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PTS and Modified Clipping Joint Algorithms for PAPR Reduction in OFDM-QAM System

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Abstract: As one of the most attractive techniques, partial transmit sequence (PTS) provides an effective solution for peak-to-average power ratio (PAPR) reduction in orthogonal frequency division multiplexing (OFDM) systems, however, results in large computational complexity simultaneously. Compared to PTS, clipping provides a simpler way towards a better PAPR performance, whereas results in degradation of the bit error rate (BER) performance. In this paper, we proposed two joint algorithms called quantization clipping (QC) and recoverable clipping (RC), which combined PTS with modified Clipping schemes. The proposed schemes achieve a better exploitation of advantages, simulation results show that the proposed joint algorithms do not only significantly improve the PAPR reduction performance but also achieve a non-loss BER performance.

Keywords: Orthogonal Frequency Division Multiplexing, peak-to-average power ratio, partial transmit sequence, quantization Clipping, recoverable clipping

1 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is the most widely used signal modulation and demodulation technology in Multi-carrier communication system, in which a serial data symbol stream is passed through a serial/parallel converter and transmitted via a large number of orthogonal subchannels [1]. It has been shown that the performance of OFDM system over frequency selective fading channels is better than that of the traditional single carrier modulation system. OFDM has also been considered as one of the critical technologies for the next generation mobile communication.

However, a major drawback of OFDM is the high peak-to-average power ratio (PAPR) of the transmitted signals. If the PAPR exceeds the nonlinearity limits of high-power amplifier (HPA), in-band interference and out-of-band radiation may occur [2]. To avoid the occurrence of large PAPR in OFDM systems, various algorithms have been proposed, and be classified into two classes [3]: signal distortion algorithm and non-distortion algorithm.

–The **signal distortion technology** limits the OFDM signal below a given threshold using nonlinear distortion [4], such as clipping [5], peak window [6], and companding transformation [7]. Several advantages have been observed in nonlinear distortion, such as simplicity, no redundant information and free of limitation with the number of subcarriers and modulation. However, the in-band distortion and out-of-band radiation still exist due to the nonlinear operation, resulting in degradation of system performance in terms of bit error rate (BER) and spectrum efficiency.

–The **signal non-distortion algorithms** optimize the carrier phase of each subchannel to find the phases combination with the lowest PAPR. These algorithms, including selective mapping (SLM) [8], partial transmit sequence (PTS) [9], tone reservation (TR) [10], etc.. The non-distortion algorithm can achieve a better PAPR reduction performance without inducing signal distortion. Besides, the application of these algorithms is not limited by the modulation type or by the number of subcarriers. However, there also exist some disadvantages, such as the need to transmit sideband information, high computational complexity, difficulty in hardware realization, etc.

Signal clipping is an appealing distortion algorithm due to its simplicity and low computation complexity.

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This technique is the simplest and has been widely used, which can limit the input signal below a given threshold level. However, clipping scheme causes serious in-band distortion and out of band radiation. To overcome the drawbacks of clipping scheme, various techniques have been proposed. Based on the schemes proposed by Armstrong et al.,which included the clipping and filtering (CF) [11] and repeated clipping and filtering (RCF) [12], many methods have been proposed [13,14]. Wang et al [15] proposed a simplified Clipping and Filtering technique, which scales the clipping noise generated in the first iteration to get a new CF technique that significantly reduces the computational complexity. Furthermore, an adaptive clipping control algorithm is proposed in [16], in which a new suboptimal peak reduction tone(PRT) set selection scheme based on the genetic algorithm (GA) is employed to solve the NP-hard problem.

To our knowledge, among all the existing signal non-distortion schemes, PTS is regarded as a promising technique. In the PTS scheme, the input symbol sequence is partitioned into a number of disjoint symbol subsequences and then being multiplied by a set of distinct rotating vectors. The PAPR is then computed for each resulting sequence, followed by the signal sequence with the minimum PAPR being selected and transmitted. However, by using an exhaustive search over all combinations of allowed phase factors, the complexity of optimum PTS technique increases exponentially with the number of subblocks. Therefore, this technique is impractical in the presence of a large number of subblocks. Recently, some extensions of PTS schemes have been proposed focused on complexity reduction [17, 18,19,20]. In [21], the OFDM signals are generated by multiplying a set of the rotating vectors to the intermediate signal that has taken k-th stage of Inverse fast Fourier transform (IFFT). After that, signals will precede the remaining N-K steps IFFT to significantly reduce the complexity of the system. Besides, a modified PTS scheme with grouping and recursive phase weighting methods is proposed in [22], which focuses on simplifying the computation for candidate sequences and obtaining the same candidate sequences compared to optimal PTS. Furthermore, another algorithm called Tree-PTS is proposed in [23], in which the nodes in the tree corresponds to phase weighting factors and layers corresponding to sub-blocks, with all the candidates being calculated by the combination of layers and weighting factors on the paths from the root to the leaves. For more schemes combine PTS with other signal distortion technique, please refer to [24,25,26,27].

In this paper, we propose two modified schemes that combine PTS and distortion approaches. Note that in the existing joint schemes, the PTS scheme is combined with signal clipping. The main idea of these joint algorithms is to perform clipping on the processed signal to reduce the probability of the peak value. However, the PAPR performance of these schemes is in the cost of the BER performance. To overcome the disadvantages of the conventional clipping schemes, we propose two modified clipping scheme called quantization clipping (QC) and Recoverable clipping (RC). By combining these two modified clipping scheme with PTS scheme, a proper PAPR performance can be guaranteed, meanwhile, a better BER can be achieved.

The rest of the paper is organized as follows. In Section 2, OFDM system and the conventional PTS and clipping scheme are explained, followed by two modified PAPR reduction schemes being proposed in Section 3. In Section 4, simulation results are given to compare the PAPR reduction performances of the proposed scheme with the conventional algorithms. Finally, the concluding remarks are given in Section 5.

2 Signal Model

In an OFDM system with N sub-carriers, the input symbol in frequency domain can be written as $X = [X_0, X_1, \cdots, X_{N-1}]$, where $X_k (k = 0, 1, \cdots, N-1)$ represents the complex data of the k-th subcarrier. The complex OFDM symbol in time domain can be generated as:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi(\frac{n}{NT})t}, 0 \le t < NT \tag{1}$$

where $x(t)$ denotes the modulated time domain signal, and T represents a period of input symbol.

The PAPR of OFDM signal sequence X is defined as the ratio of maximum to the average power of the signal [28], i.e.,

$$\text{PAPR} = \frac{\max\limits_{0 \le t \le N-1} |x(t)|^2}{E[|x(t)|^2]} \tag{2}$$

Statistically, it is possible to characterize the PAPR distribution (probability that PAPR exceeds given threshold γ) using complementary cumulative distribution function (CCDF), i.e.,

$$\Pr(\text{PAPR} > \gamma) = 1 - (1 - \exp(-\gamma))^N \tag{3}$$

2.1 Traditional PTS scheme

The basic idea of PTS scheme is to divide the input symbols into several disjoint subsequences and multiplied by a set of distinct rotating vectors, with the signal sequence corresponding to the smallest PAPR being transmitted. The structure of PTS scheme is shown in Fig.1 [15].The input symbol sequence $X = [X_0, X_1, \cdots, X_{N-1}]$ is partitioned into V subsequences,the vth subsequence X^v can be written as:

$$X^v = [X_0^v, X_1^v, \ldots, X_{N-1}^v], 0 \le v \le V-1 \tag{4}$$

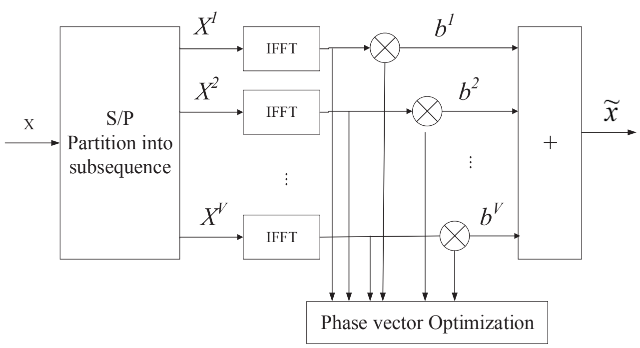

Fig. 1: The structure of conventional PTS scheme.

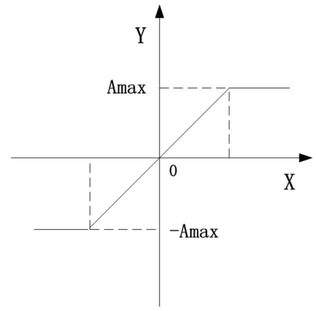

Fig. 2: The schematic diagram of traditional Clipping scheme.

$$X_n^v = \begin{cases} X_n, & \text{Belongs to the vth subsequence} \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

where $v(0 \le v \le V)$ represents the number of subsequences, $n(0 \le n \le N-1)$ denotes the subcarrier of the vth subsequence.

After transforming to the time domain by applying the inverse fast Fourier transform (IFFT) to each symbol subsequence, the time-domain vector becomes

$$\tilde{x} = \text{IFFT}\left\{\sum_{v=0}^{V-1} b^v X^v\right\} = \sum_{v=0}^{V-1} b^v \cdot \text{IFFT}(X^v) \tag{6}$$

where $b^v \in \{e^{j\frac{2\pi i}{W}}, i = 0, 1, \cdots W-1\}$. W is the number of candidate phases which is usually set as $W = 2(b^v \in \{\pm 1\})$ or $W = 4(b^v \in \{\pm 1. \pm j\})$.

The PAPR of x is computed from each of W rotation vectors, and the one with the minimum PAPR is chosen for transmission. The optimization problem can be written as:

$$\tilde{b} = arg \min_{0 \le v \le V-1} \left\{\max_{0 \le t \le N-1} |\tilde{x}|\right\} \tag{7}$$

Evidently, the larger of the number of subsequences and the phase vector implies the better PAPR reduction performance in PTS.

2.2 Traditional Clipping scheme

The fundamental principle of clipping algorithm is to detect the input signals peak before the time domain OFDM signal being supplied to the power amplifier. If any part of the signal exceeds the threshold, a non-linear processing should be implied to limit the amplitude within the pre-set threshold, or otherwise the signal will be transmitted without interference [5]. The schematic diagram of clipping scheme is shown in Fig.2.

The clipped time domain signal can be written as:

$$\hat{x}(t) = \begin{cases} x(t), & |x(t)| \le A \\ Ae^{j\phi(t)}, & |x(t)| > A \end{cases} \tag{8}$$

where $x(t)$ represents the time domain signal, A denotes the clipping threshold, and $\phi(t)$ represents the phase of input signal $x(t)$.

The clipping operation could significantly improve the systems' PAPR performance, whereas the clipping noise $n(t)$ can be defined as:

$$n(t) = x(t) - \hat{x}(t) \tag{9}$$

For conventional clipping scheme, the clipping noise $n_{\text{clipping}}(t)$ can be expressed as:

$$n_{\text{clipping}}(t) = \begin{cases} (|x(t)| - A)e^{j\phi(t)}, & |x(t)| > A \\ 0, & \text{else} \end{cases} \tag{10}$$

In order to get a better PAPR performance, the threshold A is always set to a small level. The proposed quantization clipping scheme contains several different preset thresholds so that the input signal will be quantized to different threshold values.

3 Joint PTS scheme

In order to achieve a good PAPR reduction and BER performance, two joint schemes that combine PTS and modified clipping scheme are proposed to take advantages of each traditional technique and balance the tradeoff between the PAPR performance and computational complexity.

3.1 The PTS-QC scheme

In this scheme, the PTS and the modified Quantization Clipping scheme are combined used. Fig.3 shows a block diagram of PAPR reduction scheme using the proposed PTS-QC algorithm.

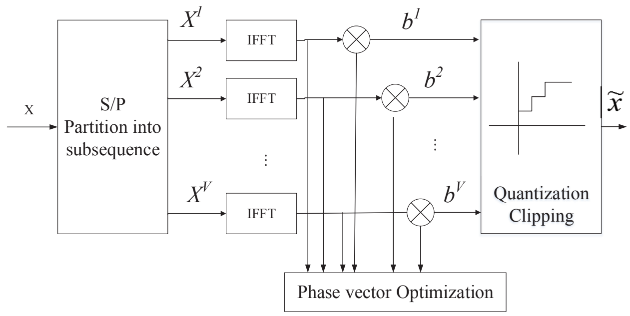

Fig. 3: Block diagram of OFDM PAPR reduction scheme using the proposed PTS-QC fusion algorithm.

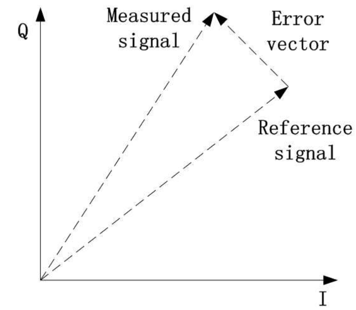

Fig. 4: The sketch map of the error vector.

The input data sequence $X = [X_0, X_1, \cdots, X_{N-1}]$ is partitioned into V subsequences to reduce the PAPR by applying the PTS technique. The PTS technique used in the first step can control the PAPR within a reasonable value, and then the modified Quantization Clipping technique is performed. The new algorithm will set distortion to a smaller level to reduce the BER and band radiation effectively.

Unlike the traditional clipping algorithm with only one threshold value, the quantized clipping algorithm contains several different preset threshold values so that the input signal would firstly be processed in another way, in which the signal value between different intervals will be quantized to different threshold values.

If there are m threshold, $m+1$ quantization interval is generated. The signal after clipping with m threshold values can be expressed as:

$$\hat{x}(t) = \begin{cases} x(t), & |x(t)| \le A_0 \\ \frac{A_0+A_1}{2} e^{j\phi(t)}, & A_0 < |x(t)| \le A_1 \\ \frac{A_1+A_2}{2} e^{j\phi(t)}, & A_1 < |x(t)| \le A_2 \\ \cdots & \cdots \\ \frac{A_{m-1}+A_m}{2} e^{j\phi(t)}, & A_{m-1} < |x(t)| \le A_m \\ A_m e^{j\phi(t)}, & |x(t)| > A_m \end{cases} \tag{11}$$

where $\hat{x}(t)$ denotes the quantified signal, $x(t)$ represents the input signal, and $\phi(t)$ denotes the phase of input signal. A set of threshold values $A_0, A_1, A_2, \cdots, A_{m-1}, A_m$ should meet the inequality $A_0 < A_1 < A_2, \cdots, < A_m$ and equation $A_2 - A_1 = A_3 - A_2 = \cdots A_m - A_{m-1} = s$, where s is the quantization step size, the phase information remains unchanged after this processing.

The error vector magnitude (EVM)[29] is used to denote the vector difference between the reference signal and the measured signal. The measured signal is the symbol points demodulated by the ideal receiver in an actual system, and the reference signal is the corresponding symbol points in an ideal system. EVM is defined as the ratio of the mean error vector to the power of the farthest point in the constellation, i.e.,

$$\mathrm{EVM} = \sqrt{\frac{\frac{1}{N}\sum_0^{N-1}(\Delta I^2 + \Delta Q^2)}{S_{\max}^2}} \tag{12}$$

where $\Delta I, \Delta Q$ denote the in-phase and quadrant components of the error vectors, respectively, N represents the number of the symbols and $S_{\max}$ denotes the maximum amplitude of the constellation points. The calculation process is illustrated in Fig.4.

Apply the EVM to the OFDM system, we obtain the expression:

$$\mathrm{EVM}\{\hat{X}^{(L)}\} = \frac{1}{X_{\max}} \sqrt{\frac{1}{n} \sum_{k \in I} |E[k]|^2} \tag{13}$$

where $X_{\max}$ is the maximum amplitude in the constellation diagram, $E[k]$ represents the error vector and can be expressed as:

$$E[k] = \hat{X}^{(L)}[k] - X^{(L)}[k],\ k \in I \tag{14}$$

If the EVM is small enough to meet the requirements in the agreement, the QAM demodulation can properly recover the original signal.

Through the quantization clipping scheme, the peak range of the signal is divided into several intervals and then different subinterval is quantized to different threshold. Therefore, the signal amplitude variation caused by the QC scheme will be much smaller than that caused by the conventional clipping method. Therefore, the BER performance of the proposed scheme is much better than that of the traditional algorithms.

Implementation process of quantization algorithm is developed as follows:

Framing intervals: Determine the appropriate quantization step according to the range and variation characteristics of the input signal, followed by dividing the signal interval into a set of intervals.

The most important parameter for the performance of clipping scheme is Clipping Ratio (CR), which is defined as

$$\mathrm{CR} = 20 \log \frac{A}{\sigma} \tag{15}$$

where A denotes limiting threshold, σ is the root mean square of signal power, a bigger CR corresponds a higher threshold, and the effect of reducing PAPR gets worse, and vice verse.

$$\sigma = \sqrt{\frac{[x_0(t)]^2 + [x_1(t)]^2 + \cdots + [x_{N-1}(t)]^2}{N}} \quad (16)$$

Where $x_0(t), x_1(t), \cdots, x_{N-1}(t)$ are the input signals, N is the number of subcarriers.

The number of subintervals: for uniform quantization, divide the signal range by the chosen quantization step size s, we get the quotient m as the number of subintervals and a remainder r, as shown in bellow:

$$m = [\text{length}(x)/s],\ r = \text{length}(x) - m \times s \quad (17)$$

where length(x) represents the function which calculates the length of the input signal $x(t)$. For non-uniform quantization, the number of subintervals is determined by the threshold number m.

Determine the quantitative value: Set a quantized value to each interval by certain rules. Quantization value in this algorithm is selected by (5). That is, the quantized value of the k-th interval is:

$$A = \begin{cases} \frac{A_{k-1}+A_k}{2}, & 1 \le k \le m \\ A_k, & \text{else} \end{cases} \quad (18)$$

The quantized signal:Detect the input signal and assign different thresholds to the signal in different intervals.

For our quantization clipping, the expression of clipping noise is:

$$n_{\mathrm{QC}}(t) = \begin{cases} (|x(t)| - \frac{A_0+A_1}{2})e^{j\phi(t)}, & A_0 \le |x(t)| < A_1 \\ (|x(t)| - \frac{A_1+A_2}{2})e^{j\phi(t)}, & A_1 \le |x(t)| < A_2 \\ \cdots & \cdots \\ (|x(t)| - \frac{A_{m-1}+A_m}{2})e^{j\phi(t)}, & A_{m-1} \le |x(t)| < A_m \\ (|x(t)| - A_m)e^{j\phi(t)}, & |x(t)| \ge A_m \end{cases} \quad (19)$$

In the modified scheme, we set the lowest threshold value A_0 equal to the threshold A in traditional clipping scheme for comparison, and other thresholds satisfy $A_0 < A_1 < A2 < \cdots < A_m$. Compare the (10) and (19), we can easily find that the clipping noise $n_{\mathrm{QC}}(t)$ caused by the QC method is much smaller than the traditional one $n_{\mathrm{clipping}}(t)$.

At the receiving end, assume that the received signal is $y(t)$ and can be expressed as:

$$y(t) = \hat{x}(t) + n_w(t) = x(t) - n(t) + n_w(t) \quad (20)$$

where $n_w(t)$ represents the Gaussian white noise. The frequency domain signal can be obtained by FFT operation on the received signal $y(t)$:

$$Y = \text{FFT}[y(t)] = \text{FFT}[x(t) - n(t) + n_w(t)] \quad (21)$$

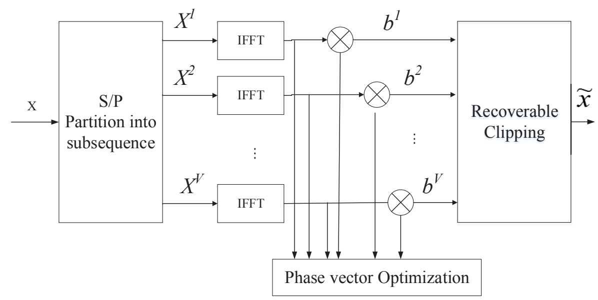

Fig. 5: Block diagram of OFDM PAPR reduction scheme using the proposed PTS-RC fusion algorithm .

From (21) we can know that the smaller the clipping noise $n(t)$, the better signal recovered. Based on the conclusion that $n_{\mathrm{QC}}(t)$ is smaller than $n_{\mathrm{clipping}}(t)$, it is easy to know the new QC scheme will have a better BER performance than the conventional clipping scheme.

Based on the rules specified in IEEE 802.16e and the demonstration discussed above, we can conclude that the QC scheme will have better noise immunity than the conventional clipping scheme. In the PTS-QC scheme, the quantization clipping technique used after PTS scheme has a much smaller clipping noise, so that this modified scheme can further improve the systems PAPR reduction performance without deteriorating the BER performance.

3.2 The PTS-RC scheme

In order to further improve the BER performance, another modified clipping scheme named recoverable clipping(RC) is proposed, which uses a marker sequence to recovery the clipped signal at the receiving end.The diagram of the PTS-RC scheme is shown in Fig.5.

The algorithm implementation process is as follows:

The processed PTS signal is set to $x(t)$, and the threshold value A, the clipping compression ratio m, a marker sequence $C = [C_1, C_2, \cdots, C_{N-1}]$. Operate the modified clipping scheme on the input signal and then the clipped signal can be expressed as:

$$\hat{x}_k = \begin{cases} x_k, & |x_k| \le A \\ m \cdot x_k, & |x_k| > A \end{cases} \quad (22)$$

where x_k is the input signal, $\hat{x}_k$ is the signal after clipping. It can be seen from (22) that in the modified scheme, the signal with a amplitude less than the threshold can pass without interference, and the signal above the threshold is no longer compressed to the uniform threshold value (but are multiplied by a scale factor m which is less than 1. Therefore, we can compress the amplitude without changing the signals phase information. At the same time, the sequence C is tagged and kth can be expressed as:

$$C_k = \begin{cases} 0, & |x_k| \le A \\ 1, & |x_k| > A \end{cases} \quad (23)$$

From the expression we can see that the sequence C is a sequence consists of $0,1$, where k is an index for subcarrier. If $C_k = 0$, the amplitude of the signal x_k on the k-th subcarrier is less than the threshold value (i.e., the signal has not been compressed). Conversely, if $C_k = 1$, the amplitude of x_k is greater than the threshold value and has been compressed m times after the clipping operation.

Send the clipped signal $\hat{x}_k$ and the marker sequence C to the receiving end through wireless channel.

Using the received marker sequence C to recover the OFDM signals. Set the received OFDM signal as $y = [y_1, y_2, \cdots, y_{N-1}]$, the signal recovered by the modified clipping scheme can be expressed as:

$$\hat{y}_k = \begin{cases} y_k, & C_k = 0 \\ y_k/m, & C_k = 1 \end{cases} \quad (24)$$

From the formula, when $C_k = 0$, the corresponding received signal y_k on the k-th subcarrier has not been compressed and can be demodulated directly; When $C_k = 1$, it indicates that the corresponding signal has been distorted, and being divided by the scale factor m to expand its amplitude of m times, which will effectively recover the original signal and greatly reduce the BER of the OFDM system.

4 The simulation results

In this part, we compare the PAPR reduction performance of the conventional PTS scheme and PTS-Clipping scheme[24] with the proposed schemes. The numerical analysis has been performed for the OFDM system specified in the IEEE 802.16 standard for the mobile wireless metropolitan area network (WMAN), which uses 256 and 16QAM modulations. The number of allowed phase factor is 2 ($W = 2 \in \{\pm 1\}$). And the number of subblocks V is set as $2,4,6$ respectively, the transmitted signal is oversampled by a factor of $L = 4$. The complementary cumulative distribution functions (CCDFs) of PAPR are numerically obtained for the modified Clipping scheme with CR1=1.1, CR2=1.15, CR3=1.2, CR4=1.25.

Firstly, we compared the performance of the quantization clipping scheme, and concluded the best experiment condition for the QC. Different number of quantization threshold are used in the simulation: three, four, five, and six. Change the number, which means change the quantifying step size s. The quantized interval is proportional to the step size s, and we can get more thresholds when s is smaller. The simulation condition is shown in the Table I.

From Fig.6 and Fig.7 we find that, the decrease of quantifying step cannot improve the performance of PAPR reduction; however it is only a little useful to the BER performance improvement. Since the difference of BER performance among the QC schemes can be ignored when the threshold is larger than 4, we will use 4 thresholds in the following simulations.

Fig.8 shows the CCDF of PAPR for the proposed PTS-QC scheme with different number of subblocks. As one can see, the proposed PTS-QC scheme with $V = 4$ has a PAPR which exceeds 5.6dB for less than 0.1%,

Table 1: The simulation condition of the quantization clipping.

	clipping ratios
1	CR1=1.1; CR2=1.2; CR3=1.3
2	CR1=1.1; CR2=1.18; CR3=1.27; CR4=1.3
3	CR1=1.1; CR2=1.15;CR3=1.2;CR4=1.25;CR5=1.3
4	CR1=1.1;CR2=1.14;CR3=1.18;CR4=1.22;CR5=1.26;CR6=1.3

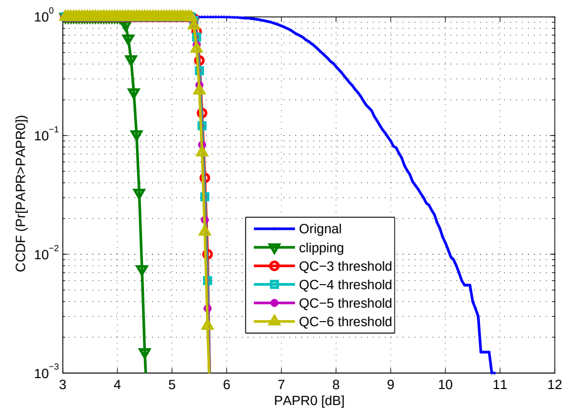

Fig. 6: The PAPR performance of QC with different number of threshold.

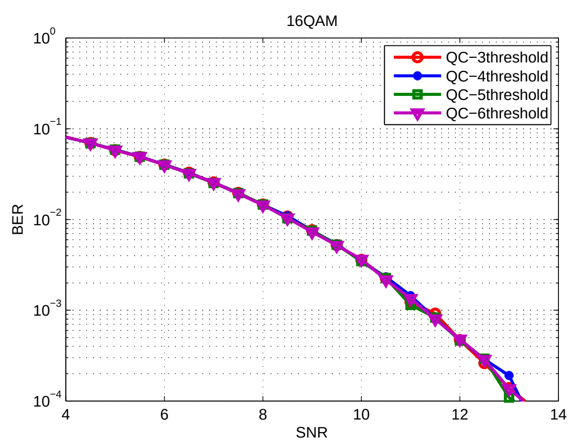

Fig. 7: The BER performance with different number of threshold.

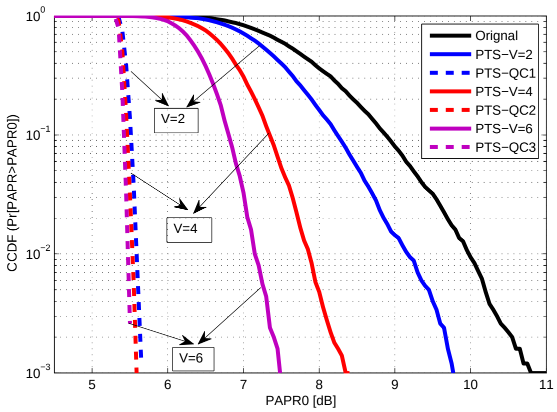

Fig. 8: The PAPR performance of the Conventional PTS and the PTS-QC scheme for $N = 256$ with $V = 2,4,6$.

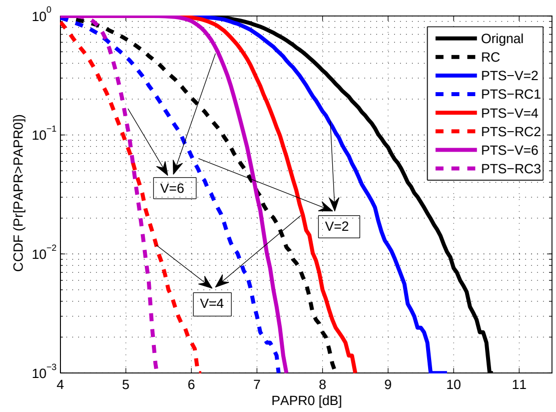

Fig. 10: The PAPR performance of the Conventional PTS and the PTS-RC scheme for$N = 256$ with $V = 2,4,6$.

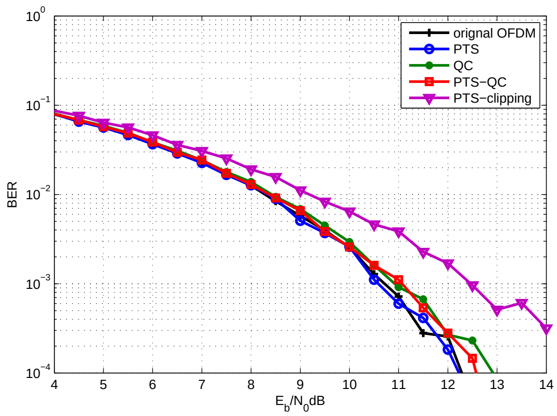

Fig. 9: The BER performance of the Conventional PTS and the PTS-QC scheme for $N = 256$.

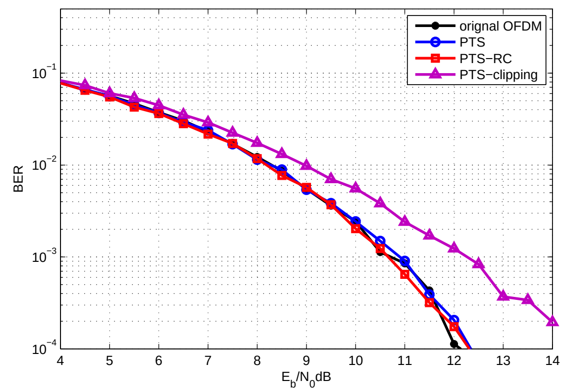

Fig. 11: The BER performance of the Conventional PTS and the PTS-RC scheme for $N = 256$.

which is much better than the 10.8dB of the original OFDM signal and the 8.4dB of the conventional PTS scheme. It can also be concluded that a larger number of subblocks can significantly improve the PAPR performance of the conventional PTS, but could not improve that of the modified PTS-QC scheme obviously. Thus, take the computational complexity into account; we set the number of subblocks V as 4 in our new scheme.

The BER performance, a function of Signal to Noise Ratio (SNR), is shown in Fig.9. As expected, the modified scheme results in better noise immunity than the conventional PTS-Clipping scheme and the QC scheme. As can be seen from the result, compared to the conventional PTS-Clipping scheme, the BER performance of the PTS-QC scheme improves E_b/N_0 by 1.1dB at BER $= 10^{-4}$.

Simulation results of the PAPR reduction performance for the proposed PTS-RC scheme are shown in Fig.10. The simulation condition is the same with the PTS-QC scheme: $N = 256$, 16QAM mapping, $W = 4$, $V = 2,4,6$. In addition, the compression ratio is set as: $m = 1.5$.

It can be seen from the result that the PAPR reduction performance of both schemes gets better with the increase of V, and when the number reaches 4, the performance of the PTS-RC scheme will not show much impact. As a result, the number of subblocks will be set as 4 in this modified PTS-RC scheme. By comparing the conventional and the modified PTS scheme we can find that the proposed PTS-RC scheme with $V = 4$ has a PAPR which exceeds 6.1dB for less than 0.1% while the PTS technique is 8.5dB and the Recoverable clipping technique is 8.2dB.

The complexity of the PTS-RC is higher than the scheme of PTS-QC, but in the quantization clipping technique, the value that exceed the fixed clipping threshold is clipped while in the recoverable clipping technique, large signals are companded an opposite transform has to be taken in the sink to recover the signal. The BER performance of scheme PTS-RC is shown in Fig.11, it shows that the modified joint technique has a BER $= 10^{-3}$ when the SNR is 10.5dB which has a small discrepancy compared with the original OFDM signal.

5 Conclusion

In this paper, we proposed two modified joint schemes that combine PTS technique with Quantization Clipping and Recoverable Clipping scheme respectively. Comparisons are performed in terms of the PAPR reduction and BER performances to demonstrate the advantages of the proposed schemes. Numerical results showed that the proposed schemes could effectively combine the advantages of both the signal distortion and non-distortion techniques. It can be concluded that both the PTS-QC and PTS-RC schemes can achieve a good BER while improving the PAPR performance.

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References

[1] A. Vahlin and N. Holte, Optimal Finite Duration Pulses for OFDM, IEEE Transactions on Communications **44**, 10–14 (1996).

[2] S. Merchan, A. G. Armada, and J. Garcia, OFDM performance in amplifier nonlinearity, IEEE Transactions on Broadcasting **44**,106–114 (1998).

[3] T. Jiang and Y. Wu, An overwiew: Peak-to-average power ratio reduction techniques for OFDM signals, IEEE Transactions on Broadcasting **54**, 257–268 (2008).

[4] X. Huang, J. Lu, J. Zheng, J. Chuang, and J. Gu, Reduction of peak-to-average power ratio of OFDM signals with companding transform, Electronics letters **37**, 506–507 (2001).

[5] S.-K. Deng and M.-C. Lin, Recursive Clipping and Filtering with Bounded Distortion for PAPR Reduction, IEEE Transactions on Communications **55**, 227–230 (2007).

[6] K. Sathananthan and C. Tellambura, Coding to reduce both PAR and PICR of OFDM signal, IEEE Communications Letters **6**, 316–318 (2002).

[7] X. Wang, T. Tjhung, and C. Ng, Broadcasting, Resuetion of peak-to-average power ratio of OFDM systems using a companding technique, IEEE Transactions on Broadcasting **45**, 303–307 (1999).

[8] R. W. Bauml, R. F. Fischer, and J. B. Huber, Reducing the peak to average power ratio of multicarrier modulation by selected mapping, Electronics Letters **32**, 2056–2057 (1996).

[9] S. H. Muller and J. B. Huber, OFDM with Reduce PeakCtoCAverage Power Ratio by Optimum Combination of Partial Transmit Sequences, Electronics letters **33**, 368–369 (1997).

[10] B. S. Krongold and D. L. Jones, An active-set approach for OFDM PAR reduction via tone reservation, IEEE Transactions on Signal Processing **52**, 495–509 (2004).

[11] J. Armstrong, New OFDM Peak-to-average Power Reduction scheme, Vehicular Technology Conference, 2001. VTC 2001 Spring. IEEE VTS 53rd, 756–760 (2001).

[12] J. Armstrong, Peak-to-average power reduction for OFDM by repeated clipping and frequency domain filtering, Electronics letters **38**, 246–247 (2002).

[13] L. Liang, J. Wang, and J. Song, Adaptive algorithm for OFDM PAPR reduction using clipping-noise guided sign-selection, Broadband Multimedia Systems and Broadcasting (BMSB), 2013 IEEE International Symposium on, 1–3 (2013).

[14] X. Zhu, W. Pan, H. Li, and Y. Tang, Tang Youxi. Simplified Approach to Optimized Iterative Clipping and Filtering for PAPR Reduction of OFDM Signals, IEEE Transactions on Communications **61**, 1891 - 1901 (2013).

[15] L. Wang and C. Tellambura, Simplified Clipping and Filtering Technique for PAR Reduction in OFDM Systems, IEEE Signal Processing Letters **12**, 453–456 (2005).

[16] Y. Wang, W. Chen, and C. Tellambura, IEEE Transactions on Broadcasting **58**, 462–471 (2012).

[17] S.-J. Ku and C.-L. Wang, Genetic Algorithm Based Nearly Optimal Peak Reduction Tone Set Selection for Adaptive Amplitude Clipping PAPR Reduction, Wireless and Mobile Computing, Networking and Communications (WiMob), 2012 IEEE 8th International Conference, 108–112 (2012).

[18] J.-C. Chen, Application of quantum-inspired evolutionary algorithmto reduce PAPR of an OFDM signal using partial transmit sequencestechnique, IEEE Transactions on Broadcasting **56**, 110–113, (2010).

[19] S.-J. Ku, C.-L. Wang, and C.-H. Chen, A reduced-complexity PTSbasedPAPR reduction scheme for OFDM systems, IEEE Transactions on Wireless Communications **9**, 2455–2460 (2010).

[20] P. Varahram, W. F. Al-Azzo, and B. M. Ali, A low complexity partial transmit sequence scheme by use of dummy signals for PAPR reduction in OFDM systems, IEEE Transactions on Consumer Electronics **56**, 2416–2420 (2010).

[21] Y. Xiao, X. Lei, Q. Wen, and S. Li, A class of low complexity PTS techniques for PAPR reduction in OFDM systems, IEEE Signal Processing Letters **14**, 680–683 (2007).

[22] L. Wang and J. Liu, PAPR Reduction of OFDM Signals by PTS With Grouping and RecursivePhase Weighting Methods, IEEE Transactions on Broadcasting **57**, 299–306 (2011).

[23] X. Qi, Y. Li, and H. Huang, A Low Complexity PTS Scheme Based on Tree for PAPR Reduction, IEEE Communications Letters **16**, 1486 - 1488 (2012).
[24] J. Wang, Y. Guo, and X. Zhou, PTS-clipping method to reduce the PAPR in ROF-OFDM system, IEEE Transactions on Consumer Electronics **55**, 356–359 (2009).
[25] P. Mukunthan and P. Dananjayan, PAPR reduction based on a modified PTS with interleaving and pulse shaping method for STBC MIMO-OFDM System, 2012 Third International Conference on Computing Communication & Networking Technologies (ICCCNT), 1–6 (2012).
[26] M. Hu and X. Chen, Syncreticscheme for PAPR reduction in OFDM system, ICEMI'09. 9th International Conference on Electronic Measurement & Instruments, 3–146 (2009).
[27] C. Ye, Z. Li, T. Jiang, C. Ni, and Q. Qi, PAPR Reduction of OQAM-OFDM Signals Using Segmental PTS Scheme With Low Complexity, IEEE Transactions on Broadcasting **60**, 141 - 147 (2014).
[28] J. Tellado, Multicarrier Modulation with Low PAR Applications to DSL and Wireless, Kluwer Academic Publishers **587**, (2000)
[29] R. J. Baxley, C. Zhao, and G. T. Zhou, Constrained Clipping for Crest Factor Reduction in OFDM, IEEE Transactions on Broadcasting **52**, 570–575 (2006).

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