A New Partitioning Scheme for PTS Technique to Improve the PAPR Performance in OFDM Systems

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Abstract

A high peak-to-average-power ratio (PAPR) is the primary drawback faced by the orthogonal frequency division multiplexing (OFDM) systems in the practical applications. Meanwhile, Partial Transmit Sequence (PTS) is regarded as one of the efficient PAPR reduction techniques in OFDM systems. PTS technique depends on partitioning the input data into the several subblocks in the frequency-domain and weighting these subblocks by a set of phase factors in the time-domain. As the result, there are three common types of subblocks partitioning schemes have been adopted in the PTS technique, interleaving scheme, adjacent scheme, and pseudo-random scheme. Each one of the conventional partitioning schemes has PAPR reduction performance and a computational complexity level different from others. In this paper, a new subblock partitioning scheme named terminals exchanging segmentation (TE-PTS) scheme has been proposed to improve the PAPR performance in PTS technique better than that of the interleaving scheme. The simulation results and the numerical calculations indicate that the PAPR reduction capacity of the proposed scheme is superior to that of interleaving scheme without increasing the computational complexity.

Keywords: OFDM, PAPR, PTS, IL-PTS, computational complexity

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is regarded as one of the useful modulation systems in high-speed communications. Many advantages have been defined in OFDM systems such as high capacity [1], easy implementation [2], low complexity [3], and robustness against multipath fading channels [4]. Therefore, OFDM has been adopted in many wireless communication standards such as IEEE 802.11 standard [5], IEEE 802.16 standard [6], and fourth generation long-term evolution (4G-LTE) standard [7]. Recently, many researchers focus on filtering OFDM framework as a new waveform candidate in 5th generation technology such as universal filter-OFDM (U-OFDM) [8], filtered-OFDM (F-OFDM) [9]. Despite the OFDM framework has many features, some obstacles restrict the system in the practical applications such as the high peak-to-average-power ratio (PAPR), out-off band leakage, and sensitivity to the frequency offset [10]. The high PAPR value is deemed the essential hurdle that restricts the OFDM system due to the nonlinearity nature of the OFDM signal at the transmitter. Hence, this leads to decrement in the efficiency in high power amplifiers (HPA) and increment in the complexity of digital-to-analogue and analogue-to-digital converters [11]. Therefore, there is considerable attention has been paid to the high PAPR problem from many researchers especially for the downlink in the 4G wireless communication systems.

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To overcome the high PAPR problem in OFDM systems, several techniques have been suggested such as clipping [12]; active constellation extension (ACE) [13], tone reservation (TR) [14], block coding [15], selective mapping (SLM) [16], the interleaving method [17], and partial transmit sequence (PTS) [18]. Indeed, each one of these techniques has its own PAPR lessening level and its own computational burden. PTS is one of the non-distortion methods that effectively reduce the PAPR issue without adding any distortion in the OFDM signal [19]. Meanwhile, the PTS method suffers from a large computational burden due to complex processing to the signal in the transmitter, where the PTS technique depends on dividing the input data signal by one of the partitioning schemes into several subblocks, transformation these subblocks by utilizing inverse fast Fourier transform (IFFT), and rotation the transformed subblocks by a set of phase factors before combining them again. Therefore, the conventional PTS technique requires two stages of the calculations: IFFT processes, and finding the optimum phase factor.

Several publications have appeared in recent years to improve the PTS technique performance regarding to the subblocks partitioning schemes as a realistic solution to improve the PAPR performance in the frequency domain. For example, Hong et al. [20] and Ibraheem et al. [21] suggested new algorithms depending on integrating two types of partitioning schemes in order to enhance the PAPR performance. Jawhar et al. [22] were proposed new algorithms by combining a couple of the ordinary segmentation schemes in a new approach to enhance the PAPR performance better than the ordinary schemes. Also, Jawhar et al. [23] developed a new scenario to distribute the data within the partitioned subblocks in order to reduce the high PAPR value. Recently, Chen in [24] proposed new algorithm to enhance the PAPR reduction performance in PTS depending on dividing the input data sequence into non-disjoint subblocks. In this paper, a new subblock partitioning scheme that improves the PAPR reduction performance without increasing the computational burden is suggested. The proposed method depends on reshaping the interleaving partitioning scheme to develop the PAPR performance better than the interleaving scheme without extra computational complexity. The rest of sections are arranged as follows: Section 2 discusses PTS and PAPR. In Section 3, the interleaving partitioning scheme is analyzed. Section 4 explains the proposed method. The simulation results are described in Section 5. Finally, the concluding remarks are given in Section 6.

2. Conventional PTS Technique and PAPR Reduction

In OFDM, the input data sequence X_k =[X_0, X_1, …, X_{N-1}] is modulated by the QAM or PSK constellation mapping technique to generate the baseband signal. After that, the discrete time-domain signal is obtained by applying IFFT operation to the baseband signal [25],

$$x(n)=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}X_k e^{j2\pi kn/N},\ 0\le n\le N-1 \tag{1}$$

where X_k is the input data sequence, $x(n)$ is the time-domain OFDM signal, k is the index of the input sequence, and N represents the number of subcarriers. Also, The PAPR value of the OFDM signal is defined as the ratio of the maximum peak power to the average power in the signal [26],

$$\text{PAPR}=10\log_{10}\frac{\max|x(n)|^2}{E\{|x(n)|^2\}}\ \text{(dB)} \tag{2}$$

where $E\{.\}$ is the mean value of the signal. In addition, to get accurate PAPR calculations, the baseband signal is sampled multiple times the Nyquist rate (oversampling operation). The oversampling operation is performed by inserting zeros between the baseband samples in the frequency domain. Moreover, to evaluate the PAPR reduction level in OFDM system, the complementary-cumulative-distribution-function (CCDF) is utilized, where CCDF represents the probability of the PAPR value that exceeds a certain threshold value [27].

$$P_r(\mathrm{PAPR}(x(n) > PAPR_0) = 1-(1-e^{-\mathrm{PAPR}_0})^{NL} \tag{3}$$

where L stumbles the oversampling factor, and PAPR_0 denotes the threshold value.

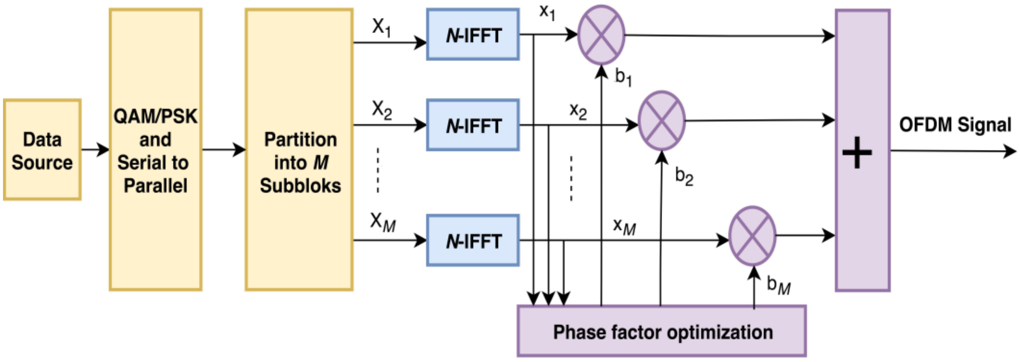

Fig. 1 PTS block diagram

Fig. 1 illustrates the OFDM system based on PTS technique. In this system, the input data sequence, X, is divided into M subblocks.

$$X = \sum_{m=1}^{M} X_m \tag{4}$$

After that, the subblocks are converted from the frequency-domain to the time-domain by applying IFFT operation. Therefore, the discrete baseband signal in the time domain can be given by

$$x(n) = \sum_{m=1}^{M} \mathrm{IFFT}\{X_v\} = \sum_{m=1}^{M} x_m \tag{5}$$

The transformed subblocks are rotated by a set of the phase factors b= [b_1, b_2, …, b_M], and the elements of rotation phase factor can be selected within (0, 2π); therefore, the phase rotation vector is generated by [28]

$$b_m = e^{j2\pi m/A}, \quad \{m = 0,1,.......,A-1\} \tag{6}$$

where b_m is the phase factor of mth subblock, $j2$□m/A is the angle of phase rotation factor, and A is the number of the allowed phase factors, which is usually constricted by {±1} or {±1, ±j} to avoid the complicated multiplication operations. Each subblock in the time-domain is rotated by the phase factor vectors, and then the weighted subblocks are combined to produce a set of candidates. Last but not the least, the PAPR value of each candidate is calculated, and the phase rotation factor that achieves the lower PAPR value is elected to rotate the combined subblocks to generate the OFDM signal that will transmit to the receiver,

$$x'(n) = \sum_{m=1}^{M} b_m x_m \tag{7}$$

The purpose of the phase rotation factors is to equilibrium the directions for combining signals to reduce the PAPR value of the OFDM signal; with the consideration that the index of the optimum phase factor should be sent to the receiver as side information (SI) to ensure recovering the data [29].

3. Interleaving Subblocks Partitioning Scheme

In the PTS technique, subdividing the input signal into several subblocks is the centric part of the algorithm. There are three common kinds of the subblock partitioning schemes have been adopted; pseudo-random scheme (PR-PTS), adjacent scheme (AD-PTS), and interleaving scheme (IL-PTS) [30]. All the subblocks dividing schemes have their own PAPR reduction performance and their own computational complexity depending on distributing the data within the subblocks. In PR-PTS, the subcarriers are assigned randomly in the subblocks, while the AD-PTS scheme allocates N/M successive subcarriers inside each subblock, sequentially. However, the IL-PTS scheme assigns N/M subcarriers with a specific distance interval of M within each subblock. Furthermore, the subblocks must be non-overlapped with each other, each subblock must be equaled with others in size, and each subblock must contain the same number of the active subcarriers, as demonstrated in Fig. 2.

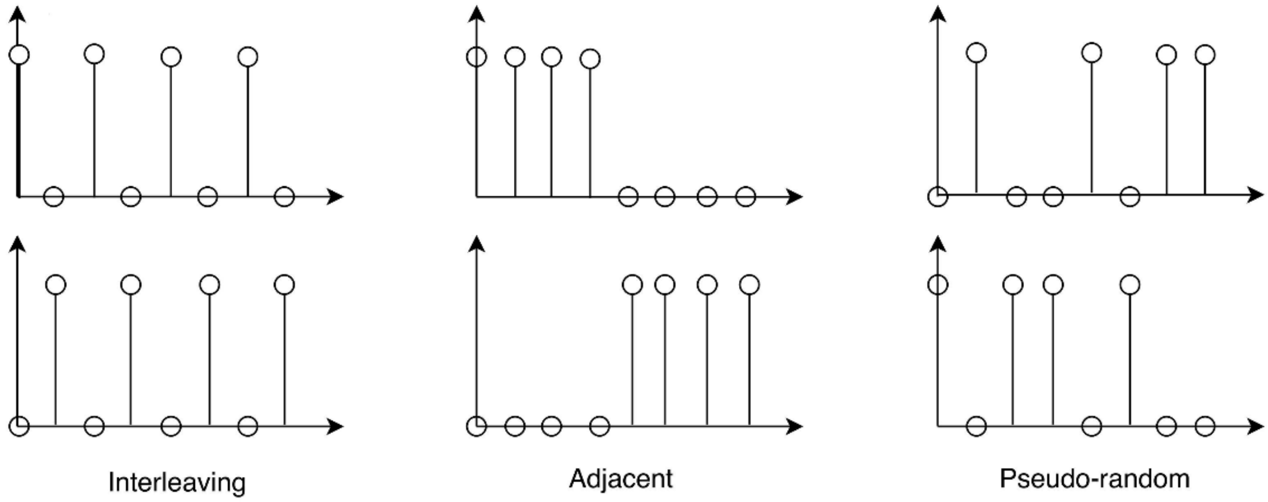

Fig. 2 Conventional subblocks partitioning schemes [22]

As mentioned above, the PAPR performance of each subblocks partitioning schemes is depended on the subcarriers distribution within the subblocks, where the low correlation level between the subcarriers leads to better PAPR performance [31]. Accordingly, the PAPR lessening performance of the PR-PTS scheme is deemed as the best among the ordinary schemes because its subcarriers have a low correlation level inside the subblocks depending on the random feature of the structure scheme. The AD-PTS scheme is classified in the second level concerning the PAPR performance because its subcarriers have higher correlation level than the PR-PTS scheme. However, the IL-PTS is the worst PAPR reduction scheme among the conventional partitioning schemes due to it has a large correlation level between its subcarriers. On the other hand, the computational complexity of the subblocks partitioning schemes is limited to the computational operations of the IFFT unit, therefore; the PR-PTS and AD-PTS schemes have larger computational burden level than the IL-PTS scheme [32]. It is because of PR-PTS, and AD-PTS implement all the stages of IFFT unit to transform the subcarriers from the frequency-domain to the time-domain, while the IL-PTS scheme needs a part of IFFT stages to implement this transformation. In this paper, we will focus on the IL-PTS scheme because it has low computational burden compared with other schemes. Therefore, the number of the addition and multiplications operations of the IL-PTS scheme is given by [33].

$$\mathrm{CC}_{\mathrm{add}}^{\mathrm{IL\text{-}PTS}} = M\left[\frac{N}{M}\log_2\left(\frac{N}{M}\right)\right] \tag{8}$$

$$\mathrm{CC}_{\mathrm{mult}}^{\mathrm{IL\text{-}PTS}} = M\left[\frac{N}{2M}\log_2\left(\frac{N}{M}\right)+N\right] \tag{9}$$

4. Proposed method

In this section, a new dividing scheme named terminal exchanging segmentation (TE-PTS) scheme has been suggested in order to improve the PAPR lessening performance better than that of the IL-PTS scheme. The proposed algorithm depends on the IL-PTS scheme primarily, where the input data is partitioned similar to the IL-PTS scheme,

$$X = \sum_{m=1}^{M} X_m \tag{10}$$

where M is the number of subblocks. Next, each subblock is subdivided into S subsets, denoted by $\{S_1, S_2, \ldots, S_M\}$, where the total number of subsets, S, equals to the total number of subblocks, M, and each subset contains N/M samples from the subblock, as shown in the following equations

$$X = \sum_{m=1}^{M} \left\{ X_{m,s} \mid s = 1, 2, \ldots, M \right\} \tag{11}$$

Thus,

$$X = \begin{bmatrix} X_{1,1} & X_{1,2} & \cdots & X_{1,M} \\ X_{2,1} & X_{2,2} & \cdots & X_{2,M} \\ \vdots & \vdots & \vdots & \vdots \\ X_{M,1} & X_{M,2} & \cdots & X_{M,M} \end{bmatrix} \tag{12}$$

and,

$$\begin{cases} X_{1,1} = \left[X_{(1,1),1} \; X_{(1,2),1} \cdots X_{(1,\frac{N}{M}),1} \right] \\ X_{1,2} = \left[X_{(1,\frac{N}{M}+1),2} \; X_{(1,\frac{N}{M}+2),2} \cdots X_{(1,\frac{2N}{M}),2} \right] \\ X_{1,M} = \left[X_{(1,\frac{(M-1)N}{M}+1),M} \; X_{(1,\frac{(M-1)N}{M}+2),M} \cdots X_{(1,N),M} \right] \end{cases} \tag{13}$$

After that, the first and last samples of each subset are exchanged with each other, so that Eq. (13) is updated to,

$$\begin{cases} X'_{1,1} = \left[X_{(1,\frac{N}{M}),1} \; X_{(1,2),1} \cdots X_{(1,1),1} \right] \\ X'_{1,2} = \left[X_{(1,\frac{2N}{M}),2} \; X_{(1,\frac{N}{M}+2),2} \cdots X_{(1,\frac{N}{M}+1),2} \right] \\ X'_{1,M} = \left[X_{(1,N),M} \; X_{(1,\frac{(M-1)N}{M}+2),M} \cdots X_{(1,\frac{(M-1)N}{M}+1),M} \right] \end{cases} \tag{14}$$

The terminal exchange operation continues until the last subset of the updated IL-PTS matrix, therefore; the new TE-PTS matrix is given by

$$X' = \begin{bmatrix} X'_{1,1} & X'_{1,2} & \cdots & X'_{1,M} \\ X'_{2,1} & X'_{2,2} & \cdots & X'_{2,M} \\ \vdots & \vdots & \vdots & \vdots \\ X'_{M,1} & X'_{M,2} & \cdots & X'_{M,M} \end{bmatrix} \tag{15}$$

in which,

$$X' = \sum_{m=1}^{M} X'_m \tag{16}$$

Last but not the least, each subblock of the TE-PTS scheme is passed to the IFFT unit and the other procedures of the PTS technique are performed to generate the OFDM signal.

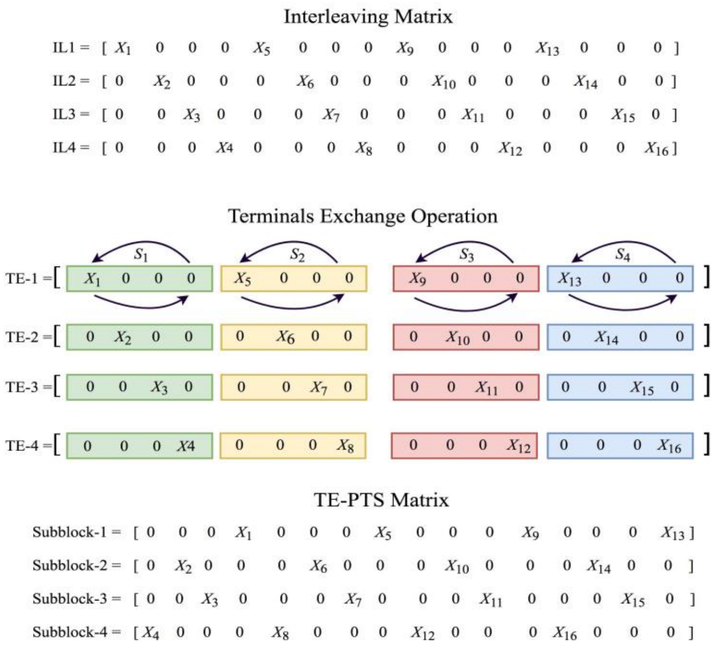

Fig. 3 TE-PTS scheme when N= 16 and M= 4

Fig. 3 illustrates an example of the TE-PTS scheme. For this example, the number of subblocks is chosen 4, and the number of subcarriers is set to 16. According to the TE-PTS mechanism, the number of the subset, S, is determined to 4, and each subset contains (N/M= 16/4 = 4) samples. It is clear that the TE-PTS algorithm reshapes the samples distribution inside the subblocks differently to that of the IL-PTS algorithm. Accordingly, the TE-PTS scheme attempts to reduce the correlation level between the subcarriers within the subblocks; thus the PAPR reduction performance is improved (as will be seen in the next section).

On the other hand, the computational complexity of the TE-PTS scheme can be calculated depending on the divide-and-conquer approach combined with the Cooley-Tukey IFFT algorithm [34]. Therefore, for each subblock of the TE-PTS matrix, the samples are arranged as columns-wise mapping. Table 1 illustrates the columns-wise mapping for one subblock of TR-PTS, where the number of subsets, S, represents the total number of columns, while the number of rows equals the total number of subblocks, M, in TE-PTS scheme.

Table 1 The columns-wise mapping for one Subblock of TE-PTS [35]

$m \setminus s$	1	2	…	S
1	X_1^m	X_{M+1}^m	…	$X_{M(S-1)+1}^m$
2	X_2^m	X_{M+2}^m	…	$X_{M(S-1)+2}^m$
…	…	…	…	…
M	X_M^m	X_{2M}^m	…	X_{MS}^m

The Cooly-Tukey IFFT algorithm is applied to the rows and columns in Table 1, therefore; the OFDM signal of TE-PTS scheme in the time-domain can be written as [35]

$$x_{(p,q)} = \frac{1}{N}\sum_{m=1}^{M}\left\{ W_N^{mq}\left[\sum_{s=1}^{S} X_{m,s} W_S^{sq}\right] \right\} W_M^{mp} \tag{17}$$

where S the number of columns in Table 1, M is the number of rows in Table 1, $X_{m,s}$ is the input sequence of mth subblock, $1 \le p \le M$ and $1 \le q \le S$ is an element in pth row and qth column of row-wise mapping of the $x(p,q)$, and $W_N = e^{j2\pi/N}$ represents the twiddle factor. According to Table 1, the active subsets at each subblock are located at only mth row depending on the interleaving property of TE-PTS. Therefore, the inner S-point IFFT of Eq. (17) is applied only to mth row of each subblock, and Eq. (17) can be simplified as

$$x_{(p,q)} = \frac{1}{N} W_N^{m(Sp+q)} \sum_{s=1}^{S} X_{m,s} W_S^{sq} \tag{18}$$

but, $W_N^{m(Sp+q)} = W_N^{Smp} W_N^{mq}$, and $W_N^{Smp} = W_{N/S}^{mp} = W_M^{mp} = 1$, if M =1, thus

$$x_{(p,q)} = \frac{1}{N} W_N^{mq} \sum_{s=1}^{S} X_{m,s} W_S^{sq} \tag{19}$$

Based on Eq. (18), each subblock of TE-PTS can be performed only one S-point IFFT and N-times complex multiplications. Therefore, the number of complex computations for the TR-PTS scheme can be given as

$$\mathrm{CC}_{\mathrm{add}}^{\mathrm{TR\text{-}PTS}} = M\left[\frac{N}{M}\log_2\frac{N}{M}\right] \tag{20}$$

$$\mathrm{CC}_{\mathrm{mult}}^{\mathrm{TR\text{-}PTS}} = M\left[\frac{N}{2M}\log_2\frac{N}{M} + N\right] \tag{21}$$

Obviously, the number of computational complexity for the TE-PTS scheme is similar as the IL-PTS scheme; it is because of the subcarriers for both schemes are distributed as interleaving manner within the subblocks. Hence, the subblocks require a part of the IFFT stages for converting them to the time-domain.

5. Simulation and Results

In this section, the PAPR reduction performance of the TE-PTS scheme compared with IL-PTS scheme as a conventional scheme is evaluated in three scenarios, when the number of subcarriers is 128, 256, and 512. The rest parameters that utilized for this simulation are the number of subblocks, M, and the number of allowed phase factor, A, are set to 4, while the oversampling factor L= 4. Moreover, 16-QAM constellation mapping is utilized to modulate the input data sequence, and CCDF is employed to evaluate the PAPR performance of 1000 of the input OFDM sub-streams. However, the MATLAB software program is adopted in this simulation.

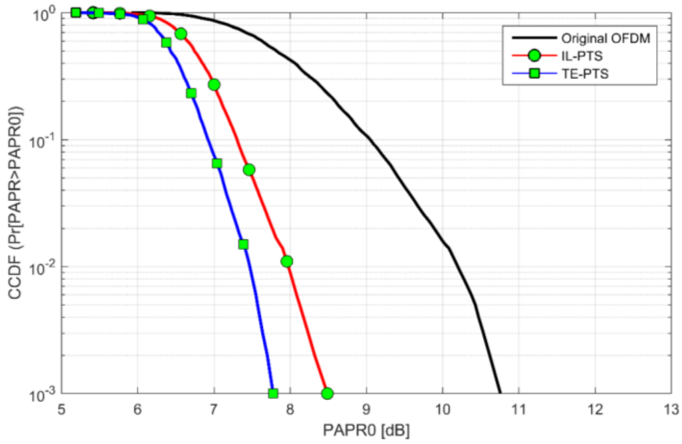

Fig. 4 Comparison the TE-PTS and IL-PTS schemes when N= 128

Fig. 4 illustrates the comparison between the TE-PTS scheme and the IL-PTS scheme when the number of subcarriers is set to 128. It is clear that the proposed scheme outperforms the IL-PTS scheme regarding to the PAPR reduction capacity by 0.73dB. Also, Fig. 5 shows the PAPR level of the TE-PTS, IL-PTS, and the original OFDM signal (without PTS), when the N= 256. From this figure, it can be seen that the TE-PTS scheme records the best PAPR reduction level at 8.19dB, and the IL-PTS scheme achieves the second level at 8.72dB, whereas the PAPR level of the original OFDM signal is 11.03dB when the CCDF= 10^{-3}. Furthermore, the third scenario is conducted to evaluate the PAPR reduction performance when the number of subcarriers is 512, as exhibited in Fig. 6. In this scenario, the PAPR performance of the proposed scheme is better than that of IL-PTS and the original OFDM by 0.46dB, and 2.62dB, respectively. Therefore, the simulation results of the three scenarios indicate that the proposed scheme can surpass the conventional scheme, IL-PTS, at any number of subcarriers.

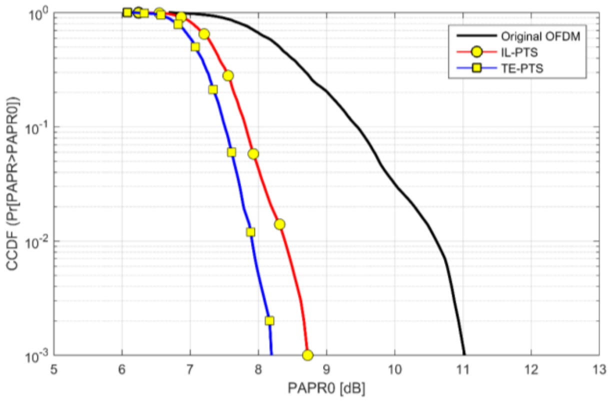

Fig. 5 Comparison the TE-PTS and the IL-PTS schemes when N= 256

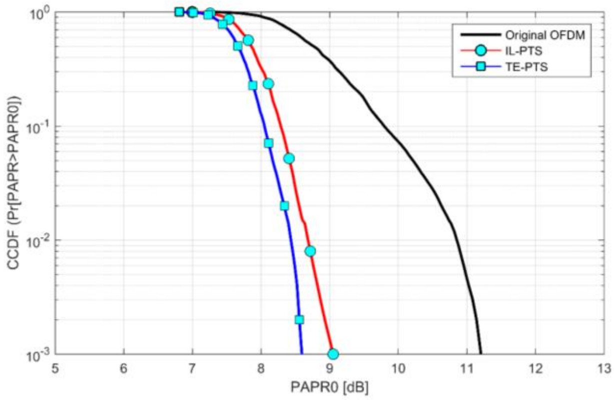

Fig. 6 Comparison the TE-PTS and IL-PTS schemes when N= 512

In addition, the proposed scheme does not largely change the PAPR performance when the modulation families changing, where the PAPR performance is simulated based on various modulation families (QPSK, 16-QAM, and 64-QAM), as shown in Fig. 7. The results show that there is a very small effect to change the modulation family on the PAPR performance. The reason behind that is the QPSK, 16-QAM, and 64-QAM digital modulation schemes do not change the amplitude of the data signal. Since, the PAPR produced by the fluctuation of the signal power, thus the PAPR value does not change greatly by changing the type of the modulation scheme. Therefore, different types of the modulation schemes have a very small influence on the peak to average power ratio performance.

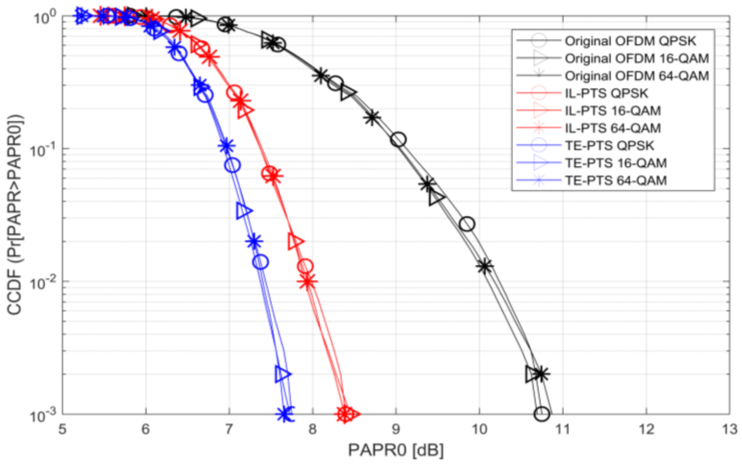

Fig. 7 Comparison the TE-PTS and IL-PTS schemes for various modulation families when N= 128

Table 2 the PAPR reduction ratio of the TR-PTS and IL-PTS schemes

M= 4 , A= 4					
N	PAPR of Original OFDM	PAPR of IL-PTS	PAPR of TR-PTS	PRR of IL-PTS	PRR of TR-PTS
128	10.76	8.49	7.77	21.09%	27.87%
256	11.03	8.72	8.19	20.94%	25.74%
512	11.21	9.05	8.59	19.26%	23.37%

Also, Table 2 records the PAPR reduction ratio (PRR) of the TE-PTS scheme and the IL-PTS scheme compared with the original OFDM signal for the three above scenarios. The results show that the proposed scheme has the superiority to the IL-PTS scheme concerning the PAPR reduction for all the three scenarios. Therefore, the PRR of the proposed scheme compared with the original OFDM signal can be defined as

$$\text{PRR(proposed scheme)} = \frac{\text{PAPR of the proposed scheme}}{\text{PAPR of the original OFDM signal}} \times 100\% \tag{22}$$

On the other hand, Table 3 records the number of complex computations for the TE-PTS scheme and the IL-PTS scheme which is considered the lowest computational complexity among the conventional schemes. As mentioned earlier, the number of addition and multiplication operations of the proposed scheme is similar to that of the IL-PTS scheme. Hence, there is no additional computation burden when applying the TE-PTS scheme in the PTS technique.

Table 3 The computational burden of the TE-PTS and IL-PTS schemes

N	M	CC_{add} (IL-PTS or TE-PTS)	CC_{mult} (IL-PTS or TE-PTS)
128	4	640	832
256		1536	1792
512		3584	3840

As a result, the simulation plots and the numerical calculations indicate that the proposed scheme can mitigate the PAPR value better than that of the IL-PTS method without an additional computational burden; with the consideration that the IL-PTS scheme has the lowest computational complexity among the conventional partitioning schemes in the PTS technique.

As a comparison, the schemes that proposed in reference [23] and [24] will be compared with the proposed scheme, TE-PTS, regarding to the PAPR reduction performance and computational complexity level. In [23] Jawhar proposed a new subblock partitioning scheme in PTS technique by dividing each subblock of IL-PTS scheme into two equal parts to generate several groups in each part, thereby some of the groups in each part are exchanged with each another. When N =256, V =4, and the CCDF probability of PAPR is 10^{-3}, the proposed partitioning scheme in reference [23] achieves better PRR percentage than that of the TE-PTS scheme, where the PRR percentage for the TE-PTS scheme is 6.077% compared with IL-PTS, while the PRR percentage for the proposed scheme in [23] is 9.97% compared with IL-PTS. This enhancement in PAPR performance of Jawhar's scheme was at the expense of computational complexity degradation, where the number of addition and multiplication operations of the TE-PTS scheme is lower than the proposed scheme in reference [23] by 57.14% and 36.36%, respectively. Therefore, the TE-PTS scheme is better than the proposed method in reference [23] regarding to the computational complexity level.

On the other hand, Chen [24] presented a modified PTS algorithm for PAPR reduction in OFDM systems by partitioning an OFDM block into non-disjoint OFDM sub-blocks. Chen's method depended on reshaping a QAM constellation into several QPSK constellations. When N = 256 and the CCDF probability of PAPR is 10^{-3}, the TE-PTS scheme achieves better PRR percentage than that of the method in [24], where the PRR percentage of the TE-PTS is 6.077% compared with IL-PTS, while the PRR percentage for Chen's method is 4.95% compared with IL-PTS; with the consideration that Chen's method divided the input data sequence into 8 subblocks, whereas the TE-PTS adopted only 4 subblocks. Moreover, the computational complexity of the proposed scheme in [24] is higher than the TE-PTS method, where the number of addition and multiplication operations for the TE-PTS scheme is lower than the Chen's method by 50% and 62.16%, respectively. Therefore, the TE-PTS scheme is better than Chen's method in terms of PAPR reduction performance and the computational complexity level.

6. Conclusion

In conclusion, this paper proposed a novel subblock partitioning scheme named terminals exchanging segmentation (TE-PTS) scheme in PTS technique. The TE-PTS scheme could improve the PAPR reduction performance better than that the interleaving partitioning scheme without additional computational complexity. The proposed scheme depended on subdividing each subblock of interleaving matrix into the specific subsets and exchanging the terminal samples of each subset with each other. Based on the results, the proposed scheme could enhance the PAPR reduction ratio about 6% better than that the IL-PTS scheme for any number of subcarriers. Furthermore, the proposed scheme has the computational complexity level similar to the IL-PTS scheme. Therefore, the TE-PTS scheme can be adopted as effective subblock partitioning scheme in the PTS technique to enhance the PAPR reduction performance with low computational complexity.

References

[1] R. Tsai and J. Huang, "PTS with non-uniform phase factors for PAPR reduction in OFDM systems," IEEE Communications Letters, vol. 12, no. 1, pp. 20-22, January 2008.

[2] W. Lim, J. Heo, and S. No, "An overview of peak-to-average power ratio reduction schemes for OFDM signals," IEEE Journal of Communications and Networks, vol. 11, no. 3, pp. 229-239, June 2009.

[3] H. Dhungana, K. Sah, and S. Shakya, "Performance evaluation of PAPR reduction in multicarrier system by PTS and SLM methods," Proc. IEEE Third Asian Himalayas International Conf. Internet, IEEE Press, January 2012, pp. 1-5.

[4] C. Yen, and C. Liu, "Hybrid OFDM/OOK modulations in OCDMA scheme for free space optics," Proceedings of Engineering and Technology Innovation, vol. 3, pp. 1-3, 2016.

[5] N. Taspiner and Y. T. Boskurt, "Peak-to-average power ratio reduction using backtracking search optimization algorithm in OFDM systems," Turkish Journal of Electrical Engineering & Computer Sciences, vol. 24, no. 4, pp. 2307-2316, January 2016.

[6] K. Pachori and A. Mishra, "An efficient combinational approach for PAPR reduction in MIMO–OFDM system," Wireless Networks. vol. 22, no. 2, pp. 417-425, February 2016.

[7] M. H. Hachemi, M. Feham, and H. E. Adardour, "Predicting the probability of spectrum sensing with LMS process in heterogeneous LTE networks," Radioengineering, vol. 25, no. 4, pp. 808-820, December 2016.

[8] R. Gerzaguet, N. Bartzoudis, L. Baltar, V. Berg, J. Doré, D. Kténas, et al., "The 5G candidate waveform race: a comparison of complexity and performance," EURASIP Journal on Wireless Communications and Networking, vol. 2017, no. 13, pp. 1-14, December 2017.

[9] J. Abdoli, M. Jia, and J. Ma, "Filtered OFDM: A new waveform for future wireless systems," Proc. 2015 IEEE 16th International Workshop on Signal Processing Advances in Wireless Communications, IEEE Press, August 2015, pp. 66-70.

[10] N. Taspinar, D. Karaboğa, M. Yildirim, and B. Akay, "Partial transmit sequences based on artificial bee colony algorithm for peak-to-average power ratio reduction in multicarrier code division multiple access systems," IET Communications, vol. 5, no. 8, pp. 1155-1162, May 2011.

[11] Y. A. Jawhar, R. A. Abdulhasan, and K. N. Ramli, "A new hybrid sub-block partition scheme of PTS technique for reduction PAPR performance in OFDM system," ARPN Journal of Engineering and Applied Sciences, vol. 11, no. 7, pp. 3904-3910, April 2016.

[12] M. Taher, M. Ismail, A. Samad, and T. Islam, "Reducing the power envelope fluctuation of OFDM systems using side information supported amplitude clipping approach," International Journal of Circuit Theory and Applications, vol. 42, no. 4, pp. 425-435, April 2014.

[13] C. Ni, Y. Ma, and T. Jiang, "A novel constellation amplitude modification method for PAPR reduction in OFDM systems," Wireless Communications and Mobile Computing, vol. 16, no.18, pp. 3307-3315, December 2016.

[14] L. Wang and C. Tellambura, "An overview of peak-to-average power ratio reduction techniques for OFDM systems," IEEE International Symposium on Signal Processing and Information Technology, IEEE Press, January 2007, pp. 840-845.

[15] H. Liang, C. Chu, and B. Lin, "Peak-to-average power ratio reduction of orthogonal frequency division multiplexing systems using modified tone reservation techniques," International Journal of Communication Systems, vol. 29, no. 4, pp. 748-759, March 2016.

[16] M. A. Taher, M. J. Singh, M. Ismail, S. A. Samad, M. T. Islam, and H. F. Mahdi, "Post-IFFT-modified selected mapping to reduce the PAPR of an OFDM system," Circuits, Systems, and Signal Processing, vol. 34, no. 2, pp. 535-555, February 2015.

[17] S. H. Han and J. H. Lee, "An overview of peak-to-average power ratio reduction techniques for multicarrier transmission," IEEE Wireless Communications, vol. 12, no. 2, pp. 56-65, February 2005.

[18] D. H. Lim and B. H. Rhee, "A low complexity PTS technique using threshold for PAPR reduction in OFDM systems," KSII Transactions on Internet and Information Systems, vol. 6, no. 9, pp. 2191-2201, September 2012.

[19] P. Varahram and B. M. Ali, "A low complexity partial transmit sequence for peak to average power ratio reduction in OFDM systems," Radioengineering. vol. 20, no. 3, pp. 677-682, September 2011.

[20] C. Hong, Q. Qin, and T. Chao, "An PTS optimization algorithm for PAPR reduction of OFDM system," Proc. IEEE International Conf. Mechatronic Sciences, Electric Engineering and Computer, IEEE Press, December 2014, pp. 3775-3778.

[21] Z. T. Ibraheem, M. M. Rahman, S. Yaakob, M. S. Razalli, F. Salman, and K. K. Ahmed, "PTS method with combined partitioning schemes for improved PAPR reduction in OFDM system," Indonesian Journal of Electrical Engineering and Computer Science, vol. 12, no. 11, pp. 7845-7853, November 2014.

[22] Y. Jawhar, S. Shah, M. Taher, M. Ahmed, and K. Ramli, "An enhanced partial transmit sequence segmentation schemes to reduce the PAPR in OFDM systems," International Journal of Advanced Computer Science and Applications, vol. 7, no. 12, pp. 66-75, 2016.

[23] Y. Jawhar, S. Shah M. Taher, M. Ahmed, K. Ramli, and R. Abdulhasan, "A low PAPR performance with new segmentation schemes of partial transmit sequence for OFDM systems," International Journal of Advanced and Applied Sciences, vol. 4, no. 4, pp. 14-21, April 2017.

[24] H. Chen and K. Chung, "A PTS technique with non-disjoint sub-block partitions in M-QAM OFDM systems," IEEE transactions on Broadcasting, vol. 64, no. 1, pp. 146-152, March 2018.

[25] A. Elshirkasi, M. U. Siddiqi, and M. H. Habaebi, "Generalized discrete fourier transform based improvement of partial transmit sequence scheme to reduce PAPR in OFDM systems," Journal of Theoretical & Applied Information Technology, vol. 76, no. 1, pp. 76-81, June 2015.

[26] H. L. Hung, "Using evolutionary computation technique for trade-off between performance peak-to average power ration reduction and computational complexity in OFDM systems," Computers and Electrical Engineering, vol. 37, pp. 57-70, 2011.

[27] Y. A. Jawhar, R. A. Abdulhasan, and K. N. Ramli, "Influencing parameters in peak to average power ratio performance on orthogonal frequency-division multiplexing system," ARPN Journal of Engineering and Applied Sciences, vol. 11, no. 6, pp. 4322-4332, March 2016.

[28] T. Jiang, W. Xiang, C. Richardson, J. Guo, and G. Zhu, "PAPR reduction of OFDM signals using partial transmit sequences with low computational complexity," IEEE Transactions on Broadcasting, vol. 53, no. 3, pp. 719-724, September 2007.

[29] L. Wang, G. Wu, L. Dan, and Y. Xiao, "A time-domain PTS without side information in SC-FDMA systems," Proc. 7th International Conf. Wireless Communications, Networking and Mobile Computing, IEEE Press, October 2011, pp. 1-4.

[30] Z. T. Ibraheem, M. Rahman, N. Yaakob, M. S. Razalli, S. A. Dawood, and K. K. Ahmed, "Performance comparison of partitioning PTS based PAPR reduction of OFDM systems under different modulations techniques," Journal of Theoretical and Applied Information Technology, vol. 66, no. 3, pp. 775-781, August 2014.

[31] L. Xia, X. Yue, T. Youxi, and L. Shaoqian, "A novel method to design phase factor for PTS based on pseudo-random sub-block partition in OFDM system," Proc. IEEE 66th Vehicular Technology Conference, IEEE Press, October 2007, pp. 1269-1273.

[32] Z. T. Ibraheem, M. M. Rahman, S. N. Yaakob, M. S. Razalli, R. A. Kadhim, and K. K. Ahmed, "Performance of PTS techniques with varied partition size in PAPR reduction of OFDM system," Proc. IEEE International Conf. Computer, Communications, and Control Technology, IEEE Press, October 2014, pp. 21-25.

[33] M. Vidya, M. Vijayalakshmi, and K. Ramalingareddy, "Performance enhancement of efficient partitioning technique for PAPR reduction in MIMO-OFDM system using PTS," Proc. IEEE Conference Proceedings on Power, Control, Communication and Computational Technologies for Sustainable Growth, IEEE Press, July 2016, pp. 247-253.

[34] S. Wen, Y. Xiao, Q. Li, H. Kayama, and C. Yan, "The implement of low-PAPR OFDM system," Proc. IEEE International Conf. Communications, Circuits and Systems, IEEE Press, July 2006, pp. 1226-1229.

[35] S. G. Kang, J. G. Kim, and E. K. Joo, "A novel subblock partition scheme for partial transmit sequence OFDM," IEEE Transactions on Broadcasting, vol. 45, no. 3, pp. 333-338, September 1999.