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A New Subblock Segmentation Scheme in Partial Transmit Sequence for Reducing PAPR Value in OFDM Systems

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Abstract: Partial transmit sequence (PTS) is considered an efficient algorithm to alleviate the high peak-to-average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) systems. The PTS technique is depended on the partitioning the input data sequence into the several subblocks, and then weighting these subblocks with a group of the phase factors. There are three common types of partitioning schemes: interleaving scheme (IL-PTS), adjacent scheme (Ad-PTS), and pseudo-random scheme (PR-PTS). The three conventional partitioning schemes have various performances of the PAPR value and the computational complexity pattern which are considered the main problems of the OFDM system. In this paper, the three ordinary partition schemes are analyzed and discussed depending on the capability of reducing the PAPR value and the computational complexity. Furthermore, new partitioning scheme is introduced in order to improve the PAPR reduction performance. The simulation results indicated that the PR-PTS scheme could achieve the superiority in PAPR mitigation compared with the rest of the schemes at the expense of increasing the computational complexity. Furthermore, the new segmentation scheme improved the PAPR reduction performance better than that the Ad-PTS and IL-PTS schemes.

Keywords: PTS, PAPR, OFDM, PR-PRS, Ad-PTS, IL-PTS

1. Introduction

Orthogonal frequency division multiplexing (OFDM) has become a reliable modulation technique for high-speed data rate frameworks. The OFDM system overcomes to the other multicarrier systems by some distinctive features, for example, high system capacity, efficient bandwidth utilization, and robustness against multipath fading [1]. Consequently, the OFDM system considered by the numerous communication systems such as the broadcast radio access network (BRAN) [2], the 4G mobile communication systems for both long-term-evaluation (LTE) standard [3], and is chosen as one of the candidates for the next generation (5G) data transmission system [4].

Although the OFDM systems have many advantages, the high PAPR value is considered a major drawback restricts the system in the real applications, because the system has non-linearity devices such as high power amplifiers (HPA) [5]. The conventional solution to restrain the high PAPR is to use HPAs with large linear scope, but these power amplifiers are typically costly and lead to the increase of system complexity [6]. Therefore, many techniques have been introduced to limit the high PAPR as a successful arrangement without additional costs such as clipping and filtering [7], peak windowing [8], selective mapping (SLM) [9], and partial-transmit-sequences (PTS) [10]. Among these techniques, the PTS method is considered an efficient algorithm to alleviate the high PAPR value, whereas its computational complexity is considered relatively high. The basic concept of the PTS method is segmentation the input symbol into the subsets and rotated them with a group of the phase weighting factors before combining the subsets again and transmission to the receiver. Consequently, the PTS methods depended on two stages for its operation; the partitioning scheme and the weighting rotation factors [11].

In literature, many algorithms have been suggested to improve the PAPR lessening performance depending on combination two partitioning schemes, for example, Hong et al. in 2013 [12] and Ibraheem et al. in 2014 [13] were combined two kinds of the segmentation schemes in order to restrain the high PAPR value. In addition, Jawhar et al. in 2016 [14], [15] presented new algorithms by combining two types of the partitioning schemes. Reference [16] showed five new segmentation schemes to

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enhance the PAPR reduction capacity without extra computational complexity.

In this paper, the PAPR and computational complexity performance of the three ordinary segmentation schemes are analyzed and simulated with two scenarios. Furthermore, a new segmentation scheme named transpose-PTS (T-PTS) scheme is introduced to improve the PAPR reduction performance without increasing the complexity of the system.

2. OFDM System and PAPR

In the OFDM framework, the input data sequence X_k = {k = 0, 1, 2, …, N-1} is mapped by one of the modulation techniques like quadrate amplitude modulation (QAM), where N denotes the number of the subcarriers. The baseband signal is converted from the serial into the parallel and then performing IFFT operation to modulate the baseband signal with N subcarriers orthogonally. The discrete signal $x(n)$ in the time-domain can be described as

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

where $j=\sqrt{-1}$. To calculate the PAPR value accurately, the baseband OFDM signal is sampled at the Nyquist rate. The oversampling operation is done by embedding (L-1) N zeros between the samples of the baseband OFDM signal [17], where (L) denotes the oversampling factor, so that $x(n)$ can be written as

$$x(n)=\frac{1}{\sqrt{NL}}\sum_{k=0}^{NL-1}X_k e^{j2\pi k\frac{n}{NL}}\ , \ 0\le n\le NL-1. \qquad (2)$$

On the other hand, the output OFDM signal is obtained by superposition of the N subcarriers with the samples of the baseband signal. Hence, when the phases of these samples are in high consistency, some of these samples might be added together, and the instantaneous power of these samples rises significantly to become much higher than the mean power of the signal. This fluctuation of the signal is named PAPR, and it is defined the maximum peak power of the OFDM signal divided by the mean power [18]. The PAPR is measured in decibel (dB), and it can be written by

$$\text{PAPR}=\frac{\max|x(n)|^2}{E\{|x(n)|^2\}}, \qquad (3)$$

where $E\{.\}$ is the mean value of the OFDM signal. The complementary cumulative distribution function (CCDF) is utilized to measure the probability of PAPR value that exceeding a specific threshold value. Accordingly, the CCDF distribution of the PAPR values is expressed by [19].

$$\Pr(\text{PAPR}>PAPR_0)=1-(1\text{-}\exp(-PAPR_0))^{NL}. \qquad (4)$$

where Pr(.) is the probability of the PAPR value, and PAPR0 represents the threshold value.

3. Conventional PTS (C-PTS)

The C-PTS strategy has been viewed as the significant probabilistic scenario to decrease the high PAPR pattern in OFDM framework. However, the computational complexity is the prominent drawback of the C-PTS method, because the system should perform a comprehensive search to select the optimum phase factor.

The principle idea of the C-PTS algorithm is clarified in the Fig. 1, where the input data sequence X is divided by one of the segmentation schemes into several of the subblocks Xv, as shown below

$$X=\sum_{v=1}^{V}X_v\ , \qquad (5)$$

where V represents the number of subblocks and the subscript {v = 1, 2, …, V}. Next, the subblocks are multiplied by a set of unity amplitude phase factor (b_v). After that, The N-IFFT is applied to modulate the data samples into the subcarriers, and then the data is transformed from the frequency-domain into the time-domain. In addition, the phase rotation factors are transformed into the time-domain by exploitation the linear property of the Inverse-Discrete-Fourier-Transform (IDFT). Afterwards, the subblocks are rotated with the weighting factors to produce a group of the candidate signals named partial transmit sequences (pts_s). At last, the PAPR values of the pts_s are calculated, and the optimum phase rotation factor that achieved the lower PAPR value is multiplied with the combined subblocks to generate the OFDM signal,

$$x=\text{IFFT}\{\sum_{v=1}^{V}b_v X_v\}, \qquad (6)$$

$$x=\sum_{v=1}^{V}b_v\,\text{IFFT}\{X_v\}, \qquad (7)$$

$$\text{OFDM signal}=\sum_{v=1}^{V}b_v x_v\ . \qquad (8)$$

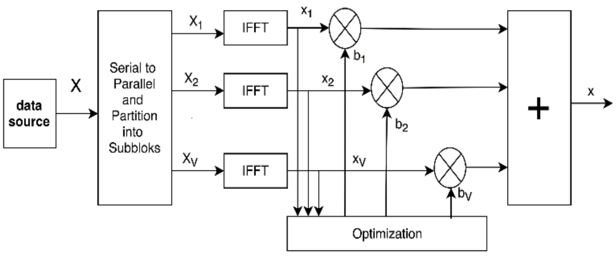

Fig. 1 C-PTS block diagram [15]

Besides, the phase rotation factors are usually limited to $b_v \in \{\pm 1\}$ or $\{\pm 1, \pm j\}$ in order to decrease the complex multiplications [20]. Therefore, the phase factor vector can be expressed as

$$b_v=[b_1,b_2,...,b_V], \qquad (9)$$

and,

$$b = \{b_v = e^{j2\pi v/W} \mid v = 0,1,.......,W-1\}, \quad (10)$$

where W represents the number of the different phase rotation factors. The optimum phase weighting factor which achieves the minimum PAPR is obtained by

$$\{b_1, b_2, ..., b_v\} = \underset{1 \le w \le W}{\arg\min} \left(\max_{0 \le n \le NL-1} \left| \sum_{v=1}^{V} b_v x_v \right| \right), \quad (11)$$

where arg min is achieving a global minimum value of the phase rotation factors. Furthermore, the computation complexity of the C-PTS method is considered high because finding the optimum phase rotation factor needs to examine W^{V-1} operations. In addition, the transmitter should send ($\log_2 W^{V-1}$) bits as the side information (SI) to the receiver to regain the original data. Therefore, the C-PTS technique relies on the segmentation scheme type, the number of the subblocks (V), the phase weighting factors, and the number of the different phase weighting factors (W) [21].

4. Ordinary Partitioning Schemes

In the C-PTS technique, there are three common kinds of segmentation schemes including interleaving segmentation (IL-PTS), adjacent segmentation (Ad-PTS), and pseudo-random segmentation (PR-PTS) [22]. Fig. 2 shows the three conventional segmentation schemes. The segmentation schemes must fulfill the follows:

i. All the subblocks must be equivalent in size.
ii. Each subblock must have N/V active subcarriers, and the other locations should set to zeros
iii. Each subcarrier must assign only one time inside the subblocks.
iv. The subblocks must be non-overlapping with each other.

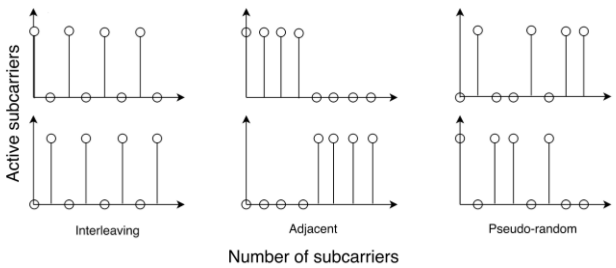

Fig. 2 Ordinary partitioning schemes [22]

In the IL-PTS scheme, the subcarriers are assigned with equally spaced of V locations inside each subblock. The Ad-PTS scheme allots the sequential subcarriers within each subblock, successively. However, the PR-PTS scheme assigns the subcarriers within the subblocks.

The three ordinary segmentations schemes have different PAPR performance based the subcarriers correlations within the subblocks [23]. The IL-PTS scheme records the worse PAPR lessening capacity among the partitioning schemes, because of the large peak correlation between its subcarriers. The PAPR reduction capacity of the PR-PTS is considered the best among ordinary schemes because its random pattern reduces the peak correlation among the subcarriers. However, the Ad-PTS scheme has PAPR performance lower than PR-PTS and higher than IL-PTS based on the subcarriers correlations.

Also, the computational complexity of the PR-PTS and Ad-PTS schemes are equaled. This can attribute of that the PR-PTS and Ad-PTS should implement all the stages of the IFFT to transmit the subblocks from the frequency-domain into the time-domain. In contrast, the IL-PTS scheme has low computation complexity when using Cooly-Tukey IFFT algorithm [24]. Because of the periodic transition of the subcarriers, the IL-PTS scheme does not perform all the IFFT stages to transform the subblock into the time- domain. Accordingly, the number of addition and multiplication operations of the IL-PTS scheme are fewer than that of the other ordinary schemes.

5. Computational Complexity Analysis

In the C-PTS technique, the computational complexity can be divided into three parts as follows:

i. The computational complexity of IFFT performing

The computational complexity of this part is the addition and multiplication operations of the IFFT performing. This complexity depends on the type of the segmentation scheme and the number of the subblocks. The number of addition operations (C_{add}) and multiplications operations (C_{mult}) for the ordinary segmentation schemes can be defined as [25].

a) PR-PTS and Ad-PTS computational complexity

$$C_{add} = V\,(N \log_2 N) \quad (12)$$

$$C_{mult} = V\,(\frac{N}{2} \log_2 N) \quad (13)$$

b) IL-PTS computational complexity

$$C_{mult} = V\,(\frac{N}{2} \log_2 N) \quad (14)$$

$$C_{mult} = V\,(\frac{N}{2V} \log_2 \frac{N}{V} + N) \quad (15)$$

ii. The computational complexity for finding the optimum phase factor

This computational complexity is because of performing the phase rotation factors in the time-domain, and it rises exponentially with increment the number of the subblocks. The C_{add} and C_{mult} operations can be expressed as [25]

$$C_{add} = W^{V-1} N (V-1) \quad (16)$$

$$C_{mult} = W^{V-1} N (V+1) \quad (17)$$

iii. The computational complexity of the pts_s comparison

This part of the complexity is because of the comparison the pts_s in order to select the best OFDM signal, and it can be written as

$$C_{comp} = W^{V-1}(N-1) \quad (18)$$

6. Proposed Scheme

A new partitioning scheme named transpose PTS scheme (T-PTS) works to transpose the IL-PTS matrix into the Ad-PTS matrix, to enhance the PAPR execution better than both IL-PTS and Ad-PTS. However, its computational complexity is similar to that of the Ad-PTS method, because the subcarriers of the T- PTS are distributed as same as the pattern of the Ad-PTS scheme.

Fig. 3 clarifies the procedure of the T-PTS scheme, in which the input sequence is partitioned into V subblocks by using the IL-PTS scheme. After that, the IL-PTS matrix is separated into S_P groups, where each row contains N/V groups and the subscript $P = \{1, 2, \ldots, N/V\}$. Afterward, the S_1 group is transposed to be the first column of the new matrix, and the S_2 group becomes the second column, and the process continues until $S_{N/V}$ group. This pattern proceeds to all groups of the IL-PTS matrix. Therefore, the new matrix allocates the subcarriers sequentially similarly to that of the Ad-PTS scheme as Fig.3.

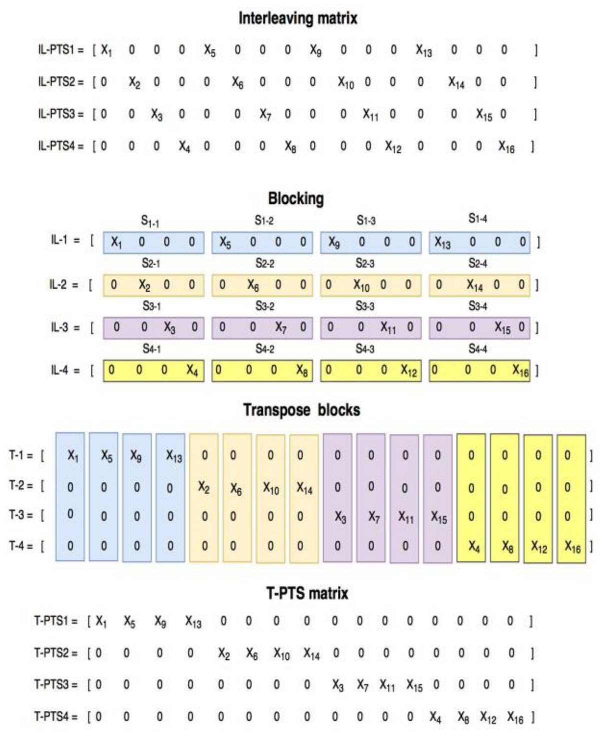

Fig. 3 T-PTS scheme when V=4 and N=16

Mathematically, the T-PTS scheme can be represented in the equations below

$$X^{\text{IL-PTS}} = \sum_{v=1}^{V} X_v^{\text{IL-PTS}} \tag{19}$$

$$X^{\text{IL-PTS}} = \sum_{v=1}^{V} [X_{v,S_1}^{\text{IL-PTS}}, X_{v,S_2}^{\text{IL-PTS}}, \ldots, X_{v,S_{N/V}}^{\text{IL-PTS}}] \tag{20}$$

$$X^{\text{T-PTS}} = \sum_{v=1}^{V} \left\{ [X_{v,S_1}^{\text{IL-PTS}}]^{\text{T}}, [X_{v,S_2}^{\text{IL-PTS}}]^{\text{T}}, \ldots, [X_{v,S_{N/V}}^{\text{IL-PTS}}]^{\text{T}} \right\} \tag{21}$$

$$X^{\text{T-PTS}} = \sum_{v=1}^{V} [X_{v,S_1}^{\text{IL-PTS}}, X_{v,S_2}^{\text{IL-PTS}}, \ldots, X_{v,S_{N/V}}^{\text{IL-PTS}}]^{\text{T}} \tag{22}$$

$$X^{\text{T-PTS}} = \sum_{v=1}^{V} [X_{v,S_P}^{\text{IL-PTS}}]^{\text{T}} \quad , 1 \le P \le N/V \tag{23}$$

The T-PTS algorithm leads to diminishing the correlation among the subcarriers within the subblocks. Moreover, the superiority of the Ad-PTS method is due to the new scheme does not organize the order of subcarriers inside the subblock successively. Therefore, T-PTS can accomplish PAPR reduction performance more prominently than both Ad-PTS and IL-PTS.

7. Results and Discussion

In this part, the three types of the segmentation schemes are compared with the original OFDM signal (without C-PTS), and the new segmentation scheme, T-PTS is simulated and compared with the IL-PTS and Ad-PTS schemes. The parameters of this simulation are: the oversampling factor L is fixed to 4, the subcarriers N = 128 and 256, the number of subblocks V equals to 2, 4 and 8, while the different phase factors W is set to 2 and 4. Moreover, 10^3 OFDM symbols are evaluated by applying CCDF function, and 16-QAM modulation is utilized to map the input data.

At first, the simulation is conducted when N = 128, and 256, whereas V and W are set to 4, as shown in Fig. 4, Fig. 5. The comparison shows that the PAPR reduction performance of the PR-PTS surpassed the original OFDM signal by 3.85dB and 3.45dB for both scenarios, respectively. Likewise, the PAPR reduction capacity of the Ad-PTS scheme was better than the original OFDM in both scenarios by 3.11dB and 2.75dB, respectively. In addition, the PAPR value of the IL-PTS was reduced compared with the original OFDM in both scenarios by 2.80dB, and 2.38dB, respectively. Accordingly, the PR-PTS method outperforms to the other segmentation methods Ad-PTS and IL-PTS for any number of the subcarriers.

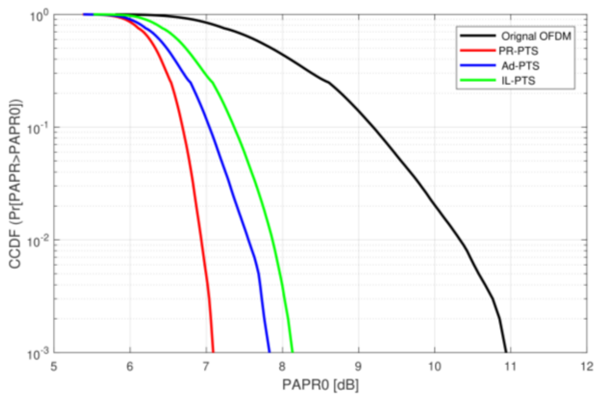

Fig. 4 Comparison the ordinary partitioning schemes when V = 4, W = 4, and N = 128

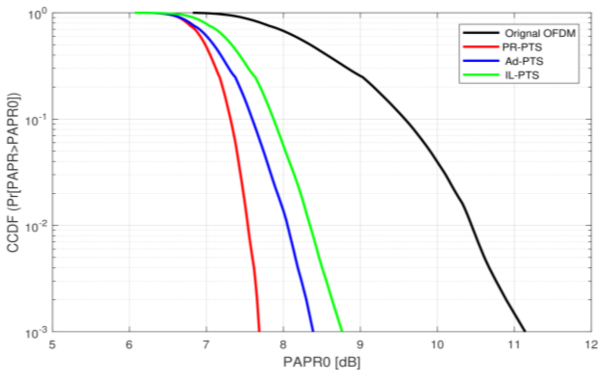

Fig. 5 Comparison the ordinary partitioning schemes when V = 4, W = 4, and N = 256

Secondly, the PAPR reduction performance of the T-TS scheme is compared with Ad-PTS, IL-PTS, and the original OFDM signals, as shown in Fig. 6 and Fig. 7. The number of subcarriers is fixed to 128 in Fig. 6, and 256 in Fig.7. The proposed method, T-PTS, could reduce the PAPR value about 3.36dB compared with the original signal when N=128, whereas the PAPR value was 3.15dB when N=256. In addition, the T-PTS scheme was superior to the Ad-PTS scheme by 0.36dB, and 0.37dB for both scenarios. Similarly, T-PTS outperformed the IL-PTS scheme in both scenarios by 0.68dB, and 0.56Db, respectively. It is obvious that the T-PTS method can achieve better PAPR reduction performance than that of the Ad-PTS and IL-PTS schemes.

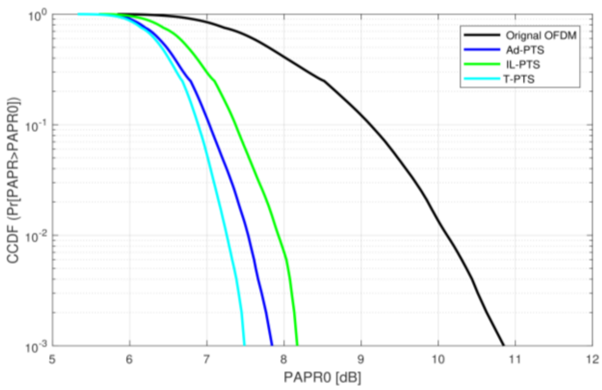

Fig. 6 Comparison T-PTS with Ad-PTS and IL-PTS when V = 4, W = 4, and N = 128

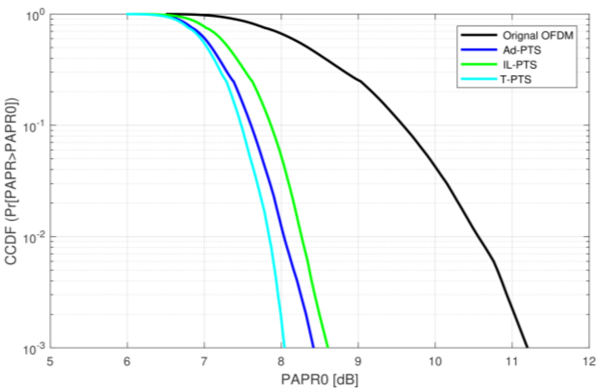

Fig. 7 Comparison T-PTS with Ad-PTS and IL-PTS when V = 4, W = 4, and N = 256

Thirdly, the comparisons between the T-TS scheme the and the other schemes with a various number of V and W are conducted in Fig. 8 and Fig. 9. In Fig. 8, dashed-lines refer to the PAPR performances when W=2 and V=4, whereas the solid-lines refer to the PAPR performances when W=2 and V=2. Furthermore, Fig. 9 illustrates another comparison of the PAPR reduction performances of the T-PTS scheme and the other related schemes, where the dashed-lines refer to the PAPR performances when W=2 and V=8, whereas the solid-lines refer to the PAPR performances when W=4 and V=2. It is clear that the T-PTS scheme can achieve superiority over Ad-PTS and IL-PTS in terms of PAPR reduction performance for any value of V and W.

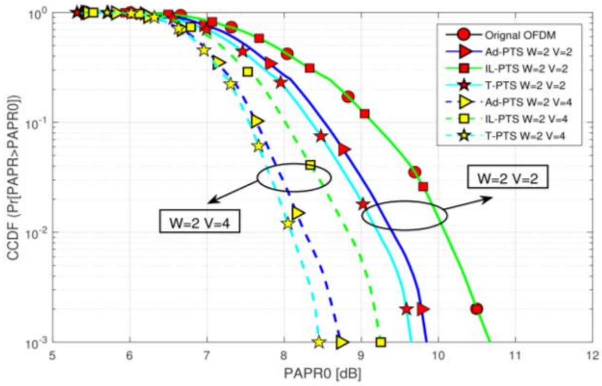

Fig. 8 Comparison T-PTS with Ad-PTS and IL-PTS when (W=2, V=2) and (W=2, V=4), N = 128

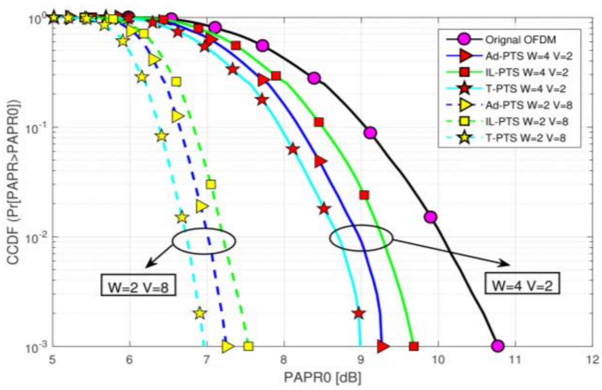

Fig. 9 Comparison T-PTS with Ad-PTS and IL-PTS when (W=4, V=2) and (W=2, V=8), N = 128

Fourthly, the T-PTS scheme does not largely change the PAPR performance when the modulation families changing, where the PAPR performance is simulated based on various modulation families (BPSK, QPSK, and 16-QAM), as shown in Fig. 10. 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 BPSK, QPSK, and 16-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 with changing the type of the modulation scheme [26]. In general, different types of the modulation schemes have a small influence on the peak to average power ratio performance.

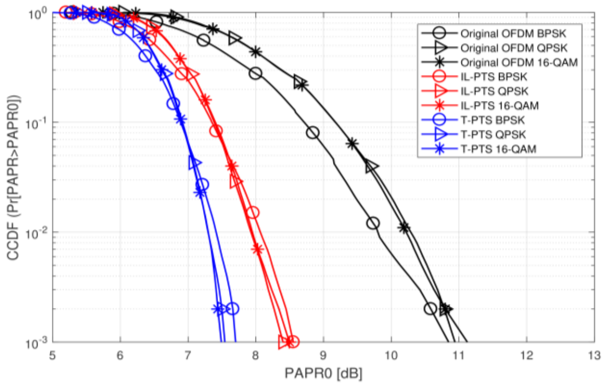

Fig. 10 Comparison the PAPR performances of various modulation families when *W*=4, *V=4* and *N* = 128

On the other hand, Table 1 recorded the computational complexity of the three ordinary segmentation schemes when numbers *N*= 128, and 256, while *V*, and *W* are set to 4. The computational complexity of the system is divided into the IFFT complexity, phase factors complexity, and comparison complexity. As mentioned, the computational complexity of the PR-PTS, Ad-PTS, and T-PTS schemes are the same value, because of all the stages of the IFFT are performed when transforming the subblocks into the time-domain. In contrast, the IL-PTS scheme recorded less computational complexity compared with other schemes because it needs fewer stages of the IFFT to transfer the subblocks into the time domain.

Table 1 Computational complexity of the subblocks partitioning schemes

PTS	IFFT complexity		Phase factors complexity		Total system complexity	
	C_{add}	C_{mult}	C_{add}	C_{mult}	C_{add}	C_{mult}
N=128						
PR-PTS	3584	1792	24576	40960	28160	42752
Ad-PTS						
T-PTS						
IL-PTS	640	832	24576	40960	25216	41792
N=256						
PR-PTS	8192	4096	48384	80640	56576	84736
Ad-PTS						
T-PTS						
IL-PTS	1536	1792	48384	80640	49920	82432

8. Summary

In this paper, the C-PTS strategy for reducing the high PAPR value in OFDM system is analyzed in terms of partitioning schemes and computational complexity. Furthermore, new partitioning scheme named T-PTS is introduced to improve the PAPR reduction performance better than that two types of the ordinary subblock partitioning schemes, Ad-PTS, and IL-PTS. Also, the computational complexity of the partitioning schemes was analyzed, and the numerical calculations of the PR-PTS, Ad-PTS, and T-PTS recorded the same number of the addition and multiplication operations. However, the IL-PTS scheme recorded less value of the computational complexity compared with the other schemes. Therefore, the proposed scheme, T-PTS can reduce the PAPR reduction performance better than that of the Ad-PTS without increasing the computational complexity.

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