

Low Complexity SLM-Based PTS PAPR Reduction Scheme for OFDMA Uplink Systems

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Abstract

High peak to average power ratio (PAPR) is one of the main drawbacks of Orthogonal Frequency Division Multiple Access (OFDMA) systems. In this paper we will introduce a PAPR reduction scheme based on selected mapping (SLM) and partial transmit sequence (PTS) techniques. The deficiency for PAPR reduction in SLM is computational complexity. We investigate one of the low complexity SLM schemes and apply partial transmit sequence continuously. The main idea is to generate some candidate signals from original data and then partition the data into subblocks. Evaluating computational complexities in terms of subcarriers and the number of candidate signals show that the number of complex operations for proposed scheme is lower than SLM or combined SLM-PTS techniques. In addition, the performance of complementary cumulative distribution function (CCDF) of proposed method gets close to SLM or combined SLM-PTS schemes by incrementing the number of candidate signals.

Keywords: Peak-to-Average Power Ratio (PAPR), Orthogonal Frequency Division Multiple Access (OFDMA), Selective Mapping (SLM), Partial Transmit Sequence (PTS)

1. Introduction

Orthogonal Frequency Division Multiple Access architecture has been used in wireless networks such as IEEE 802.16, wimax series and ETSI DVB-RCT. Because of multiuser diversity, high spectral efficiency and immunity to interference, there is widespread use of this architecture. Despite many advantages of OFDMA, there are some disadvantages such as the high amount of peak to average power ratio (PAPR) of the transmitted signal.

Various schemes have been developed to reduce the amount of PAPR in OFDM systems, including clipping [1], amplification [2], selected mapping (SLM) [2,3], partial transmit sequence (PTS) [4,5], coding based schemes [6], tone reservation [7] and active constellation extension [8]

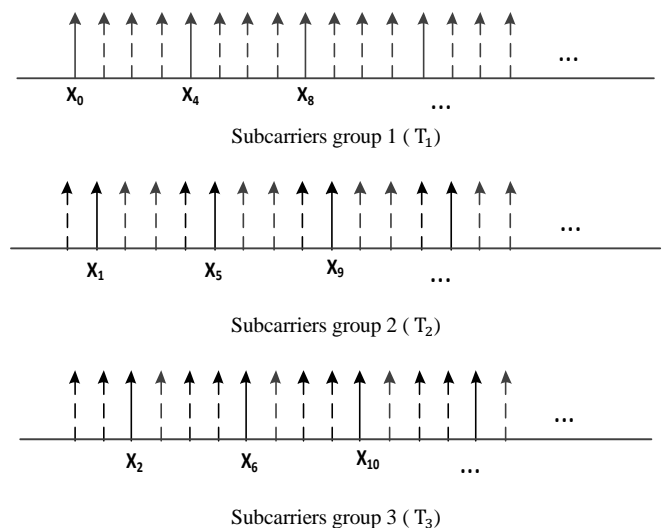
In comparison with other PAPR reduction schemes, selected mapping and partial transmit sequence schemes have better PAPR reduction performance, while they require high order of computational complexity. So, multiple techniques have been proposed to reduce their complexities [9-11]. In this paper we introduce a PAPR reduction scheme based on low complexity SLM and PTS for OFDMA systems. Our system is an interleaved OFDMA uplink system which subcarriers are divided into four independent groups.

The rest of this study is organized as follows. Section 2 describes the Interleaved OFDMA system that we have considered. Low complexity selected mapping and partial transmit sequence schemes are explained in section 3. The proposed scheme and the computational complexity of the scheme are described in section 4. Simulation results are presented in section 5. Finally, section 6 concludes this paper.

2. System Description

We consider an uplink OFDMA system with N subcarriers where each user communicates with base station through an independent multipath channel. We use the interleaved method for assigning subcarriers to different users. In this method, we divide all subcarriers into four interleaved groups denoted by T_ψ , $\psi = 1, \dots, \Psi$ (Fig. 1). Each user occupies the whole group of subcarriers. For the u th user, the modulated symbol of k th subcarrier can be written as

$$X_u[k], \quad k = 0, 1, 2, \dots, N-1 \quad (1)$$



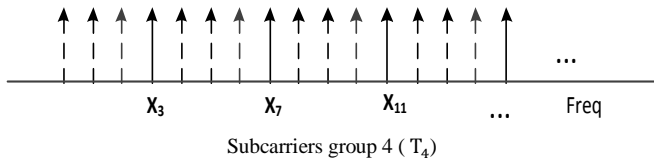


Fig. 1. Subcarrier assignment for interleaved OFDMA

The upsampling factor, L , can be represented by inserting $(L-1) \cdot N$ zeros in the middle of modulated vector, i.e.

$$\mathbf{x}_u = [X_u[0] \ X_u[1] \ \dots \ X_u[\frac{N}{2}-1] \ \underbrace{0 \ \dots \ 0}_{(L-1) \cdot N} \ X_u[\frac{N}{2}] \ X_u[\frac{N}{2}+1] \ \dots \ X_u[N-1]]^T \quad (2)$$

By applying LN point IFFT on the above equation, the time domain signal, \mathbf{x}_u , is obtained. The n th element of \mathbf{x}_u has the following form

$$x_u[n] = \frac{1}{\sqrt{N}} \left\{ \sum_{k=0}^{LN-1} [X_u[k] e^{(j \frac{2\pi n k}{LN})}] \right\} \quad (3)$$

The PAPR of transmitted signal can be defined as

$$\text{PAPR}(\mathbf{x}_u) = \frac{\max_{0 \leq n \leq LN-1} |x_u[n]|^2}{E[|x_u(n)|^2]} \quad (4)$$

The metrics that have been evaluated for this research are complementary cumulative distribution function (CCDF) and computational complexity. CCDF is one of the fundamental metrics in evaluating PAPR reduction schemes which shows the probability that the amount of PAPR goes higher than a given PAPR_0 , i.e.

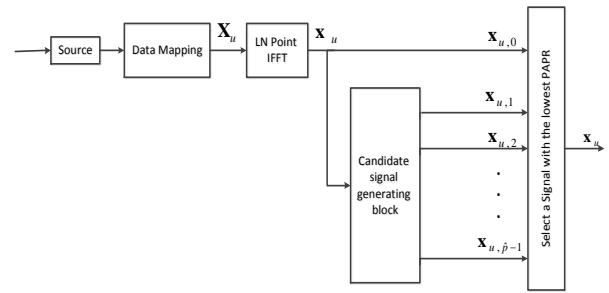
$$\text{CCDF} = \Pr(\text{PAPR}(\mathbf{x}_u) > \text{PAPR}_0) \quad (5)$$

3. PAPR Reduction Techniques

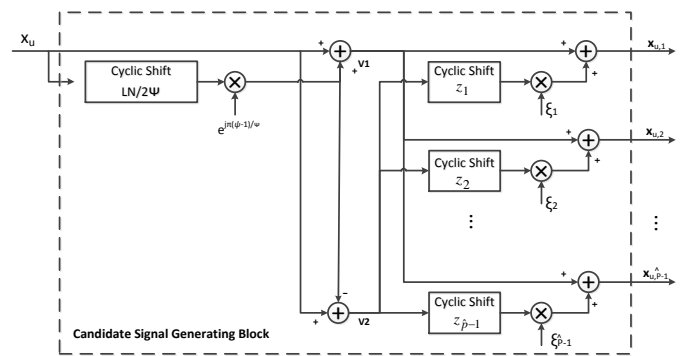
3.1. Low Complexity SLM

In conventional SLM scheme, we needed to do a set of IFFT operations. Applying selected mapping scheme requires LN point IFFT for P modified data blocks. In order to decrease the number of IFFT operands and hence, the computational complexity, Wang and Sie have presented a method in [11] that decreases the number of IFFT operations to one operand.

In this technique, $\hat{P} - 1$ signals in the time domain are generated from candidate signal generating block. Fig. 2 depicts the structure of candidate signal generating block. As seen in the figure, each candidate signal is a linear combination of the original signal and multiple cyclic shifts of the signal which have been multiplied by complex numbers.



(a) Low complexity SLM scheme



(b) The structure of candidate signal generating block

Fig. 2. The block diagram of low complexity selected mapping scheme

Consider an Interleaved OFDMA uplink system with N subcarriers which subcarriers are divided into ψ groups where

$$T_\psi = \left\{ k \cdot \Psi + \psi - 1 \mid k = 0, 1, \dots, \left(\frac{N}{\Psi} - 1\right) \right\}, \psi = 1, \dots, \Psi \quad (6)$$

In this system, \mathbf{x}_u is the u th user time domain signal. The subcarriers assigned to the user are Γ_u , which $\Gamma_u \subseteq T_\psi, \psi = 1, \dots, \Psi$. Therefore, the \hat{p} th candidate signal for the u th user has the following form

$$\mathbf{x}_{u,\hat{p}} = \mathbf{v}_1 + \xi_{\hat{p}} \cdot \mathbf{v}_2^{z_{\hat{p}}} \quad (7)$$

where

$$\mathbf{v}_1 = \mathbf{x}_u + e^{j\pi(\psi-1)/\Psi} \cdot \mathbf{x}_u^{LN/2\Psi} \quad (8)$$

$$\mathbf{v}_2 = \mathbf{x}_u - e^{j\pi(\psi-1)/\Psi} \cdot \mathbf{x}_u^{LN/2\Psi} \quad (9)$$

$$\xi_{\hat{p}} = e^{j\varphi_{\hat{p}}}, \quad \varphi_{\hat{p}} \in [0, 2\pi), \quad z_{\hat{p}} \in \{0, 1, \dots, LN - 1\} \quad (10)$$

$\mathbf{v}_2^{z_{\hat{p}}}$ is the $z_{\hat{p}}$ th cyclic shift of \mathbf{v}_2 and $\mathbf{x}_u^{LN/2\Psi}$ is the shifted version of \mathbf{x}_u by $LN/2\Psi$.

This technique provides a suitable method to construct a low complexity PAPR reduction scheme. In fact, generating candidate signals cause reduction in complexity. On the other hand, as the number of candidate signals increases, computational complexity grows. It is notable that $\xi_{\hat{p}}$ and $z_{\hat{p}}$ which generate signal with the lowest PAPR, have to be transmitted as side information, so that receiver can recover

the original signal. At the receiver, the transmitted frequency domain signal can be expressed as

$$X_{u,\hat{p}}[k] = H[k] \cdot \{V_1[k] + \xi_{\hat{p}} \cdot V_2[k] \cdot e^{-j2\pi k z_{\hat{p}}/N}\} + W[k] \quad (11)$$

where $H[k]$ is the channel frequency response and $W[k]$ represents the additive white Gaussian noise of the k th subcarrier. The term $\xi_{\hat{p}} \cdot e^{-j2\pi k z_{\hat{p}}/N}$ is a unit magnitude complex number and can be seen as a phase rotation. Since the nonzero elements of $V_1[k]$ and $V_2[k]$ do not overlap and $\xi_{\hat{p}} \cdot e^{-j2\pi k z_{\hat{p}}/N}$ is known from the side information, the original signal can be recovered by removing the phase rotation from $V_2[k]$.

3.2. Partial Transmit Sequence

The main idea in partial transmit sequence scheme is to divide input data, \mathbf{X}_u , into Q disjoint subblocks, i.e.

$$X_u[n] = \sum_{q=1}^Q X_u^{(q)}[n] \quad (12)$$

There are three main subblock dividing methods including adjacent partitioning, interleaved partitioning and random partitioning. Random partitioning has the best PAPR reduction performance, while the interleaved technique has the worst.

Fig. 3 illustrates the block diagram of partial transmit sequence scheme. Input data after dividing into subblocks is multiplied by a set of rotating phases, $\mathbf{C}_{u,w} = [c_{u,w}^{(1)}, c_{u,w}^{(2)}, \dots, c_{u,w}^{(Q)}]$, $w = 1, 2, \dots, W$, which can reduce the amount of PAPR. The time domain signal after weighting is

$$\tilde{x}_u[n] = \sum_{q=1}^Q c_{u,\hat{w}}^{(q)} x_u^{(q)}[n] \quad (13)$$

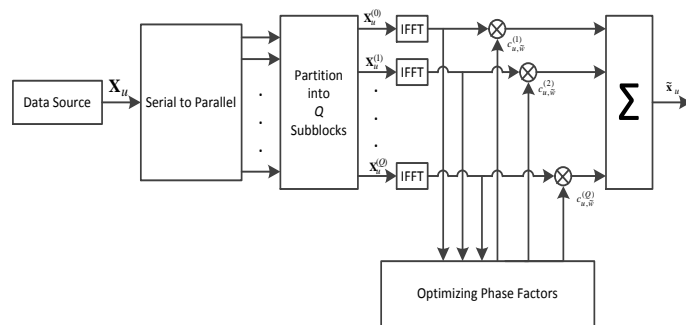


Fig. 3. The block diagram of partial transmit sequence scheme

In order to minimize the PAPR of transmitted signal, phase rotations have to be convinced the following equation

$$= \operatorname{argmin}_{1 \leq w \leq W} \left\{ \max_{0 \leq n \leq LN-1} \left| \sum_{q=1}^Q c_{u,w}^{(q)} x_u^{(q)}[n] \right| \right\} \quad (14)$$

After optimizing phase rotations, the signal with the lowest PAPR is selected for transmitting. In order to reduce computational complexity, phases are usually selected from a

set with a finite number of elements. Complexity of partial transmit sequence scheme increases exponentially with the number of subblocks [5].

The receiver should know the index information to recover the original input data. Therefore, $\mathbf{C}_{u,\hat{w}}$ has to be sent as the side information.

4. The Proposed Scheme for PAPR Reduction in OFDMA Uplink Systems

4.1. Proposed Scheme

In this method depicted in Fig. 4, after applying LN point IFFT, input data is shifted and multiplied by complex numbers. $\hat{P}-1$ candidate signals are generated by candidate signal generating block. Candidate signal generator works based on equation 11. The signal with the lowest PAPR is chosen from candidate signals and original data, i.e.

$$\hat{\mathbf{x}}_u = \operatorname{argmin}_{0 \leq \hat{p} \leq \hat{P}-1} \left(\frac{\max_{0 \leq n \leq LN-1} |x_{u,\hat{p}}[n]|^2}{E[|x_{u,\hat{p}}[n]|^2]} \right) \quad (15)$$

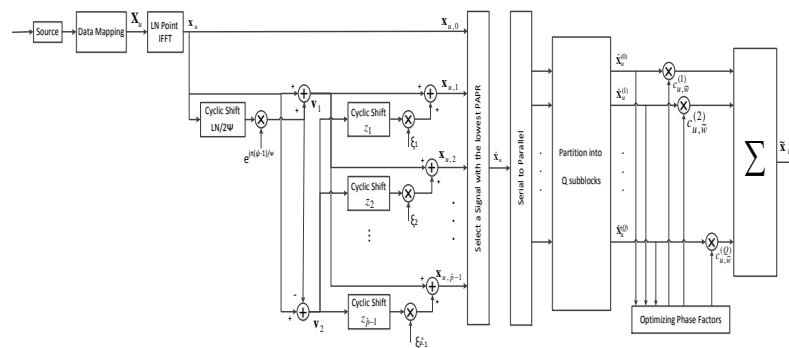


Fig. 4. The block diagram of proposed scheme

After selecting the signal with the lowest PAPR, the selected signal is divided into Q subblocks, i.e.

$$\hat{\mathbf{x}}_u = \sum_{q=1}^Q \hat{\mathbf{x}}_u^{(q)} \quad (16)$$

The subblock partitioning scheme that is used in this scheme is adjacent partitioning. Consider input data, $\hat{\mathbf{x}}_u$, can be expressed as

$$\hat{\mathbf{x}}_u = [\hat{x}_u[0] \ \hat{x}_u[1] \ \dots \ \hat{x}_u \left[\frac{LN}{\psi} - 1 \right]]^T \quad (17)$$

The partitioned subblocks have the following form

$$\begin{aligned} \hat{\mathbf{x}}_u^{(1)} &= [\hat{x}_u[0] \ \hat{x}_u[1] \ \dots \ \hat{x}_u \left[\frac{LN}{Q\psi} - 1 \right]]^T \\ \hat{\mathbf{x}}_u^{(2)} &= [\hat{x}_u \left[\frac{LN}{Q\psi} \right] \ \dots \ \hat{x}_u \left[\frac{2LN}{Q\psi} - 1 \right]]^T \\ &\vdots \\ \hat{\mathbf{x}}_u^{(Q)} &= [\hat{x}_u \left[\frac{(Q-1)LN}{Q\psi} \right] \ \dots \ \hat{x}_u \left[\frac{LN}{\psi} - 1 \right]]^T \end{aligned} \quad (18)$$

The subblocks are multiplied by unit magnitude factors, $\mathbf{C}_u^{(q)}$, which can reduce the amount of peak to average power ratio of signal, i.e.

$$\mathbf{C}_u^{(q)} = [c_{u,1}^{(q)}, c_{u,2}^{(q)}, \dots, c_{u,W}^{(q)}]^T \quad (19)$$

where $1 \leq q \leq Q$ and $\mathbf{C}_u^{(q)}$ is the corresponding q th block with data subblock length of $\frac{LN}{Q\Psi}$. After inserting PAPR reduction factors which usually are chosen from $\{\pm 1, \pm j\}$, we have

$$\mathbf{C}_u^{(q)} \hat{\mathbf{x}}_u^{(q)} = \left[\hat{x}_u \left[\frac{(q-1)LN}{Q\Psi} \right] \cdot c_{u,1}^{(q)}, \dots, \hat{x}_u \left[\frac{qLN}{Q\Psi} \right] \cdot c_{u,W}^{(q)} \right]^T \quad (20)$$

After multiplying subblocks by phase rotating vectors, they are summed up, i.e.

$$\bar{\mathbf{x}}_u = \sum_{q=1}^Q \mathbf{C}_u^{(q)} \hat{\mathbf{x}}_u^{(q)} \quad (21)$$

where $\bar{\mathbf{x}}_u$ is the weighted input signal. The amount of PAPR of $\bar{\mathbf{x}}_u$ are computed for W rotating phases. Then the signal with the lowest PAPR is selected for transmission. Considering $\bar{\mathbf{x}}_u$ as an index with the minimum PAPR, optimum phase factors are computed from following equation

$$\tilde{w} = \underset{1 \leq w \leq W}{\operatorname{argmin}} \left\{ \max_{\frac{(q-1)LN}{Q\Psi} \leq n \leq \frac{qLN}{Q\Psi}} \left| \sum_{q=1}^Q c_{u,w}^{(q)} x_{u,n}^{(q)} \right| \right\} \quad (22)$$

In comparison with the low complexity selected mapping scheme, the proposed scheme has better PAPR reduction performance, since in this case, the amount of PAPR of transmitted signal is reduced in two stages. In receiver, in order to recover the original signal, \tilde{w} , $z_{\hat{p}}$ and $\xi_{\hat{p}}$ have to be transmitted as side information.

4.2. Comparing Computational Complexities

In this section computational complexities for discussed schemes are evaluated in terms of the number of candidate signals and subcarriers. Table 1 presents the computational complexities of SLM, PTS, combined SLM-PTS and proposed scheme for an interleaved OFDMA system. The conventional SLM requires LN point IFFT for each P phase factors. Therefore, it needs $P \frac{LN}{2} \log_2(LN)$ complex multiplications and $PLN \log_2(LN)$ additions [12].

Table 1. Number of complex operations of various schemes

Scheme	Number of multiplications	Number of additions
Conventional SLM	$\frac{PLN}{2} \log_2(LN)$	$PLN \cdot \log_2(LN)$
Conventional PTS	$LN \cdot W^{Q-1}$	$(Q-1) \cdot LN \cdot W^{Q-1}$
Low complexity SLM	$\frac{LN}{2} \log_2(LN) + LN$	$LN \log_2(LN) + LN \left(1 + \frac{1}{\Psi}\right) + (\hat{P} - 1) \cdot \left(\frac{LN}{\Psi}\right)$
Proposed scheme	$LN \cdot W^{Q-1} + \frac{LN}{2} \log_2(LN) + LN$	$(Q-1) \cdot LN \cdot W^{Q-1} + LN \log_2(LN) + LN \left(1 + \frac{1}{\Psi}\right) + (\hat{P} - 1) \cdot \left(\frac{LN}{\Psi}\right)$

There are LNW^{Q-1} multiplication operands in partial transmit sequence scheme, where W^{Q-1} is the number of iterations to find the optimum phase sequences. In addition, because of applying Q subblocks in this scheme, it requires $(Q-1)LN \cdot W^{Q-1}$ complex additions [13].

As depicted in Fig. 4, there are LN complex multiplications after $\frac{LN}{2\Psi}$ cyclic shifts in proposed scheme. Also, after dividing the data block into Q subblocks, LMW^{Q-1} searches for finding optimum phase rotations are needed. After applying LN point IFFT, we have LN additions to find \mathbf{v}_2 and $\frac{LN}{\Psi}$ to find \mathbf{v}_1 . On the other hand, computing PAPR of \hat{P} candidate signals requires $(\hat{P} - 1) \cdot \frac{LN}{\Psi}$ and adding subblocks together requires $(Q-1)LN \cdot W^{Q-1}$ complex additions in the proposed scheme.

Fig. 5 shows the variation of operational complexity versus the number of candidate signals for the case of $LN=512$, $Q=2$, $W=16$ and $\Psi=4$. As shown in figure, for $\hat{P}=32$ candidate signals, the proposed scheme requires just 10.13% the number of complex multiplications and additions required by combined SLM-PTS scheme.

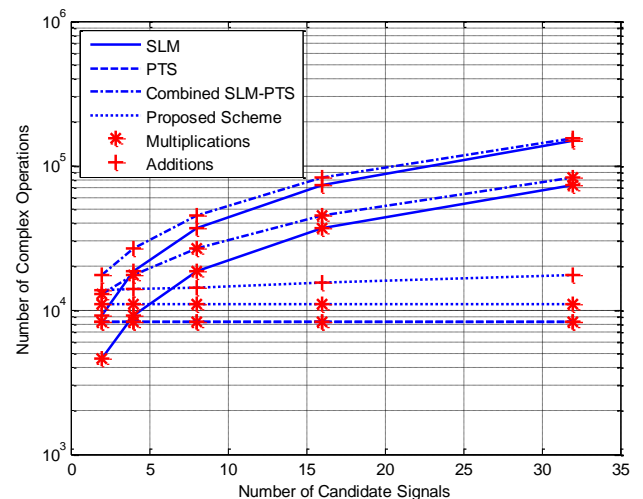


Fig. 5. Number of complex operations versus the number of candidate signals ($LN=512$, $Q=2$, $W=16$, $\Psi=4$)

Fig. 6 illustrates the number of complex operations versus the number of subcarriers for $L=4$, $Q=2$, $P=4$, $W=16$ and $\Psi = 4$. In the case of $N=512$ subcarriers, the number of complex multiplications and additions required in the proposed scheme is about 10.7% and 10.8% that of required in the combined SLM-PTS scheme.

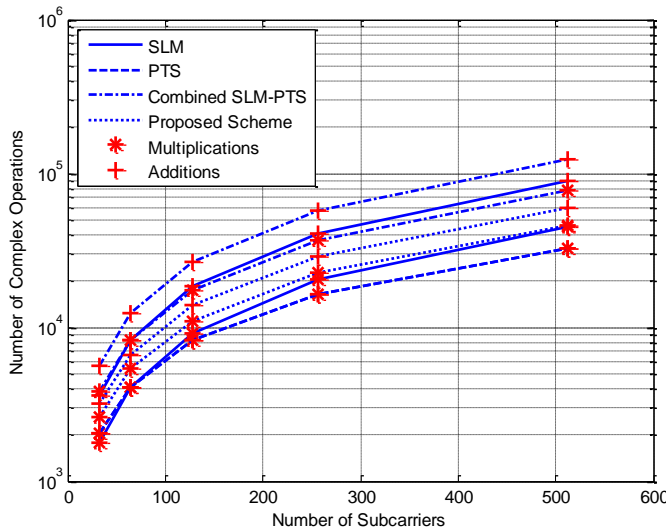


Fig. 6. Number of complex operations versus the number of subcarriers ($L=4$, $Q=2$, $P=4$, $W=16$, $\Psi = 4$)

5. Simulation Results

This section presents the simulation results of evaluating CCDF of an Interleaved OFDMA uplink system. In this system, subcarriers are divided into $\Psi = 4$ groups, which each group is used by a user and a user occupies 32 subcarriers. As the simulations for each group of subcarriers are the same, for convenience, we consider the first group of subcarriers. The upsampling factor, $L=4$ and 16QAM modulation is used. Simulations are done for 4 states, $\hat{P}=8,16$ and $Q=2,4$. There are $P=16$ phase factors and $W=16$ phase rotations, respectively. Also, $\xi_{\hat{p}}$ is chosen from a set of $\{\pm 1, \pm j\}$.

Fig. 7 shows the CCDF of PAPR for $\hat{P}=8$ candidate signals and $Q=2$ subblocks. As it can be seen, the proposed scheme has 1.2dB PAPR reduction improvement in comparison with PTS and 0.1dB improvement in comparison with low complexity SLM scheme. Although the proposed scheme has lower performance compared to SLM or combined SLM-PTS scheme, it just needs one IFFT and consequently has less complexity.

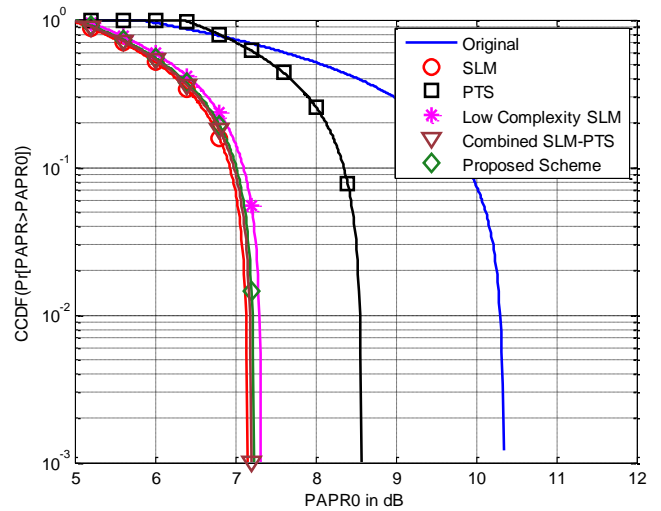


Fig. 7. The PAPR reduction performance of proposed scheme ($\hat{P}=8$, $Q=2$, $W=16$)

In Fig. 8 the number of candidate signals are $\hat{P}=16$. In this condition, 0.2dB improvement in PAPR reduction is achieved in comparison with $\hat{P}=8$ candidate signals. As you can see, the proposed scheme has 0.2dB improvement compared to the low complexity SLM scheme and the graph gets closed to combined SLM-PTS scheme, while the computational complexity is lower. For this case, the probability that the PAPR goes higher than 10^{-3} is 7dB.

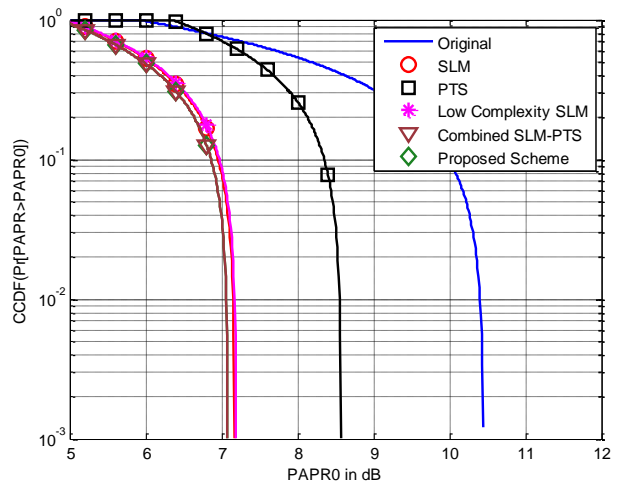


Fig. 8. The PAPR reduction performance of proposed scheme ($\hat{P}=16$, $Q=2$, $W=16$)

Figs. 9 and 10 show the CCDF in case of $Q=4$ subblocks for $\hat{P}=8$ and $\hat{P}=16$ candidate signals, respectively. As it is cleared in the figures, increasing the number of candidate signals have improved PAPR reduction performance, while computational complexity grows. Also, $Q=4$ subblocks has been improved the PAPR reduction about 0.2dB Compared to $Q=2$ subblocks.

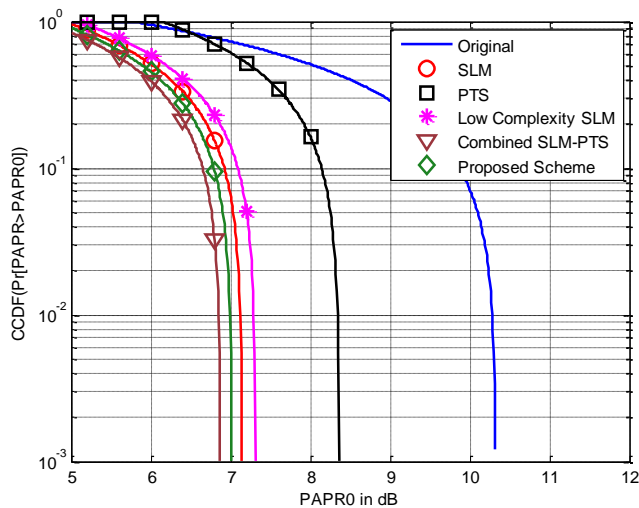


Fig. 9. The PAPR reduction performance of proposed scheme ($\hat{P}=8, Q=4, W=16$)

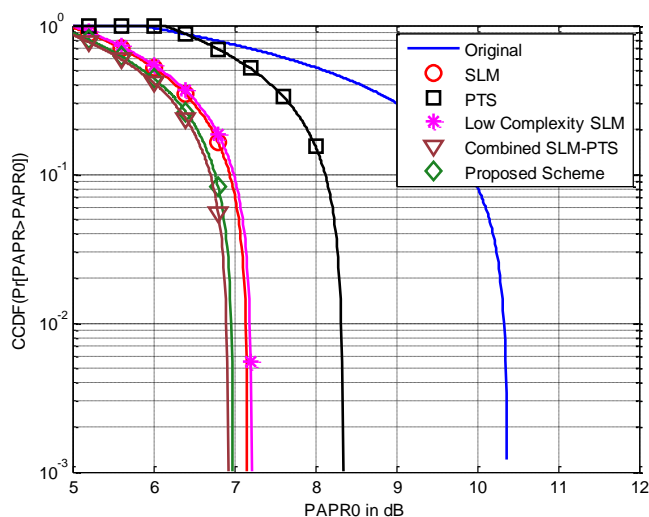


Fig. 10. The PAPR reduction performance of proposed scheme ($\hat{P}=16, Q=4, W=16$)

6. Conclusion

This paper has introduced a PAPR reduction scheme based on low complexity SLM and PTS techniques for OFDMA uplink systems. To minimize the amount of PAPR, the proposed scheme used some candidate signals and divided the signal with the lowest PAPR into subblocks to apply rotation phases. Based on the examination of complementary cumulative distribution function, reduction of the PAPR has been achieved about 0.2dB compared to SLM technique. On the other hand, the algorithm has lower computational complexity compared to the conventional SLM or combined SLM-PTS techniques.

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