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Reduction of the PAPR in OFDM Systems by Intelligently Applying Both PTS and SLM Algorithms

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Abstract The orthogonal frequency division multiplex (OFDM) technique, which is used in the 4G communications, has a shortcoming of having a high peak to average power ratio (PAPR), and thus a lot of research has been conducted to reduce the PAPR in OFDM systems. The typical algorithms in this research area are the multi-time clipping algorithm, the μ-law compression algorithm, SLM algorithm, PTS algorithm, and Golay complement sequence algorithm. It is found in this paper that the SLM and PTS algorithms have good performance in reducing the PAPR while having less information overhead than the Golay complement sequence algorithm, less distortion than the μ-law compression algorithm, and less BER than the clipping algorithm. Thus, a new PAPR reduction algorithm is proposed, which tries to intelligently apply both PTS and SLM algorithm, while utilizing their complementary advantages and avoiding their disadvantages. According to simulation results, the performance of the proposed algorithm has much better performance in reducing the PAPR than the SLM and PTS algorithms, with comparable computational complexity, BER performance, and information overhead.

Keywords OFDM · PAPR · Golay complement sequence · SLM algorithm · PTS algorithm

1 Introduction

The basic principle of an OFDM system is to use the serial-to-parallel transform to allocate the high data rate stream on some of the relative low data rate parallel and orthogonal sub-channels [1]. Due to the low transmission data rate of the sub-channels, the period to transmit one data symbol is enlarged and it reduces the influence of the multi-path and fading effects of wireless channels on the system performance. Furthermore, by adding the cyclic prefix in an OFDM symbol as the guard interval, it can reduce the inter-channel interference (ICI) and

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inter-symbol inference (ISI). Although the OFDM system has the advantage of the resistance against fading effects and high spectrum efficiency, etc., in the practical implementation, this system needs a large number of carriers to transmit the data. When these carriers superpose each other, it will cause a very large peak to average power ratio (PAPR) [1]. When the large PAPR signal is inputted to the power amplifier of an OFDM system, it requires the amplifier to have a very large linear amplification interval; otherwise, it will bring non-linear distortions of the OFDM signal, non-orthogonality between sub-channels, and out-of-band spectrum interferences. However, in reality, this kind of power amplifier either cannot be designed or implemented, or has an extraordinary cost. For this reason, the research on the reduction of the PAPR in OFDM systems both has theoretical value and practical importance.

Currently, the PAPR reduction algorithms in the literature can be categorized as the following three classes of algorithms as (1) the pre-distortion algorithms [2–6], (2) coding algorithms [7,8], and (3) statistical algorithms [9–18].

In the pre-distortion algorithms, a lot of distortions and out-of-band interferences unavoidably occurred by reducing the PAPR. In the coding algorithms, the information transmission rate is unavoidably small by reducing the PAPR. The statistical algorithms, such as the PTS algorithm [9], and the SLM algorithm [12], have relatively good performance in regards to the out-of-band interferences and information transfer rate.

The purpose of this paper is to further enhance the performance of PAPR reduction by intelligently applying both the PTS and the SLM algorithms without reducing the bit error ratio (BER) performance. The advantages of the two algorithms are utilized while trying to avoid their disadvantages. Simulation results demonstrate the superior performance of the proposed algorithm.

This paper is organized as follows. In Sect. 2, the definition and the feature of the PAPR in the OFDM systems are given. In Sect. 3, the exiting PAPR reduction algorithms are reviewed, and the proposed algorithm is described in details in Sect. 4. Then, the paper concludes in Sect. 5.

2 The PAPR Feature of the OFDM Signal

2.1 The Definition of the PAPR [1]

For an OFDM system, with the number of carriers of N, let $X(k), 0 \le k \le N$ represent the sequence when the encoding of the input data is finished, then the equivalent low-pass signal after the inverse fast Fourier transform (IFFT) of the signal can be expressed as

$$x(t) = \sum_{k=0}^{N-1} X(k) \exp(j2\pi f_k t), \quad t \in [0, T]. \tag{1}$$

After this signal is sampled using the sampling period of T/N, the discrete signal can be obtained and written as

$$x(n) = \sum_{k=0}^{N-1} X(k) \exp\left(j\frac{2\pi}{N}nk\right), \quad 0 \le k \le N, \tag{2}$$

where $X(k)$ is the modulation signal in a kth sub-channel, $x(n)$ is a sampling signal in the time domain, and all of the $x(n)$s consist of one OFDM symbol. The PAPR of the OFDM symbol is defined as the ratio between the maximum power at a particular sampling time

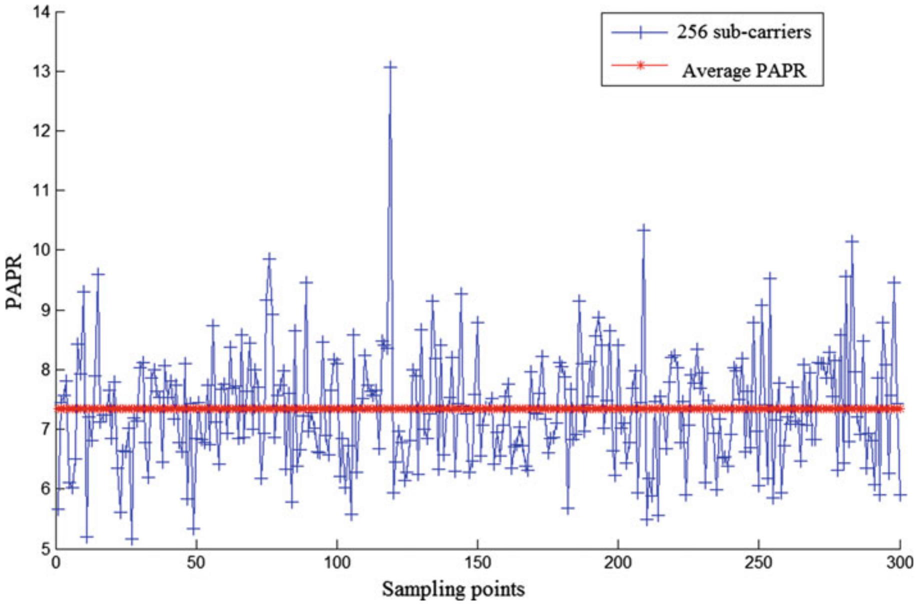

Fig. 1 A *curve* of the PAPR when N = 256

in the time domain of the OFDM symbol and the average power of the OFDM symbol [1]. Figure 1 illustrates the simulation results of the PAPR for one OFDM symbol. From the variation interval of the PAPR, it can be seen that an OFDM symbol usually has a high value of PAPR. Figure 2 demonstrates the corresponding changes of the PAPR, when the number of the sub-channels in one OFDM symbol is changed from 128 to 1,024. From this figure, it can be seen that when the number of the sub-channels increases, the value of the PAPR of an OFDM symbol usually becomes larger and larger.

2.2 The Statistical Distribution of the PAPR [19]

The crest factor (CF) of an OFDM signal can be defined as the ratio of the maximum magnitude of the signal to the average signal power [3], i.e.

$$CF\left[x(n)\right] = \frac{\max\left[|x(n)|\right]}{\sqrt{E\left[|x(n)|^2\right]}} = \sqrt{PAPR} \tag{3}$$

According to the central limit theory, for a relative large number of the sub-channels of N, the real and image parts of $x\ (n)$ comply with the Gaussian distribution with the mean of 0 and variance of 0.5. The magnitude of an OFDM symbol complies with the Rayleigh distribution. Its power comply with the χ^2 distribution with the central free degree of 2, and the cumulative distribution function of it is [19]

$$F(z) = 1 - e^{-Z} \tag{4}$$

where Z is the threshold value. Thus, when the sampling values in an OFDM period are uncorrelated, the cumulative distribution function of Z is the probability that PAPR is less than Z. Commonly, people use the complementary cumulative distribution function (CCDF)

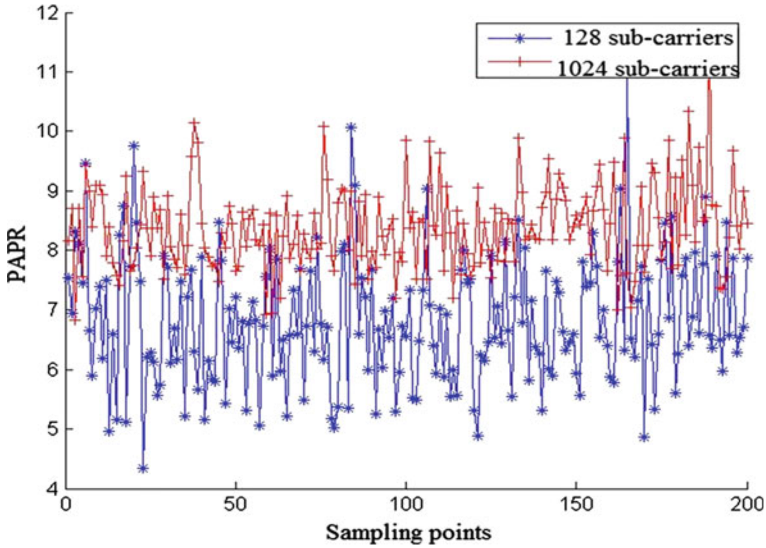

Fig. 2 The PAPR comparison between N = 128 and N = 1,024

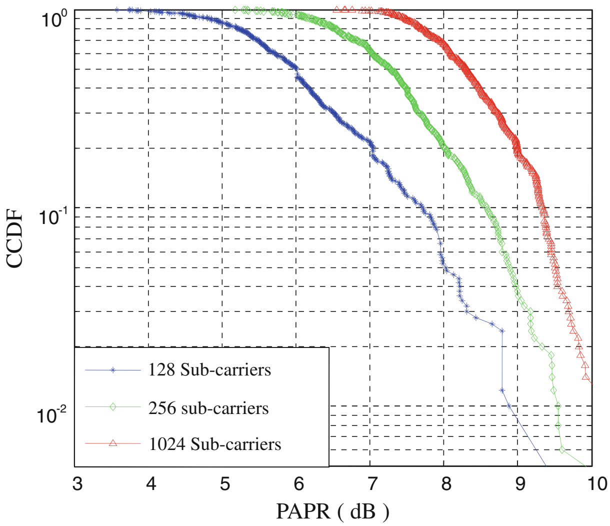

Fig. 3 The CCDF *curves* for the different number of sub-channels of N

that is the probability that PAPR is larger than a value of Z, i.e. $CCDF = 1 - P\{PAPR \leq Z\} = 1 - (1 - e^{-Z})^N$, to describe the distribution of PAPR in the OFDM systems.

Figure 3 gives the simulation results of the CCDF curves of the PAPR when the number of sub-channels in one OFDM symbol of N is 128, 256, and 1,024, respectively. The results demonstrate that given the threshold of the value of PAPR, the CCDF will usually increase when the number of sub-carriers of N becomes larger, i.e. the probability that an OFDM signal's PAPR is larger than the threshold will increase.

3 The Existing Algorithms in the OFDM Systems to Reduce the PAPR

3.1 The Overview of the Existing PAPR Reduction Algorithms

The basic idea of signal pre-distortion PAPR reduction algorithms is to use non-linear processing for the locations of the OFDM sampling signals where their values are larger than a threshold, and also for their neighboring areas, to reduce the PAPR. This kind of processing is simple and effective. However, it will bring large out-of-band interferences, reduce the spectrum efficiency, and deteriote the BER of the systems. The algorithms in this class consist of the threshold limiting algorithm [2] and the compressive algorithm [3], and some companding algorithms [5,6], etc.

The basic principle of the coding algorithms is to use the coding technique to generate the set of the codes which has a low value of PAPR to transmit and avoids the generation of the high magnitude signal. The classic codes [7,8] for this purpose consist of the block code, Golay code, Reed-Muller code, etc. The block code is only suitable when the number of sub-carriers is small. The Reed-Muller code is a high efficient coding scheme. It can split the second order Reed-Muller code into several cosets and separate the codes with high PAPR to reduce the PAPR. The application of the Reed-Muller code can reduce the PAPR to more than 3dB and have a good error-correction performance. However, the constellation classes of this kind of code are restrictive and thus its application is restrictive. The method of Golay complementary sequences (GCS) is to use the GCS as its input and then obtain the signal with low magnitudes. Furthermore, this kind of codes has good channel estimation and correction ability. For the GCS sequence pair, its main advantage is that it is not restrictive in the number of the sub-carriers. However, it can only at most reduce the PAPR to 3dB. Furthermore, its shortcoming is that when the number of sub-carriers increase, it is very hard to find the optimal generation matrix and phase rotation vector. The performance gain of the PAPR for the coding technique under the same transmission rate is achieved at the cost of the increase of the system bandwidth, or the reduction of the energy per bit under the same transmission power.

The basic idea of the statistical algorithms is to carry out various kinds of randomization of the signal. Their representative algorithms are the partial transmit sequence (PTS) algorithm [9], and the selective mapping (SLM) algorithm [12]. PTS like algorithms [9–11] carry out the phase optimization processing after the IFFT process, and select the phase combination which has the minimum PAPR to transmit, while SLM like algorithms [12–17] carry out the phase optimization process before the IFFT process, and also select the phase combination with the minimum PAPR to transmit. These kinds of algorithms reduce the probability that the maximum magnitude of PAPR will occur. They do not change the BER of the system, and thus the BER performance of the PTS and SLM algorithms is the same as the BER performance of the original OFDM signal. Furthermore, the information overhead of the PTS or the SLM algorithm is small, and thus the information transmission rate of the PTS or the SLM algorithm is comparable to the original OFDM signal.

3.2 The Pre-distortion Technique

3.2.1 Clipping

In the traditional clipping algorithm [2], a pre-determined threshold of A is set before the digital to analog signal conversion. Those sampling values which are larger than the threshold

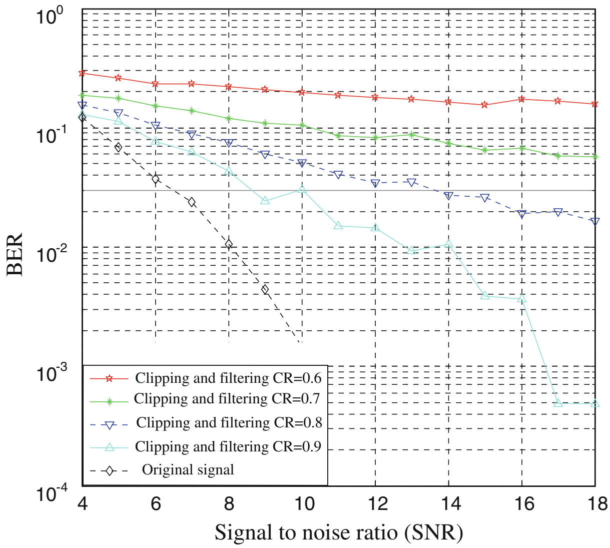

Fig. 4 The BER comparisons among different CRs

are directly clipped and only the values below A are kept unchanged, i.e. when the input signal is $x(n)$, the output signal is $y(n)$, the following formula is utilized in the clipping method

$$y(n) = \begin{cases} A, |x(n)| > A \\ x(n), |x(n)| \leq A, \end{cases} \tag{5}$$

and the crest factor (CR) is defined as a function of A to indicate the degree of clipping in these algorithms. Figure 4 illustrates the BER performance of these algorithms.

The contribution of the traditional clipping algorithms is that they provide an approach to reduce the PAPR. But, these algorithms face the problem of the introduction of clipping noise, the deterioration of the system performance, and the reoccurrence of peak value in the up-sampling. To reduce the clipping noise, some windowing functions, such as the Gaussian window, cosine window, and Kaiser window, are utilized to filter the signal. However, the clipping noise is unavoidable. For the peak value reoccurrence problem, the paper [2] has proposed a method to carry out iteratively clipping at many times. However, the more times of the clipping, the worse the BER performance of the system.

3.2.2 Companding Technique

The main idea for the companding technique comes from the compressive approach in the processing of the audio signal, i.e. the companding is carried out before the D/A conversion of the signal. The commonly used companding algorithms are the μ-law companding and the A-law companding. At the receiver, the reverse processing is carried out before the FFT. The objective of these algorithms is to amplifier the relative small-valued signal and condense the large-valued signal to increase the average power of the signal and reduce the peak values to reduce the PAPR [5].

Paper [6] proposes a revised companding algorithm and it can keep the transmission power unchanged to transmit the OFDM symbols through the forward and reverse companding at

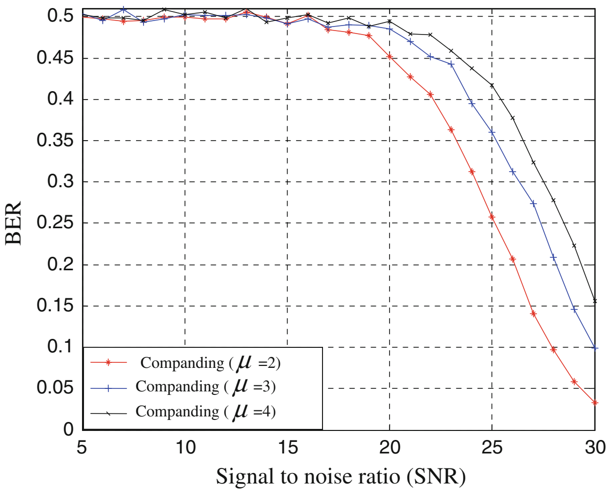

Fig. 5 The BER *curves* of the companding algorithm using different μ

the transmission and receiver side, respectively. Figure 5 illustrates the BER performances under the various parameter settings in the μ-law companding.

It can be seen that the BER performance deteriorates with the increase value of μ. Thus, in practical implementations, the tradeoff between the reduction of the PAPR and the increase of the BER should be wisely made. Overall, the companding algorithms are only suitable for the situations that the number of sub-channels is small and the transmission rate is low, and thus it is not suitable for high data transmission situations.

3.3 Coding Technique

The GCS [7,8] can be utilized to construct the transmission code which has a low PAPR. This method has the following two features: (1) It can limit the PAPR in the range below the 3dB, irrespective of the kind of the input data and the number of the sub-carriers. (2) It has the ability to correct the wrong code in the receiver and can reduce the BER of the system.

This method can both significantly reduce the PAPR and correct some kind of wrong code. Furthermore, it has a low computational complexity for encoding and decoding. However, this method is restricted for the number of the sub-carriers. The larger the number of sub-carriers, the more difficult the search of the optimal generate matrix, and significantly the lower the efficiency of encoding. It increases the system's bandwidth with the same transmission rate, compared with other schemes. Thus, the information transmission rate is greatly reduced.

3.4 Signal Randomization Techniques

3.4.1 Partial Transmission Sequence (PTS)

In this type of algorithms [9–11], the utilization of different rotation factors can reduce the PAPR of the OFDM symbol. In practical implementations, the exhaustive search is usually conducted for the selected set of phase factors and the one with the minimum PAPR is obtained.

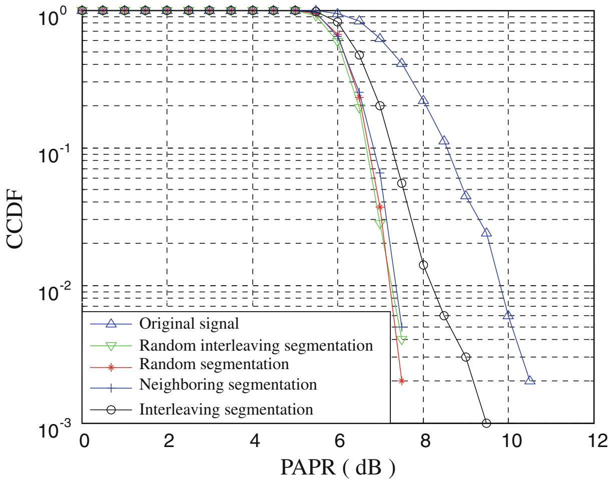

Fig. 6 The CCDF *curves* using different segmentation algorithm

In the PTS algorithm, since it exhaustively searches the optimal sub-carrier weighting factor in a set, it brings an extraordinary computational complexity with the increase of the number of sub-carriers. In paper [10], it proposes the method to select the suitable partition scheme to reduce the signal's autocorrelation. Figure 6 illustrates the simulation results of the CCDF curves when the sub-block partition schemes are pseudo-random partition, adjacent partition, interleaving partition, where the pseudo-random partition scheme has a relatively good PAPR suppression performance, and the interleaving partition scheme can effectively reduce the computational complexity of the PTS-OFDM system.

3.4.2 Selective Mapping Algorithm (SLM)

The type of selective mapping (SLM) algorithms [12–18] utilizes random phase sequences to construct the statistically independent symbol vectors for the same information, and then selects the symbol with the minimum PAPR to transmit.

Figure 7 illustrates the improvement of PAPR after the SLM algorithm, i.e. after the SLM algorithm, the probability of the occurrence of high PAPR is significantly reduced.

4 Proposed Algorithm

4.1 The Idea of the Proposed Algorithm

In this paper, it tries to propose a new algorithm to take the advantages of both the SLM and the PTS algorithms and avoids their shortcomings. If the PTS algorithm is utilized after the SLM algorithm, such as the methodology utilized in the paper [18], some advantages of the first randomization by using the SLM algorithm will be mitigated in the second randomization by using the PTS algorithm, since the randomization in the second time by using the PTS algorithm will interference the randomization in the first time by using the SLM algorithm, and that is the reason why the performance of the PAPR reduction in [18] cannot be much better than that of the PTS algorithm. However, an alternative approach can be utilized, where

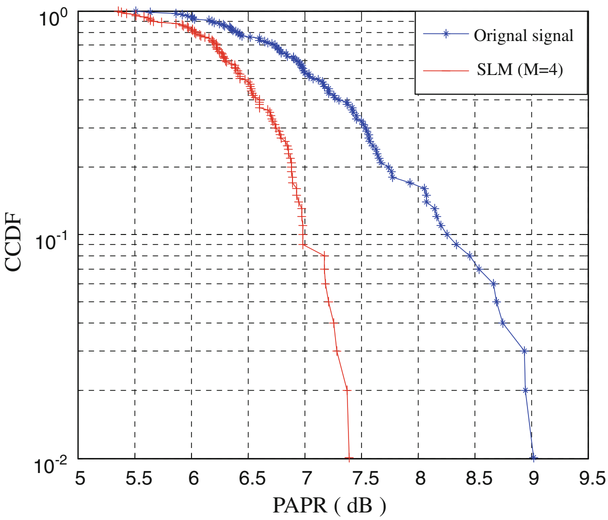

Fig. 7 The CCDF *curve* after the processing of the SLM algorithm

the PTS algorithm are only used for some data in an OFDM symbol, and the SLM algorithm are used for the remaining data. Since these two algorithms now do not interfere with each other, both of their advantages can be utilized. By following this approach, the following four algorithms are proposed in the next sub-section.

4.2 The Details of the Proposed Algorithms

In order to achieve the above objective, four algorithms are proposed and they are listed in the following.

(1) Algorithm I

In this algorithm, the OFDM symbol is first partitioned in the first half section and the second half section. For the first half section, the SLM algorithm is employed to reduce the PAPR of this section, while the PTS algorithm is employed to reduce the PAPR of the second section.

(2) Algorithm II

In this algorithm, the first half section consists of the data in the OFDM symbol whose index in the symbol is odd, and the second half section consists of the data in the OFDM symbol whose index is even. After this interleaving process, the first section employs the SLM algorithm to reduce its PAPR, while the second half section utilizes the PTS algorithm to reduce its PAPR.

(3) Algorithm III

In this algorithm, the OFDM symbol is partitioned using the same process as in the Algorithm I and the SLM algorithm is employed to reduce the PAPR of the first section. However, in this algorithm, the optimal PTS parameters are searched for the whole OFDM symbol

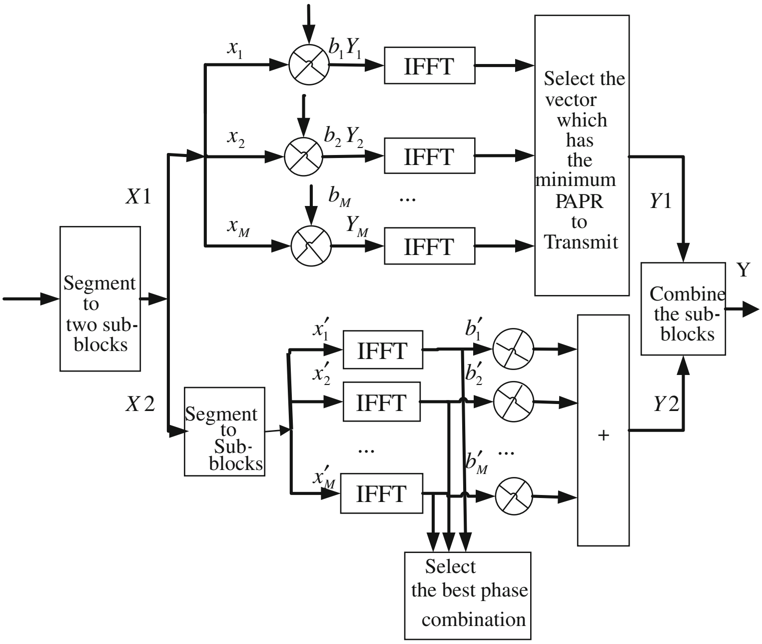

Fig. 8 The diagram of the proposed algorithm

instead of only the second half section. This algorithm will have much larger computational complexity than the Algorithm I.

(4) Algorithm IV

In this algorithm, the OFDM symbol is segmented using the same process as in the Algorithm II and the SLM algorithm is employed to reduce the PAPR of the first section. However, in this algorithm, the optimal PTS parameters are searched for the whole OFDM symbol instead of only the second half section. Similarly, this algorithm will have much larger computational complexity than the Algorithm II.

4.3 The Determination of the Proposed Algorithms from These Four Algorithms

According to our extensive simulation results and analysis, the performance of the Algorithm III is similar to the Algorithm I, and the performance of the Algorithm IV is similar to the Algorithm II, i.e. the corresponding algorithms have about the same PAPR reductions. For this reason and the fact that the computational complexity of the Algorithm III is much larger than that of the Algorithm I, and the computational complexity of the Algorithm IV is much larger than that of the Algorithm II, only the Algorithm I and II are further investigated in this paper, and they are referred to as the algorithm with segmentation and with interleaving, respectively. Among these two algorithms, when the input data has some correlations between neighboring sampling values, the performance of the Algorithm II will be better than the Algorithm I. The flowchart of the proposed algorithms is shown in the Fig. 8.

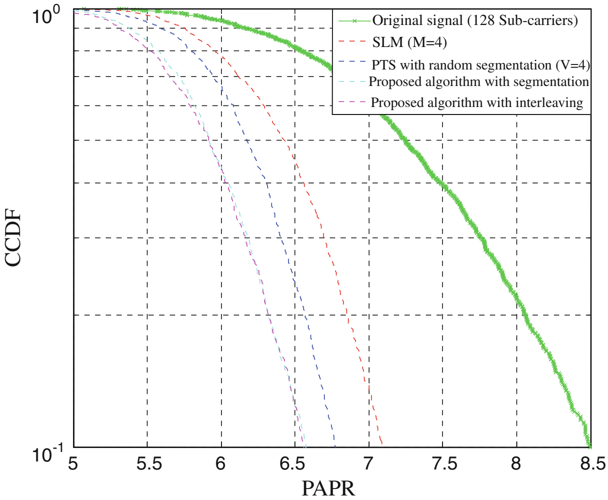

Fig. 9 The CCDF *curve* of the proposed algorithm when N = 128

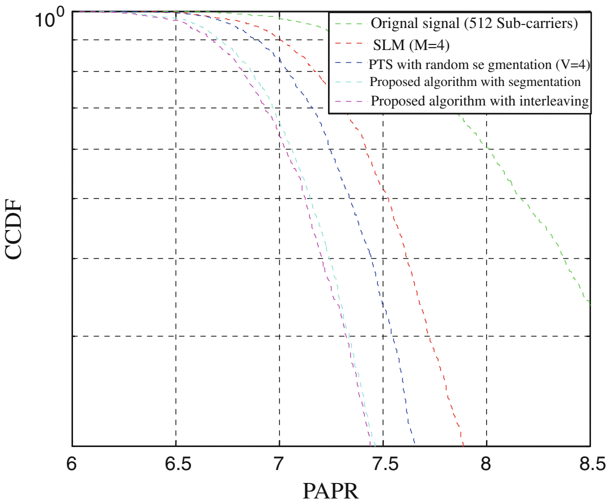

Fig. 10 The CCDF *curve* of the proposed algorithm when N = 512

4.4 PAPR Performances of the Proposed Two Algorithms

The simulations of the proposed algorithms are conducted for various lengths of the OFDM symbols. For example, performances of the proposed algorithms when the OFDM symbol length is 128, 512, and 1,024 are evaluated and compared with the original PTS algorithm and the SLM algorithm. The simulation results are illustrated in the Figs. 9, 10 and 11, respectively. From these figures, it can be easily seen that the proposed algorithms perform much better than the conventional PTS or SLM algorithm in the respect of the reduction of the PAPR. At the same level of the PAPR, the CCDF of the proposed Algorithms are much smaller than that of the conventional PTS or SLM algorithm.

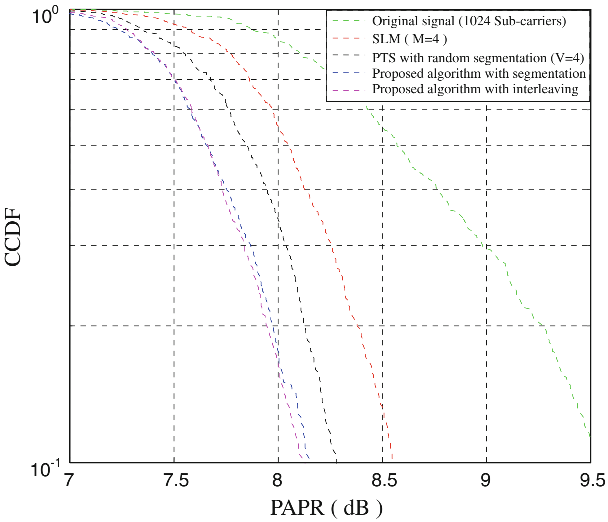

Fig. 11 The CCDF *curve* of the proposed algorithm when N = 1,024

It can also be seen that the performances of the proposed Algorithm I (the algorithm with segmentation) and Algorithm II (the algorithm with interleaving) are about the same. This is due to the fact that the data in an OFDM symbol are uncorrelated in our simulations. When there are some correlations between the data in an OFDM symbol, it can be expected that the proposed Algorithm II will perform better than the Algorithm I, since the correlations between data is utilized in the Algorithm II.

4.5 Computational Complexity of the Proposed and Conventional Algorithms

In the evaluation of the computational complexity of different algorithms, the number of the times that the additions, subtractions, shifts, multiplications, and divisions are counted and summed to measure the computational complexity. This assumption is usually correct in current CPUs or digital signal processors (DSPs), when the time to take an addition is about the same as that to take a multiplication. When N is the number of the sub-channels (data) in an OFDM symbol, the computational complexity of the SLM algorithm is about 62N (when M = 4), that of the PTS algorithm is about 388N (when V = 4), and that of the proposed algorithms are 221N. From these results, it can be seen that the computational complexities of these algorithms are of $O(N)$ and are all linear to the number N, and the proposed algorithms have about the same level of the computational complexity as the PTS and SLM algorithms.

4.6 The BER Performance of the PTS, SLM, and Proposed Two Algorithms

Paper [18] gives the BER analysis of the PTS and SLM algorithms, and reaches the conclusion that the PTS and SLM algorithms have about the same BER performance. By following similar analysis, it can be derived that the BER performances of the PTS algorithm, the SLM algorithm, and the two proposed algorithms are about the same.

4.7 The Recent and Future Research Directions in the Reduction of PAPR

Paper [18] proposes the algorithm to combine the SLM and PTS. It first carries out the SLM and then the PTS to reduce the PAPR. Paper [12] proposes an improvement for the PTS. For example, it uses iterative shift linear searching method and m sequence to reduce the computational complexity to select the optimal phase rotation sequence. From this perspective, they can dramatically reduce the computational complexity without affecting the performance of the PTS. However, since their PAPR reduction performance is about the same as the PTS algorithm, it can be seen that the PAPR reduction performance of the proposed two algorithms is much better than that of those algorithms.

4.8 Summary of the Two Proposed Algorithms

In this paper, some new algorithms are proposed to take the advantages of the PTS and SLM algorithms and overcome their shortcomings at the same time. This is achieved by dividing the OFDM symbol into two sections and employing SLM algorithm only for the first section and PTS algorithm only for the second section. Simulation results demonstrate that the proposed algorithms perform much better than the conventional PTS or SLM algorithm in the respect of the reduction of the PAPR. At the same time, the computational complexity of the proposed algorithms lies between that of the SLM and PTS algorithms. The BER performances of the PTS, SLM, and proposed algorithms are about the same.

5 Conclusions

For the improvement of the PAPR performance, the clipping technique is simple and effective. However, it can bring out-of-band interferences, and much degradation of the BER performance of the system.

The coding technique can obtain a relatively simple and stable system performance. Its shortcoming is that when the number of sub-carriers increases, the throughput of the system will be significantly degraded and the efficiency of the spectrum usage will be lowered. This technique is only suitable for the system with a relatively low number of sub-channels and a high requirement of system stability.

In the signal randomization algorithms, such as the PTS algorithm and the SLM algorithm, its main objective is to reduce the probability that a high PAPR will occur. Thus, this technique avoids the clipping noise in the clipping technique, and this technique has the least affect of the system performance among all the three technical classes of algorithms.

For these reasons, this paper applies both the PTS algorithm and SLM algorithm to randomize the transmitted OFDM signal. Two blocks are firstly formed from the original OFDM data. Then the SLM algorithm is applied for the first block and the PTS algorithm is applied for the second block. After this, these two blocks are combined to make the transmission signal. Since the proposed two algorithms take the advantages of both the PTS and SLM algorithms in the randomization, it can further reduce the PAPR. At the same time, the computational complexity and BER performance of the proposed two algorithms are about the same as that of the original PTS or SLM algorithm. In summary, the proposed algorithms have much better PAPR reduction performances than the existing randomization algorithms at about the same costs.

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References

1. Han, S. H., & Lee, J. H. (2005). An overview of peak-to-average power ratio reduction techniques for multicarrier transmission. *IEEE Wireless Communications*, *12*(2), 56–65.
2. Armstrong, J. (2002). Peak-to-average power reduction for OFDM by repeated clipping and frequency domain filtering. *Electronic Letters*, *38*(8), 246–247.
3. AI-Safadi, B. E., & AI-Naffouri, T. Y. (2012). Peak reduction and clipping mitigation in OFDM by augmented compressive sensing. *IEEE Transactions on Signal Processing*, *60*(7), 3834–3839.
4. Ochiai, H., & Imai, H. (2002). Performance analysis of deliberately clipped OFDM signals. *IEEE Transaction on Communications*, *50*(1), 89–101.
5. Wang, L. H., Ge, J. H., & Ai, B. (2012). Nonlinear companding transform technique for reducing PAPR of OFDM signals. *IEEE Transactions on Consumer Electronics*, *58*(3), 752–757.
6. Xiao, J., & Yu, J. (2012). Hadamard transform combined with companding transform technique for PAPR reduction in an optical direct-detection OFDM system. *IEEE Journal of Optical Communications and Networking*, *4*(10), 709–714.
7. Davis, J. A., & Jedwab, J. (1999). Peak-to-mean power control in OFDM, Golay complementary sequence, and Reed-Muller codes. *IEEE Transactions on Information Theory*, *45*(7), 2397–2417.
8. Wilkinson, T. A., & Jones, A. E. (1995). Minimization of the peak to mean envelope power ratio of multicarrier transmission schemes by block coding. In *Proceedings of IEEE vehicular technology conference* (Vol. 2, pp. 825–829).
9. Muller, S. H., & Huber, J. B. (1997). OFDM with reduced peak-to-average power ratio by optimum combining of partial transmit sequences. *Electronic Letters*, *33*(5), 368–369.
10. Tellambura, C. (2001). Improved phase factor computation of the PAPR reduction of an OFDM signal using PTS. *IEEE Communication Letters*, *5*(4), 135–137.
11. Han, S. H., & Lee, J. H. (2004). PAPR reduction of OFDM signals using a reduced complexity PTS technique. *IEEE Signal Processing Letters*, *11*(11), 887–890.
12. Bauml, R., Fischerand, R., & Huber, J. (1996). Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping. *Electronic Letters*, *32*(22), 2056–2057.
13. Teiling, M. B., & Muller-Weinfurtne, S. H. (2001). SLM peak-power reduction without explicit side information. *IEEE Communications Letters*, *5*(6), 239–241.
14. Lim, D.-W., No, J.-S., Lim, C.-W., & Chung, H. (2005). A new SLM OFDM scheme with low complexity for PAPR reduction. *IEEE Signal Processing Letters*, *12*(2), 93–96.
15. Handali, Y., Nizan, I., & Wulich, D. (2006). On channel capacity of OFDM with SLM method for PAPR reduction. In *Proceedings of 24th convention of IEEE electrical and electronics engineers in Israel*, pp. 138–140, November 2006.
16. Cho, Y. C., Han, S. H., & Lee, J. H. (2004). Selected mapping technique with novel phase sequences for PAPR reduction of an OFDM signal. In *Proceedings of IEEE vehicular technology conference* (Vol. 7, pp. 4781–4785).
17. Yang, S., & Shin, Y. (2006). Partitioned-SLM scheme with low complexity for PAPR reduction of OFDM signals. In *Proceedings of IEEE international symposium on personal, indoor and mobile radio communications*, September 2006.
18. Chou, H.-J., Lin, P.-Y., & Lin, J.-S. (2012). PAPR reduction techniques with hybrid SLM-PTS schemes for OFDM systems. *Proceedings of 75th IEEE vehicular technology conference*, pp. 1–5.
19. Ochiai, H., & Imai, H. (2001). On the distribution of the peak-to-average power ratio in OFDM signals. *IEEE Transactions on Communications*, *49*(2), 282–289.

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