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EFFICIENT PAPR REDUCTION OF OFDM SIGNAL USING PTS TECHNIQUE WITH HYBRID PARTITIONING METHOD

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ABSTRACT
The high peak-to-average power ratio (PAPR) is one of the major problems of orthogonal frequency division multiplexing (OFDM) systems in wireless transmission. Therefore, partial transmit sequence (PTS), a promising scheme that can provide good PAPR reduction performance, has been proposed for OFDM transmission to eliminate distortion. The PTS method divides the input data block into disjoint sub-blocks, computes Inverse Fourier Transform of the sub-blocks, rotates the sub-blocks with appropriate phase factors and combines them to form the transmitted signal. This paper presents an enhanced PTS approach that combines two PTS partitioning schemes (adjacent and interleaved) to effectively reduce the PAPR of the OFDM systems. The influence of the proposed approach on performance is investigated by varying the size of the disjoint sub-blocks. The PAPR reduction performance of the proposed PTS method is compared with two well known sub-blocks partitioning schemes, namely, Adjacent Partitioning (AP), Interleaved Partitioning (IP). The various computer simulation results for the various sub-blocks confirmed that the proposed method provides better PAPR reduction performance compared with AP and IP partitioning based PTS scheme. In addition, these PTS schemes largely depend on the chosen size of the partitions.

Keyword: adjacent partitioning PTS (AP-PTS), interleaved partitioning PTS (IP-PTS), orthogonal frequency division multiplexing (OFDM), peak-to-average power ratio (PAPR), partial transmit sequences (PTS).

INTRODUCTION
Orthogonal frequency division multiplexing (OFDM) is a promising multi-carrier modulation technique for achieving high data transmission rate over frequency selective fading channels in wireless communication system [1]. This technique has been widely employed in digital transmission, such as in digital video/audio broadcasting systems and wireless local area networks. Furthermore, OFDM is considered as an attractive transmission technique for fourth-generation wireless mobile communications [2]. However, one of the main drawbacks of the implementation of RF of an OFDM is the high peak to-average power ratio (PAPR) of the transmitted signal. Larger peaks lead to reduced power efficiency, signal distortion, and an increased complexity of a digital-to-analog and analog-to-digital converters [3]. Various methods have been proposed to control the PAPR of the transmitted signals in OFDM systems [4], including deliberate clipping [5], transmit filtering [6], companding [7], block coding [8], partial transmit sequence (PTS) [9], selective mapping (SLM) [10], tone reservation [11], and constellation extension [12]. Probabilistic methods, such as SLM and PTS, can achieve PAPR reduction with only a small rate of data loss [1]. SLM and PTS require numerous IFFTs and rotating phase vector that must be transmitted to achieve high PAPR performance. However, the performance of the system would affect the PAPR reduction in methods such as deliberate clipping; transmit filtering and companding schemes because of signal distortion. Among these methods, PTS is an attractive and well-known scheme that provides less distortion based on combining signal sub-blocks that are multiplied by weighting factors. In addition, the PAPR performance can be improved by multiplying the optimal phase rotating factor [13]. This study focuses on the use of a probabilistic method to reduce the PAPR in an OFDM-based system and proposes an effective PTS method. A modified PTS scheme is compared with other existing ones with varying lengths of disjoint sub-blocks. Furthermore, the proposed PTS method combines two types of sub-block partitioning schemes (adjacent and interleaved) for PAPR reduction in OFDM systems compared with the ordinary PTS scheme. The proposed PTS method can significantly reduce the PAPR with less computational complexity. The paper is organized as follows: Section II presents the PAPR of the OFDM system and the conventional PTS method. Section III presents the sub-block partitioning methods. Section IV explains the proposed PTS method for improved PTS technique. Section V shows the simulation result and Section VI draws a conclusion.

PAPR AND THE PTS TECHNIQUE

A. PAPR of OFDM signals
For N be the number of subcarriers, k is the frequency index, and $X(K)$ is denote a vector of phase shift keying (PSK) or quadrature amplitude modulation (QAM) complex symbols. This vector is transmitted using one OFDM symbol $x(n)$, where the discrete-time index is n. The $x(n)$ of the discrete time samples can obtained by taking an N - point inverse discrete Fourier transform (IDFT).

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

To assess the difference in the time domain samples $x(n)$, the PAPR of an OFDM symbol $x(n)$ is defined as the ratio of the maximum instantaneous power to the average power [14]

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

where $E\{\}$ denote the expected value.

The complementary cumulative distribution function (CCDF) of the PAPR was employed to evaluate the PAPR reduction [15]

$$CCDF(PAPR(x(n))) = Pr(PAPR(x(n))) > PAPR_0 \tag{3}$$

This phrase represents the probability that the PAPR of a symbol exceeds the threshold level $PAPR_0$.

B. OFDM System with PTS to Reduce the PAPR

As shown in Figure-1, the input data block is partitioned into smaller M disjoint sub-blocks in the PTS scheme and can be expressed as $X_1, X_2, \dots, X_M$, such that

$$X = \sum_{x=0}^{M} X_m \tag{4}$$

where each sub-block consists of a group of subcarriers of equal size. The sub-blocks partitions are then transferred from the frequency domain to the time domain by using inverse fast Fourier transform (IFFT), which can expressed as

$$x_m = \sum_{m=1}^{M} IDFT\{X_m\} \tag{5}$$

The PTS scheme aims to configure a weighted combination of the M sub-blocks. All sub-carriers for each sub-block are multiplied by the weighted factor. The weight factors are then selected to achieve the minimal PAPR. The time domain signal after combination is given by

$$x = \sum_{m=1}^{m} b_m x_m \tag{6}$$

The PTS sub-block partition methods can be classified into three categories; interleaved, adjacent, and pseudorandom sub-block partition. In [16], the interleaved sub-block partition method achieved the lowest PAPR reduction, whereas the pseudorandom sub-block partition method has the best PAPR reduction. Adjacent partitioning (AP) method is simple to implement and its PAPR reduction performance is close to pseudorandom partitioning [17]. Therefore, we limit our analysis to comparison between performance of the proposed method with those of interleaved and adjacent partition methods.

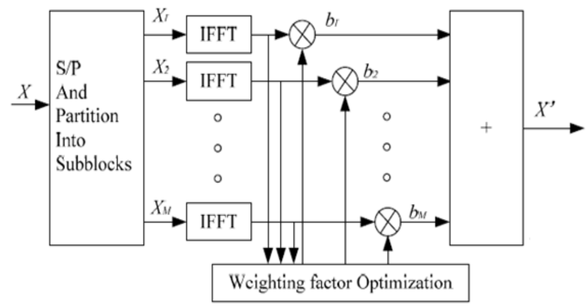

Figure-1. Block diagram of PTS technique.

SUB-BLOCK PARTITIONING FOR PTS METHODS

Disjoint sub-blocks partitioning was simulated based on PTS technique. The interleaved partition and adjacent partition methods were considered in this simulation. The details will be explained in subsequent sub-sections. The mathematical frameworks of the two different methods can described as follows.

Interleaved parition

In the interleaved partitioning PTS (IP-PTS) scheme, the N subcarriers are first divided into M groups with each group having $L = \frac{N}{M}$ contiguous subcarriers. Every subcarrier signal spaced apart is allocated at the same sub-block. The i-th interleaved partition is formed by assigning the i-th subcarrier of each group to the i-th interleaved partition. This method has lower computational complexity compared with adjacent partitioning PTS (AP-PTA) and pseudorandom partitioning PTS (PRP-PTS) [18]. However, the PAPR reduction performance of IP-PTS is worse than other methods when the number of generated candidates is the same [19]. The partitions can be represented by the following equations,

$$P_0 = \left[P_0^{(1)} 0 \dots 0 P_0^{(2)} 0 \dots\dots 0 P_0^{(M)} 00 \dots 0\right] \tag{7a}$$

$$P_1 = \left[0 P_1^{(1)} 0 \dots 00 P_1^{(2)} 0 \dots\dots 00 P_1^{(M)} 0 \dots 0\right] \tag{7b}$$

$$P_L = \left[00 \dots 0 P_L^{(1)} 0 \dots 0 P_L^{(2)} 0 \dots\dots 0 P_L^{(M)}\right] \tag{7c}$$

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where, P_i^j is the j-th element of the i-th interleaved partitioning (IP). The remaining steps to generate transmitted signal are similar to those of AP-PTS.

Adjacent partition

In the AP-PTS scheme, successive subcarriers are sequentially assigned into the same sub-block. Nevertheless, AP-PTA has the capacity to reduce PAPR reduction performance similar to PRP-PTS, but with less computational complexity [c]. The partitions can be represented by the following equations,
[Partitioning]

$$X = [P_0' \, P_1' P_2' \ldots\ldots P_{M-1}'] \quad (8)$$

$$P_0 = [\quad P_0' \quad , 00000\ldots\ldots 0] \quad (9a)$$

$$P_1 = [00000\ldots\ldots 0, \quad P_1', \quad 00000\ldots\ldots 0] \quad (9b)$$

$$P_{M-1} = [00000\ldots\ldots 0, \quad (P_{M-1}')] \quad (9c)$$

where, P'_i is the variable length disjoint subsets of OFDM frame and P_i are the corresponging disjoint partitions; that is, partiions with disjoint equal length supports.

In the two schemes described above, an input symbol sequence of N sub-carriers is partitioned into M disjoint sub-blocks with equal size. The IFFT of each sub-block is computed to transform the sub-blocks partitioning into time domain. The outputs of all the IFFT results are rotated by a set of rotation phase factors and summed to produce a set of candidates. The candidate with minimum PAPR is then selected for transmission. The mathematical process for any of sub-block partitioning is represented by Eq. (11-13).
[IFFT]

$$x_0(n) = \mathrm{IFFT}(P_0) \quad (11a)$$

$$x_1(n) = \mathrm{IFFT}(P_1) \quad (11b)$$

$$x_{M-1}(n) = \mathrm{IFFT}(P_{M-1}) \quad (11c)$$

[Rotation]

$$x_0^{(\gamma_0)}(n) = x_0(n) \quad (12a)$$

$$x_1^{(\gamma_1)}(n) = x_1(n) \quad (12b)$$

$$x_{M-1}^{(\gamma_{M-1})}(n) = x_{M-1}(n) \quad (12c)$$

[Transmitted Signal]

$$\tilde{x}(n) = \sum_{i=0}^{M-1} x_i^{(\gamma_i)}(n) \quad (13)$$

PROPOSED PTS METHOD

The data frames of OFDM signals have large PAPRs because of their high correlation. Thus, a fixed permutation (adjacent and interleaved) is employed in this method to break down the long correlation patterns.

In this study, a concatenation of the PTS technique was chosen for the proposed PTS method. The basic algorithm of this method is employed to combine the sub-block partitions of the adjacent and interleaved schemes. The proposed method is similar to AP, which begins with frequency domain data frame as an input into v adjacent blocks. The blocks are then divided into sub-blocks with size s. Finally, blocked interleaved partitions P_i are constructed by appointing the sub-blocks into the partitions as follows

$$P_i\binom{q}{r} = Sb_{ri}(q) \quad (7)$$

where, $P_i\binom{q}{r}$ represents the q-th element of the sub-block r within the partition P_i and $Sb_{ri}(q)$ represents the q-th element of the sub-block i within the block r of the original data. A blocked interleaved partition consists of a sub-block from each of the v blocks. Each sub-block has a size of s, and thus, the partition size is $s.v$.
In the proposed approach, each of the blocked interleaved partitions contains $s.v$ elements. The IDFT of each partition are then obtained independently. The output of the IDFT in each of the partitions P_i is given by

$$x_n^{(i)} = \sum_{q=0}^{s-1} \square \sum_{r=0}^{v-1} P_i\binom{q}{r} e^{\frac{j2\pi(rl+is+q)n}{N}} \quad (8)$$

where $x_n^{(i)}$ represents n-th sample in the PTS sequence corresponding to partition P_i, N is the total number of subcarriers, and l is the number of blocks $\left(l = \frac{N}{v}\right)$. Moreover, r is the sub-block index within the partition and q is the index within the sub-block.

The PTS sequences $x_n^{(i)}$ are phase rotated with a rotation factor w_i, whereas the first sequence $x_n^{(0)}$ is kept constant, that is, w_0 =1. The phase factors w_i are given by the exponentials

$$w_i = e^{j\varphi_i}, \qquad i = 0, 1, \ldots\ldots (z-1) \quad (9)$$

where, φ_i are randomly selected numbers within the range $0 \le \varphi_i \le 2\pi$, z is the number of block interleaved partition. Subsequently, the rotated sequences

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$\tilde{x}_n^{(i)} = w_i . x_n^{(i)}$ are then combined to generate a transmission signal candidate $\tilde{x}_n$ that contains the same information within a phase factor.

$$\tilde{x}_n = \sum_{i=0}^{V-1} \tilde{x}_n^{(i)} \tag{10}$$

The process is repeated with a different set of phase rotation values for a particular number of times (τ). With each repetition, the PAPR of the candidate transmitted signal is computed. The candidate transmits signals, as well as the computed PAPR and the equivalent set of phase factors, are stored. After τ iterations, the OFDM symbol with the lowest PAPR is transmitted.

SIMULATION RESULTS

In this section, extensive simulations were performed to evaluate and compare the PAPR reduction performances of the proposed and the ordinary PTS technique. In the computer simulations, the numbers of subcarriers were set as $\mathbf{N}$ =64, $\mathbf{N}$ =128 and $\mathbf{N}$ =256, which were divided into $\mathbf{M}$ =2, $\mathbf{M}$ =4 and $\mathbf{M}$ =8 number of sub-blocks; data symbols are modulated by 16QAM.

Firstly, the performance of the proposed approach was compared with original OFDM (signal without PTS) and other signals obtained by the ordinary PTS schemes, as shown in Figure-2. The CCDF of the PAPR was considered with $\mathbf{M}$ =8 sub-blocks and number of subcarriers $\mathbf{N}$ =64. When CCDF=10^{-3}, the $PAPR_0$ of the original OFDM was 9.9 dB, whereas that of IP-PTS was 8.3 dB, AP-PTS was 7.3, and the proposed method with PTS was 7.1 dB. Therefore, the proposed PTS scheme can reduced PAPR by around 2.8 dB, AP-PTS by 2.6 dB and IP-PTS by 1.6 dB from the original signal.

Figure-3 shows the CCDF of the PAPR, the original OFDM signal and other signals obtain by the AP-PTS, IP-PTS, and proposed PTS methods for the sub-blocks of $\mathbf{M}$ =8 and number of subcarriers $\mathbf{N}$ =128. The proposed PTS method was compared with the original OFDM signal and traditional PTS schemes (AP and IP). The proposed PTS method can reduce PAPR better the than original OFDM signal, IP-PTS, and AP-PTS by 2.8 dB, 1.5 dB, and 0.3 dB, respectively.

The simulation results are shown in Figure-4. The proposed PTS method was compared with AP-PTS, IP-PTS and original OFDM signal for $\mathbf{M}$ =8 sub-block and number of subcarriers $\mathbf{N}$ =256. When CCDF=10^{-3}, the $PAPR_0$ of the original OFDM signal was 11.2 dB, IP-PTS was 9.5 dB, AP-PTS was 8.2 dB and the proposed PTS method was 7.8 dB. Therefore, the proposed PTS reduced PAPR by approximately 3.4 dB, AP-PTS by 3 dB and IP-PTS by 1.7 dB from the original.

Figures 2, 3, and 4 show the performance of proposed PTS method compared with the ordinary PTS schemes (AP and IP) with original OFDM when the modulation technique was 16QAM, sub-blocks partition $\mathbf{M}$ =8, with number of subcarriers $\mathbf{N}$ =64, $\mathbf{N}$ =128, and $\mathbf{N}$ =256, respectively. The results of the PAPR reduction for the different scenarios are listed in Table-1.

Table-1. Numerical simulation parameters for M= 8 and 16QAM.

Number of subcarriers	CCDF	PAPR of Proposed PTS (dB)	PAPR of AP-PTS (dB)	PAPR of IP-PTS (dB)	PAPR of original OFDM (dB)
64	10^{-3}	7.1	7.3	8.3	9.9
128	10^{-3}	7.5	7.8	9	10.3
256	10^{-3}	7.8	8.2	9.5	11.2

Figure-5 shows that the IP-PTS scheme achieves as much as 1.6 dB of PAPR reduction compared to the original OFDM signal when CCDF=10^{-3} by using $\mathbf{M}$ =4 with $\mathbf{N}$ =64. Furthermore, the proposed PTS method reduced the PAPR by 0.5 dB compared with AP-PTS.

Figure-6 shows that when $\mathbf{M}$ =4 and $\mathbf{N}$ =128, the proposed PTS method can achieve PAPR reduction of approximately 0.3 dB, 1.1 dB and 2.8 dB better than that of the AP-PTS, IP-PTS and original OFDM, respectively. Similarly, Figure-7 shows different performances of PAPR reduction using the proposed PTS method as compared with ordinary PTS schemes and original OFDM for $\mathbf{M}$ =4 with $\mathbf{N}$ =256 when CCDF=10^{-3}. The proposed PTS method reduced PAPR by approximately 2.8 dB, AP-PTS by 2.6 dB and IP-PTS by 1.5 dB from the original signal. Figures 5, 6, and 7 show the performance of proposed PTS method versus AP and IP schemes, with original OFDM, using $\mathbf{N}$ =64, $\mathbf{N}$ =128 and $\mathbf{N}$ =256 number of subcarriers, respectively. Table-2 shows the PAPR reduction for the proposed PTS method compared with ordinary PTS for $\mathbf{M}$ =8.

Table-2. Numerical simulation parameters for M= 4 and 16QAM.

Number of subcarriers	CCDF	PAPR of Proposed PTS (dB)	PAPR of AP-PTS (dB)	PAPR of IP-PTS (dB)	PAPR of original OFDM (dB)
64	10^{-3}	6.5	7	8.3	9.9
128	10^{-3}	7.8	8.1	8.9	10.6
256	10^{-3}	8.4	8.6	9.7	11.2

Figures 8, 9, 10 show the PAPR performance of the proposed PTS method as compared with the original, IP-PTS, and AP-PTS schemes when using number of sub-

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blocks $\mathbf{M}$ =2 with $\mathbf{N}$ =64, $\mathbf{N}$ =128, and $\mathbf{N}$ =256 number of subcarriers, respectively.

The Figures showed that the original OFDM signal exceed 9.9 dB, 10.7 dB and 10.9 dB of the $PAPR_0$, respectively. By contrast, when CCDF=10^{-3}, the IP, AP, and proposed the PTS method only exceed 8.9 dB, 9.1 dB and 9.3 dB, respectively for IP-PTS; 8 dB, 8.7 dB and 9 dB, respectively for AP-PTS; and 6.6 dB, 7.7 dB and 8.2 dB, respectively, for proposed approach. Therefore, the IP-PTS can reduce the PAPR more than original OFDM by 1 dB, 1.6 dB and 1.6 dB, respectively.

Alternately, the AP-PTS can reduce the PAPR more than the IP-PTS by 0.9 dB, 0.4 dB and 0.3 dB for AP-PTS. Likewise, the proposed method can reduce the PAPR more than the IP-PTS by 2.3 dB, 1.4dB and 0.8 dB. Thus, the proposed PTS method can achieve better PAPR reduction compared with the traditional adjacent and interleaved PTS schemes. The PAPR reduction performance results for the different scenarios are summarized in Table-3.

Table-3. Numerical simulation parameters for M= 4 and 16QAM.

Number of subcarrier	CCDF	PAPR of Proposed PTS (dB)	PAPR of AP-PTS (dB)	PAPR of IP-PTS (dB)	PAPR of original OFDM (dB)
64	10^{-3}	6.6	8	8.9	9.9
128	10^{-3}	7.7	8.7	9.1	10.7
256	10^{-3}	8.2	9	9.3	10.9

The proposed method, AP-PTS and IP-PTS schemes were compared with the original OFDM signal in all Figures of the simulation results by using any number of sub-blocks ($\mathbf{M}$ = 2, $\mathbf{M}$ = 4 and $\mathbf{M}$ = 8) and subcarriers ($\mathbf{N}$ = 64, $\mathbf{N}$ = 128, and $\mathbf{N}$ = 256). Results showed that the performance of the three schemes was better compared to the original OFDM signal. The proposed method also performed better than AP-PTS and IP-PTS. Therefore, the proposed approach can enhance the effectiveness of the PAPR reduction performance for OFDM systems, as well as achieve good PAPR reduction with low complexity.

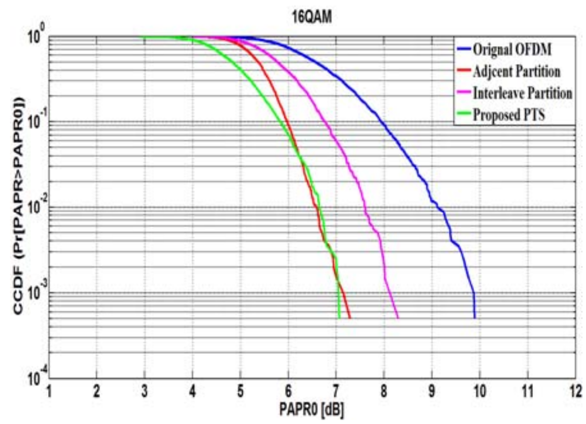

Figure-2. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=64 and number of sub-blocks M=8.

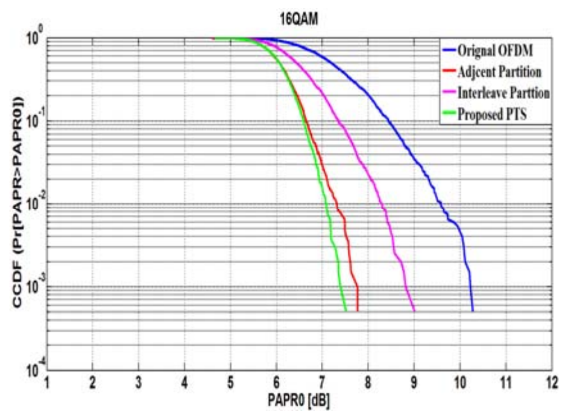

Figure-3. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=128 and number of sub-blocks M=8.

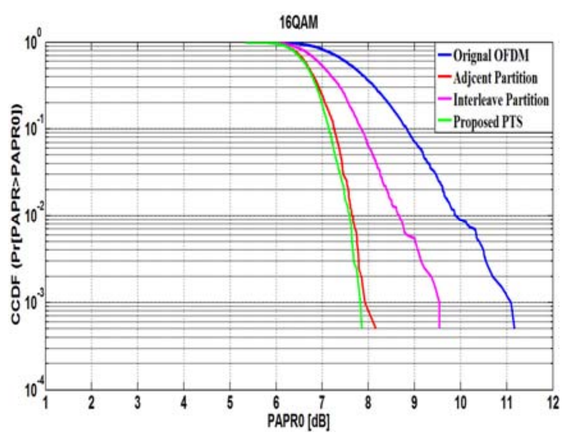

Figure-4. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=256 and number of sub-blocks M=8.

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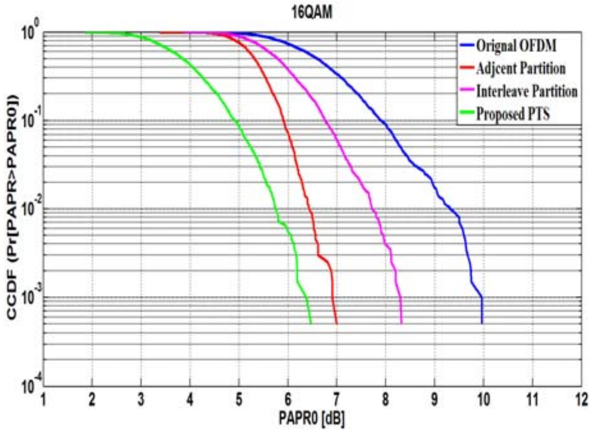

Figure-5. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=64 and number of sub-blocks M=4.

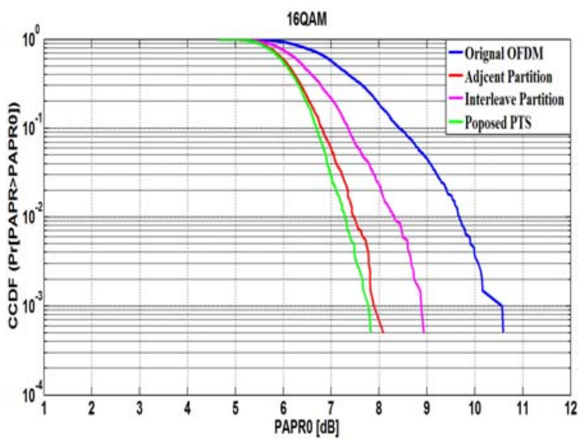

Figure-6. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=128 and number of sub-blocks M=4.

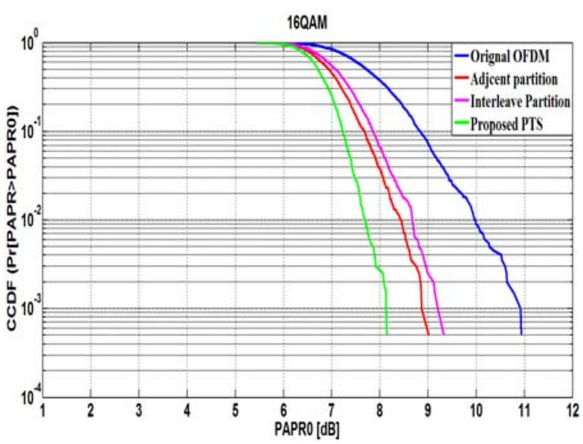

Figure-7. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=256 and number of sub-blocks M=4.

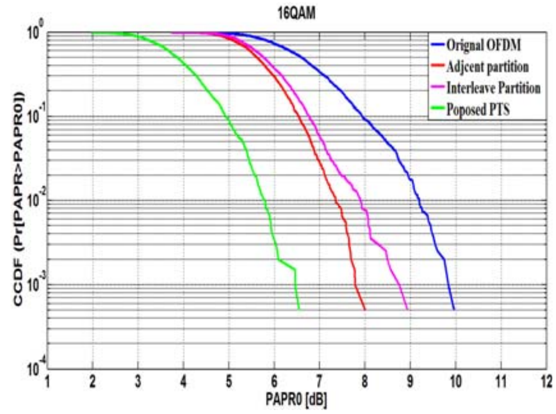

Figure-8. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=64 and number of sub-blocks M=2.

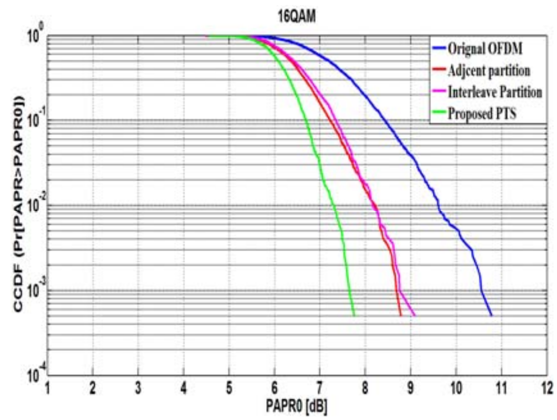

Figure-9. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=128 and number of sub-blocks M=2.

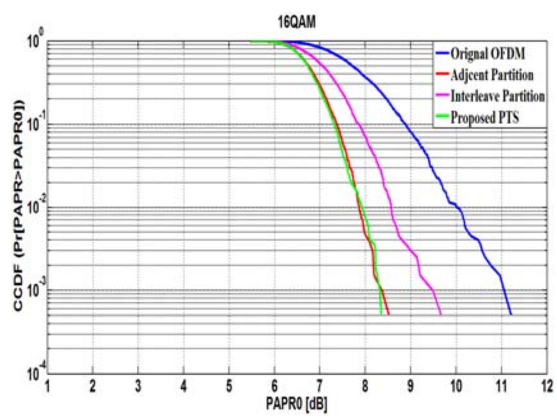

Figure-10. Comparison of CCDF of PAPR reduction performance for number of subcarriers N=256 and number of sub-blocks M=2.

CONCLUSIONS

An enhanced PTS partitioning technique for PAPR reduction in OFDM system was proposed. The PTS

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approach combined two PTS partitioning schemes (adjacent and interleaved) to effectively reduce the PAPR of the OFDM systems. The influence of the proposed approach on performance was investigated by varying the size of the disjoint sub-blocks. Simulation results showed that the proposed PTS scheme with any number of subcarriers and sub-block partition sizes is efficient and valid, and can yield better PAPR reduction performance as compared with two well-known sub-block partitioning schemes, namely AP and IP. Therefore, the proposed method provides better PAPR reduction performance compared with AP and IP partitioning-based PTS schemes.

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