

# Overlapped Segmental Clipping for the PAPR Reduction of the OFDM-OQAM system

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## **Abstract**

Orthogonal frequency division multiplexing with offset quadrature amplitude modulation (OFDM-OQAM) technique has drawn significant interests in recent years. However, most of the existing OFDM peak-to-average ratio (PAPR) reduction schemes cannot be used in the OFDM-OQAM system directly. In this paper, a modified scheme called overlapped segmental clipping (OS-clipping) is proposed to deal with the high PAPR problem specifically in the OFDM-OQAM system. For the proposed OS-clipping scheme, the input signals are divided into a number of overlapped segments and then the clipping operation is processed on each segment. Simulation results show that the modified scheme used in the OFDM-OQAM system can provide better performance than conventional clipping scheme directly used in the OFDM-OQAM system, and even outperforms conventional clipping scheme applied in the OFDM system.

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**Keywords:** OFDM-OQAM, peak-to-average power ratio, clipping, overlapped segment

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## 1. Introduction

Orthogonal frequency division multiplexing (OFDM) is one of the most popular multicarrier modulation scheme which has been widely used in many broadband communication systems [1]. However, the OFDM system uses rectangular pulse shaping on each subcarrier, which leads to relatively serious out-of-band radiations. Besides, the insertion of the cyclic prefix (CP) will reduce the data transmission rate of the OFDM system. In order to overcome the shortcomings of the OFDM systems, the OFDM with offset quadrature amplitude modulation (OFDM-OQAM) technique has drawn significant interests in recent years [2-3]. Compared with the OFDM system, the OFDM-OQAM systems provides lower side lobes due to the use of pulse shaping filters [4]. Moreover, the OFDM-OQAM systems provides higher spectral efficiency and lower narrow-band interference since it operates without CP [5]. Based on the above advantages, the OFDM-OQAM technology has been considered for the physical layer of wireless communication systems recently.

However, as a multicarrier modulation technology, the OFDM-OQAM system inevitably produces high peak-to-average power ratio (PAPR), which degrades the efficiency of the high power amplifier (HPA) [6]. In the OFDM systems, much research has been done to deal with the PAPR problem, which can be classified into three categories: signal distortion algorithm, probability algorithm and block coding algorithm. The signal distortion algorithm limits the OFDM signal below a given threshold by nonlinear distortion and includes: signal clipping [7] and companding transformation [8]. The probability algorithm improves the PAPR performance by significantly reducing the probability that large peak power signal appears and optimizing multicarrier signal PAPR statistical properties. It includes selective mapping (SLM)[9], partial transmit sequence (PTS)[10, 11], and tone reservation (TR)[12]. The coding algorithm [13] limits the signals that can be used for transmission, only the signals whose peak value is lower than the maximum peak threshold are allowed to be sent. Among these technologies, signal clipping is an appealing distortion algorithm due to its simplicity and low computation complexity, although the degraded BER and spectrum dispersion may deteriorate the system performance. To overcome the drawbacks of clipping scheme, various techniques have been proposed. The clipping and filtering (CF)[14] and repeated clipping and filtering (RCF)[15] proposed by Armstrong are of the most classical algorithms. Other modified clipping based schemes can refer to [16-18].

Due to the similarity between the OFDM-OQAM and the OFDM system, most research in recent years has been focused on employing the conventional PAPR reduction schemes for the OFDM systems in the OFDM-OQAM systems. Whereas, because of the filtered OQAM-OFDM signals are overlapped with adjacent data blocks, it is not very effective to employ these algorithms into the OQAM-OFDM systems directly.

In recent years, several schemes for the PAPR reduction specifically in the OQAM-OFDM systems have been proposed. The clipping-based method of the OFDM-OQAM system was discussed in [19], simulation results show that the algorithm designed for the OFDM system can be fully applied to the OFDM-OQAM system with similar performance in the synchronized case. An overlapped selective mapping (OSLM) scheme was proposed in [20], for this modified algorithm, the current data block and its adjacent data blocks are jointly considered to choose the optimal phase rotation sequence. Besides, a sliding window tone reservation (SW-TR) technique was proposed in [21], which uses the peak reduction tones of several consecutive data blocks to cancel the peak power of the OFDM-OQAM signal inside a

window. In [22], the authors proposed an improved partial transmit sequence (PTS) scheme by employing multi-block joint optimization (MBO) for the PAPR reduction of OFDM-OQAM signals. The MBO-based scheme exploits the overlapping structure of the OFDM-OQAM signal and jointly optimizes multiple data blocks. In [23], a novel segmental PTS (S-PTS) scheme is proposed, the key idea of the S-PTS scheme is to divide the overlapped OQAM-OFDM signals into a number of segments, and then some disjoint subblocks are divided and multiplied with different phase rotation factors in each segment. Aim at the overlapped structure of the OFDM-OQAM signals, all of the above schemes provide effective solution for the high PAPR problem, and the main idea can be summarized as: deal with the multiple adjacent data blocks simultaneously instead of optimizing each data block independently.

In this paper, we proposed a modified scheme called overlapped segmental clipping (OS-clipping) for the OFDM-OQAM system. In this new OS-clipping scheme, the input filtered signals are divided into several segments and then the clipping scheme is operated on each segment. For a better PAPR reduction performance, the adjacent segments are overlapped with each other. The simulation results show that, compared to the conventional clipping scheme directly used in the OFDM-OQAM system, the modified scheme can provides a better PAPR reduction performance while maintain the same BER performance. Furthermore, the OS-clipping scheme used in the OFDM-OQAM system even shows better performance than the OFDM system with the conventional clipping scheme.

The rest of the paper is organized as follows. In Section 2, OFDM-OQAM system model is illustrated, followed by the 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 and the conventional algorithm. Finally, the concluding remarks are given by Section 5.

## 2. Signal Model

In a baseband OFDM-OQAM system with  $N$  subcarriers, real valued symbols modulated by offset QAM are transmitted on each sub-carrier, and then the transmitted signal can be written as [2]:

$$s(t) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} x_m^n g_m^n(t) \quad (1)$$

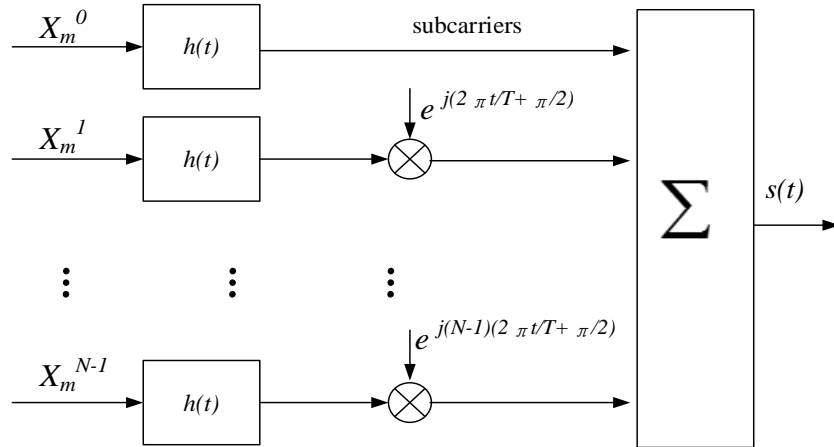
where  $M$  represents the number of input data block,  $x_m^n$  denotes the baseband modulated signal on the  $n$ th subcarrier of the  $m$ th data block,  $g_m^n(t)$  represents the pulse shape of index  $(m, n)$  in the synthesis basis which is derived by the time-frequency translated version of the prototype filter function  $h(t)$  in the following way:

$$g_m^n(t) = h(t - mT) e^{j\frac{2\pi n}{T}t} e^{j\varphi_m^n} \quad (2)$$

where  $\varphi_m^n = \frac{\pi}{2}(m+n) - \pi mn$  and  $T$  represents the symbol period. In order to maintain the orthogonality among the synthesis and analysis basis, the modified inner product can be written as:

$$\langle x, y \rangle = \Re \left\{ \int_R x^*(t) y(t) dt \right\} \quad (3)$$

$\Re\{\cdot\}$  is the real part operator, and  $(\cdot)^*$  denotes the conjugate operation. That means only the real part of the correlation function is taken into consideration.



**Fig. 1.** The OFDM-OQAM system model

The OFDM-OQAM system model is show in **Fig. 1**, to understand the OFDM-OQAM signal structure better, we rewrite the complex input symbols  $x_m^n$  as:

$$x_m^n = a_m^n + jb_m^n, \quad 0 \leq n \leq N-1, 0 \leq m \leq M-1 \quad (4)$$

where  $a_m^n$  and  $b_m^n$  are the real and imaginary parts of the  $m$ th symbol on the  $n$ th subcarrier respectively. For two successive subcarriers, the time offset  $\tau_0 = T/2$  is introduced onto the real part for the first one and onto the imaginary part for the second one, so the number of the input data block  $M$  has to be even. Then, the time domain staggered symbols are passed through a bank of transmission filters and are modulated with  $N$  subcarrier modulators. Thus, the OFDM-OQAM modulated signal  $s(t)$  in **(1)** can be written as

$$s(t) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} [a_m^n h(t-mT) + jb_m^n h(t-mT-\tau_0)] e^{j\phi_m^n} \quad (5)$$

Here the length of the prototype filter  $h(t)$  is  $LT$ . Apparently, the impulse response of prototype filters in the OFDM-OQAM systems has longer time duration than  $T$ , and the real and imaginary parts of input symbols are time staggered, which leads to the signals of adjacent data blocks overlap with each other.

The definition of PAPR in the OFDM system is the ratio of maximum to the average power of the transmitted symbol. Let  $s(t)$  represents the transmitting complex symbols of duration  $T$ , then the PAPR of this continuous-time baseband signal can be expressed as:

$$PAPR = \frac{\max_{0 \leq t \leq T} |s(t)|^2}{E[|s(t)|^2]} \quad (6)$$

where  $E[\cdot]$  represents the expectation operation. Since the OQAM-OFDM signals are overlapped with adjacent data blocks due to the bank of filters and the time offset between the real and imaginary parts, the conventional definition of PAPR for OFDM systems no longer match perfectly to the OQAM-OFDM systems. However, it was declared in [17] that as both systems transmit the equivalent of one complex symbol at the same rate  $T$ , we can keep the same measurement for the OFDM/OQAM to provide a fair comparison with the OFDM system.

The PAPR is a random variable, so it is possible to characterize the PAPR distribution (probability that PAPR exceeds a given threshold  $\gamma$ ) using complementary cumulative distribution function (CCDF) defined as:

$$\Pr(PAPR > \gamma) = 1 - (1 - e^{-\gamma})^N \quad (7)$$

### 3. The Proposed Clipping Scheme

#### 3.1 Traditional Clipping Scheme

The fundamental principle of the traditional clipping algorithm is to detect the amplitude of the input signals before the time domain OFDM signal is supplied to the power amplifier. If any part of the signal exceeds the preset threshold, a non-linear processing should be implied to limit the amplitude within the preset threshold; otherwise let the signal through without interference [6]. The schematic diagram of clipping scheme is shown in Fig. 2.

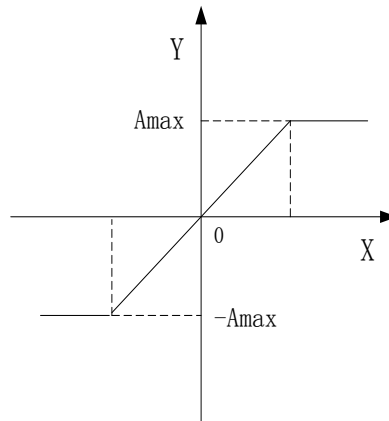


Fig. 2. The schematic diagram of traditional Clipping scheme

The clipped time domain signal can be written as:

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

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

The most important parameter for the performance of clipping scheme is Clipping Ratio (CR) [6], which is defined as

$$CR = 20 \log \frac{A}{\sigma} \tag{9}$$

where  $\sigma$  is the root mean square of the signal power.

$$\sigma = \sqrt{\frac{[x_0(t)]^2 + [x_1(t)]^2 + \dots + [x_{N-1}(t)]^2}{N}} \tag{10}$$

$x_0(t), \dots, x_{N-1}(t)$  is the input signal,  $N$  the number of sub-carriers. With  $A$  denotes clipping threshold, a bigger  $CR$  corresponds a higher threshold and a worse effect of PAPR reduction performance. And vice versa.

In the OFDM systems, the signal is processed by the conventional clipping scheme in each data block independently. However, the signals in the OFDM-OQAM system are overlapped with multiple adjacent data blocks, and the actual PAPR in a certain time interval depends on several consecutive data blocks [21]. If we conduct the conventional clipping scheme in the OQAM-OFDM systems directly, the peak signal in each data block may be decreased. However, the true PAPR in a certain time interval might not be reduced effectively, since the current data block is affected by multiple consecutive data blocks. Therefore, directly employing the conventional clipping scheme in the OFDM-OQAM systems is not very effective.

### 3.2 The Proposed Clipping Scheme

In the OFDM-OQAM system, since the adjacent filtered signals are overlapped with each other, we conduct the clipping scheme on the signal which is composed of multiple overlapped data blocks, instead of on each data block independently. For our OS-clipping scheme, we firstly divide the overlapped data blocks into several segments and then reduce the PAPR of each segment.

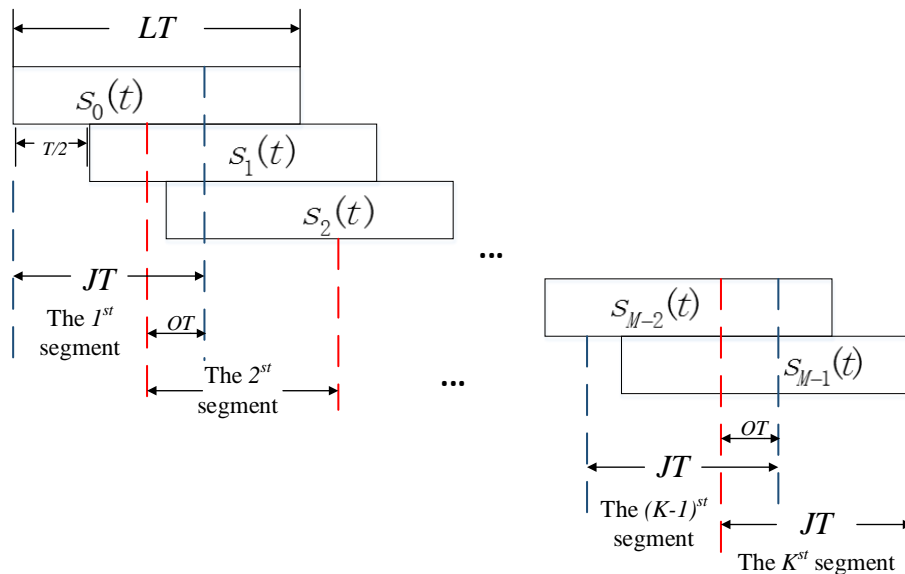


Fig. 3. The overlapped segmental scheme for the OFDM-OQAM signals

The structure diagram of the modified scheme is showed in **Fig. 3**. The time domain OFDM-OQAM signal on the  $m$ th data block  $s_m(t)$  can be expressed as a superposition of  $N$  subcarriers:

$$s_m(t) = \sum_{n=0}^{N-1} a_m^n g_m^n(t) = \sum_{n=0}^{N-1} x_m^n h(t - mT) e^{j\frac{2\pi n}{T}t} e^{j\varphi_m^n} \quad (11)$$

As the length of the filtered data block is  $LT$  (which is the same with the length of the prototype filter) and the overlapped part between two adjacent data blocks is  $T/2$ , we can obtain the overall length of the  $M$  input data block:

$$T_{ol} = \frac{T}{2}(M - 1) + LT \quad (13)$$

As can be seen from **Fig.3**, the overlapped signal is divided into  $K$  segments and the length of each segment is  $JT$ , where  $J$  is an integer no less than 1. The overlapped part of two adjacent segments is expressed as  $OT$ . The value of  $O$  ranges from 0 to  $J-1$ . Notice that  $O$  cannot be equal to  $J$ , otherwise the OS-clipping scheme wouldn't make sense. Theoretically, the larger the length of each segment  $J$ , the more data blocks can be processed each time, so the better the PAPR performance. However, when  $J$  is larger than  $L$ , the performance improvement will not be significantly any more. That is because the length of each filtered data block is  $LT$ , and only the overlapped part of adjacent data blocks can have influence on the former data blocks. The PAPR performances with different  $J$  and  $O$  are given in Section 4.

Specifically, when  $J=1$ ,  $O=0$ , it means each segment is the same length as one data block and there is no overlap between two segments. Under this special circumstance, the modified OS-clipping scheme is just equal to the conventional clipping scheme.

After  $J$  and  $O$  are defined, the number of the segments  $K$  can be obtained by:

$$K = \left\lceil \frac{T_{ol}}{JT - OT} \right\rceil = \left\lceil \frac{(M - 1)/2 + L}{J - O} \right\rceil \quad (14)$$

where  $\lceil \cdot \rceil$  means the round up operation. As  $M$  represents the number of input symbols and is usually set larger than four figures,  $L$  is usually set as 4. Considering  $M \gg L$ ,  $L$  can be ignored and the simplified expression of  $K$  can be obtained by:

$$K = \left\lceil \frac{M}{2(J - O)} \right\rceil \quad (15)$$

From equation (15) we can conclude that the number of the segment is primarily determined by  $J-O$ , which represents the time offset between two adjacent data blocks.

Then the filtered signals are divided into  $K$  segments and the modified OS-clipping scheme is conducted on each segment. Assume that the previous  $k-1$  ( $1 \leq k \leq K$ ) segments have already been processed, then extract the signal  $s_k(t)$  in the  $k$ th segment from  $s_m(t)$ , and  $s_k(t)$  can be expressed as:

$$s_k(t) = \begin{cases} s_m(t), & (k-1)(JT - OT) \leq t \leq (k-1)(JT - OT) + JT \\ 0, & \text{else} \end{cases} \quad (16)$$

Operate the clipping scheme on the signal  $s_k(t)$  in the  $k$ th segment. If the amplitude of  $s_k(t)$  exceeds the preset threshold, it will be clipped to  $A$ ; otherwise,  $s_k(t)$  will remain unchanged. Then the clipped signal can be written as:

$$\tilde{s}_k(t) = \begin{cases} s_k(t), & |s_k(t)| \leq A \\ Ae^{j\phi_k(t)}, & |s_k(t)| > A \end{cases} \quad (17)$$

where  $\phi_k(t)$  is the phase of  $s_k(t)$ . It can be seen from (17), the phase information of  $s_k(t)$  remain unchanged after clipping operation.

After the signal in the  $k$ th segment has been clipped, increase  $k$  by 1 and repeat the procedure until all  $K$  segments have been processed.

When operating the conventional clipping scheme directly in an OFDM-OQAM system with  $N$  subcarriers, the  $LN$  ( $L$  is the length factor of the prototype filter) input signals in each filtered data block need to be compared with the threshold  $A$  and the computational complexity can be seen as  $LN$  complex additions. As for the proposed OS-clipping scheme, the data in the overlapped part need to be compared twice, which will result in  $ON$  more complex additions ( $O$  is the overlapped factor and usually set less than  $J$ ). However, in an OFDM-OQAM system,  $(L+1)MN$  ( $M$  is the number of the input data blocks) real multiplications are required to create the filtered signals [21], so the increase of complexity in the modified scheme can be ignored in the OFDM-OQAM system. Besides, we can also set a reasonable value for  $O$  so the computational complexity and the PAPR reduction performance can be well balanced.

#### 4. Simulation Results

In this section, the PAPR reduction performance and the BER performance of the proposed OS-clipping technique are conducted for comparison. The OFDM-OQAM system employs 64 subcarriers with 5000 input data blocks. The length of the prototype filter  $h(t)$  is set as  $4T$ , which means the time duration of the filtered signals is about four times of that of the input signals. The Complementary cumulative distribution function (CCDF) is applied as measurement of PAPR reduction performance in the simulations.

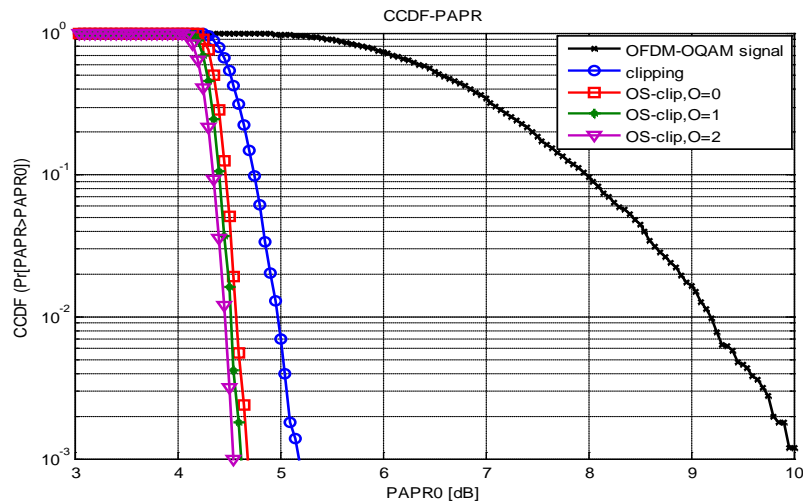


Fig. 4. The PAPR performance of the OS-clipping scheme with different  $O$



Firstly, we compare the PAPR performance of the modified OS-clipping scheme with different lengths of the overlapped part  $O$ . In the simulation, the clipping ratio is  $CR=1.0$ , the length of each segment is set as  $3T$ , i.e.,  $J=3$ ; and the length of the overlapped parts is  $O=0, 1, 2$ , where  $O=0$  means there is no overlap between adjacent segments. It can be seen from Fig. 5 that the OS-clipping scheme is effective in reducing the PAPR for the OFDM-OQAM system, and a larger  $O$  can improve the performance of the OS-clipping scheme a little.

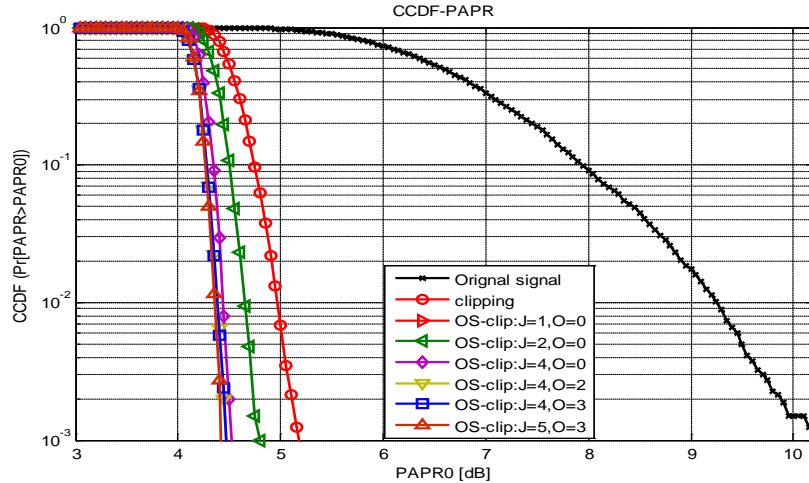


Fig. 5. The PAPR performance of the OS-clipping scheme with different  $J$  and  $O$

The PAPR performance of the OS-clipping scheme with different  $J$  is shown in Fig. 5. It is obvious that the overlapped segment structure is quite effective in reducing the PAPR and among all simulated conditions, the best PAPR reduction performance is achieved with  $J=5, O=4$ . It can also be concluded from the results that the larger the length of each segment  $J$ , the better the PAPR reduction performance. When  $J$  is increased to 4, the performance difference can be ignored. Besides, the increasing of  $O$  can also help to improve the PAPR performance, but the performance improvement is not as evident as that of when  $J$  increases. From equation (14) we can know that the number of the segments  $K$  is determined by  $(J-O)$ , and a larger  $O$  means higher computational complexity. As a result, we will use  $W=4, O=2$  in the following simulations to reduce the calculation costs.

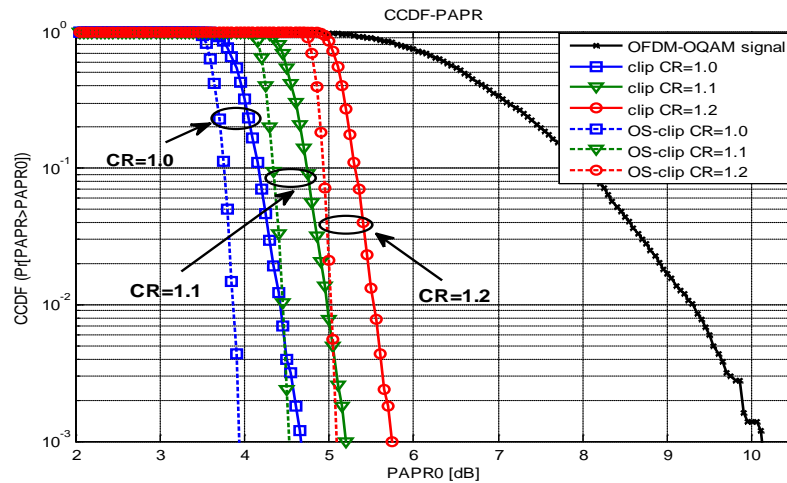
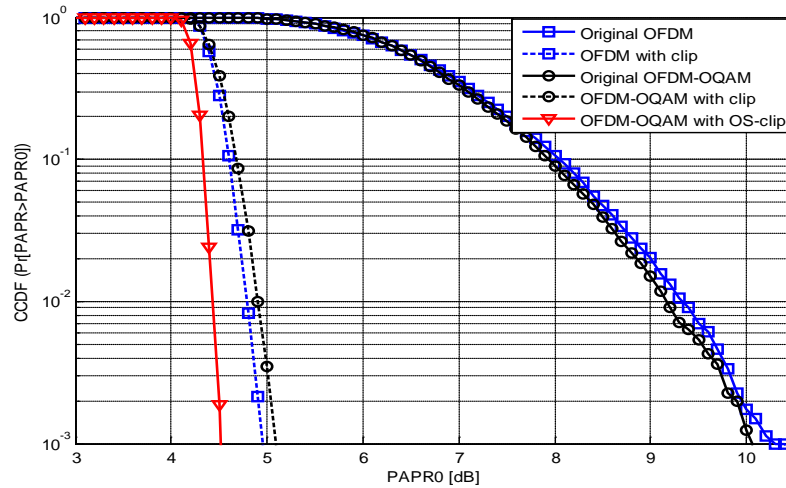


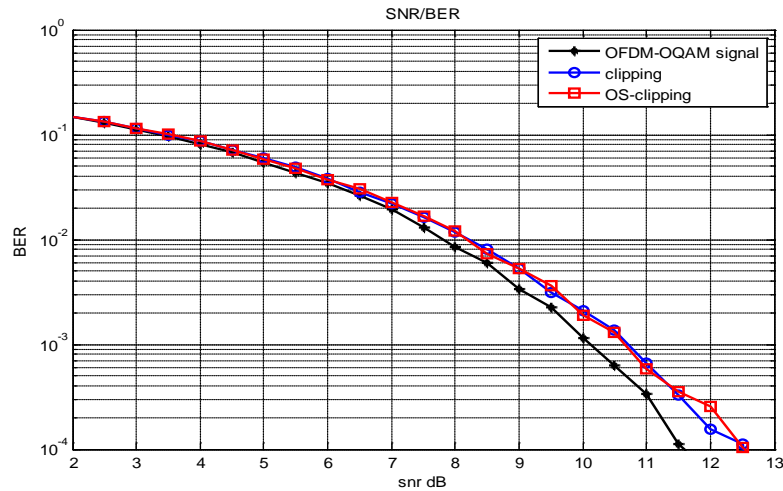
Fig. 6. The PAPR performance of the OS-clipping with different thresholds

**Fig. 6** shows the PAPR performance of the proposed OS-clipping technique and the conventional clipping scheme with different thresholds. The clipping ratios are:  $CR1=1.0$ ,  $CR2=1.1$ ,  $CR3=1.2$ . For the OS-clipping scheme, the length of each segment is  $J=4$ , and the length of the overlapping part is set as  $O=2$ . It can be concluded that the PAPR performance of both schemes improves as  $CR$  decreases. When  $CR=1.1$ , the modified OS-clipping scheme has a PAPR that exceeds 4.5dB for less than 0.1%, which is 0.7dB better than the 5.2dB of the conventional clipping scheme.



**Fig. 7.** The PAPR performance of the OFDM and the OFDM-OQAM system

In addition, the PAPR reduction performance of the OFDM system and the OFDM-OQAM system are compared in simulation. Both of the two systems employ 64 subcarriers and 5000 input data blocks. The clipping ratio is set as  $CR=1.1$  in the conventional and the modified clipping schemes. From the simulation results shown in **Fig. 7**, we know that the conventional clipping scheme directly used in the OFDM-OQAM system is not as effective as that used in the OFDM system. However, when the modified OS-clipping scheme is applied, the PAPR reduction performance of the OFDM-OQAM system is even better than that of the OFDM system with the conventional clipping scheme.



**Fig. 8.** The BER performance of the OS-clipping scheme

The Bit Error Rate (BER) performance as a function of Signal to Noise Ratio (SNR) is shown in **Fig. 8**. As in the simulations above, the clipping ration of both clipping scheme is  $CR=1.1$ , and  $J=4$ ,  $O=2$  is set for the modified OS-clipping scheme. As can be seen from the results, the BER performance of the conventional clipping scheme decreases the SNR by about 0.6dB at  $BER=10^{-3}$ , and the modified OS-clipping scheme shows almost the same performance as the traditional clipping scheme. Considering the better PAPR reduction performance, we can conclude that the proposed OS-clipping scheme can improve the performance of the whole OFDM-OQAM system.

## 5. Conclusion

In this paper, a modified OS-clipping scheme is proposed to reduce the PAPR of the OFDM-OQAM system. Considering the overlapped structure of the OFDM-OQAM signals, the modified OS-clipping scheme divides the filtered signal into a number of segments and each segment is composed of multiple consecutive data blocks. Therefore, the influence of adjacent overlapped data block can be eliminate and the PAPR during a certain time interval can be reduced effectively. In addition, the overlapped structure of the adjacent segments can further improves the PAPR reduction performance. The simulation results showed that the OS-clipping scheme could provide a better PAPR reduction performance than the OFDM-OQAM system applying the conventional clipping scheme. Still, the BER performance remained unchanged. Besides, the OFDM-OQAM system with the OS-clipping scheme even outperformed the OFDM system with the conventional clipping scheme.

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