A Genetic-Simulated Annealing Algorithm Based On PTS Technique for PAPR Reduction in OFDM System

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***Abstract*—In this paper, we propose a genetic-simulated annealing algorithm (GSAA) with partial transmit sequence (PTS) technique (GSAA-PTS) to reduce the peak-to-average power ratio (PAPR) for orthogonal frequency division multiplexing (OFDM) system. Genetic algorithm based PTS method (GA-PTS) is a novel and suboptimal PAPR reduction approach, which has lower computational load than original PTS method. However, researchers still focus on how to improve the PAPR performance. The proposed method GSAA-PTS takes the advantages of genetic algorithm and simulated annealing algorithm to search the best phase factors of PTS. In this method, we initialize the population firstly, and then selection, crossover and mutation are used to generate the new population, finally using the simulated annealing algorithm to update each chromosome in the population. The simulation results show that the better performance of PAPR have been achieved by adopting GSAA-PTS scheme.**

Keywords—OFDM; PAPR; Partial Transmit Sequence (PTS); Genetic Algorithm (GA); Simulated Annealing Algorithm (SAA); GSAA-PTS

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a unique multi-carrier modulation technique. In recent years, it has been used extensively in communication systems and radar systems. Due to its high spectrum efficiency and channel robust, it is becoming more and more popular in commercial and academic research. But OFDM signals still remain some limitations, one of the main drawbacks is high Peak-to-Average Power Ratio (PAPR) of time-domain signals. OFDM signals are composed of many individual sub-carriers, when the phases of output sub-carriers are identical, the peak power of the transmitted signal will be higher than the average power. High PAPR raises a higher requirement to linearity of transmit power amplifier, but many amplifiers are nonlinear and have the finite dynamic range, when the OFDM signal transmitted by a nonlinear power amplifier, it may suffers from spectral spreading and in-band distortion. While, the increase of dynamic range in a transmit power amplifier will lead to lower efficiency and higher costs. So we must try to reduce the PAPR in OFDM system.

In order to reduce the PAPR effectively, various techniques have been proposed such as clipping [1], coding [2], Selective Mapping (SLM) [3], Partial Transmit Sequence (PTS) [4] and so on. Among these techniques, PTS is a perfect phase optimization technique that can obtain better PAPR performance. In the process of PAPR reduction, PTS does not deteriorate the orthogonality of sub-carriers, but it needs lots of Inverse Fast Fourier Transformations (IFFT) and requires an exhaustive search over all combinations of allowed weighting coefficients, which brings much higher computational load.

In order to solve this problem, several different solutions have been proposed in recent years. Modified PTS technique [5] is an effective way to cut down the computational complexity, but compared with the ordinary PTS technique, the performance of PAPR is still a limitation. Modified PTS with interleaving scheme [6] is proposed by using interleaved sub-block partition and pulse shape technique to avoid multiple IFFT in PAPR reduction, although this method can reduce computational complexity, it does not improve the performance of PAPR well. In [7], PTS with iterative method can avoid extensive search and reduce the search times in the process of searching the possible phase factors, but it still does not improve the performance of PAPR reduction. In [8], a new PTS method combining with genetic algorithm [9] is proposed, which can lower computational complexity and improve the PAPR performance, but the genetic algorithm is easy to fall into local minimums and appears premature phenomenon. In [10], the authors propose a PCGA method based on GA-PTS, PCGA-PTS method uses a two-step crossover operator and a mutation operator to generate a set of phase factors, and then selects the proper phase factor to improve the performance of PAPR.

In this paper, we propose a genetic-simulated annealing algorithm based on GA-PTS technique named GSAA-PTS to further improve the PAPR performance. We embed simulated annealing operator [11, 12] into genetic algorithm, therefore the method takes the advantages of both genetic algorithm and simulated annealing algorithm. Fitness function is constructed by using specific genetic algorithm operators. What's more, penalty function is applied to deal with constraint conditions. GSAA-PTS technique can not only avoid to misleading local

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minimums but also converge quickly to achieve the optimal solution. In our simulation results, GSAA-PTS technique has better PAPR reduction than GA-PTS technique.

The remaining parts of this paper are organized as follows. In Section II, we briefly introduce the theory of PAPR in OFDM signals, original PTS technique and GA-PTS. Then, the idea we proposed that the GSAA-PTS scheme to reduce PAPR is presented in section III. Finally, the simulation results and the conclusion are demonstrated in section IV and section V respectively.

II. PRELIMINARIES

A. PAPR of OFDM signals

An OFDM signal of N modulated sub-carriers is written as

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k exp\left(j2\pi kn/N\right), 0 \le n \le N-1 \quad (1)$$

where X_k, k=0,1,…,N-1 is input symbols modulated by PSK or QAM, and n is the time index.

The PAPR is defined as the ratio of the maximum to the average power of the OFDM signal

$$PAPR\left(x(n)\right) = \frac{\max\limits_{n}\left[\left|x(n)\right|^2\right]}{E\left[\left|x(n)\right|^2\right]} \quad (2)$$

In addition, the performance of PAPR reduction techniques is always measured by calculating the complementary cumulative distribution function (CCDF) of PAPR. Assume that the PAPR level PAPR_0, CCDF is the probability that the PAPR of a randomly generated N-OFDM symbol exceeds the given threshold PAPR_0. CCDF can be written as

$$\text{CCDF} = \Pr\left(\text{PAPR>PAPR}_0\right) = 1 - \left(1 - exp\left(-\text{PAPR}_0\right)\right)^N \quad (3)$$

B. PTS Technique

The principle of PTS technique can be seen in Fig.1. The process of PTS technique is presented as follows:

1) The input symbols of N sub-carriers $\mathbf{X}=[X_0, X_1,\ldots, X_{N-1}]^T$ are divided into M disjoint sub-blocks $\mathbf{X}_m$, where $\mathbf{X}_m = \left[X_0^{(m)}, X_1^{(m)}, \ldots, X_{N-1}^{(m)}\right]^T$, m=1,….., M. Therefore we have $\mathbf{X} = \sum_{m=1}^{M} \mathbf{X}_m$.

2) Then, we use IFFT operator to transfer M sub-blocks into the time-domain signals. According to the linear character of IFFT, these time-domain signals can be expressed as

$$\mathbf{x}_m = IFFT\{\mathbf{X}_m\} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k^{(m)} exp\left(j\frac{2\pi kn}{N}\right), m = 1,2,\ldots,M \quad (4)$$

3) These time-domain signals are multiplied by complex phase factors, which can be written as

$$b_m = exp\left(j\phi_m\right), \phi_m \in \left[0, 2\pi\right) \quad (5)$$

We select the proper weighted coefficients of phase factors by combing them with M sub-blocks to minimize the PAPR. The resulting time domain signals after combinations are given by

$$\mathbf{x} = \sum_{m=1}^{M} b_m \cdot IFFT\{\mathbf{X}_m\} = \sum_{m=1}^{M} b_m \mathbf{x}_m \quad (6)$$

Usually, $\phi_m = 2\pi\omega/W$, $\omega = 0,1,\ldots,W-1$, where W is the number of allowed phase angles. Therefore PTS technique needs to search W^M phase factors to find the optimal phase factors which can minimize the PAPR of OFDM signals. When M or W increases, the computational load becomes high. If we set b_1=1 without loss of performance, there are only W^{M-1} possible OFDM signals.

4) Hence, our objective is to find the optimal phase factor which can minimize the PAPR. The set of best phase factors can be expressed as

$$\{b_1, b_2, \ldots, b_m\} = \underset{\{b_1, b_2, \ldots, b_m\}}{argmin}\left(\max\left|\sum_{m=1}^{M} b_m \cdot \mathbf{x}_m\right|^2\right) \quad (7)$$

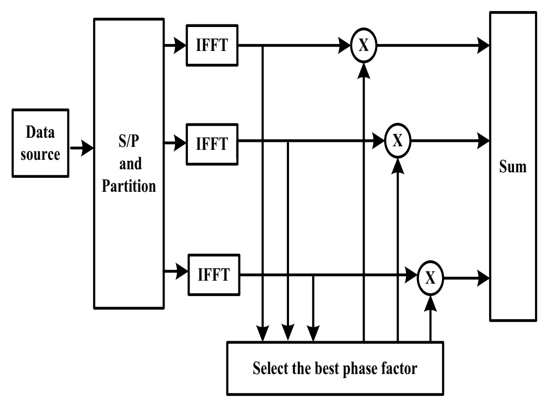

Fig. 1. Block diagram of the PTS technique

C. GA-PTS

The drawback of PTS is the high computational load. In [8], the genetic algorithm is combined with PTS technique to solve this problem. GA-PTS uses genetic algorithm as selection operator to search the best phase factors for PAPR reduction. Compared to PTS scheme, GA-PTS is a suboptimal approach but reduces the computational complexity.

The procedure of GA-PTS for PAPR reduction is presented as follows: First, an initial population is generated randomly, the chromosomes in population are represented by binary vectors, and the bits in chromosomes are corresponding to phase factors of PTS technique. The PTS multiply by the phase factors that are transformed from the chromosomes to calculate the PAPR of OFDM signals. The fitness value of each chromosome in the population is calculated by a fitness function chosen by the user. The selected chromosomes directly enter the next generation of the population are generated by employing the Roulette wheel algorithm. Then, new chromosomes in the next generation of the population can be generated through crossover operator, mutation operator. When the maximum number of generation iterates over, we can find the set of chromosomes that has the minimum PAPR.

However, how to improve the performance of GA-PTS is still a popular research. In this paper, a new method named GSAA-PTS is proposed based on GA-PTS to further improve the performance of PAPR and described in the next section.

III. PROPOSED GSAA-PTS TO REDUCE PAPR

In the paper, we add the annealing operator into the genetic algorithm to search the optimal combination of phase factor for PTS technique. In GSAA-PTS, the chromosomes represented by binary vectors in the initial population are generated randomly. One chromosome is transformed into a set of phase factors by associating each $log_2 W$ bits of it. We give the coding rule when W=4 and M=4. In this case, $\mathbf{b}=(b_1,b_2,b_3,b_4)=(1,j,-1,-j)$, two bits of a chromosome are corresponding to a phase factor, see Table I for details. There are some symbols we should illuminate, see Table II for details.

The flow chart of GSAA-PTS scheme is presented in Fig.2. The procedure of GSAA-PTS scheme is presented as follows:

1) Initialize the population: In GSAA-PTS, the population is generated randomly, which can be represented as $P=[h_1,\ldots,h_R]$.

2) Evaluation: We will calculate the fitness value of each chromosome using the fitness function [8]:

$$Fitness(\mathbf{x}) = \frac{1}{10log_{10}PAPR(\mathbf{x})} \tag{8}$$

3) Selection: In this generation of the population, we use the Roulette wheel algorithm to select $(1-p_c)R$ individuals and add them into P_s directly, the probability of selection of h_i is $P_r(h_i) = f_i \Big/ \sum_{i=1}^{R} f_i$.

4) Crossover: We take the one-point crossover with probability p_c to the $p_c R/2$ pairs of chromosomes which are not selected in step (3), and then add the offspring into P_s.

5) Mutation: Each chromosome of P_s mutates with the mutation probability p_m. Mutation means flipping a bit of the chromosome randomly.

6) Update the population $P \leftarrow P_s$.

7) Calculate the fitness value: We calculate the fitness value f_i of h_i (i=1,…,R) in the new population, then generate a new chromosome randomly, and calculate the fitness value $f_i^{'}$ of it. If $f_i^{'} > f_i$, replacing h_i with the new chromosome, otherwise, replacing h_i with the new chromosome according to the probability $exp\left((f_i^{'} - f_i)/T\right)$.

8) Update the annealing temperature $T \leftarrow \alpha T$, where α is usually chosen in the range $0.8<\alpha<1$.

9) Return to step (2) if not achieve the maximum number of generations G.

10) The chromosome with highest fitness value is picked out from the $G\times R$ chromosomes, and the chromosome is decoded according to the coding rule to obtain the phase factor vector.

TABLE I. THE CODING RULE WHEN W=4 AND M=4

Binary code	phase factor
00	b_1=1
10	b_2=j
01	b_3=-1
11	b_4=-j

TABLE II. THE MEANING OF SOME SYMBOLS

Symbol	Meaning
P	This generation of the population
P_s	Next generation of the population
R	the number of chromosomes of the population
G	the number of generations
h_i	the i-th chromosome of the population
f_i	the fitness value of the i-th chromosome
p_c	the crossover probability
p_m	the mutation probability
T	the initial annealing temperature
α	the annealing factor

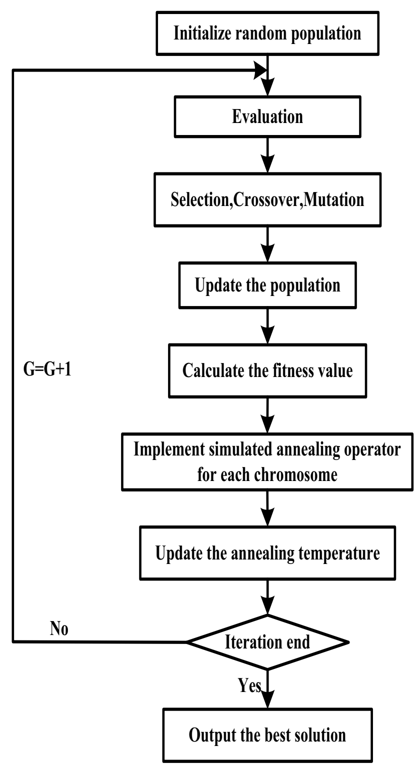

Fig. 2. The flow chart of GSAA-PTS scheme

IV. SIMULATIONS

In our simulations, all the experiments are carried out in MATLAB 7.10.0(R2010a), CPU is Intel Pentium G630 2.70GHz, memory is 2G, the configuration parameters of GSAA-PTS are shown in Table III. QPSK modulation was employed with N=128 and 64 sub-carriers. We used random-interleaved as the sub-block partitioning method of PTS technique. The 128 (64) sub-carriers were divided into four sub-blocks, the length of each sub-block is 128 (64). In order to generate the CCDF of the PAPR, 100000 OFDM blocks were chosen randomly.

In Fig.3, the CCDF curves of PAPR reduction are shown with 64 sub-carriers and the Fig. 4 is the detailed zoom-in version of Fig. 3. It is noticed that, when CCDF=10^{-2}, the PAPR of original OFDM and PTS are 9.43dB and 5.66dB, the PAPR for GA-PTS and GSAA-PTS with population sizes 10 and generations 5, 10 are 6.04dB, 5.87dB and 5.78dB, 5.68dB, meanwhile, the PAPR of GA-PTS and GSAA-PTS under the condition of generations 5 and population sizes 10, 20 are 6.04dB, 5.83dB and 5.78dB, 5.67dB respectively.

The CCDF curves of PAPR reduction with 128 sub-carriers are shown in Fig.5，the comparison of the PAPR reduction with 64 sub-carriers is illustrated in Fig.4, the corresponding PAPR of the same CCDF is presented in Fig.6. When CCDF=10^{-2}, the PAPR is 6.67dB, 6.53 dB, 6.44 dB, 6.36 dB for GA-PTS with population sizes 10 and generations 5, 10 and for GSAA-PTS with population sizes 10 and generations 5, 10 respectively, the PAPR is 6.67 dB, 6.48 dB, 6.44 dB, 6.35 dB for GA-PTS with generations 5 and population sizes 10, 20 for GSAA-PTS with generations 5 and population sizes 10, 20 respectively.

From Fig.3 and Fig.5, we can conclude that PTS technique has the superior PAPR performance among these three methods. Although the original PTS technique has the best PAPR performance, the computational load of PTS technique is higher than our proposed method. What's more, our proposed method has better PAPR performance than the GA-PTS technique.

As we can see from Fig.4 and Fig.6, when the sub-carriers change from 64 to 128, the PAPR performance of the GA-PTS technique and the GSAA-PTS technique becomes worse, but the GSAA-PTS technique still has better PAPR performance than GA-PTS technique. When generations change from 5 to 10, the performance of GA-PTS technique and GSAA-PTS technique becomes better under the condition of the same population sizes, and GSAA-PTS technique has better PAPR performance than GA-PTS technique. When the population sizes change from 10 to 20, the PAPR performance of the GA-PTS technique and GSAA-PTS technique becomes better under the condition of the same generations, and GSAA-PTS technique has the better PAPR performance than GA-PTS technique. No matter how the generations and population sizes change, the computational load of GA-PTS technique and GSAA-PTS technique is lower than PTS technique, the PAPR performance of the GSAA-PTS technique has a significant improvement in PAPR performance compared with the GA-PTS technique.

TABLE III. THE CONFIGURATION PARAMETERS OF GSAA-PTS

parameter	value
the number of generations (G)	5, 10
the number of chromosomes of the population (R)	10, 20
the crossover probability (p_c)	0.95
the mutation probability (p_m)	0.2
the initial annealing temperature (T)	0.005
the annealing factor (α)	0.9
the number of sub-carriers (N)	128, 64
the number of allowed phase angles(W)	4
the number of disjoint sub-blocks (M)	4
the set of phase factors (**b**)	(1,j,-1,-j)

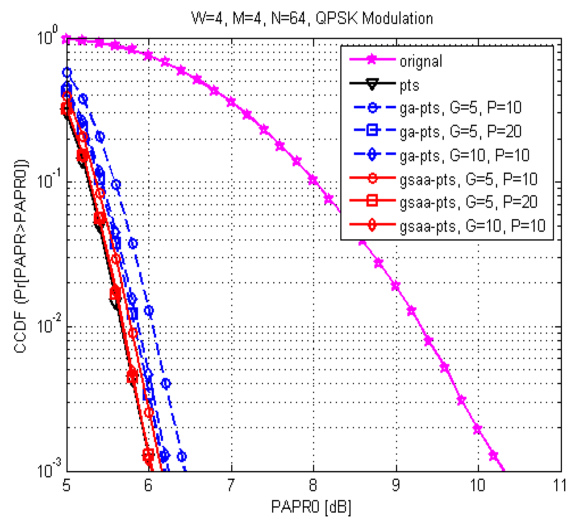

Fig. 3. Comparison of PAPR CCDF of GA-PTS and GSAA-PTS with 64 sub-carriers

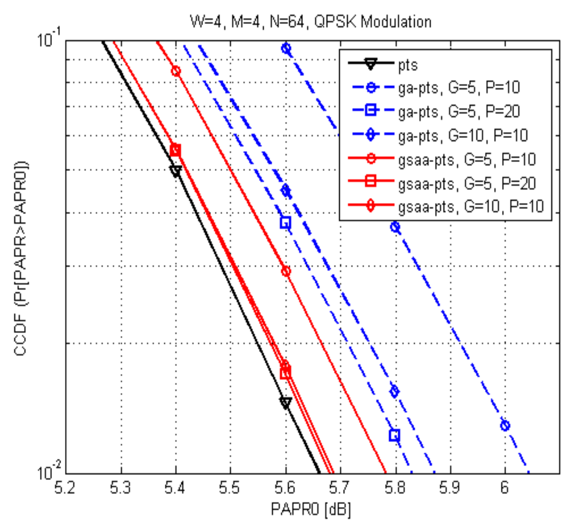

Fig. 4. Zoom-in view of PAPR CCDF of GA-PTS and GSAA-PTS with 128 sub-carriers

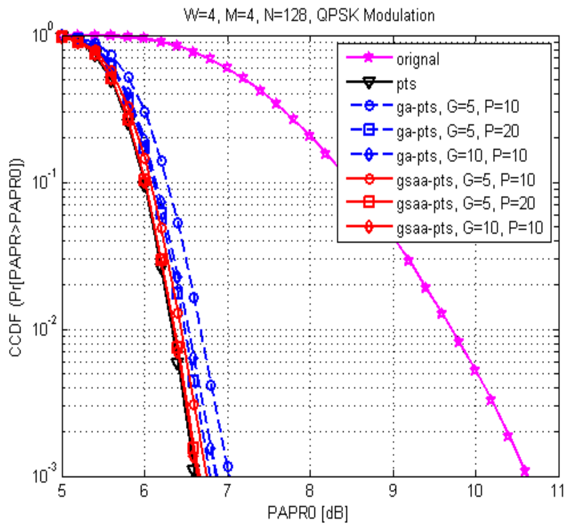

Fig. 5. Comparison of PAPR CCDF of GA-PTS and GSAA-PTS with 128 sub-carriers

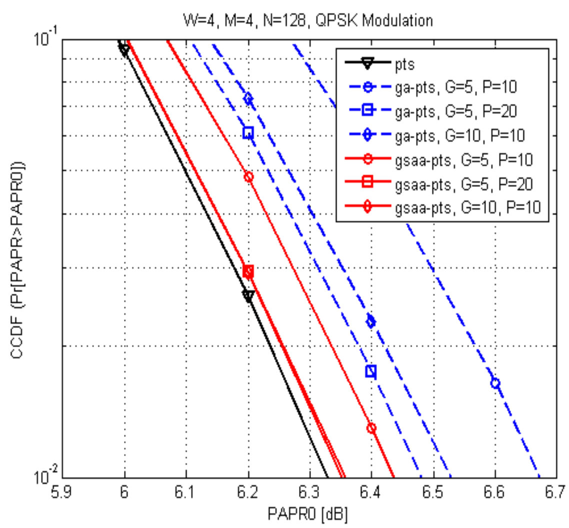

Fig. 6. Zoom-in view of PAPR CCDF of GA-PTS and GSAA-PTS with 128 sub-carriers

V. CONCLUSION

In this paper, we proposed a novel method that embed simulated annealing operator into genetic algorithm, which takes the advantages of both genetic algorithm and simulated annealing algorithm to search the best phase factors. As the simulation results show, it is evident that the proposed GSAA-PTS scheme can not only overcome the drawbacks of GA-PTS method, but also prevent the mature phenomenon. Meanwhile, it can also achieve better PAPR performance, compared with GA-PTS method, the PAPR of GSAA-PTS scheme can be improved by 0.13dB to 0.26dB.

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