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A Novel Partial Transmitting Sequence Technique for Peak-to -Average Power Ratio Reduction in Multicarrier Transmission Systems

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Ho-Lung Hung

Department of Electrical Engineering, Chienkuo Technology University,

No.1, Chien Shou N. Rd,Changhua City,Taiwan 500, R.O.C

E-mail: hlh@ctu.edu.tw

Abstract

As an attractive technique for the reduction of the peak-to-average power ratio (PAPR) of multi-carrier transmission systems is proposed. The conventional partial transmitting sequence (PTS) combining can improve the PAPR statistics of a multi-carrier transmission systems signal. However, the optimum PTS technique requires an exhaustive search over all combinations of allowed phase factors, the search complexity increases exponentially with the number of sub-blocks. In this paper, a novel PTS based on electromagnetism-like (EMPTS) algorithm with threshold control structure is proposed to search the optimal combination of phase factor. The EMPTS algorithm not only reduces the PAPR significantly, but also decreases the computational complexity. Simulation results are conducted to demonstrate that the proposed scheme can achieve a good PAPR reduction with a better convergence rate compared with the various stochastic search techniques.

Keywords: multi-carrier transmission systems, partial transmitting sequence, peak-to-average power ratio, Electromagnetism-like Method

1. Introduction

Multi-carrier code division multiple-access (MC-CDMA) communication systems are an attractive technique for high-speed data transmission because it has high spectral efficiency and is robust against multipath fading [1-4]. However, one of the major challenges in the design of practical MC-CDMA systems is high peak-to-average power ratio (PAPR) of the transmitted time-domain MC-CDMA signals when the number of sub-carriers is large. A high PAPR requires high power amplifier (HPA) with a large linear range and it also leads to high complexity of analog-to-digital converter. If the linear range and complexity of HPA are insufficient, a large PAPR results in both in-band distortion and out-of-band radiation. Therefore, the MC-CDMA receiver's detection efficiency is very sensitive to the nonlinear devices used in its signal processing loop, such as high power amplification, which may severely impair system performance due to induced spectral re-growth and detection efficiency degradation. Thus, PAPR reduction techniques play an important role in multi-carrier transmission systems. Various methods for reducing PAPR have been proposed for MC-CDMA system, such as deliberate clipping [5], partial transmit sequences [6-9], block coding [10], code selecting [11], and selective mapping (SLM) [12-13], subcarrier scrambling [14], etc. In deliberate clipping, the simplest method, signals are deliberately clipped before amplification. Although some techniques of PAPR reduction have been summarized in [15], it is still indeed needed to give a comprehensive review including some motivations of PAPR reductions, such as power saving, and to compare some typical methods of PAPR reduction through theoretical analysis and simulation. In code selecting, the number of codes with low PAPR available is limited and the resulting PAPR may not be really low. Partial transmitting sequence (PTS) is based on the same principle as SLM. In this scheme, an input data sequence is partitioned into a number of disjoint subblocks and each subblock multiplied by a rotating phase vector. Therefore, the subblock subsequences can be educed. Later, the PAPR is computed for each resulting sequence and the signal sequence with the minimum PAPR is selected to be transmitted. Simultaneity, PTS method does not require data mapping. Therefore, PTS method can reduce PAPR in the MC-CDMA system with a large number of subcarriers. However, the big issue of finding the optimal phase combination for PTS sequence is complex and difficult when the number of subcarriers and the order of modulation are increased. It turns out that search complexity increases exponentially with the number of sub-blocks. To reduce the searching complexity and avoid/reduce the usage of side information, many extensions of PTS have been developed recently [7-10] [16-17]. Famous stochastic techniques for PAPR reduce include the simulation annealing algorithm [17] [23], Genetic algorithm (GA) [18-19], particle swarm optimization [20-22]. Based on the above points, we state our interest to employ a novel PTS technique based on the EM algorithm to reduce the PAPR of MC-CDMA signals through this paper.

In this paper, we present a new technique for computing the phase weighting factors that achieves a better performance than the exhaustive search approach does. In proposed techniques, an Electromagnetism-like (EM) method [24-25] with threshold control structure is performed to find the phase weighting factors. It shows that a low-complexity technique has been implemented in the PTS approach, which seeks the best trade-off between performance and complexity. In this paper, we present a novel approach to tackle the PAPR problem to reduce the computational complexity based on the relationship between the weighing factors and the transmitted bit vectors. A preset threshold is considered for further reducing the computational complexity to stop the searching if the minimum PAPR value is below a preset threshold. Simulation results show that the performance of this new technique is similar to that of the optimum case; however, our technique only needs significantly lower complexity.

The rest of this paper is organized as follow. In Section 2, a typical MC-CDMA system is given and the PAPR problem is formulated and PTS is explained. Then, EM method is proposed to search the optimal combination of phase weighting factors for PTS in Section 3. In Section 4, the performance of MC-CDMA signals are studied and evaluated using the proposed scheme to reduce the PAPR through computer simulation, followed by conclusions in Section 5.

2. System Model

MC-CDMA system has been proposed for a variety of topologies. The configuration used in this paper is similar to the design in [15]. Let *N* be the number of sub-carriers, *L* be the spreading factor of frequency domain, and *M* be the number of parallel input data symbol per an MC-CDMA symbol. The modulated signals of each user are fed into serial to parallel converter. The parallel signals are copied into *L* parallel sub-carriers. First, as the number of sub-carriers is *N*, the same as the length of spreading code, a data symbol d_k is copied to *N* parallel taps. Each copy is multiplied by a single chip of the spreading sequence, $c_{k,n}$, $k = 0,1,\cdots,K$, and *n*=0, ..., *N*-1, which is a chip of the *k*th user's spreading code at the *n*th sub-carrier. The *k*th user's frequency-domain spread spectrum X_k , is given by

$$X_k = d_k c_k \tag{1}$$

where $X_k = [X_{k,0}, X_{k,1}, \cdots X_{k,N-1}]^T$ and $c_k = [c_{k,0}, c_{k,1}, \cdots, c_{k,N-1}]^T$. $X_{k,n}$ and $c_{k,n}$ denote the *k*th user's spread data and chip of the spreading code, respectively, at the *n*th sub-carrier. Each user's channel is modeled as an independent flat fading channel $H_k = diag\{[H_{k,0}, H_{k,1}, \cdots, H_{k,N-1}]\}$, where $H_{k,n}$ is a frequency domain channel response at the *n*-th sub-carrier for the *k*-th user. The received signal also experiences additive white Gaussian noise of zero mean and variance [9].

These signals are converted into time domain using inverse fast Fourier transform of size $N = V \times L$. MC-CDMA signals $x(t)$ can be written as

$$x(t) = \sum_{n=0}^{N-1} \sum_{i=0}^{N_d-1} \sum_{k=0}^{K=1} d_{k,n}(t - iT_s) c_{k,n} e^{j2\pi nt/T_s} \tag{2}$$

where N_d is the number of symbols in a frame and T_s is inserted between symbols to eliminate the ISI caused by multipath fading.

2.1 Peak to-Average Power Ratio Definition

To evaluate the envelope variations of orthogonal frequency division multiplexing (OFDM) system, the ratio of the peal power to average envelope power of the signal is used. The discrete time PAPR of $x(t)$ is defined as ratio of maximum power of the transmitted signal divided by the average, is expressed as follow:

$$\mathbf{PAPR(x)} \overset{\Delta}{=} \frac{\mathbf{Max}_{0 \le t \le N-1} \left| x(t) \right|^2}{\mathbf{E}[| x(t) |^2]} \tag{3}$$

where $x(t)$ is an MC-CDMA signal, $\left| x(t) \right|^2$ represents the envelope power and $\mathbf{E}[\cdot]$ denotes the expected value

[15]. PAPR is evaluated per symbol. If a nonlinear amplifier is used to amplify the MC-CDMA signal, the large peak power brings about its nonlinearity and significantly degrades performance.

2.2. *Partial Transmit Sequences (PTS) Method*

PTS method is one kind of multi-signal representations techniques. A block diagram of MC-CDMA system using the PTS is shown in Fig.1 as that in Ref [7-9]. In the PTS technique, the input data block is partitioned into the *V* disjoint clusters that approach, the input data block is partitioned into disjoint sub-blocks. Each sub-block is multiplied by a phase weighting factor, which is obtained by the optimization algorithm to minimize the PAPR value. We define the data block as a vector $X = [X_1 \quad X_2 \ldots \quad X_N]^T$, where *N* denotes the number of sub-carriers in the MC-CDM frame. Then, **X** is partitioned into *V* disjoint sub-blocks represented by the vector $X_i,\ i = 1,\ 2, \ldots,\ V$ such that

$$X = \sum_{i=1}^{V} X_i \tag{4}$$

Here, it is assumed that the clusters X_i consist of a set of sub-blocks and are of equal size. Then, a weighted sum combination of the *V* sub-blocks which are written as

$$X' = \sum_{i=1}^{V} W_i X_i, \quad W_i = e^{j\phi_i} \tag{5}$$

where $W_i,\ i = 1,\ 2, \ldots,\ V$, is the phase weighting factor which has phases consisting of $\varphi = [0 \quad 2\pi)$. The phase weight factor can be chosen freely within $[0, 2\pi)$; however, phase weighting factor can be generally chosen from a certain discrete group such as $\{\pm 1\}$ for reducing the calculation complexity. After transforming to the time domain, the new time domain vector becomes

$$\mathbf{x} = IFFT\left\{\sum_{i=1}^{V} W_i \mathbf{X}_i\right\} = \sum_{i=1}^{V} W_i IFFT\{X_i\} \tag{6}$$

The optimal phase weighting factor W_i that minimize the PAPR can be obtained from a comprehensive simulation of all possible combination, 2^{V-1} . The objective of the optimum PTS (OPTS) method is to choose a vector $\mathbf{W} = \{W_1, W_2, \cdots, W_i\}$ to reduce the PAPR of X' , and the optimum phase weight factor for an MC-CDMA symbol are given by

$$\hat{\mathbf{W}} = \arg \min_{W} \left\{ \max \left| \sum_{i=1}^{V} W_i \ \mathbf{x}_i \right| \right\} \tag{7}$$

For OPTS technique, minimizes the PAPR can be found after searching 2^{V-1} computation if the number of sub-block is *V*. In order to further reduce the number of searching, a preset threshold P_{th} is used, where the search is stopped once the minimum PAPR drops below the P_{th}. If the minimum PAPR is below the P_{th} , then stop the search and take the W_i as the output.

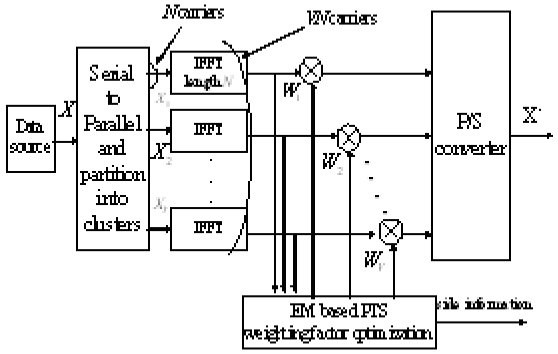

Fig. 1 A block diagram of the EM based PTS technique.

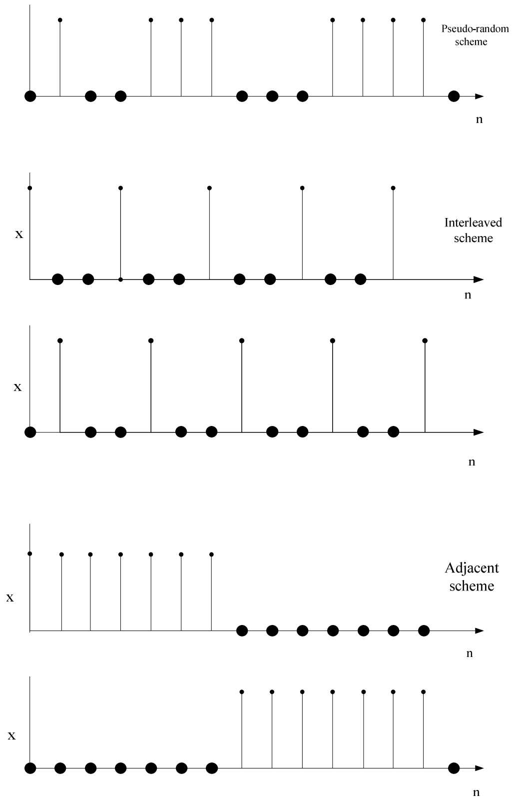

Fig. 2 Generation of sub-blocks partitioning method.

2.3. *Sub-block Partition Schemes (SPS)*

The sub-block partition [26] for PTS technique is a method of division on sub-carriers into multiple disjoint sub-blocks. Fig. 2 shows a generation of the sub-blocks partitioning method. In general, it can be classified into three categories: adjacent method, pseudo-random method and interleaving method. For the adjacent method, *N/V* successive sub-carriers are assigned into the same sub-block sequentially. In pseudo-random method, *N/V* sub-carriers are randomly assigned into each sub-block. In interleaving method, every sub-carrier space *L* part is allocated in the same sub-block. In the viewpoint of PAPR reduction [26], pseudo-random sub-block partitioning has better performance than others.

2.4. *Nonlinear amplifier model*

In this paper, threshold control techniques may be combined in to the HPA in the MC-CDMA after peak value of MC-CDMA signal is reduced. To simulate a non-linear power amplifier, the following Rapp's model [11] [27] is employed for amplitude conversion.

$$g(A) = \frac{A}{(1 + (|A| / A_{sat})^{2p})^{\frac{1}{2p}}}, \tag{8}$$

where A is the amplitude of an input signal, A_{sat} is the saturation amplitude of an amplifier, $g(A)$ is the amplitude of an output signal and p is a constant representing the characteristic of a non-linear amplifier. In this paper, $p = 3$ is assumed, which is general value for solid-state power amplifiers (SSPA) [11]. The operating point of an amplifier is determined by input backoff (IBO) given by

$$IBO = \frac{p_{sat}}{E\{| x(t) |^2\}}, \tag{9}$$

where p_{sat} is the input power corresponding to the saturation point of an amplifier and $E\left\{|x(t)|^2\right\}$ is the average input power.

3. PTS based on Electromagnetism-like Method

3.1 The EM Optimization Algorithm

In recent years, global optimization has become a rapidly developing field and many stochastic search methods have been proposed in order. Birbil and Fang [24-25] introduced one of these meta-heuristic algorithms known as Electromagnetism-like method. The method utilizes an attraction-repulsion mechanism to move the sample points towards the optimality. EM-like algorithm has four main phases [24], i.e., initialization, local search, calculation and movement, respectively. We subdivide the procedures into four steps. At first, the dimension of the solution will be determined according to the fitness function. Secondly, we determine the upper and lower bounds in each dimension. Furthermore, the population size and criterion (i.e., iteration number) should be determined in applying EM-like algorithm to the optimization of phase weight factor. In this study, the allowable region of position will be changed through iteration. For example, the allowable region of *W* is within the range of $(0, 2\pi)$. Therefore, the bounds of each dimension should be calculated again after each loop of iteration.

3.2 *The EM Algorithm Based PTS Technique*

In the following, we employ the EM method to search the optimal phase factor for the PTS technique in Order to reduce the PAPR. The procedure of the proposed EM-based PTS can be described as follows:

3.2.1.Initialize: At first, one group solution is randomly produced as initial state. Each solution is regarded as a charged particle and all particles are assumed to be uniformly distributed between the upper and lower bounds. The optimum particle in the population will then be found by the fitness function. Initialize the particle population at $t = 0$. The procedure "Initialize" generates *m* sample points (i.e. solutions, phase factor vector *W*) randomly from the feasible domain, which is an *n* dimensional space. Each coordinate of a particle is assumed to be uniformly distributed between the corresponding upper bound and lower bound. After a particle is sampled from the space, the objective function value for the particle is calculated using the function pointer $f(W_u^k)$. The procedure ends with *m particles* identified, and the particle that has the best function value is stored in $\mathbf{W}_{best}^k$. The words particle and point are interchangeably used. $W_{u,v}$ from the feasible region, where *V* is the dimension of the problem(i.e., the number of sub-blocks) and $W_{u,v}^K$ denotes the v th coordinate of the particle *u* of the population at iteration k .Analogous to electromagnetism, each point $\mathbf{W}_u^k = \{W_{u,v}^k\}_{v=1}^V$ is regarded as a virtually charged particle that is released in the space. As such, each coordinate of a point, denoted as $W_{u,v}^K$, is computed by

$$W_{u,v}^k = \zeta_v + \beta(\xi_v - \zeta_v) \tag{10}$$

where ξ_v is the upper bound of the *v*th dimension; ζ_v is the lower bound of the *v*th dimension; and β is a uniform random number generator within [0,1]. After a point is sampled from the search space, the objective function value for the point is calculated. Given a point $\mathbf{W}_u^k$, the fitness function, defined as the amount of PAPR reduction, can be expressed as

$$f(W_u^k) = \arg_w\{\max \frac{\left|x'(W_u^k)\right|^2}{E[\left|x'(W_u^k)\right|^2]}\}\,. \tag{11}$$

3,2,2.Local search: Local search should be able to find better solution in theory. Local search is used to gather the neighborhood information for a sampled point, which can be applied to one point or to all point in the population for local refinement at each iteration. The procedure of the local search can be described as follows: Calculate maximum feasible step length $s_{\max}$ based on the parameter $\delta \in [0,1]$,where the maximum feasible step length can be computed using the following equation:

$$S_{\max} = \delta\left(\max_{1\le v\le V}(\xi_v - \zeta_v)\right). \tag{12}$$

Then, generate a candidate of point $\hat{\mathbf{W}} = \left(\hat{\xi}_v\right)_{v=1}^{V}$ .A new particle $\hat{\mathbf{W}}$ is generated from the current best point $\mathbf{W}_{best}^k$ As $\hat{\mathbf{W}}$ is a small random change coming from $\mathbf{W}_{best}^{\kappa}$ here, we randomly change two coordinates to generate $\hat{\mathbf{W}}$, where the modified coordinate of the current best point, denoted as $\hat{\mathbf{W}}_v$,is computed using the following equation:

$$\hat{\mathbf{W}}_v = W_{best,v}^k + \beta \cdot s_{\max} \tag{13}$$

Decide whether to update the current best point $\mathbf{W}_{best}^k$ .If the new point $\hat{\mathbf{W}}$ observes a better point, the sample point $\mathbf{W}_{best}^k$ is replaced by this new point $\hat{\mathbf{W}}$.

3.2.3 Calculation of total force vector: This procedure is a comparatively important one in the whole scheme of EM for balancing searching time and searching quality. The particle moves according to Coulomb's force produced among the particles, as we assign a charge-like value to each particle. The charge of each particle is determined by its fitness function value, which can be evaluated as

$$Q_m^k = \exp\left\{-V \frac{f\left(W_m^k\right) - f\left(W_{best}^k\right)}{\sum_{m=1}^{M}\left[f\left(W_m^k\right) - f\left(W_{best}k\right)\right]}\right\} \tag{14}$$

In Eq.(14), the particle with the best fitness function value is called "optimum particle", and will have the highest charges. A particle will have stronger attraction, as it appears near the optimum particle. The particle attracts other particles with better fitness function values, and repels other particles with worse fitness function values.

The resultant force among particles determines the effect for optimization process. The resultant force of each particle can be evaluated by Coulomb's law and superposition principle as that $f\left(W_m^k\right) < f\left(W_r^k\right)$, which implies that $Q_m^k > Q_r^k$,in this case the one that has better fitness function value is preferred, that is W_m^k is the preferred point and particle W_r^k should be "attracted" to particle W_m^k . That means the particle attracts other particles with better with better fitness function values and repels other particles with fitness cost function values. After determining the charge of each point on $\left\{W_m^k\right\}_{m=1}^{M}$ and defining the rule of attraction-repulsion mechanism of artificial charge the force vector, $F_{m,r}^k$, between two points W_m^k and W_r^k , is computed as

$$F_{m,r}^k = \begin{cases} (Q_m^k - Q_m^k)\dfrac{Q_r^k \cdot Q_m^k}{\| Q_r^k - Q_m^k \|^2}, \text{ if } f(W_r^k) < f(W_m^k) - -(\mathit{attraction}) \\ (Q_m^k - Q_r^k)\dfrac{Q_r^k \cdot Q_m^k}{\| Q_r^k - Q_m^k \|^2}, \text{if } f(W_r^k) \ge f(W_m^k) - -(\mathit{repulsion}) \end{cases} \tag{15}$$

The total force $\wp_m^k$ exerted on each point W_m^k by the other (M-1) points is then calculated by

$$\wp_m^k = \sum_{\substack{r-1 \\ r\neq m}}^{M} F_{m,r}^k, \quad m = 1,2,\cdots,M. \tag{16}$$

3.2.4 ***Movement of particles:*** Each particle moves according to the resultant force which can be given as

$$W_{m,v}^{k+1} = \begin{cases} \tau_{m,v}^k + \beta \dfrac{\wp_{m,v}^k}{\| \wp_{m,v}^k \|}(\xi_v - W_{m,v}^k), & \text{if} \quad \wp_{m,v}^k > 0 \\ \tau_{m,v}^k + \beta \dfrac{\wp_{m,v}^k}{\| \wp_{m,v}^k \|}(W_{m,v}^k - \zeta_v), & \text{if} \quad \wp_{m,v}^k \le 0 \end{cases} \quad m = 1,2,\cdots,M; \quad m \neq best. \tag{17}$$

Finally, running the EM-like procedures until the predetermined iteration or allowable error is met. In other words, the procedures will be terminated as the criterion is reached.

4. **Results and Discussions.**

In this section, a modified PTS system is evaluated in terms of performance index of PAPR complementary cumulative distribution function (CCDF) and bit error rate (BER) by computer simulation. The modulation method is QPSK and the number of sub-carriers is *N*=256, the same as the length of the spreading code. In our simulation, PTS and modified PTS with random sub-blocks partitioning are used. We also investigate the complexity of two techniques with several of number of sub-blocks *V*. The number of DFT points is 256×4 , meaning that signals are oversampled by a factor of four (i.e., S=4). The effect of varying several simulation parameters is examined. These parameters are the number of clusters and the number of allowed phase weighing factors W for transmit sequences. The cumulative distribution function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. The CDF of the amplitude of a signal sample is given by $CDF = 1 - \exp(PAPR_0)$. In the performance comparison, the parameter of CCDF [15] is defined as

$$\begin{aligned} CCDF &= P_r(PAPR > PAPR_0) \\ &= 1 - P_r(PAPR \le PAPR_0) = 1 - (1 - \exp(-PAPR_0))^N \end{aligned} \tag{18}$$

This expression assumes that the N time domain signal samples are mutually independent and uncorrelated. In the EM method, the population size is assumed to be P=20; the maximum number of iterations is $P_{Max} = 100$, the maximum number of local search iterations is P_L =10; and the corresponding maximum number of iterations are G=20, 40, 60, 80, and 100, respectively.

Fig. 3 illustrates the CCDFs of the PAPR of QPSK-modulated OFDM signals in OPTS, GA-, PSO- and EM-based PTS when W=2, respectively, for V= 2 and M=16 (V is the number of sub-blocks). Clear, the PAPR reduction performance of EM-based PTS is worse than that of OPTS, but the performance for PAPR reduction of the proposed EM method is almost the same as that of OPTS. This means that the EM method outperforms GA- and PSO-based PTS schemes. It can be seen that when the number of sub-blocks increases, the performance of peak power depression improves. For instance, given CCDF=0.1 %, the PAPR of the normal MC-CDMA is about 10.3 dB, and those of OPTS, EM-, PSO-, and GA-based PTS are 7, 8.2, 9.2, and 9.8 dB for V=2, respectively; those of OPTS, EM-, PSO-, and GA-based PTS are 7, 7.2, 7.4, and 7.8 dB for V=16, respectively. It indicates relatively increasing the number of sub-block V will improve the system performance evidently it can be seen that the EM-based PTS curves are very close to the OPTS. In addition, we can see that the performance of the proposed EM method not only provides an approximate PAPR reduction as with that of the OPTS but also has a much lower computational complexity than OPTS.

Fig. 4 compares the performance of restraint PAPR with three categories of sub-block partitions, when V=8, W=8. It can be observed that probability of very large peak power has been increased significantly if PTS techniques are not used. That is, probability of PAPR ≥ 7.2 [dB] is 10^{-3} at the pseudo-random SPS while it almost reaches 10.3 dB at the system without using PTS. The probability of PAPR ≥ 7 [dB] is about 10^{-1} at the interleaved SPS and 0.5 at the adjacent SPS, respectively. And it is about 10^{-2} at pseudo-random SPS.

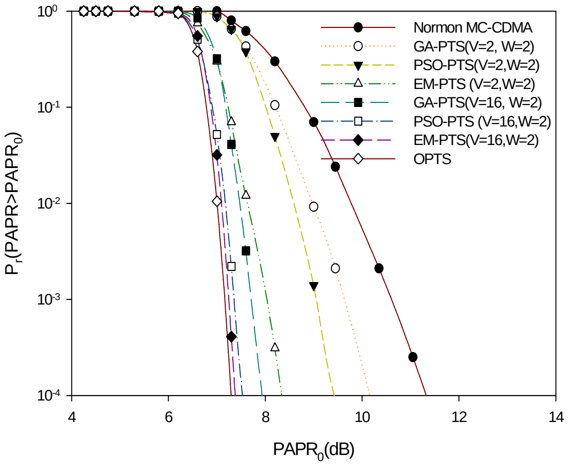

Fig. 3 CCDFs comparison of the EM, PSO, and GA based-PTS scheme with different combinations of sub-blocks when N=256, V=2 and 16, W=2.

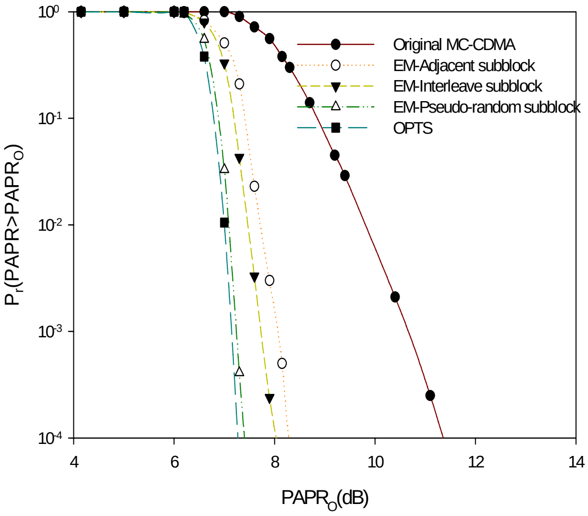

Fig. 4 CCDF of the sub-block phase weighting using three partitioning techniques.

It is clear that the pseudo random SPS is outstanding. Thus, it can be analyzed that the pseudo-random SPS shows the best PAPR reduction performance as expected. However, the PAPR reduction performance and the computational complexity of PTS scheme depend on the method of subblock partitioning. In other words, there is a trade-off between PAPR reduction performance and computational complexity in OPTS scheme.

Fig. 5 shows PAPR reduction performance of PTS using the threshold control structure. A MC-CDMA system with $N = 256$ subcarriers and QPSK modulation in each subcarrier is considered. For instance, given CCDF=0.1

%, the PAPR of the normal MC-CDMA is about 11.3 dB, and those of OPTS, PSO-, EM-, and iterative-based PTS are 7.6, 7.6, 7.2, and 8 dB for *V*=2, respectively. Using the threshold control structure search, EM-PTS method shows a little better performance in PAPR reduction than the OPTS, and the gap is about 0.5 dB in most CCDF range. The improved PTS algorithm will enhance the systematic functions through threshold control structure, and can reduce the systematic calculation complexity with the slight degradation of PAPR. Therefore, threshold EM-PTS technique can offer good PAPR reduction with low complexity.

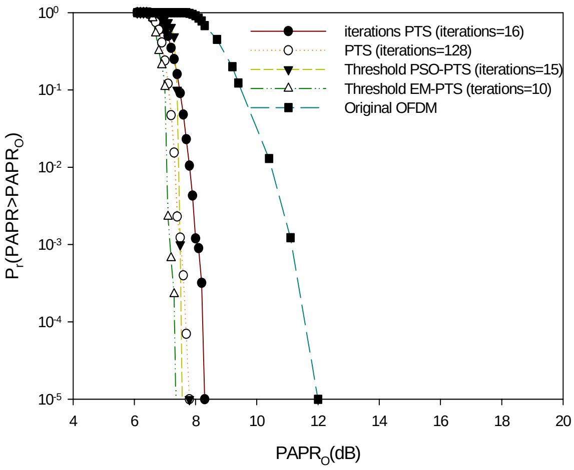

Fig. 5 PTS performance using threshold structured (*N*=256, *V*=4).

Fig. 6 depicts the CCDF of the PAPR with the PTS sequence search by PSO technique and GA with *V*= 8, 16 and *W*=4. The results presented in Fig. 6 imply that the proposed method and GA can provide the same performance, but with much lower computational complexity. As the number of sub-blocks and the set of phase weighting factor are increased, the performance of the PAPR reduction becomes better. However, the processing time gets longer because of much iteration. For a fair comparison, both the PSO-based and the GA-based optimization run 20 times. Just as expected, the PAPR performance of our proposed EM-based PTS scheme with (V,W)=(2,2), is not only almost the same as that of the GA-based PTS scheme with(V,W)=(4,4), but also having much lower computational complexity. In general, in order to obtain optimal PAPR search for the number of sub-blocks and phase weight factor must be accomplished. As the number of sub-blocks and phase weight factors increases, PAPR reduction improves. The number of calculation increases as the number of sub-blocks increases, such that complexity increases exponentially and process delay occurs simultaneously. As one can see, the PTS with EM technique has almost the same performance of PAPR reduction as that of the optimal PTS scheme. Finally, this paper presents that investigates the trade-off between number of sub-blocks and phase weight factors for reduce PAPR.

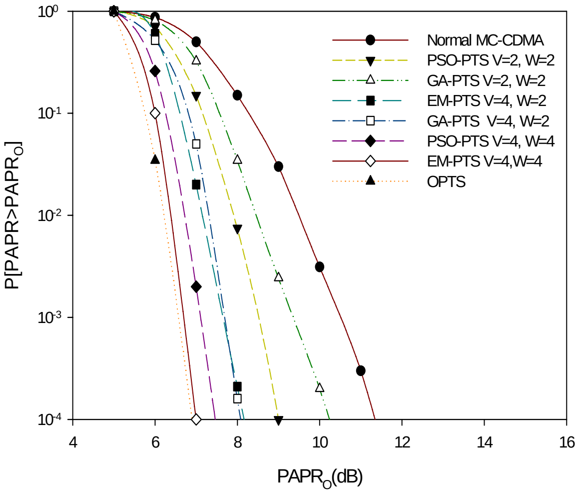

Fig. 6 Comparison of the PAPR CCDF of several PTS methods.

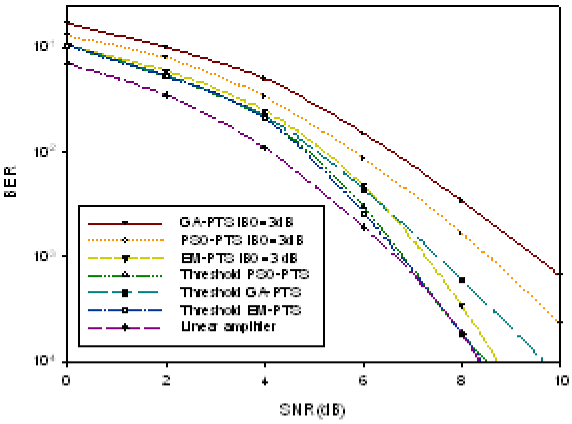

Fig. 7 BER performance of MC-CDMA system with EM method.

BER performance show in Fig. 7 is about the orignal MC-CDMA system with and without threshold control restruct search. In the Fig. 7, the more input backoff, the better BER performance and the poorer HPA power efficiency. Threshold makes a small improvement in the BER performance. It can see that the BER 10^{-4} at input backoff (IBO)= 3 dB, the proposed method can achieve 1.2 dB SNR gain than PSO-PTS method, and can achieve 1.5 dB SNR gain than GA-PTS method, respectively. Consequently, it is clear than in the case using at IBO=3dB, BER performance closely matches with linear amplifier. From the simulation results, it is

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show that the necessary input backoff is 3 dB in the PTS without threshold and 5 dB IBO with threshold to closely match with the linear amplifier.

From the results, it can be observed that the number of complex computations of the GA, PSO, and the EM are all population-based search methods; we may therefore fix the number of samples, to find the suboptimal solutions with low complexity. In this case, the complexity for GA [28], PSO [20], and EM method can further be expressed in term of the number of samples, where each sample is calculated using the *N*-point IFFT. Accordingly, the number of samples for GA, PSO, and the EM are P_{Max} * *pop*, P_{Max} * *pop*, and (*pop* + G)* P_{Max} , respectively, where P_{Max} is the maximum number of iteration, *pop* is the number of sample point (particle), and G is the maximum number of local search iterations. It should be that the complexity for each sample to find a suboptimal solution is $O(N \log N)$ multiplications. Therefore, the trade-off between PAPR reduced performance and computation complexity of PTS techniques may be alleviated extensively with the proposed threshold control techniques.

5. **Conclusions.**

Large PAPR of transmitted signals may be a main cause of performance degradation of multi-carrier transmission systems signal. In conventional PTS techniques to solve the problem, computational complexity has been increased extensively with increase of number of subbands. In this paper presented an EMPTS method that was used to obtain the optimal phase weighting factor for the PTS technique to reduce computational complexity and improve PAPR performance. We formulated the phase weighting factors search of the PTS technique as a global optimization problem with bound constraints. The computer simulation results showed that compared with the various stochastic search techniques developed previously, the proposed EMPTS method obtained the desirable PAPR reduction with low computational complexity. By the sake of its flexibility, i.e. the number of sub-blocks, the number of admitted angles and SPSs, the resulting peak power reduction can be achieved with several levels of acceptable PAPR. Since the computational complexity reduction ratio increases as the number of sub-carriers increases, the proposed scheme becomes more suitable for the high data rate multi-carrier transmission systems.

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