocity is used to calculate the new velocity. The separation between the particle's actual location and best location and the best location can be determined by the group. The particle travels to the new position in accordance with Eq. (13) after computing its velocity. The fitness of particles has been evaluated using the following evaluation:

$$fitness(s)=\frac{1}{PAPR(s)} \qquad (15)$$

```
Algorithm
Initialize all parameters;
$a1, a2, Max. iteration, p, particles, r1, r2, V_{max}, \omega$
Initialize particles with random positions in the space
Let $k=1$
While($k \le$ Max. iteration)
    $k=k+1$
    For each particle do
        Compute the position of the particle using $\omega$
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                Update $p_{best}$ of the particle
        End
        Select the best position find by all particles as a $g_{best}$ for swarm
        For each particle do
                Evaluate the velocity of the particle using $V_{jb}(k+1)$
                Update position of the particle using $l_{jb}(k+1)$
        End
End While
Return the phase factor set with lower PAPR as the solution.
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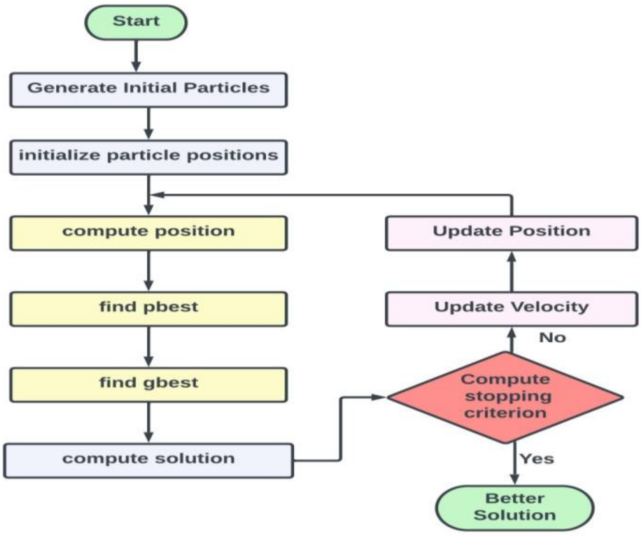

Figure 5. Flowchart : PSO-PTS process

4. RESULTS

Various simulations have been performed to analyze the effectiveness of the PSO-PTS algorithm for PAPR minimization in OFDM. MATLAB R2018a software was used to perform simulations.
Table 1. Simulation parameters

Parameters	Value
No. of subcarriers	512
No. of symbols	1e4
Modulation	QPSK
No. of sub-blocks	2,4,8,16
Over sample rate	4
Partition	adjacency partition
No. of particles per generation	10
Iteration numbers	[1 4 8 10 20 30]
Max iteration number	30
Learning factors	a1 = 2; a2 = 2
Max velocity	$V_{max} = 0.2$
Length of weighting factor set	1,2,3
Min inertia weight vector	$w_{min} = 0.4$
Max inertia weight vector	$w_{max} = 0.9$

Threshold value	6.7
Channel	AWGN

The CCDF of the PAPR analysis for OFDM and PTS-based OFDM signals with different numbers of sub-blocks is shown in Figure 6. From figure 6; at CCDF=10^{-4}, the PAPR of the system without PTS is 11.9dB, for N=2 the PAPR is 11.2dB, for N=4 the PAPR is 10.2dB, for N=8 the PAPR is 8.8dB and for N=16 the PAPR is 8.12dB. From figure, we can notice that, as the no. of sub-blocks increases the PAPR of the system reduces. The PAPR comparison with various phase factors is represented in figure 7. The phase weighting factor can be selected from a greater range of 2,4, and 8. It is demonstrated that the greater degree of flexibility in selecting the weighting factors for the combining phase results in an additional minimization. The PAPR reduction performance is improved as the number of phase weighting factors increases. However, due of the many iterations, the processing time increases.

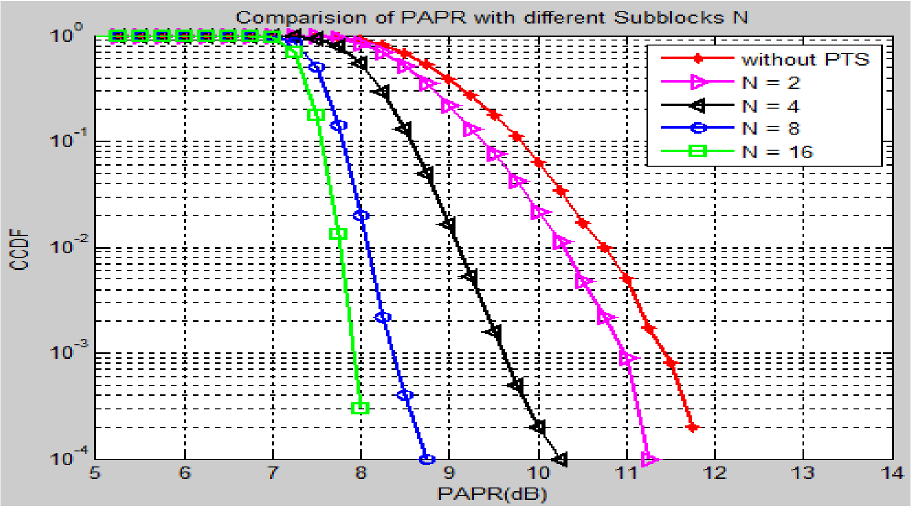

Figure 6. PAPR comparison with various sub-blocks

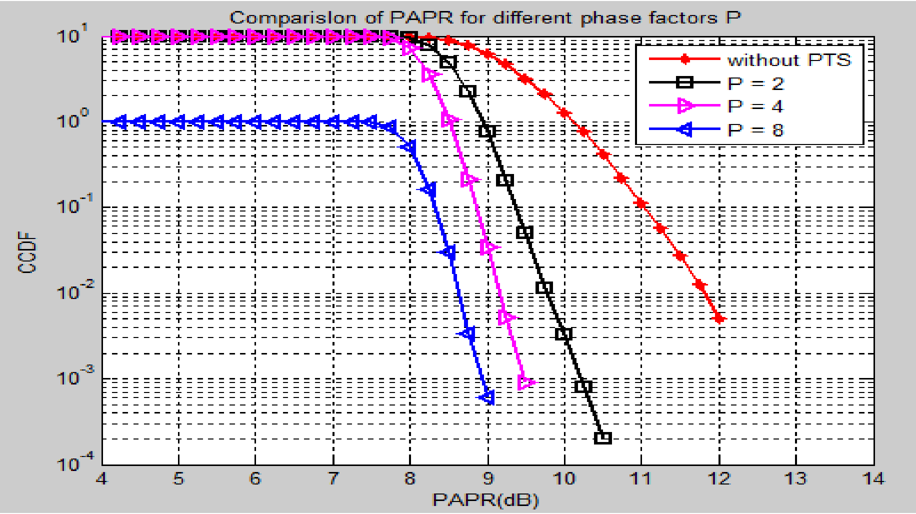

Figure 7. PAPR comparison with various phase factors

Figure 8 shows some simulated results from the CCDF of the PAPR analysis for the OFDM system with different iterations. The CCDF of the PAPR has improved as the number of generations has increased. When K is more than 40 however, the degree of improvement is constrained. With K, the computational complexity increases. K increases lead to an improvement in PAPR performance.

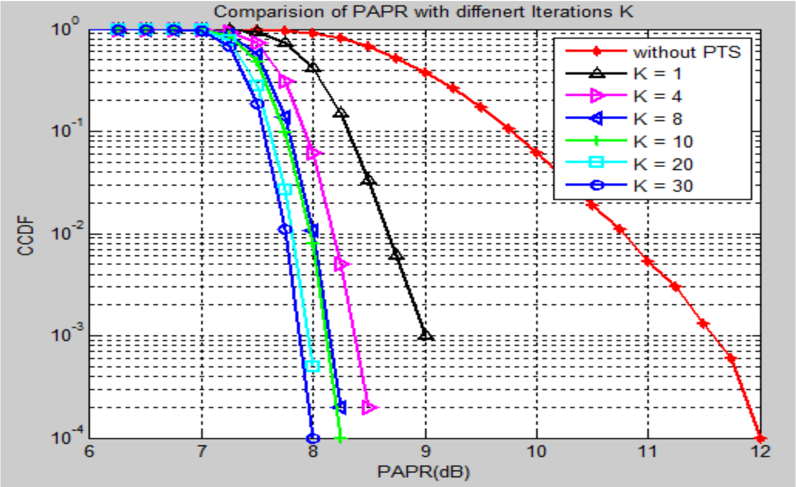

Figure 8. PAPR comparison with various iteration factors

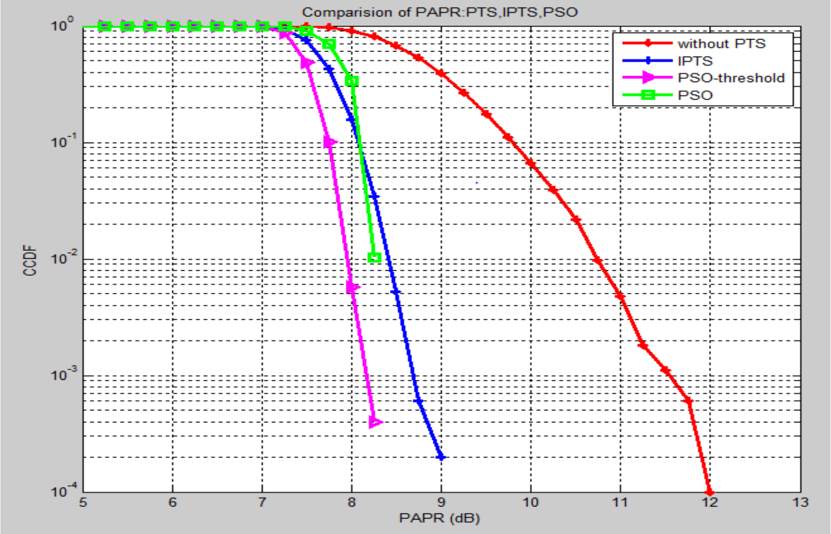

Figure 9a. PAPR comparison: without PTS, IPTS, PSO-threshold and PSO

The suggested PSO for the PTS approach is shown in Figure 9 along with the CCDF comparison of IPTS and PSO. At CCDF=10^{-3}, the PAPR of OFDM without PTS is 11.62dB, for IPTS and proposed method, the PAPR values are 8.7 dB, and 8.25dB respectively. From figure, PSO performs better in terms of PAPR minimization. With a threshold value, the PSO-PTS approach shows less complexity. The PSO-PTS with threshold method is less difficult than the OPTS IPTS method.

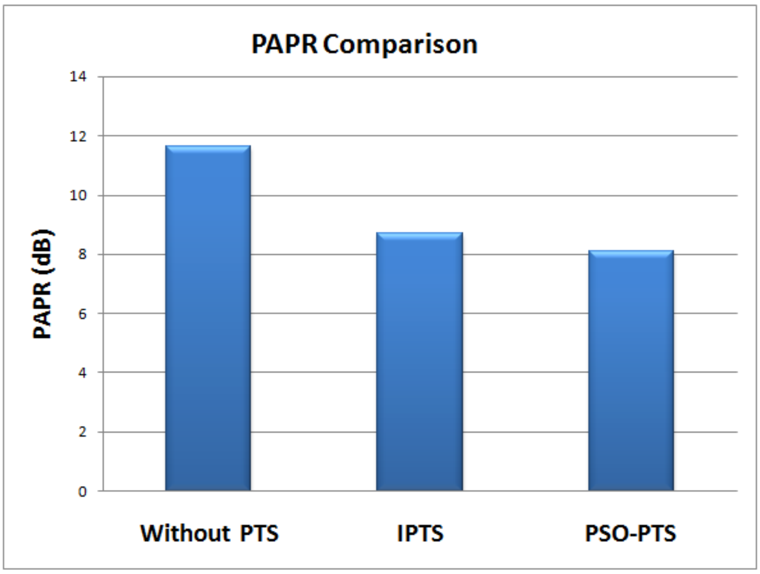

Figure 9b. PAPR comparison: without PTS, IPTS, OPTS, PSO-threshold and PSO

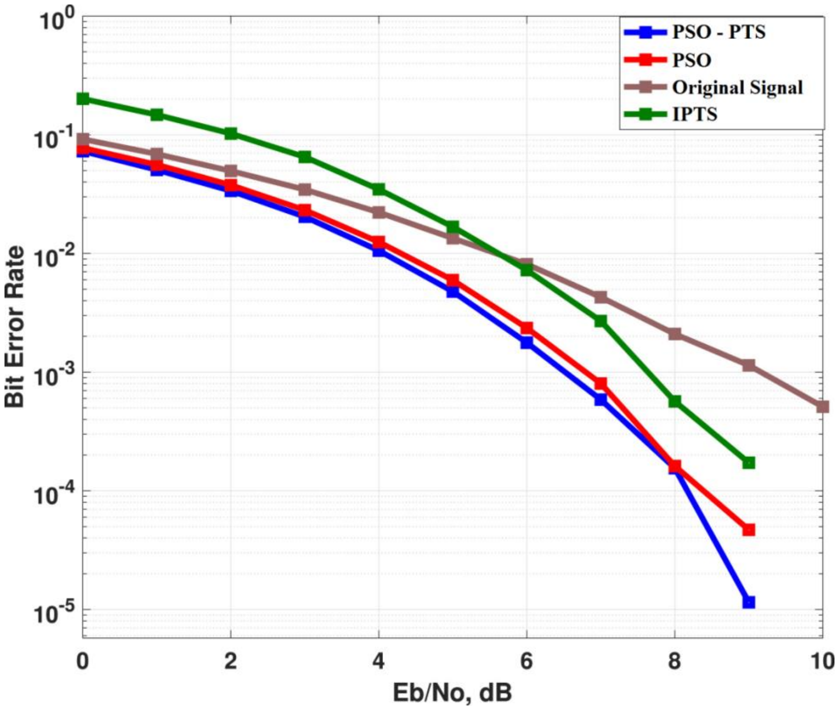

Figure 10. BER Performance

Figure 10 shows a comparison of the BER effectiveness of the PSO-PTS approach to other methods. The SNR for the original signal is 9dB at a CCDF of 10^{-3}. The SNR is 7.3db, 6.8dB and 6.2dB for IPTS, PSO and PSO-PTS, respectively. When the PSO-PTS approach is applied, the BER performance improves. Figure 11 shows the spectral efficiency(SE) of the OFDM system with various methods. When SNR=20dB, the SE values are 0.7, 1, 1.4 and 2 for original signal, IPTS, PSO and PSO-PTS. The PSO-PTS provides higher spectral efficiency.

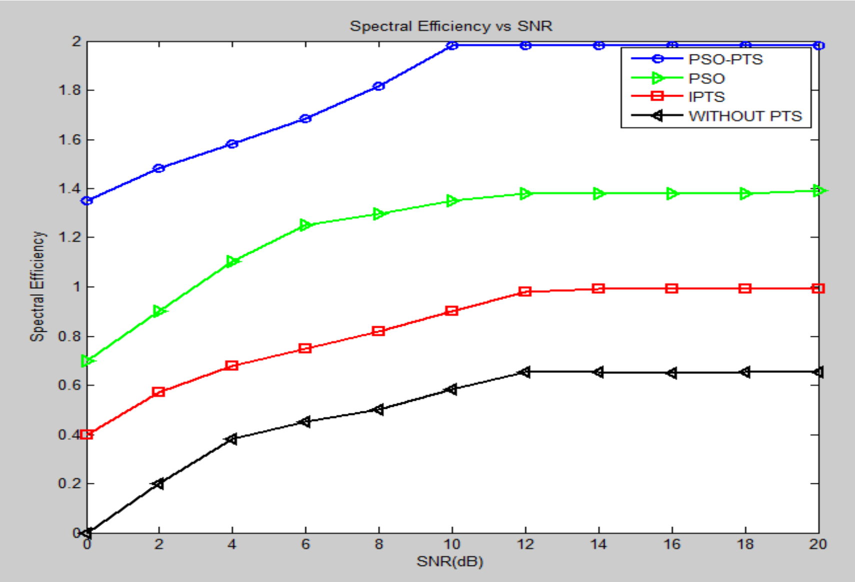

Figure 11. Spectral efficiency

5. CONCLUSION

The PAPR reduction performance of the PTS approach was examined in this article. An exhaustive search was used to simulate the PTS's phase rotation factors search. An adaptive PSO was presented to identify the optimal phase rotation parameters with less complexity in order to minimize the complexity of the exhaustive search. In this article, a PSO algorithm is used to find the optimal phase factors for the PTS approach to minimize PAPR more quickly. Experimental analysis show that the suggested approach works better than previous evolutionary computation techniques by reducing the PAPR when compared to other methods. The suggested method is efficient since it offers a good PAPR reduction, higher spectral efficiency, better BER performance and low computing complexity.

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