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# An Analysis on the Conventional Partitioning Schemes of Partial Transmit Sequence in OFDM Systems

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## ABSTRACT

Partial transmit sequence (PTS) is considered an efficient algorithm to overcome the problem of high peak to average power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) systems. PTS technique is depending on the partitioning of the input data sequence into the several subblocks, and weighting these subblocks with a set of the phase rotation 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 ordinary partitioning schemes have various performances in terms of the PAPR reduction and the computational complexity. In this paper, the three ordinary partition schemes are analyzed and discussed depending on the PAPR mitigation performance and the computational complexity. The simulation results indicated that the PR-PTS scheme could achieve the superiority in terms of PAPR reduction compared with other schemes. Furthermore, the numerical calculations recorded that the computational complexity of the ordinary partitioning schemes increases exponentially with increasing the number of the subblocks.

**Key words :** PTS; PAPR; OFDM; PR-PRS; Ad-PTS; IL-PTS.

## 1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) has been become a dependable modulation technique for high-speed data rate systems. Due to the distinguishing features of OFDM frameworks, many wireless systems adopted the OFDM as a reliable data trans-mission technique in modern communication environments. The OFDM system is differentiated by some distinctive features, for example, high system capacity, the efficiency of bandwidth utilization, immunity to inter-symbol-interference, and robustness against multipath fading [1] [2]. Consequently, the OFDM system adopted by numerous communication systems such as broadcast radio access network (DRAN), digital video broadcasting (DVB), and digital television broadcasting (DTVB) [3] [4]. Moreover, the 4G mobile communication systems adopted the OFDM technique in downlink transmission data for both long-term-evaluation (LTE) standard and worldwide interoperability for microwave access (WiMAX) standard [5] [6].

Although the OFDM systems have many advantages, the high PAPR is regarded a major drawback which faces the system in the real applications. The high PAPR runs some devices such as high power amplifier (HPA) out of the linear scope of these devices. Hence, the spectral efficiency and the inter-symbol-interference (ISI) for the system are deteriorated [7]. The conventional solution to restrain the high PAPR is using HPA with large linear scope, but these power amplifiers are typically costly and increase the complexity of the system. Therefore, many techniques have been proposed to limit the high PAPR as a successful arrangement without additional cost such as coding techniques, clipping and filtering [8], peak windowing [9], selective mapping (SLM) [10], and partial transmit sequences (PTS) [11]. Among these techniques, the PTS method is considered an efficient algorithm to alleviate the high PAPR value, whereas its computational complexity considered relatively high. The basic idea of the PTS method is partitioning the input data symbols into subblocks and then modulation the data subblocks with subcarriers by applying inverse fast Fourier transform (IFFT). The transferred subblocks are rotated with the phase weighting factors and combined again before transmission to the receiver. Consequently, the PTS methods depended on two stages for its operation; the partitioning scheme and the weighting rotation factors [12].

In the PTS method, three conventional segmentation schemes have been adopted to partition the data block. The conventional partitioning schemes have various performances for PAPR reduction and computational complexity. In addition, the phase rotation factors increase the computational complexity of the system.

In literature, many algorithms have been proposed to improve the PAPR mitigation performance of the PTS method, for example, Hong et al in 2013 [13] and Ibraheem et al in 2014 [14] were combined two kinds of the segmentation schemes together in order to restrain the high PAPR. In addition, Jawhar et al in 2016 [15] presented a new algorithm by combining two partitioning scheme. Reference [16] showed five new segmentation schemes to enhance the PAPR alleviation rendering without extra computational complexity. On the other hand, the authors in [17] and [18] suggested new techniques decrease the computational complexity of the OFDM system.

In this paper, the three ordinary segmentation schemes are analyzed and simulated with several scenarios. Furthermore, the computational complexity of the conventional partitioning schemes was calculated with various scenarios. The comparison of the ordinary partitioning schemes appears the PR-PTS superior to the other ordinary schemes in PAPR reduction, whereas, IL-PTS has lower computational complexity for any number of subcarriers. Further-more, the computational complexity increases when the number of the subblocks is increased.

The paper is organized as follows: Section 2 explained the OFDM system and the PAPR problem. The conventional PTS is discussed in Section 3. Section 4 and Section 5 analyzed the ordinary partitioning schemes and the computational complexity of the C-PTS. The results and discussion are presented in Section 6. Finally, the conclusion remarks are written in Section 7.

## 2. OFDM SYSTEM AND PAPR

In the OFDM, The input data sequence $X_k$ = {k = 0, 1, 2, …, N-1} is mapped by one of the modulation techniques such as phase shifting keying (PSK), and quadrate amplitude modulation (QAM), where N denotes the number of the subcarriers. The baseband signal is converted from the serial into parallel and then performing IFFT to modulate the baseband signal with N subcarriers orthogonally [19]. The discrete baseband signal *x(n)* in the time-domain can be written as

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

where $j = \sqrt{-1}$ .

To calculate the PAPR value accurately, the baseband OFDM signal which is sampled at Nyquist rate can be extended by the oversampling factor (*L*). The oversampling operation is done by embedding (*L*-1) N zeros between the samples of the baseband OFDM signal [20]. Therefore, the continuous baseband OFDM signal with *L*>4 is sufficient to calculate the PAPR precisely, so that *x(n)* can be defined as

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

where *L* represents the oversampling factor. 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 theses samples are in large consistency, some of these samples might be added together, and the instantaneous power of these samples rises greatly to become much larger than the mean power of the signal. This fluctuation of the signal is named the PAPR, and it defined the maximum peak power of the OFDM signal divided by the mean power [21]. The PAPR is measured in decibel [dB], and it can be expressed by

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

where *E{.}* represents 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 certain threshold value. Accordingly, the CCDF of the PAPR values can be written as [22]

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

where *Pr* is the probability of the PAPR value and *PAPR0* represents the threshold value.

## 3. CONVENTIONAL PTS (C-PTS)

C-PTS strategy has been viewed as the powerful probabilistic technique to decrease the high PAPR pattern in OFDM framework. The PTS method is classified as an effective PAPR reduction method which outperformed to other signal scrambling methods such as selective mapping method and interleaving method. 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.

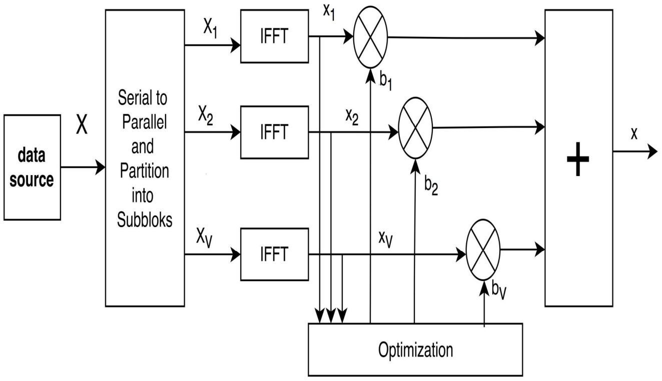

**Figure 1:** C-PTS block diagram [16]

The principle idea of the C-PTS method is shown in the Figure 1, where the input data sequence $X$ is divided by one of the segmentation schemes into several of the subblocks $X_v$, as shown below.

$$X = \sum_{v=1}^{V} X_v \tag{5}$$

where $V$ represents the number of subblocks and the subscript $\{v = 1, 2, \ldots\ldots, V\}$. 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 in the time-domain are rotated by the weighting factors to generate a set of the candidate signals named PTS, Finally, the PAPR of the PTSs are calculated, and the optimum phase rotation factor that achieved the lower PAPR value is selected to multiplying by the combined subblocks. Hence, the OFDM signal which has the lowest PAPR value is transmitted to the receiver. The output OFDM signal can be expressed as

$$x = \text{IFFT}\{\sum_{v=1}^{V} b_v X_v\} \tag{6}$$

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

$$\text{OFDM signal} = \sum_{v=1}^{V} b_v x_v \tag{8}$$

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 [23]. Therefore, the phase factor vector can be expressed as

$$b_v = [b_1, b_2, \ldots, b_V] \tag{9}$$

$$b = \{b_v = e^{j 2\pi v / W} \mid v = 0, 1, \ldots\ldots, W - 1\} \tag{10}$$

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

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

where are 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 of finding the optimum phase rotation factor needs to examine $W^{V-1}$ operations; with the consideration that the first phase factor is fixed to 1 without loss of performance. In addition, the transmitter should send ($\log 2W^{V-1}$) bits as the side information (SI) to the receiver side in order to recover the original data sequence. Therefore, the C-PTS technique relies on the partitioning scheme type, the number of the subblocks ($V$), the phase rotation factors, and the number of the different phase rotation factors ($W$) [24].

## 4. ORDINARY PARTITIONING SCHEMES

In C-PTS method, there are three common kinds of segmentation schemes including interleaving segmentation (IL-PTS), adjacent segmentation (Ad-PTS), and pseudo-random segmentation (PR-PTS) [25]. Figure 2 shows the three conventional segmentation schemes. The segmentation schemes must fulfill the following conditions:

1. All the subblocks must be equivalent in size.
2. Each subblock must have $N/V$ active subcarriers, and the other locations should set to zeros.
3. Each subcarrier must assign only one time inside the sub-blocks.
4. The subblocks must be non-overlapping with each other.

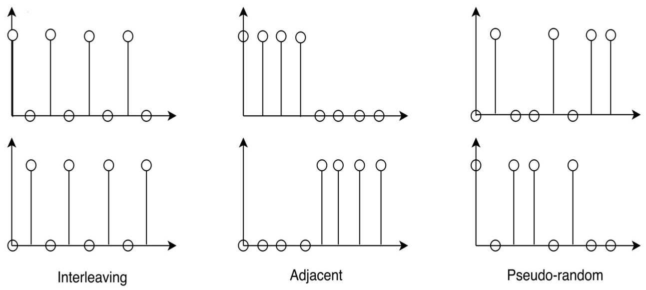

**Figure 2:** Ordinary partitioning schemes [16]

In 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 randomly [26].

The three ordinary segmentations schemes have different PAPR diminishment execution depending on the subcarriers autocorrelations within the subblocks. The IL-PTS scheme records the worse PAPR diminishing performance among the partitioning schemes, because of the large peak correlation between its subcarriers. The PAPR alleviation implementation of the PR-PTS is considered the best among ordinary segmentation. This can attribute of the random pattern of PR-PTS structure which leads to the subcarriers correlation to be a minimum value. However, the Ad-PTS scheme can achieve the reduction in PAPR value lower than that of the PR-PTS scheme and better than that of the IL-PTS scheme [27].

In contrast, the computational complexity of the three segmentation schemes is equivalent in both PR-PTS and Ad-PTS schemes. This can attribute of that the PR-PTS and Ad-PTS should implement all the stages of the IFFT to convert the subblocks from the frequency-domain into the time-domain. However, the IL-PTS scheme has lower computation complexity among the ordinary partitioning schemes when using Cooly-Tukey IFFT algorithm [28]. Because of the periodic transition of the subcarriers, the IL-PTS scheme does not perform all the IFFT stages to transform the subblock from the frequency domain into the time- domain. Hence, the number of additions and multiplications of the IL-PTS scheme are less than that of the other ordinary schemes. Therefore, there is a trade-off between the PAPR diminishment execution and the computational complexity of the conventional segmentation schemes.

## 5. COMPUTATIONAL COMPLEXITY ANALYSIS

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

### 5.1 The computational complexity of the IFFT performing

The computational complexity of this part is the additions and multiplications of the IFFT performing. This complexity depends on the type of the partitioning scheme and the number of the subblocks. The additions computational complexity ($C_{add}$) and the multiplications computational complexity ($C_{mult}$) for the conventional segmentation schemes can be expressed as [25]

1. PR-PTS and Ad-PTS computational complexity

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

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

2. IL-PTS computational complexity (Cooly-Tukey IFFT algorithm)

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

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

### 5.2 The computational complexity of finding the optimum phase weighting factor

This computational complexity is because of performing the phase rotation factors in the time-domain. This complexity performs an exhaustive search to find the optimum phase rotation factors, and it increases exponentially with increasing the number of the subblocks. The $C_{add}$ and $C_{mult}$ can be expressed as [29]

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

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

### 5.3 The computational complexity of the PTSs comparison

This part of the complexity is because of the comparison the PTSs in order to select the o the best OFDM signal and it can be written as [30]

$$\mathrm{C_{comp}} = W^{V-1} N \tag{18}$$

## 6. RESULTS AND DISCUSSION

In this section, the three types of the segmentation schemes are compared with the original OFDM signal (without C-PTS), and the numerical calculations of the computational complexity is conducted with various numbers of *V*, *W*, and *N*. The parameters of this simulation are: the number of the subcarriers *N* = 128 and 256, the number of subblocks *V* equivalents to 4, and 8, the number of the different phase weighting factors *W* is set to 2 and 4, and the oversampling factor *L* equals to 4. Moreover, 103 symbols are evaluated by the CCDF, and 16-QAM is utilized to mapping the input data sequence.

At first, the simulation is conducted when *N* = 128, *V* and *W* are set to {4, 2}, {4, 4}, and {8, 2}, as shown in Figure 3, Figure 4, and Figure 5. The comparison showed that the PAPR alleviation performance of the PR-PTS surpassed the original OFDM signal in three scenarios by 2.83dB, 3.68dB, and 3.96dB, respectively. Likewise, the PAPR mitigation rendering of the Ad-PTS was better than the original OFDM by 2.27dB, 2.83dB, and 3.4dB, respectively. In addition, the PAPR diminishing execution of the IL-PTS was superior to the original OFDM by 1.7dB, 2.27dB, and 3.11dB, respectively. Accordingly, the PR-PTS method outperforms to the other segmentation methods Ad-PTS and IL-PTS for all scenarios.

Figure 6 displays the comparison that performed when $N$ = 256, $V$ = 4, and $W$ is set 2 and 4. When the parameters are set to $N$ = 256, $V$ = 4, and $W$ = 2, the PAPR reduction rendering of the PR-PTS was superior to Ad-PTS, IL-PTS, and the original OFDM by 0.57 dB, 0.85 dB, and 2.55 dB, respectively. Moreover, when the parameters are set to $N$ = 256, $V$ = 4, and $W$ = 4, the comparison between ordinary segmentation schemes and the original OFDM signal showed that the PR-PTS achieved the superiority on the Ad-PTS, IL-PTS, and original OFDM by 0.57 dB, 1.14 dB, and 3.4 dB, respectively, as demonstrated in Figure 7. Consequently, the PR-PTS scheme can be accomplished the best PAPR diminishing performance compared with the other ordinary segmentation schemes.

Table 1 recorded the PAPR reduction rendering for various numbers of $N$, $V$, and $W$. We can be seen that the PR-PTS achieved the best PAPR reduction rendering and the Ad-PTS the second best. However, the IL-PTS recorded the worse PAPR mitigation performance.

**Table 1:** Comparison PAPR value of the ordinary partitioning schemes when N = 128

| *N* | *V* | *W* | Original OFDM PAPR [dB] | IL-PTS PAPR [dB] | Ad-PTS PAPR [dB] | PR-PTS PAPR [dB] |
|---|---|---|---|---|---|---|
| 128 | 4 | 2 | 10.79 | 9.09 | 8.52 | 7.96 |
| | 4 | 4 | | 8.52 | 7.96 | 7.11 |
| 256 | 8 | 2 | | 7.68 | 7.39 | 6.83 |
| | 4 | 2 | 11.07 | 9.37 | 9.09 | 8.52 |
| | 4 | 4 | | 8.81 | 8.24 | 7.67 |

Furthermore, the PAPR reduction ratio (PAPR-R-R) of the or-dinary partitioning schemes is illustrated in Table 2, and Table 3. We can be observed that the PAPR-R-R of the three ordinary schemes increased when the number of the subblocks was in-creased.

$$\text{PAPR-R-R} = \left(1 - \frac{\text{PAPR of the PTS}}{\text{PAPR of the original OFDM}}\right) \times 100\% \quad (19)$$

**Table 2:** PAPR-R-R of ordinary partitioning schemes when N =128

| $N$ = 128 | | | | |
|---|---|---|---|---|
| *V* | *W* | IL-PTS PAPR-R-R | Ad-PTS PAPR-R-R | PR-PTS PAPR-R-R |
| 4 | 2 | 15.75% | 21.03% | 26.22% |
| 4 | 4 | 21.03% | 26.22% | 34.10% |
| 8 | 2 | 28.82% | 31.51% | 36.70% |

**Table 3:** PAPR-R-R of ordinary partitioning schemes when N =256

| $N$ = 256 | | | | |
|---|---|---|---|---|
| *V* | *W* | IL-PTS PAPR-R-R | AD-PTS PAPR-R-R | PR-PTS PAPR-R-R |
| 4 | 2 | 15.35% | 17.88% | 23.03% |
| 4 | 4 | 20.41% | 25.56% | 30.71% |

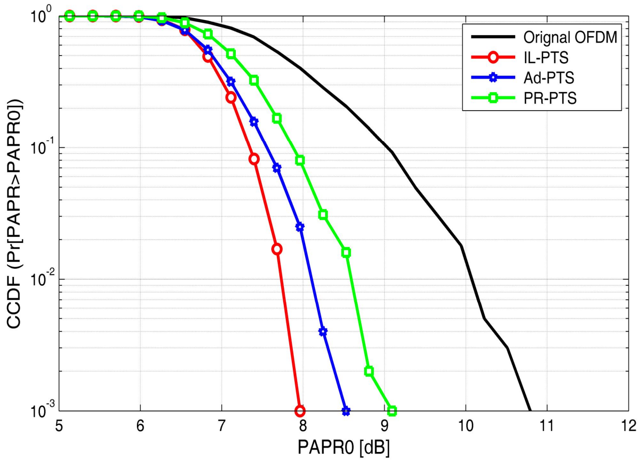

**Figure 3:** Comparison the ordinary partitioning schemes when $V$ = 4, $W$ = 2 , and $N$ = 128

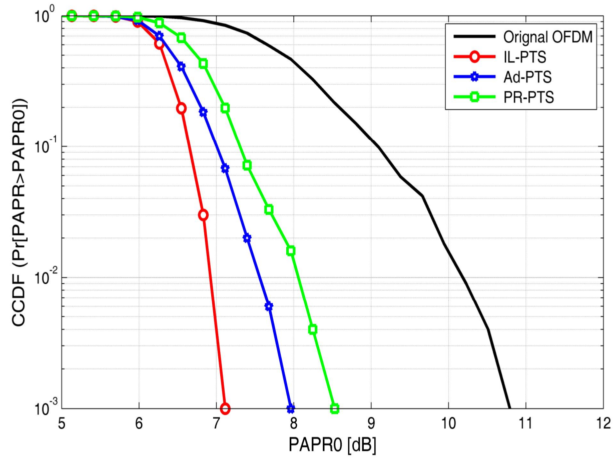

**Figure 4:** Comparison the ordinary partitioning schemes when $V$ = 4, $W$ = 4, and $N$ = 128

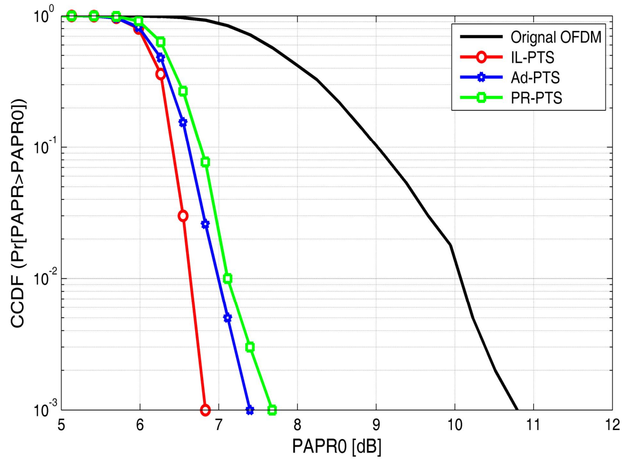

**Figure 5:** Comparison the ordinary partitioning schemes when $V$ = 8, $W$ = 2, and $N$ = 128

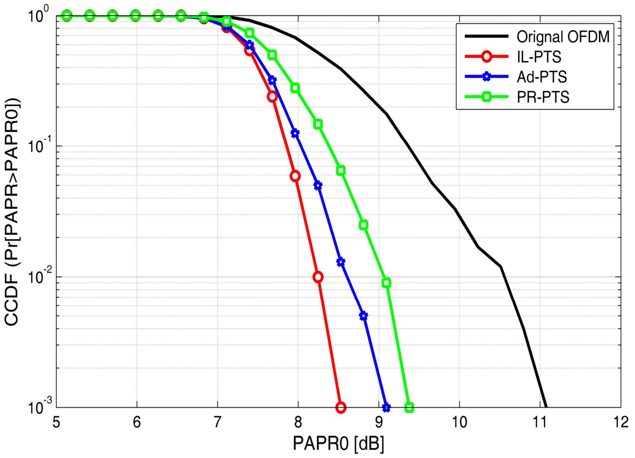

**Figure 5:** Comparison the ordinary partitioning schemes when $V$ = 4, $W$ = 2, and $N$ = 256

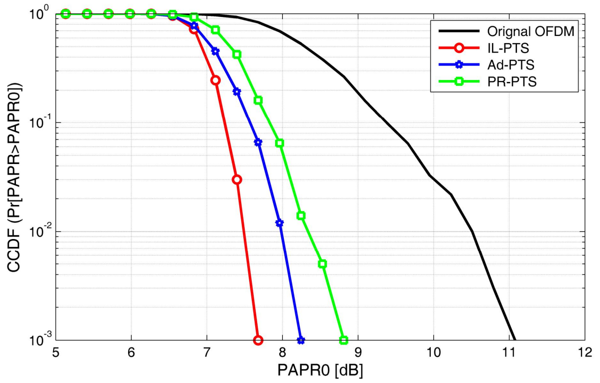

**Figure 7:** Comparison the ordinary partitioning schemes when $V$ = 4, $W$ = 4, and $N$ = 256

On the other hand, Table 4 and Table 5 recorded the computational complexity of the three ordinary segmentation schemes with different numbers of the *V*, *W*, and *N*. The computational complexity of the OFDM system is divided into the IFFT complexity, phase factors complexity, and comparison complexity. As mentioned, the computational complexity of the PR-PTS and Ad-PTS are the same, because of all the stages of the IFFT are performed when transforming the subblocks into the time-domain. Moreover, the IL-PTS scheme applied Cooly-Tukey IFFT algorithm in order to reduce the computational complexity.

The total computational complexity on the system when $N$ = 128, $V$ and $W$ are set to {4, 2}, {4, 4}, and {8, 2} are recorded in Table 4. In PR-PTS or Ad-PTS scenarios, the total Cadd was 6656, 28160, and 121856, respectively. However, the total Cadd of the IL-PTS under the same circumstance was 3712, 25216, and 115200, respectively.

In addition, Table 5 clarified the total computational complexity with the same parameters of Table 4 except that the number of the subcarriers is set to 256. The total Cmult of the PR-PTS or Ad-PTS was 14332, 84736, and 303104, respectively. However, the total Cmult of the IL-PTS was 12032, 82432, and 297600, respectively. We can be seen that the computational complexity increases exponentially with increasing the number of the subblocks. Moreover, the complexity of the IL-PTS algorithm is lower than that of the PR-PTS and Ad-PTS algorithms.

**Table 4:** Computational complexity of the ordinary partitioning schemes when N = 128

| ***N* = 128** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **PTS** | ***V*** | ***W*** | **IFFT complexity** | | **Phase factors complexity** | | **Total system complexity** | |
| | | | **$C_{add}$** | **$C_{mult}$** | **$C_{add}$** | **$C_{mult}$** | **$C_{add}$** | **$C_{mult}$** |
| **Ad or PR** | 4 | 2 | 3584 | 1792 | 3072 | 5120 | 6656 | 6912 |
| | 4 | 4 | 3584 | 1792 | 24576 | 40960 | 28160 | 42752 |
| | 8 | 2 | 7168 | 3584 | 114688 | 147456 | 121856 | 151040 |
| **IL** | 4 | 2 | 640 | 832 | 3072 | 5120 | 3712 | 5952 |
| | 4 | 4 | 640 | 832 | 24576 | 40960 | 25216 | 41792 |
| | 8 | 2 | 512 | 1280 | 114688 | 147456 | 115200 | 148040 |

**Table 5:** Computational complexity of the ordinary partitioning schemes when N = 256

| ***N* = 256** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **PTS** | ***V*** | ***W*** | **IFFT complexity** | | **Phase factors complexity** | | **Total system complexity** | |
| | | | **Cadd** | **$C_{mult}$** | **$C_{add}$** | **$C_{mult}$** | **$C_{add}$** | **$C_{mult}$** |
| **Ad or PR** | 4 | 2 | 8192 | 4096 | 6144 | 10240 | 14336 | 14332 |
| | 4 | 4 | 8192 | 4096 | 48384 | 80640 | 56576 | 84736 |
| | 8 | 2 | 16384 | 8192 | 229376 | 294912 | 245760 | 303104 |
| **IL** | 4 | 2 | 1536 | 1792 | 6144 | 10240 | 7680 | 12032 |
| | 4 | 4 | 1536 | 1792 | 48384 | 80640 | 49920 | 82432 |
| | 8 | 2 | 1280 | 2688 | 229376 | 294912 | 230656 | 297600 |

## 7. CONCLUSION

In this paper, the C-PTS strategy for decrease the high PAPR value in OFDM system is analyzed. The C-PTS procedure relied on the subblocks segmentation schemes and the phase rotation factors. Moreover, the partitioning scheme type and the number of subblocks play a major role in terms of the PAPR mitigation rendering and the value of computational complexity. When the subblocks equal to 8, the PAPR reduction ratio of the PR-PTS, Ad-PTS, and IL-PTS was 36.70%, 31.51%, and 28.82%, respectively. However, the percentage was 26.22%, 21.03%, and 15.75%, respectively, when the number of subblocks is set to 2. Furthermore, the computational complexity of the ordinary schemes increases exponentially with increasing the number of the subblocks. Therefore, there is a trade-off between the PAPR reduction and the computational complexity of the C-PTS technique.

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