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An Enhanced Partial Transmit Sequence Based on Combining Hadamard Matrix and Partitioning Schemes in OFDM Systems

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Abstract: The partial transmit sequence (PTS) considered as one of the efficient approaches to restrain the high peak to average-power ratio (PAPR) in orthogonal frequency division multiplexing (OFDM) frameworks. PTS relied on partitioning the input data block and rotate them with a set of the phase vectors. In this study, a novel technique is suggested to improve the PAPR reduction performance in the PTS technique by combining Hadamard matrix and the popular kinds of the partitioning schemes interleaving scheme (IL-PTS), adjacent scheme (Ad-PTS), and pseudo-random scheme (PR-PTS). The new approach employed Hadamard matrix to change some of the subcarrier phases of the partitioning scheme in the frequency-domain. The simulation results demonstrated that the new method improved the PAPR diminishment performance better than that of the PR-PTS and Ad-PTS. However, the proposed method achieved the same PAPR performance compared with the IL-PTS scheme.

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

1. Introduction

OFDM is an effective technology for the high-speed data rate in wireless communication system because of the prominent features of the OFDM system such as the simplicity of implementation [1], durability against multipath fading channels [2], and efficiency of bandwidth utilization [3]. Accordingly, many communication frameworks depended on the OFDM systems as a transmission data technology such as digital video broadcasting (DVB) [4], wireless local area network (WLAN) IEEE.802.11 [5], and worldwide interoperability for microwave access IEEE.802.16 [6]. In addition, the fourth generation (4G) frameworks utilized OFDM as a data transmission system in the standard Long-Term Evaluation (LTE) [7]. On the other hand, the high PAPR is the major shortcoming of the OFDM system, which leads to the spectrum deterioration in transmission side [8]. If the system is run with high PAPR, some components of the system, for example, high power amplifiers will be worked out the scope of the linear region, and this leads to out-of-band radiation and in-band distortion. Hence, the system suffers from bit error rate degradation and spectrum inefficiency.

Several approaches have been suggested to mitigate the high PAPR value, for example, clipping and filtering [9], Partial transmit sequence (PTS) [10], selective-mapping (SLM) [11], and interleaving technique [12]. PTS is considered as one of the influential approaches to improve the PAPR mitigation performance compared with the other probabilistic techniques [13]. The PTS method depends on two parts of its procedure, partitioning the input data sequence and changing the phases of the partitioned data sequence. In literature, many scenarios have been proposed to enhance the PAPR alleviation performance in terms of developing the partitioning schemes such as Jawhar [14][15] proposed several methods to improve the PAPR lessening performance better than the ordinary partitioning approaches. Also, Ibraheem [16] and Hong [17] proposed new methods to diminish the PAPR value better than the conventional PTS methods by combining two types of the ordinary segmentation schemes.

The target of this paper is PAPR lessening performance improvement better than the conventional PTS algorithm. The proposed method integrates Hadamard matrix with the partitioning schemes (H-PTS) in the frequency-domain to change the high consistency phases of the input data sequence. The results indicated that the PAPR diminishing performance of the new method outperforms to the PR-PTS and Ad-PTS schemes. However, the proposed approach achieves the same performance of the IL-PTS method.

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2. OFDM Framework

In OFDM, the input data sequence X one of the mapping techniques such as quadrature amplitude modulation (QAM) modulates in order to generate the baseband signal in the frequency domain. Next, the data signal is converted from the serial into parallel pattern. Therefore, the baseband signal can be described as

$$X_k = [X_0, X_1, ..., X_{N-1}]^{\mathrm{T}} \quad (1)$$

where N represents the number of subcarriers. After that, the inverse fast Fourier transform (IFFT) is applied to the baseband signal to produce the discrete time domain signal $x(n)$, which can be defined as [18]

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

where $j = \sqrt{-1}$. In the time domain, the OFDM signal is generated by superposition the baseband signals so some peaks power of the subcarriers may be added together and then will become much larger than the mean power when the subcarriers have the same phases. This degradation named PAPR, and can be written as [19]

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

where $E\{.\}$ symbolizes the mean power. The complementary-cumulative-distribution-function (CCDF) is utilized to evaluate the probability of the PAPR that surpasses a certain threshold value and can be written as [20]

$$\mathrm{P_r}(\mathrm{PAPR}(x(n) > PAPR_0) = 1 - (1 - e^{-PAPR_0})^N \quad (4)$$

where $PAPR_0$ represents the threshold value. Moreover, The PAPR calculations will be more accurate, if the oversampling operation is applied. This operation is done by inserting (L-1) N zeros between the OFDM subcarriers [21], where L is the oversampling factor. Accordingly, the CCDF of the OFDM signal can be established as

$$\mathrm{P_r}(\mathrm{PAPR}(x(n) > \mathrm{PAPR}_0) = 1 - (1 - e^{-\mathrm{PAPR}_0})^{NL} \quad (5)$$

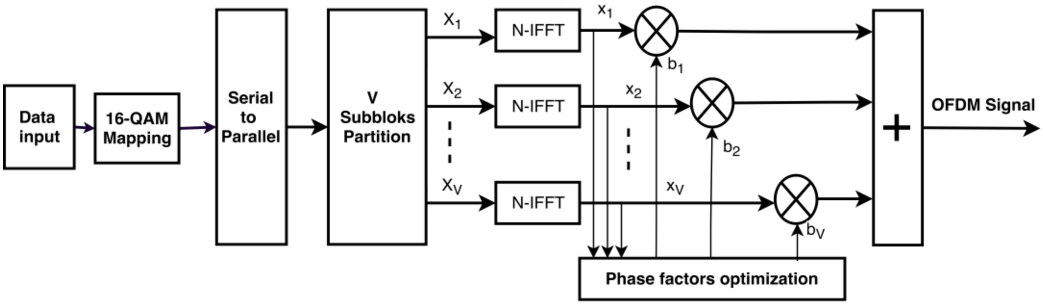

Fig. 1: PTS block diagram [22]

3. Partial transmit sequence (PTS)

As can be observed in Figure 1, PTS procedure starts when partitioning the baseband sequence into V subblocks before applying N-IFFT. Consequently, the partitioned baseband signal can be demonstrated as

$$X = \sum_{v=1}^{V} X_v \quad (6)$$

After that, the subblocks is rotated by set of the phase rotation factors (b_v), so the OFDM signal in the time domain is defined as

$$x(n) = \mathrm{IFFT}\{\sum_{v=1}^{V} b_v X_v\} \quad (7)$$

The linear property of the IFFT is applied to the (b_v), so the OFDM signal in the time-domain can be written as

$$x(n) = \sum_{v=1}^{V} b_v \ \mathrm{IFFT}\{X_v\} \quad (8)$$

and,

$$x(n) = \sum_{v=1}^{V} b_v x_v \quad (9)$$

The elements of the phase rotation factors can be obtained as

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

where W expresses the number of the allowed phase factors, which is usually limited in order to avoid more of the complex multiplication operations, so $b_v \in \{\pm 1\}$ or $\{\pm 1, \pm j\}$ [22]. In the time-domain, every subblock is weighted by phase rotation vectors b_v, and combines with other subblocks to produce a set of candidate signals. The PAPR is calculated for each candidate, and the candidate signal that has the minimum PAPR is elected for transmission. Accordingly, the system must check (W^{V-1}) groups of the phase factors to find the optimum phase rotation factor; with the consideration that the first element of the phase factors b_1 usually determines to 1, without any influence on the PAPR performance. Moreover, the transmitter side should send ($\log_2 W^{V-1}$) bits to the receiver in order to ensure recovering the original data, so this operation limits the bandwidth of the system [23].

4. PTS partitioning schemes

In PTS, there are three popular forms of the partitioning schemes including interleaving scheme, adjacent scheme and, pseudo-random scheme, as demonstrated in Fig. 2. Each one of the partitioning schemes has a PAPR reduction performance different of another depending on the correlation between the subcarriers [24]. In IL-PTS, N/V of the subcarriers is assigned with a constraint interval of V for each subcarrier within subblock. However, the Ad-PTS scheme assigns N/V consecutive subcarriers inside each subblock, successively. On the same hand, the PR-PTS scheme allocates N/V of the subcarriers randomly inside each subblock. All the partitioning schemes must fulfil the following condition; the sub-blocks must be equaled in size and non-overlapping with each other.

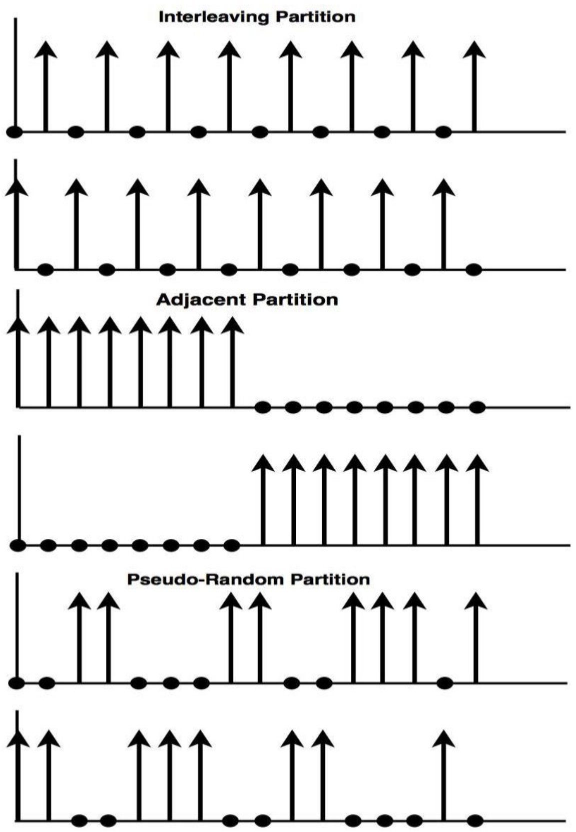

Fig. 2 Conventional partitioning schemes [22]

In addition, the PAPR detraction performance of the PR-PTS is the best among the three partitioning schemes, whereas the Ad-PTS scheme is the second best. However, the IL-PTS is considered the worst partitioning scheme concerning of the PAPR reduction [25]. In contrast, the PR-PTS and Ad-PTS have computational complexity higher than that of the IL-PTS scheme.

5. Hadamard matrix

Hadamard matrix (H matrix) is a square matrix, and its elements either +1 or -1. Moreover, the rows of the H matrix are orthogonal to each other [26]. The low order of the H matrix can be written as

$$\mathrm{H}_1 = [1] \ , \ \ \mathrm{H}_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \tag{11}$$

Likewise, the H matrix can be established by

$$\mathrm{H}_{2\mathrm{M}} = \begin{bmatrix} \mathrm{H}_\mathrm{M} & \mathrm{H}_\mathrm{M} \\ \mathrm{H}_\mathrm{M} & -\mathrm{H}_\mathrm{M} \end{bmatrix} \tag{12}$$

where M is a decimal number.

6. Hadamard-PTS method

The contribution of this paper is the achievement of PAPR lessening performance better than that of the conventional PTS algorithm, so the Hadamard-PTS method (H-PTS) is proposed to enhance the PAPR lessening performance. The H-PTS approach integrates H matrix with PTS partitioning scheme in the frequency-domain, in which the H matrix is produced depending on the subblocks number V, as follow

$$\mathrm{H}_V = \begin{bmatrix} \mathrm{H}_{V/2} & \mathrm{H}_{V/2} \\ \mathrm{H}_{V/2} & -\mathrm{H}_{V/2} \end{bmatrix} \tag{13}$$

After that, the H_V matrix is duplicated relying on the number of the subcarriers N, so the H_V matrix is repeated (N/V) times to produce the HD_r matrix, which can be defined as

$$\mathrm{HD}_r = [\mathrm{H}_{V,1}, \mathrm{H}_{V,2}, ..., \mathrm{H}_{V,N/V}] \tag{14}$$

where $r = \{1, 2, \ldots, N/V\}$, and represents the duplication times, this operation ensures the length of the rows of the Hadamard matrix equal to that of the partitioning scheme matrix. Afterwards, the HD_r matrix is multiplied by the petitioning scheme matrix to produce a new partitioning scheme matrix (H-PTS), as follow

$$\text{H-PTS} = \mathrm{HD}_r^\mathrm{T} * X_{V,N}^\mathrm{T} \tag{15}$$

where $X_{V,N}^\mathrm{T}$ represents the conventional partitioning scheme matrix. Finally, the rest of the PTS procedure is applied to the H-PTS scheme, and the OFDM sequence that achieves the minimal PAPR value is chosen for transmission.

In summary, the PAPR alleviation performance of the H-PTS algorithm is enhanced, because the H matrix can reduce the autocorrelation between the subcarriers within the subblocks [27]. Equations (16-19) illustrate the H matrix integration with Ad-PTS (H-Ad-PTS) method, as example, where the number of subblocks V is chosen to four, and the number of subcarriers N is chosen to eight. The H_V matrix is duplicated to produce HD_r matrix, which is multiplied by the Ad-PTS matrix. As can be seen in H-Ad-PTS matrix, the signs of the Ad-PTS matrix are changed depending on the corresponding elements of the HD_r matrix. Accordingly, the proposed method works to alter the phases of the subcarriers within the subblocks. Hence, the PAPR decreasing performance of the proposed method will be improved.

The H_V matrix can be obtained by

$$\mathrm{H}_V = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & +1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix} \tag{16}$$

The HD_r matrix can be produced by

$$\mathrm{HD}_r = [\mathrm{H}_{V,1}, \mathrm{H}_{V,2}] = \begin{bmatrix} +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 & +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 & +1 & -1 & -1 & +1 \end{bmatrix} \tag{17}$$

The Ad-PTS matrix can be written as

$$X_{V,N} = \begin{bmatrix} X_{1,1} & X_{1,2} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & X_{2,3} & X_{2,4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & X_{3,5} & X_{3,6} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & X_{4,7} & X_{4.8} \end{bmatrix} \tag{18}$$

Therefore, the H-Ad-PTS matrix $= \mathrm{HD}_r^{\mathrm{T}} * X_{V,N}^{\mathrm{T}}$, and can be expressed as

$$\text{H-Ad-PTS} = \begin{bmatrix} X_{1,1} & X_{1,2} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & X_{2,3} & -X_{2,4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & X_{3,5} & X_{3,6} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -X_{4,7} & X_{4.8} \end{bmatrix} \tag{19}$$

7. Results and Discussion

In this part, the proposed method is simulated and compared with the conventional partitioning schemes. The H matrix is integrated with PR-PTS, Ad-PTS, and IL-PTS to produce H-PR-PTS, H-Ad-PTS, and H-IL-PTS schemes, respectively. The parameters of this simulation are: the number of subblocks V=4, the number of subcarriers N=128 and 256, the number of the different phase rotation factors W=2, and the oversampling factor L is fixed to 4. Moreover, 16-QAM is employed to generate 1000 random symbols.

Fig. 3 and Fig. 4 demonstrates the comparison between the H-PR-PTS method and PR-PTS method when N=128 and 256. The PAPR value of the original OFDM signal (without PTS) was 10.79 dB, and the PAPR value of the PR-PTS method achieved 8.208 dB, while the PAPR value of the H-PR-PTS method fulfilled 7.945 dB, as shown in Fig. 3. The simulation result as demonstrated in Fig. 4 indicated that the H-PR-PTS method achieved the superiority to the PR-PTS method concerning the PAPR reduction performance by 0.263 dB when N=256. Therefore, the H-PR-PTS scheme can achieve greater PAPR detraction performance than that of the PR-PTS scheme in both scenarios.

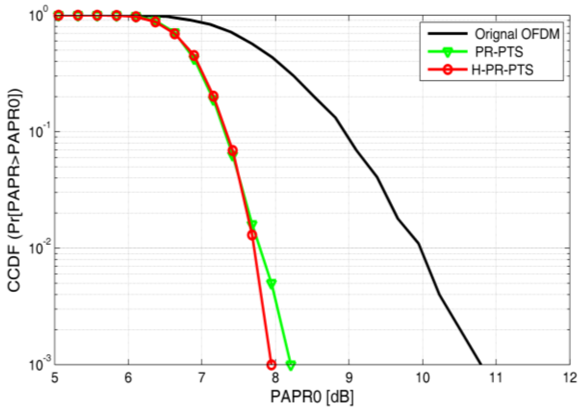

Fig. 3 Comparison between the H-PR-PTS and PR-PTS when N= 128

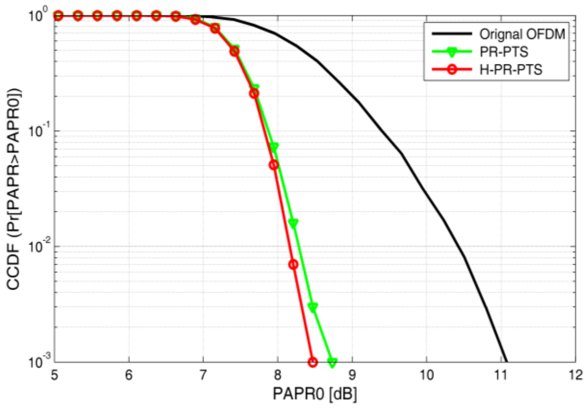

Fig. 4 Comparison between the H-PR-PTS and PR-PTS when N= 256

As can be observed in Fig. 5 and Fig. 6, the H-Ad-PTS algorithm was compared with the Ad-PTS algorithm when N=128 and 256. It is clearly seen that the H-Ad-PTS can be exceeded the Ad-PTS by 0.36 dB when N=128. Also, H-Ad-PTS accomplished the superiority to the Ad-PTS by 0.4 dB when N=256. Consequently, the PAPR detraction performance of the H-Ad-PTS outperforms to the Ad-PTS in any number of the subcarriers.

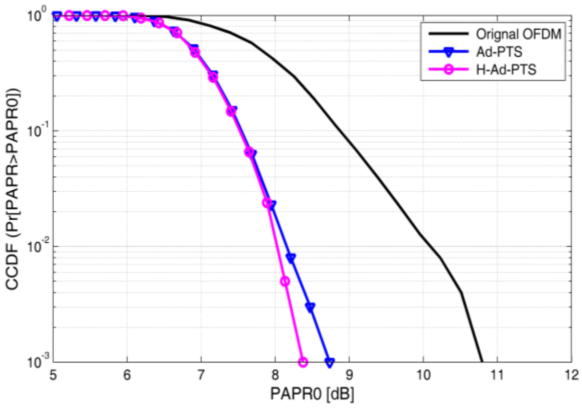

Fig. 5 Comparison between the H-Ad-PTS and Ad-PTS when *N*= 128

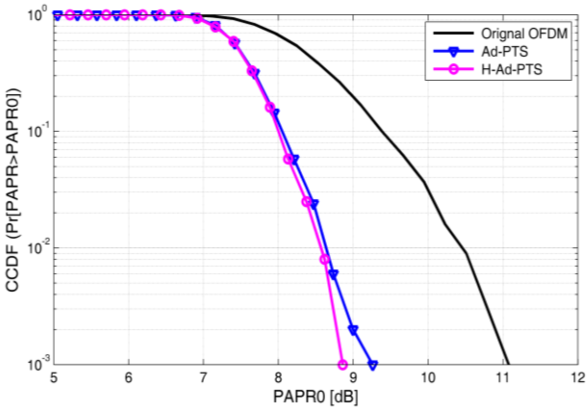

Fig. 6 Comparison between the H-Ad-PTS and Ad-PTS when *N*=256

On the other hand, the comparison of the H-IL-PTS scheme and IL-PTS scheme is conducted when the number of the subcarriers is 128 and 256, as demonstrated in Fig. 7 and Fig. 8. In both scenarios, the H-IL-PTS and IL-PTS have the same value of the PAPR, 9.06 dB when *N*=128, and 9.566 dB when *N*=256. Consequently, the H-IL-PTS cannot enhance the PAPR decreasing performance higher with IL-PTS scheme.

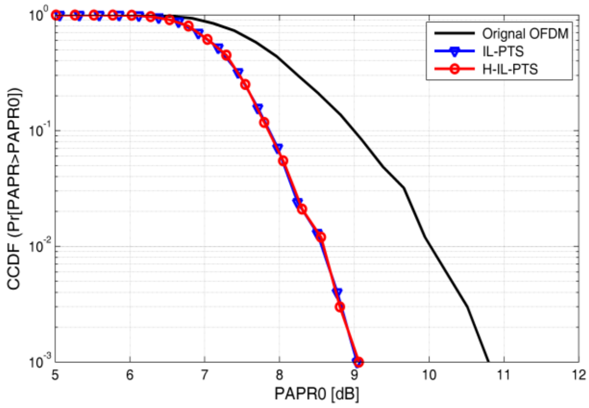

Fig. 7 Comparison between the H-IL-PTS and IL-PTS when *N*=128

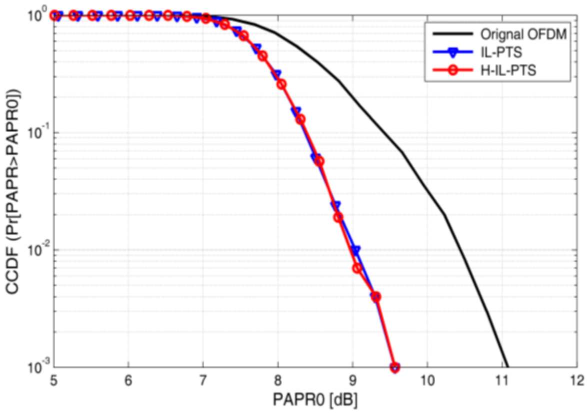

Fig. 8 Comparison between the H-IL-PTS and IL-PTS when *N*=256

According to the simulation results above, the H matrix can affect to the PR-PTS and Ad-PTS schemes, because the structure matrix of these schemes is non-periodic, so the H matrix works to change some phases of the subcarriers in these schemes. Hence, the H-PR-PTS and H-Ad-PTS schemes outperform to the PR-PTS and Ad-PTS schemes in PAPR reduction. In contrast, the H-IL-PTS approach achieved the same PAPR diminishing performance of IL-PTS scheme. This can be attributed to that the IL-PTS matrix is a periodic matrix so that the H matrix cannot change the phases of subcarriers in IL-PTS matrix. Hence, the PAPR performance of the H-IL-PTS scheme is similar to that of the IL-PTS matrix.

In general, the proposed methods can slightly improve the PAPR reduction performance compared with PR-PTS and Ad-PTS segmentation schemes, this can be attributed of that the Hadamard matrix elements contains either +1 or -1, thereby in each row of the Hadamard matrix, the elements which have negative signs (-1) will change the phases of corresponding subcarriers of the PR-PTS matrix or Ad-PTS matrix by 180°. Depending on the OFDM operation, the high PAPR value of the output OFDM signal is due to superposition *N* subcarriers at the output of IFFT in the transmitter; with the condition the phases of these subcarriers are the same value. Therefore, the Hadamard matrix works to improve the PAPR performance by changing the phases of the subcarriers.

The simulation results in Fig 3, Fig 4, Fig 5, and Fig 6 show the PAPR reduction values about 0.3 dB in H-PR-PTS and about 0.4 dB in H-Ad-PTS. The one can be observed that the PAPR reduction performance is slightly improved, but this improvement considers good if we compared the performance with the PR-PTS which is well-known as the best PAPR reduction method among the conventional segmentation schemes. Also, the Hadamard matrix changed some of the subcarrier phases depending on the (-1) locations in the matrix. Hence, the phases of these subcarriers influence positively to the PAPR lessening performance. Moreover, the Hadamard can be saved in the receiver memory, and it can be easily removed from the OFDM signal when recovering the original data in the receiver side. In other words, the proposed methods do not need to send extra side information to receiver side to inform it of the changes by Hadamard matrix. Therefore, the proposed methods improved the PAPR reduction performance better than that of the ordinary methods without additional complexity.

8. Summary

A novel method has been proposed in this paper named H-PTS; this method accomplished PAPR diminishing performance better than that of the PR-PTS and Ad-PTS schemes in PTS technique. The new method works to combine Hadamard matrix with partitioning scheme of the PTS to produce a new scheme which can change the phases of the subcarriers inside the subblocks in the frequency-domain. The new approach is applied to the three well-known types of the partitioning schemes. The simulation results indicated that the H-PR-PTS and H-Ad-PTS methods outperform to the PR-PTS and Ad-PTS schemes in terms of PAPR reduction because the influence of the Hadamard matrix on the partitioning schemes led to changing the phases of the subcarriers of the partitioning schemes and then the PAPR detaction performance is improved. Nevertheless, the H-IL-PTS method achieved the same PAPR decreasing performance of the IL-PTS, because the Hadamard matrix cannot affect to the periodic scheme as the IL-PTS scheme. Therefore, the proposed method considers simple execution algorithm to improve the PAPR mitigation performance in PTS technique.

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