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# PAPR Reduction in OFDM Signal by Incorporating Mu-Law Companding Approach into Enhanced PTS Scheme

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**Abstract:** Orthogonal Frequency Division Multiplexing (OFDM) is a potential transmission approach for high capacity communication systems. Despite the many advantages of OFDM, the major downside is the high peak-to-average power ratio (PAPR) which increases the system complexity, reduces the efficiency of the system, causes degradation in BER performance, and makes OFDM sensitive to nonlinear distortion in the transmission. Various methods have been proposed to deal with the PAPR problem, including the partial transmit sequence (PTS) that has attracted considerable attention. Hence, this paper presents a hybrid approach combining an enhanced PTS technique with Mu-Law companding. The PTS technique was enhanced through improving its sub-block partitioning scheme, where the enhanced partitioning scheme consolidated a conventional interleaved partitioning into an adjacent partitioning scheme. This incorporation of Mu-Law characteristic in time domain for PAPR reduction in OFDM essentially enhances the PAPR reduction performance, based on using numerical simulation results. Consequently, though the pseudorandom sub-block partition method obtains better PAPR reduction more than the other sub-block partition schemes (interleaved and adjacent) of ordinary PTS, it is quite difficult to be designed. The findings show that the enhanced PTS technique with Mu-Law companding, while maintaining low computational complexity, performs significantly better than the pseudorandom partitioning PTS on various types of modulation formats and subcarriers.

**Keywords**: OFDM, PAPR, PTS, sub-block partitioning schemes, Mu-Law speech

## 1 Introduction

Orthogonal frequency division multiplexing (OFDM) system is an alluring solution for transmitting a high data capacity in the wireless communication. OFDM system has numerous benefits, including high spectral efficiency, resistance to interference, and robustness against signal fading [1]. OFDM system is commonly used in digital audio and video broadcasting, mobile multimedia access communication (MMAC); therefore, it has been proposed as standard in wireless communication [2]. However, OFDM is subjected to a large peak-to-average power ratio (PAPR) in the time-domain transmit signal, which may cause a nonlinear distortion after the power amplifiers and degrades the performance of OFDM system; which are common issues in the multiplexing techniques either in optical domain such as Wavelength Division Multiplexing (WDM) [3–6], Mode Division Multiplexing (MDM) [7–10] or wireless domain such as OFDM Based on reviewing the literature [11], several schemes have been proposed to reduce PAPR, including clipping [12], coding [13], clipping and filtering [14], tone injection (TI) [15], active constellation extension (ACE) [16], tone reservation (TR) [17], and multiple signal representation schemes, such as selected mapping (SLM) [18], interleaving [19], and partial transmit sequence (PTS) [20]. Among the current schemes, the PTS is one of the most important probability technology in enhancing the statistics of the PAPR of an OFDM signal due to its linear technique and having no signal distortion [21, 22]. It is important to mentioned that PTS has two approaches which are, first is partitioning the original OFDM into a set of disjoint sub-blocks and second, is to create a set of candidate signals by adding phase rotated sub-blocks in order to choose the smallest PAPR for transmission [23]. Therefore, a hybrid technique is proposed in the present paper which combines an enhanced PTS scheme with Mu-Law companding approach. The enhanced PTS

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***Corresponding author: Yousef Fazea,** InterNetWorks Research Laboratory, School of Computing, Universiti Utara Malaysia, 06010 Sintok Kedah, Malaysia, E-mail: yosiffz@internetworks.my
**Zeyid T. Ibraheem,** Ministry of Science and Technology, Baghdad, Iraq
**Md. Mijanur Rahman,** Deptartment of Computer Science and Engineering, Uttara University, Dhaka, Bangladesh
**Kawakib K. Ahmed,** Ministry of Science and Technology, Baghdad, Iraq

scheme incorporates traditional interleaved partitioning into an adjacent partitioning scheme to enhance the overall PAPR reduction capability of the PTS scheme.

An overview of OFDM system with the concept of PAPR problem, techniques, and Mu-Law companding technique is presented in Section 2. The sub-block partitioning schemes is presented in Section 3. Section 4 presents the enhanced approach with Mu-Law companding technique. The results are demonstrated in Section 5, followed by the conclusion in Section 6.

## 2 Analaytical model

### 2.1 PAPR in OFDM systems

The OFDM signal for $N$ subcarriers are formed by several blocks of data symbols $X = \{X_k, k = 0, 1, \cdots\cdots, N-1\}$, which is chosen from the quadrature amplitude modulation (QAM) or phase shift keying (PSK). The discrete time domain OFDM signal $x_n$, can be expressed as follows:

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

The PAPR of OFDM signals $x(n)$ in eq. (1), is given in Ref. [24]:

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

where $E\{.\}$ indicates the average power. For performance evaluation of PAPR reduction technique, the complementary cumulative distribution function (CCDF) is utilized, which represents the probability that the PAPR of OFDM symbol surpasses a given threshold level $\text{PAPR}_0$, as defined in Ref. [25]

$$CCDF(PAPR_0) = P_r\,(PAPR > PAPR_0) \tag{3}$$

### 2.2 PTS technique

The main role of PTS method is to divide the input data block $X$ in frequency domain into $M$ disjoint sub-blocks, which is represented by the vectors $\{X_m, m = 0, 1, \cdots\cdots, M-1\}$ [26] as

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

Each sub-block's length is still, and null value is set for sub-block that does not have the location. Each sub-block in the time domain is transformed by Inverse Fast Fourier Transform (IFFT) operation as:

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

Each IFFT sub-block $x_m$ is rotated using a phase factor. Thus, the time domain signal after combination is presented as

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

The PTS-OFDM method's sub-block partitioning techniques can be divided into adjacent, interleaved, and pseudorandom partitioning [27]. Among these partitioning techniques, the pseudorandom sub-block partitioning has the best PAPR reduction performance. However, this

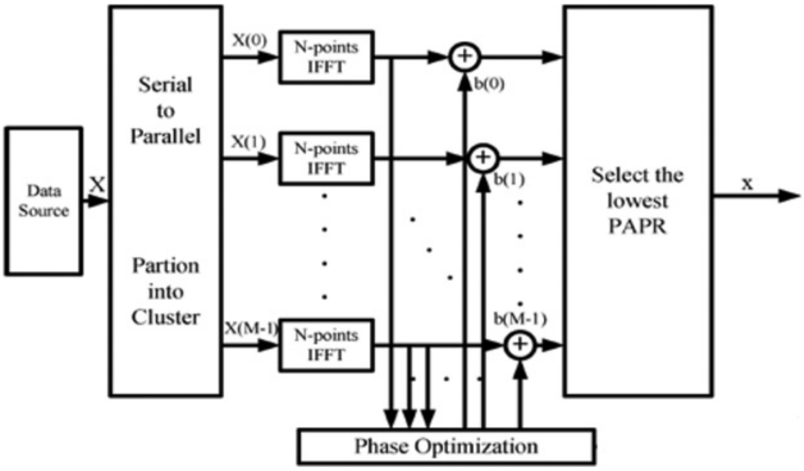

**Figure 1:** PTS method: block diagram.

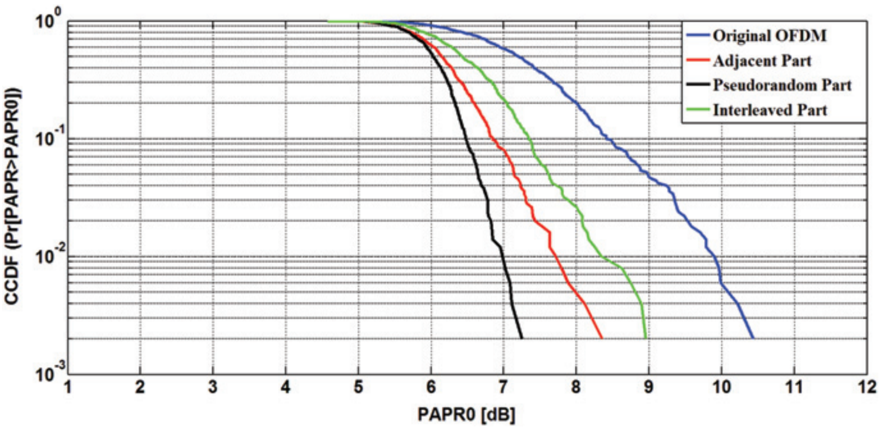

**Figure 2:** Comparison of PAPR reduction performance with different sub-block partitions.

partitioning incurs a higher computational complexity, and is difficult to be designed [28, 29]. The mathematical frameworks of these three different schemes are presented in detail in Section 3. In order to demonstrate the comparative performance of these three partitioning techniques, Figure 2 shows their CCDFs versus $\mathrm{PAPR}_0$ in traditional PTS.

## 2.3 Mu-Law companding technique

Mu-Law is a powerful compression technique that can be used to reduce PAPR [30]. In the digital telecommunication system, a Mu-Law ($\mu$-law) companding method is used in speech processing Mu-Law algorithm companding transform which focuses mainly on compressing the peak signals and expanding the small signals for PAPR reducing. Therefore, PAPR is not only significantly reduced, but the immunity of the small signals against noise is also increased. The companding techniques for PAPR reduction were simply reviewed in Refs [31, 32]. The compression process is applied after the IFFT at the transmitter end and expansion before the FFT at the receiver end. An OFDM transmitter based on Mu-Law companding technique is shown in Figure 3.

Mu-Law compression signal at the transmitter is expressed as:

$$S_u(t) = \frac{\ln\left[1 + u\frac{|S(t)|}{S_{\max}(t)}\right]}{\ln(1+u)} S_{\max}(t).\,Sgn(S(t)) \qquad (7)$$

Where the input instantaneous amplitude denoted as $S(t)$, $S_{\max}(t)$ is the peak amplitude of $S(t)$, s Sign function is $Sgn$, and $\mu$ is the Mu-Law compand parameter.

## 3 PTS scheme sub-block partitioning

### 3.1 PTS adjacent partitioning

OFDM Frame's subcarriers $N$ are divided into equal sub-blocks size $M$ disjoint, and in each sub-block IFFT was computed. Then IFFT output in each of the partitions is multiplied by a set of rotating phase factors. The blocks are summed to produce transmitted signal in order to have low PAPR. The transmitted signal is explained as [33]

$$\tilde{x}(n) = \sum_{i=0}^{M-1} x_i^{(r_i)}(n) \qquad (8)$$

where $x_i^{r_i}(n)$ is the phase-rotated version of the time domain signal for partition $P_i$ with length $L_i$. As mentioned, the length partitions are generated as follows:

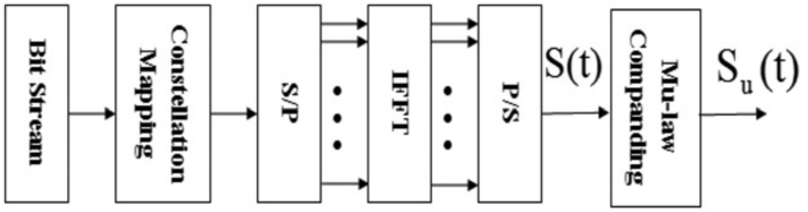

**Figure 3:** Mu-Law companding technique in the OFDM transmitter.

$$X = [P'_0\, P'_1 \cdots\cdots P'_{M-1}] \tag{9}$$

$$P_0 = [\quad P'_0 \quad ,0000 \cdots\cdots 0] \tag{10}$$

$$P_1 = [0000 \cdots\cdots 0, \quad P'_1, \quad 0000 \cdots\cdots 0] \tag{11}$$

$$P_{M-1} = [0000 \cdots\cdots 0, \qquad P'_{M-1}] \tag{12}$$

Then by taking IFFT out of these partitions as shown by eq. (13), time domain signal is obtained as follows:

$$x_i(n) = IFFT(P_i) \tag{13}$$

where $i = 0, 1, 2, \cdots\cdots, M-1$. Then the phase-rotated version $x_i^{r_i}(n)$ of the time domain signals is obtained by multiplying the phase factors, $\varphi(r_i) = e^{j\varphi_i}$ as in eq. (14) where $\varphi_i$ are the rotation angles.

$$x_i^{(r_i)}(n) = \varphi(r_i)\, x_i(n) \tag{14}$$

### 3.2 Interleaved Partitioning PTS Scheme (IP-PTS)

The partitions of the $M$ groups given by $L = N/M$ and the $i^{th}$ interleaved partition that is formed by assigning $i^{th}$ subcarrier of each group to the $i^{th}$ interleaved partition can be represented as [34]

$$P_0 = [P_0^{(1)} 0 \cdots 0 P_0^{(2)} 0 \cdots\cdots 0 P_0^{(M)} 00 \cdots 0] \tag{15}$$

$$P_1 = [0 P_1^{(1)} 0 \cdots 00 P_1^{(2)} 0 \cdots\cdots 00 P_1^{(M)} 0 \cdots 0] \tag{16}$$

$$P_L = [00 \cdots 0 P_L^{(1)} 0 \cdots 0 P_L^{(2)} 0 \cdots\cdots 0 P_L^{(M)}] \tag{17}$$

where, $P_i^j$ is the $j^{th}$ element of the $i^{th}$ IP.

### 3.3 PTS pseudorandom partitioning scheme

In the pseudorandom scheme, the subcarrier signal and the partitions are assigned into each other randomly. The partitions can be represented as [35]

$$P_0 = [0 P_0^{(1)} 000 P_0^{(M)} 0000 P_0^{(3)} P_0^{(2)} 0000] \tag{18}$$

$$P_1 = [P_1^{(M)} 0000 P_0^{(3)} 00 P_1^{(2)} 0 \cdots 00 P_1^{(1)}] \tag{19}$$

$$P_L = [00 \cdots 0 P_L^{(2)} 0 \cdots 0 P_L^{(1)} 0 \cdots\cdots 0 P_L^{(M)}] \tag{20}$$

where, $P_i^j$ is the $j^{th}$ element of the $i^{th}$ pseudorandom partition. Residual steps to produce transmitted signal are similar to those of partitioning schemes mentioned above.

## 4 Proposed enhanced hybrid PTS scheme

This section presents the proposed hybrid approach which combines an enhanced PTS technique with Mu-Law companding technique as shown in Figure 4. The enhanced PTS scheme, which incorporates IP into adjacent partitioning scheme, was proposed [36]. Similarly, for adjacent partitioning, the enhanced PTS scheme starts with a data input frame partitioned into $v$ adjacent blocks. Then, blocks are divided into $s$ size sub-blocks. Eventually, interleaved partitions $P_i$ are constructed by assigning the sub-blocks into the partitions as follows:

$$p_i \binom{q}{r} = Sb_{ri}(q) \tag{21}$$

where, $P_i \binom{q}{r}$ represents the $q^{th}$ which is the sub-block elements $r$ in $P_i$ as the partition, $sb_{ri}(q)$ indicates the $q^{th}$ component of the $i$ sub-block within the block $r$ of the original data. The interleaved partition of the blocks consists of several sub-blocks $v$. $s$ is the size of the sub-block.

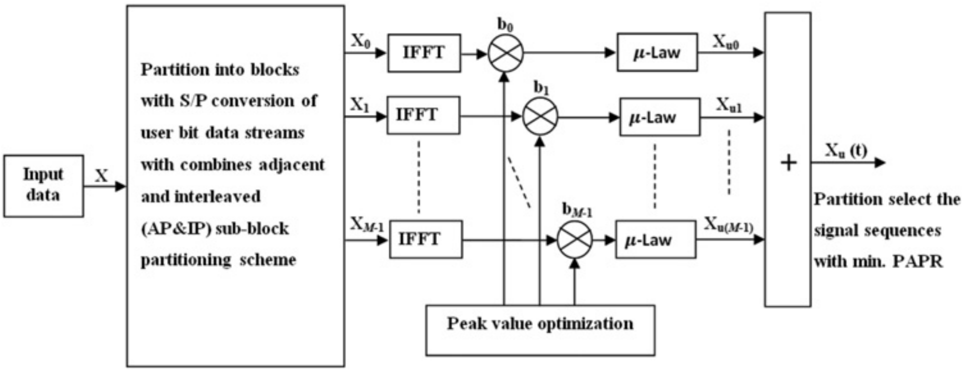

**Figure 4:** Block diagram depicting the hybrid approach involving enhance PTS technique and Mu-Law companding.

Then each of the blocked interleaved partitions contains $s.v$ elements. Regarding the original frequency of the frequency domain data $X_k$, the IDFT of each of the partitions is taken independently. Thus, IDFT output for the partition $P_i$ is given by

$$x_n^{(i)} = \sum_{q=0}^{s-1} \sum_{r=0}^{v-1} P_i \binom{q}{r} e^{j2\pi(rl + is + q)\,n/N} \tag{22}$$

where $x_n^{(i)}$ represents $n^{th}$ PTS sequence sample that corresponds to partition $P_i$, the number of subcarrier is presented as $N$, whereas $l$ is the block's number $(l = N/v)$. $r$ is the index of the sub-block in the partition, whereas $q$ is the sub-block index $x_n^{(i)}$ is the PTS sequences that have phase rotation with a factor $w_i$, excluding the first sequence $x_n^{(0)}$ that remains constant $w_0 = 1$. The phase factors $w_i$ is expressed as follows:

$$w_i = e^{j\varphi_i}, \quad i = 0, 1, \cdots\cdots (z-1) \tag{23}$$

where $\varphi_i$ randomly selects numbers between $0 \le \varphi_i \le 2\pi 0 \le \varphi_i \le 2\pi$, $z$ is interleaved partition block's number, $\tilde{x}_n^{(i)} = w_i \, . \, x_n^{(i)}$ is the rotated sequences that are used to be combined in order to generate the candidate's transmit signal $\tilde{x}_n$ that has similar information in the phase factor.

$$\tilde{x}_n = \sum_{i=0}^{v-1} \tilde{x}_n^{(i)} \tag{24}$$

Consequently, through the application of Mu-Law companding technique as given by eq. (7) on the transmit signal candidate $\tilde{x}_n$, the new signal is obtained as follows:

$$x_u(t) = \frac{\ln\left[1 + u \frac{|(\tilde{x}_n)|}{\max(\tilde{x}_n)}\right]}{\ln(1+u)} \max(\tilde{x}_n) \, . \, Sgn(\tilde{x}_n) \tag{25}$$

The process is repeated by number of times $(\tau)$, each time with a various set of phase rotation values. In every repetition, PAPR of the candidate signal and the candidate signal itself are computed and the corresponding set of the phase factors is stored. After $\tau$ iterations, the OFDM symbol with the lowest PAPR is transmitted.

## 5 Simulation results

The numerical simulations to evaluate and compare the performance of the combined technique with the ordinary PTS schemes of three different types of sub-blocks partitioning (IP-PTS, AP-PTS, and PRP-PTS) are presented. In the simulation, the number of the sub-carriers was set to $N = 128$, which was further divided into $M = 4$ sub-blocks. In addition, the different modulation schemes, QPSK, 8PSK, 16QAM, and 64QAM, were accounted for as well. In the Mu-Law compression compand parameter $\mu$ was set to 1, and for the CCDF analysis, a threshold of $\text{CCDF} = 10^{-3}$ was set.

Figure 5 shows the performance analysis of the combination of enhanced PTS scheme with Mu-Law technique (combined technique) compared to the ordinary PTS schemes and the original OFDM signal (signal without PTS) for QPSK modulation. For the ordinary PTS scheme, three kinds of partitioning schemes (IP, AP, and PRP) are considered, whereby the $\text{PAPR}_0$ of the original OFDM signals is 11.3 dB, IP-PTS is 9.7 dB, AP-PTS is 8.5 dB, PRP-PTS is 7.2 dB, and combined technique is 6 dB. Therefore, the combined technique reduced PAPR by around 5.3 dB, PRP-PTS by 3.9 dB, AP-PTS by 2.5 dB, and IP-PTS by 1.8 dB from the original signal.

The simulation results for 8PSK modulation are shown in Figure 6, which compares the combination of enhanced

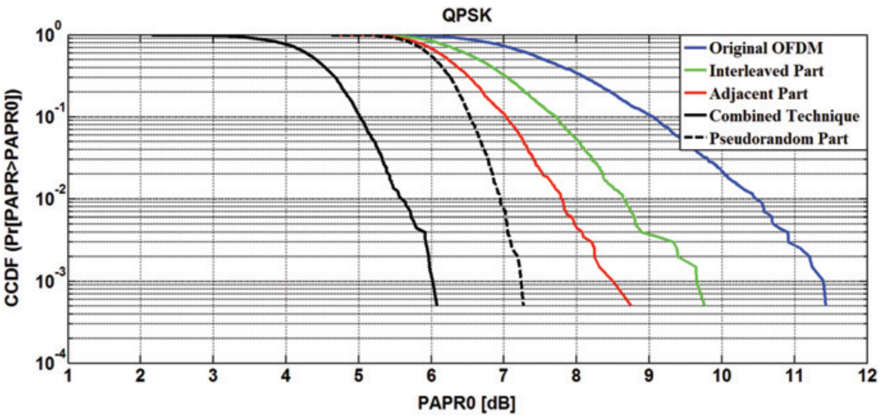

**Figure 5:** PAPR performance evaluation of the enhanced PTS scheme in combination with Mu-Law technique (combined technique) for QPSK modulation.

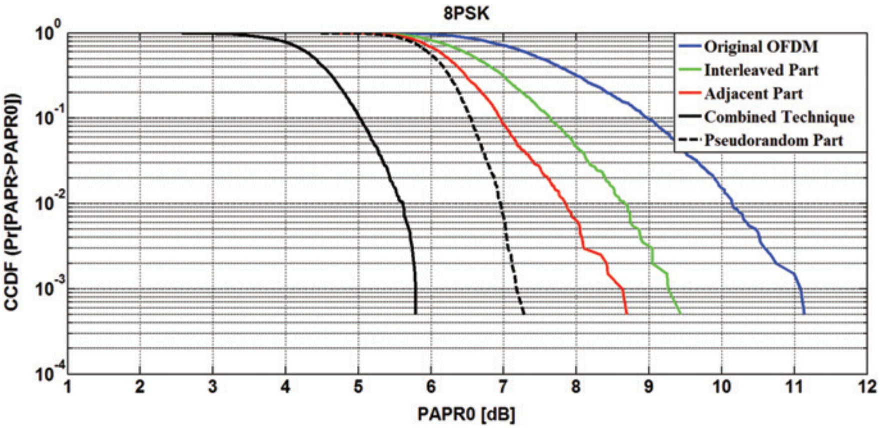

**Figure 6:** PAPR performance evaluation of the enhanced PTS scheme in combination with Mu-Law technique (combined technique) for 8PSK modulation.

PTS method with Mu-Law technique (combined technique) against the ordinary PTS and the original OFDM signal. For 8PSK modulation, the $PAPR_0$ of the original OFDM signal is 11.1 dB, IP-PTS is 9.2 dB, AP-PTS is 8.6 dB, PRP-PTS is 7.2 dB, and the combined technique is 5.8 dB. The enhanced PTS with Mu-Law scheme reduced PAPR by around 5.3 dB, PRP-PTS by 3.9 dB, AP-PTS by 2.5 dB, and IP-PTS by 1.9 dB from the original signal.

The comparison process is repeated as shown in Figure 7. In this figure, the PAPR0 of the original OFDM signal is 10.8 dB, IP-PTS is 9 dB, AP-PTS is 8.3 dB, PRP-PTS is 7.1 dB, and the enhanced PTS with Mu-Law scheme is 5.7 dB. Thus the enhanced PTS scheme with Mu-Law technique (combined technique) reduced PAPR by around 5.1 dB, PRP-PTS by 3.7 dB, AP-PTS by 2.5 dB, and IP-PTS by 1.8 dB.

Figure 8 shows the comparisons of the PAPR reduction evaluation performance between the enhanced PTS scheme with Mu-Law technique (combined technique) against the ordinary PTS scheme and the original OFDM signal for 64QAM modulation. The results simulated when the CCDF = $10^{-3}$, the $PAPR_0$ of the original OFDM signal is 10.5 dB, IP-PTS is 8.8 dB, AP-PTS is 7.9 dB, PRP-PTS is 7.2 dB and the enhanced PTS with Mu-Law scheme is 5.7 dB. Hence, it is noticeable that the enhanced PTS with Mu-Law scheme can achieve further 1.5 dB, 2.2 dB, and 3.1 dB PAPR reduction compared to the ordinary PTS scheme PRP-PTS, AP-PTS, and IP-PTS.

The significant results show that better results are obtained by using enhanced PTS scheme with Mu-Law technique (combined technique) against the ordinary PTS and original OFDM signals when the modulation techniques are QPSK, 8PSK, 16QAM, and 64QAM. These experiments clearly indicate that the enhanced PTS scheme with Mu-Law technique has positive PAPR reduction more than the ordinary PTS techniques with IP, AP, and PRP sub-block partitioning schemes. To be more specific, its PAPR reduction performance is better than that of PTS with the pseudorandom sub-block partition; the latter is considered to have the best PAPR reduction performance, but at the same time, it has the highest design and computational complexities among the traditional PTS techniques. The results show that the combined approach

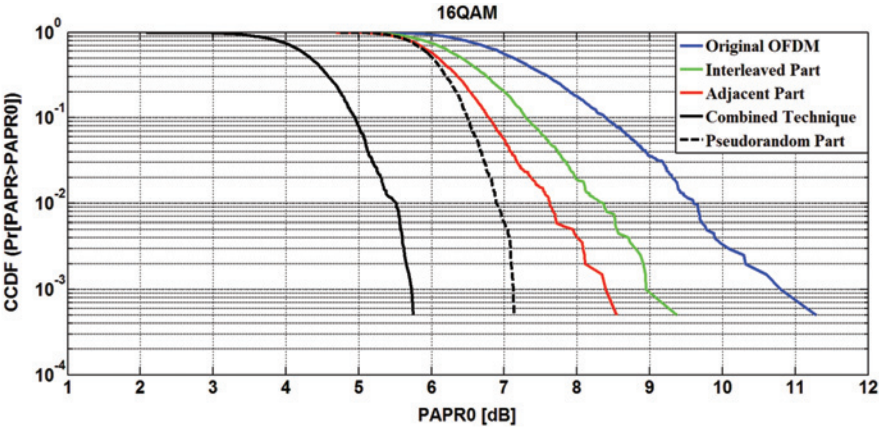

**Figure 7:** PAPR performance evaluation of the enhanced PTS scheme in combination with Mu-Law technique (combined technique) for 16QAM modulation.

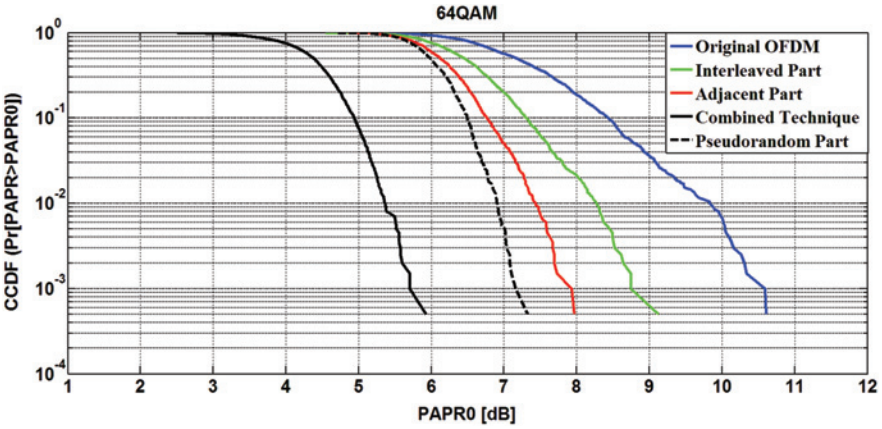

**Figure 8:** PAPR performance evaluation of the enhanced PTS scheme in combination with Mu-Law technique (combined technique) for 64QAM modulation.

can substantially reduce the PAPR and enhance the overall performance of OFDM. In addition, the combined technique can be applicable with any numbers of subcarriers, modulation format and is attractive for its simplicity and effectiveness. Therefore, it is evident that the proposed hybrid approach can significantly enhance the performance of PAPR reduction. Moreover, the improvement in PAPR reduction capability is achieved without adding much overhead in terms of computational cost and design complexity.

## 6 Conclusion

This paper presented a hybrid approach to the PAPR reduction problem; the approach is a combination of the enhanced PTS technique and Mu-Law companding. The enhanced PTS scheme incorporates IP into an adjacent partitioning scheme, and an appropriate Mu-Law with low computational complexity is applied on the output of this enhanced PTS. The basic principle of the nonlinear companding transform scheme, being a compression of large signals and an enhancement of small signals that keep the overall power of the signal unchanged, significantly reduces PAPR in addition to the PAPR reduction provided by enhanced PTS. Thus, beside the PAPR reduction, the immunity of small signals against noise is also achieved. Consequently, the simulations results confirm that the suggested scheme on various types of modulation format and subcarriers is better than the pseudorandom partitioning PTS. Since the suggested scheme has low computational complexity, this makes the proposed approach an effective technique to achieve a significant reduction of PAPR.

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