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Enhancing the Odd Peaks Detection in OFDM Systems Using Wavelet Transforms

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Abstract

This work aims to study the effect of unwanted peaks and enhance the performance of wireless systems on the basis of tackling such peaks. A new proposition has been made based on wavelet transform method and its entropy. Signals with large peak-to-average power ratio (PAPR) will be examined such as the ones that are considered as the major Orthogonal Frequency Division Multiplexing (OFDM) systems drawbacks. Furthermore, aspatial diversity Multiple-Input Multiple-Out-put (MIMO) technology is used to overcome the complexity addition that could arise in our proposition. To draw the best performance of this work, a MATLAB simulation has been used; it is divided into three main stages, namely, MIMO-OFDM symbols' reconstruction based on wavelet transform, a predetermined thresholding formula, and finally, moving filter. This algorithm is called Peaks' detection based Entropy Wavelet Transform; PD-EWT. Based on the simulation, and under some constrains such as the bandwidth occupancy and the complexity structure of the transceivers, a peak detection ratio has been achieved and reaches around 0.85. Comparing with our previously published works, the PD-EWT enhances detection ratio for 0.25 more peaks.

Keywords

Wavelet Transform, Entropy, MIMO, OFDM, PAPR

1. Introduction

The overwhelming huge data due to the highly demand for the various wireless and cellular system's applications attract the researchers' interest to handle these effects on the wireless systems. Thus, and during the last two decades, their attentions have been focused on the combination between the Orthogonal Frequency Division

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Multiplex (OFDM) modulation technique and the Multiple-Input Multiple-Output (MIMO) technology.

Therefore, we are talking a data rate of around more than 100 Mbps for such systems. The OFDM systems use the parallel transmission, while the MIMO technologies have been employed to reduce the effect of the rich scattering environments.

Moreover, the OFDM has been adopted at the both wireless and wired application to the high data rates as significant advantages over the conventional ones, and shows robustness to multipath fading and a greater simplification of channel equalization.

Furthermore, the multiple antennas have been employed to support the extraordinary data rates due to the rapid growth of the wireless systems and to make use of the rich scattered environments [1]-[5]. The MIMO technologies that could be used for this purpose are either the spatial multiplexing or BLAST [6].

OFDM technique is considered as a multi-carrier system that utilizes a parallel processing technique and allowing the simultaneous transmission of data on many closely spaced, orthogonal sub-carriers. This is attained by making use of the Inverse fast Fourier transforms (IFFT) and fast Fourier transform. However, the peak-to-average power ratio (PAPR) is found as a major deficiency of the OFDM signal, which limits the efficiency of the non-linear devices such as the power amplifiers, mixers, and analog to digital converters. Therefore, the wavelet transform method has been used to tackle the effect of such deficiency as will be discussed in section two [7]. Previously in [8], another proposition of PAPR reduction technique has been addressed based also on wavelet transformation technique. It was based on De-noise the OFDM using some DWT, after that defining an adaptive threshold to limit those peaks, and finally replace these peaks and valleys using an average filter. This algorithm gives an enhancement around 0.65 of reducing the peaks production. The PAPR could be defined as shown in Equation (1) on the maximum power of the OFDM symbol and its average power as:

$$\text{PAPR} = 10\log_{10}\left[\frac{P_{\text{peak}}}{P_{\text{avg}}}\right] \tag{1}$$

P_{peak} is the maximum power of an OFDM symbol, and P_{avg} is the average power. The PAPR can be reformulated as given in (2). T is the symbol duration, $x(t)$ is the OFDM symbol at time, t. X_n is the data modulating the n^{th} sub-carrier and f_o is the nominal subcarrier frequency spacing. Moreover, the average power of the OFDM symbol presented in Equation (2) will be given in Equation (3):

$$\text{PAPR} = \frac{\left|\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X_n \mathrm{e}^{j2\pi f_0 n t}\right|^2}{\frac{1}{NT}\int_0^{NT}\left|\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} X_n \mathrm{e}^{j2\pi f_0 n t}\right|^2 \mathrm{d}t} \tag{2}$$

$$P_{\text{avg}} = \frac{1}{T}\int_0^T\left(\sum_{v=0}^{N-1} c_v^2\right)\mathrm{d}t \tag{3}$$

Here, c_v is the magnitude of the modulated data. For the sake of simplicity; $|c_v| = 1$, which can be attained by using BPSK modulation with channel coding less techniques at the interval of $\tau \in [0, T]$. This will result a direct relationship between the average power and the total number the IFFT points, N. It is clearly shown from Equation (4) as follows:

$$P_{\text{avg}} = N\frac{1}{T}\int_0^T c_v^2 \mathrm{d}t = N, \tag{4}$$

From [4] and based on the mathematical modelling that was used to combat the effect of the PAPR; the PAPR will be decreased if the average power of the OFDM symbol is decreased. The following flowchart shows the previously proposed technique in **Figure 1**.

Another technique to compare with could be found in **Figure 2**. It can be summarized by the following steps:

1) Read a segment of the OFDM signal.
2) Denoise the OFDM signal from additive white Gaussian noise (AWGN) using wavelets technique [8]. In this step the unwanted random addition to a wanted signal is removed using the following sub steps:

- Applying discrete wavelet transform DWT to the noisy signal.

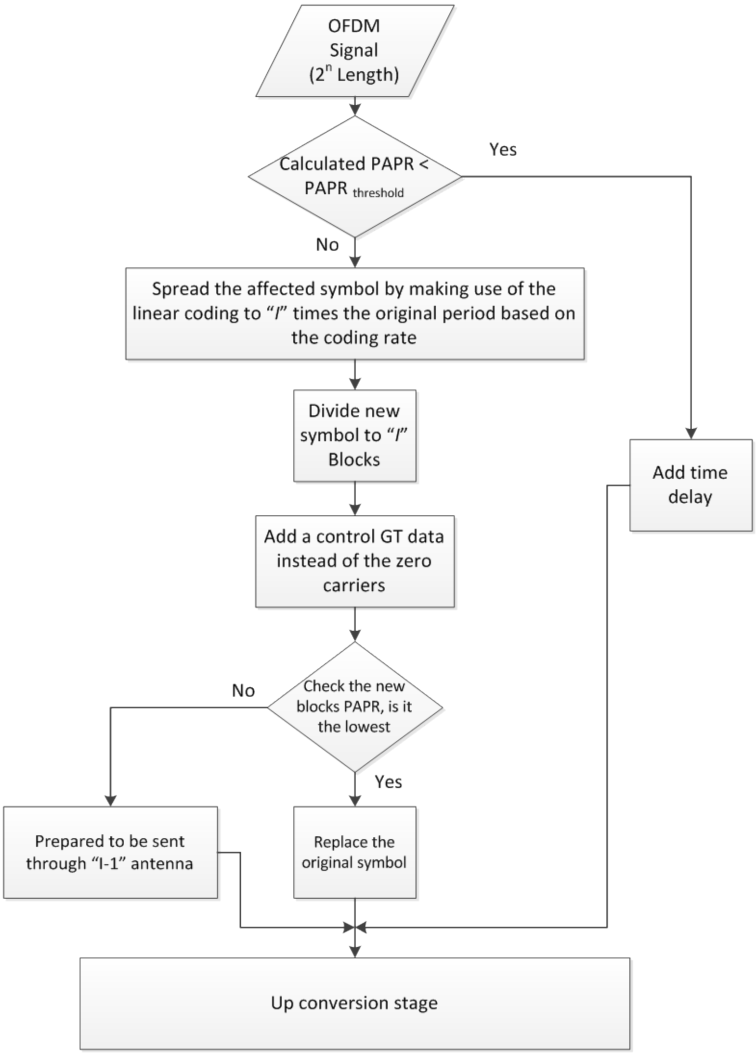


Figure 1. The flowchart of the algorithm based linear coding [9].

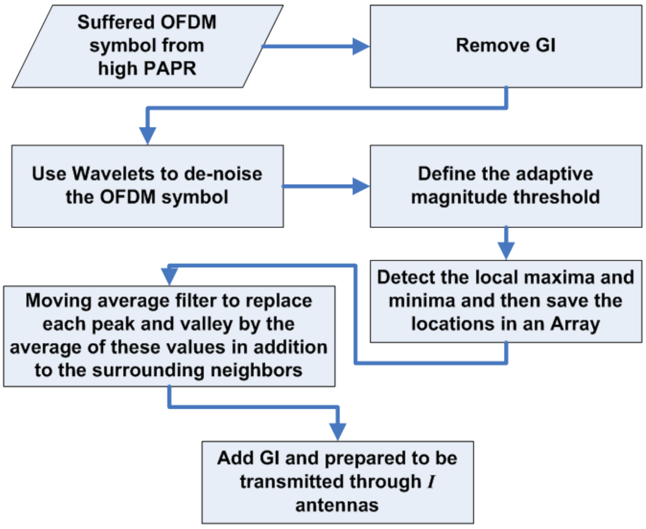


Figure 2. The flowchart of the algorithm based on the wavelet [8].

- Applying soft thresholding operator (wavelet shrinkage) [8] to highlight large values of wavelet coefficients which almost correspond to the OFDM signal and suppress small values which correspond to noise.
- Applying inverse discrete wavelet transform IDWT to the thresholded wavelet coefficients to reconstruct a denoised OFDM signal.

In this work, the wireless systems' performance will be drawn for the PD-EWT and compared to the previously published work in [8] [9]. This performance will be based on the BER. It is known that either the wrong detection or the noisy channels will cause burst error and then special protection is necessary.

Let us define first the received OFDM symbol as shown below in Equation (5)

$$\hat{S} = s_0 + s_1 \tag{5}$$

where s_0 is the useful information, s_1 is the interference signals. After that, the SINR expression could be deduced as

$$\text{SINR} = \frac{E\left\{|s_0|^2\right\}}{E\left\{|s_1|^2\right\}} \tag{6}$$

Then, the BER comes from defining the relationship between the bit error probabilities with the SINR. Thus, a mapping function could be defined through the link level simulation with the needed channel. Making use of the definition that is found in [10] which is based on Chernoff Union bound.

The rest of paper is organized as follows; the introduced structure of the proposed algorithm in the MIMO-OFDM wireless system is defined in Section 2, the simulation results are presented in Section 3, while the last section summarizes the conclusion.

2. The Description of the Used PD-EWT in the Wireless Systems

Figure 3 shows the description of the used wireless system; MIMO-OFDM system, and it is divided into three main stages; OFDM stage, PD-EWT stage and the MIMO stage.

From **Figure 1**, the transmission layer contains three different stages; the OFDM stage, the proposed O-EWT; which proposed to overcome the effect of the PAPR, and the MIMO stage. For the OFDM stage, it consists of three main blocks as shown in **Figure 4**.

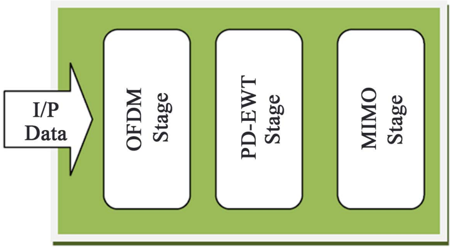


Figure 3. The proposed work block diagram.

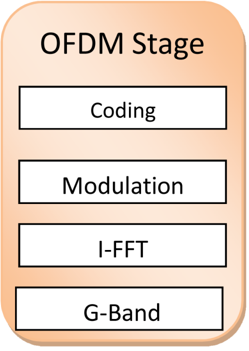


Figure 4. The OFDM stage structure.

In **Figure 4**, the turbo encoder of 1/2 coding ratio is used in the coding block, 16 QAM for the modulation block, the overall throughput expressed in terms of bits/symbol for OFDM symbols, and generated by applying the IFFT. After the IFFT stage and due to the coherent addition of the independently modulated subcarriers to produce OFDM symbol, a large PAPR ratio could appear.

The generated OFDM signal will pass through the second stage which is capable of detecting the high PAPR peaks and overcoming their effect. The whole work in this stage could be divided into four blocks as shown in **Figure 5**. After that, the achieved results will be compared with our previously published work [8] [9].

The continuous wavelet transform (CWT) is attained as a sum of time signals multiplied by a scaled and a shifted version of small wavy functions that are proficiently limited duration with an average of zero. Moreover, and if these scaled versions have been generated based on powers of two, therefore the discrete wavelet transform (DWT) will be obtained. In addition to the wavelet transforms that are based on the decomposition high and low pass filters namely wavelet packet transform is the WP. A pair of low and high pass filters is used to recognize two sequences capturing dissimilar frequency sub-band features of the original signal. These sequences are then decimated (dissembled by a factor of two). It was indicated by many works that WP features have better presentation than the DWT [11].

In [12], the authors define the mathematical meaning of the Entropy for a discrete random variable X as:

$$H(X) = -\sum P(X = a_i)\log\left(\sum P(X = a_i)\right) \tag{7}$$

H is the entropy, a_i are the discrete random variable, X, possible values. This equation reflects the disorder degree that the variable acquires. Then, the discrete wavelet decomposition for sampled values of the signal $S(t)$ could be written as:

$$S(t) = \sum_{j=-N}^{-1} \sum_{k} C_j(k)\psi_{j,k}(t) \tag{8}$$

The signal $S(t)$ is given by the sampled values, $C_j(k)$ is the wavelet coefficient and limited to following frequency interval $2^{j-1}\omega_s \le |\omega| \le 2^j \omega_s$.

Moreover, the wavelet entropy could be defined in terms of wavelet coefficients relative wavelet energy as follows:

$$P_j = \left(\frac{E_j}{E_{\text{total}}}\right) \tag{9}$$

E_j is the energy at each j resolution level, E_{total} is the sum of E_{js}, $j = N, \cdots, 1$. After defining the meaning of the wavelet transforms, we can conclude that the scope of this work is the use of DWT while it could be further emphasized in the future to cover the WP. Thus, the proposed algorithm starts with scanning the resultant $x(t)$ that is defined previously. This signal will be processed as follows:

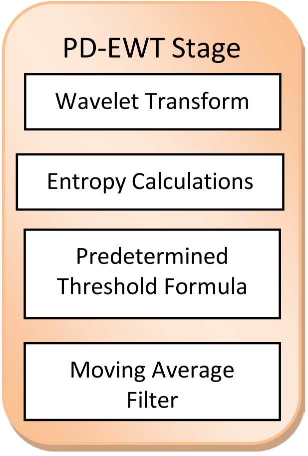


Figure 5. The PD-EWT architecture stage.

- The preprocess stage:
- Remove the noise from a signal using wavelet technology.
- Perform P-level Haar wavelet decomposition of a signal (P = 8).
- Construct the approximations, CAP and the details CDP.
- Zero Crossing mechanism
- The entropy Calculation
- Case studies based on decomposition process using the depicted flowchart in **Figure 6**, the results of these case studies clearly depicted in **Figure 7**.
- Case Study 1: Detect true and false local extremes points using all details coefficients (CDP1-CDP8)
- Case Study 2: Detect true and false local extremes points using details coefficients (CDP1,CDP2)
- Case Study 3: Detect true and false local extremes points using all details coefficients except (CD3, CD7 and CD8).
- Thresholding process
- Moving average (MA) filter.

In this section, a new technique has been proposed to allocate peaks in the OFDM signal based on the entropy wavelet packets. It is clearly seen in **Table 1**, the entropy of the original signal is about 100.4268. After dividing the used signal into eight levels using the wavelet packets, the entropy has been divided into the range of 0.68262 to 74.2432. Therefore and based on the entropy we can use the best combination that results the best peaks allocation process.

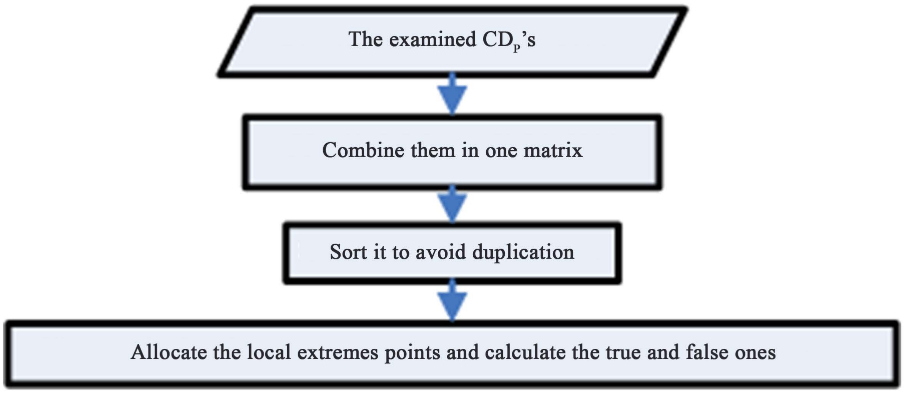
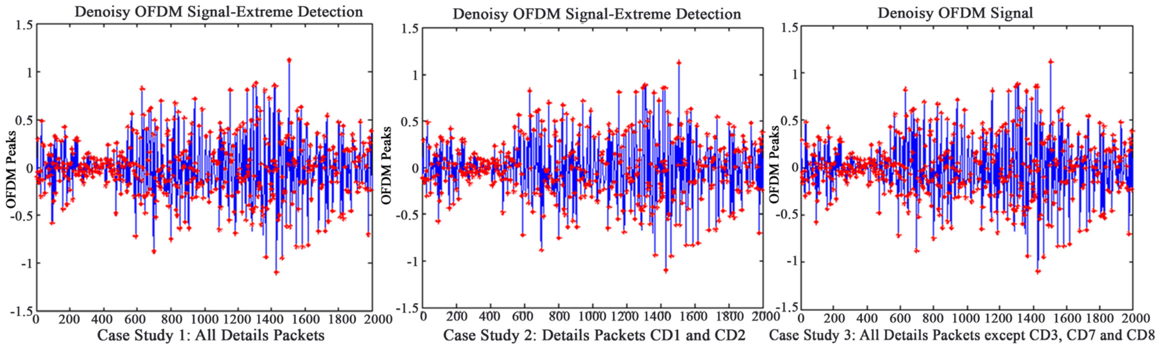


Figure 6. The used procedure flowchart.

Table 1. Packet's entropy values.

P level	Entropy				Decomposition Acceptance*
	CDp	CAp	Summation	Original Signal	
1	13.3924	60.8508	74.2432	100.4268	Accepted
2	26.5319	32.917	59.4489		Accepted
3	16.3553	20.7162	37.0715		Not Accepted
4	8.2519	9.7128	17.9647		Accepted
5	6.3765	3.2822	9.6587		Accepted
6	1.6068	0.93369	2.5405		Accepted
7	1.541	0.54864	2.0897		Not Accepted
8	0.62314	0.059486	0.68262		Not Accepted

(*) Accepted, if the sum of the entropies at certain level is less than the entropy above this level.



(a) (b) (c)

Figure 7. Odd peaks detection based on the different three case studies.

3. Simulation Results and Discussion

The MATLAB simulation program was performed and limited to the use of

- Theoretical randomly generated test data,
- Simple linear convolutional encoder,
- 16-Quadrature Amplitude Modulation (16 QAM) and Binary-Phase Shift Keying (BPSK),
- IFFT size of 256.

The novelty in this work rises from the way of dealing with the entropy of the wavelet coefficients to determine the peaks in the OFDM signal before the transmission. For checking the system performance, two main key factors will be studied; the bit error rate (BER) and the complementary cumulative distribution function (CCDF) curves for the processed OFDM signal.

As a comparison, **Table 2** demonstrates powerfulness of the proposed work over either the work that are found in the literature or our previously published works; It is in the range of 15% - 81% as an extra PAPR reduction ratio.

Table 2 shows clearly the improvement of the proposed work comparing either to our previously published work or to the SLM technique that found in the literature. The achieved reduction rate varies between 8% - 81.62% based on the selected case study and the used technique.

Figure 8 and **Figure 9** show the simulation part that is based on the CCDF and BER curves with different modulation techniques. These results check the performance of our system from reducing the PAPR problem point of view for two different modulation techniques; 16QAM and BPSK, respectively. These figures compare the threshold value against the probability that the PAPR will exceed the threshold value. From these figures the reduction improvements are clearly shown over what have been achieved in the literature for the conventional MIMO-OFDM systems.

The CCDF plots that are shown in **Figure 8** show that the probability of the peaks that will exceed the 16 dB could be reduced to be 3.9×10^{-3} while it was 53×10^{-2}. Moreover, it shows an extra 15% reduction percentage over the PAPR combating technique that is in [9]. **Figure 9** shows the BER curves for different modulation technique; BPSK to confirm the reliability of the proposed work in combating the PAPR problem. Thus, the performance of the MIMO-OFDM based FFT is still better than either that of the conventional PAPR reduction techniques or our previously published work in [8] [9]. At 20 dB threshold, the BER curve for the conventional MIMO-OFDM system shows a reduction from 48×10^{-2} to 36×10^{-2}.

4. Conclusions

A new proposition has been made in this paper; PD-EWT. This work introduces a new OFDM transceivers design. It is based on allocating the peaks and valleys of OFDM signal to be analyzed. In the PD-EWT, the entropy of DWT has been analyzed and used to specify those peaks. The allocated peaks then will be processed using a special thresholding algorithm to overcome its effect.

Making use the analytical derivation of this technique to build a MATLAB simulation, which ease the study of its feasibility. This is in order to enhance the MIMO-OFDM wireless systems' performance even in a condensed Multipath channel using two different modulation techniques; BPSK and 16 QAM.

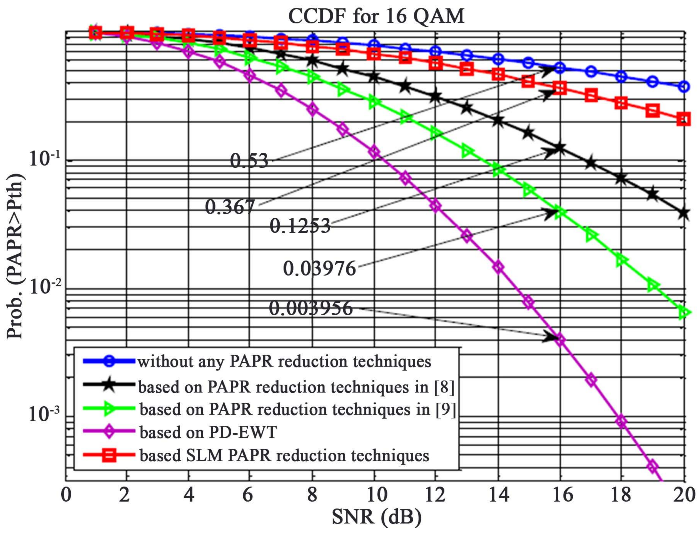


Figure 8. Compared CCDF curves for different reduction technique using case study II.

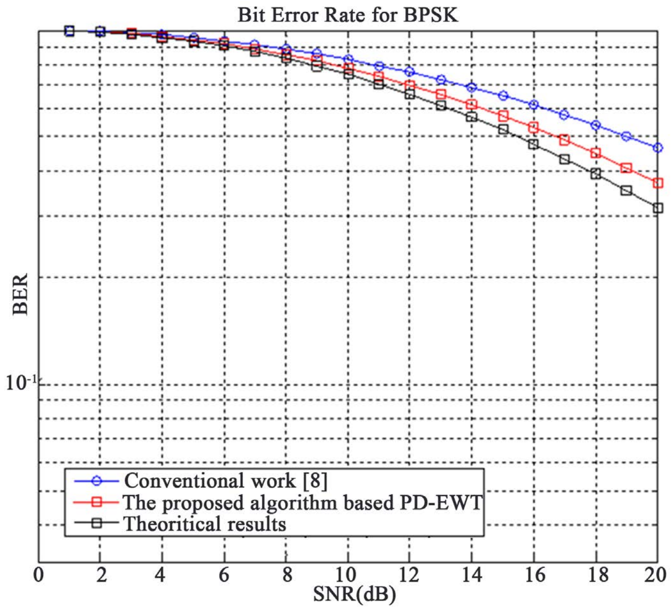


Figure 9. Compared BER curves for different reduction technique using case study II.

Table 2. Compared simulation results among different PAPR reduction techniques for different case studies.

Modulation Technique		PAPR (dB)				Additional Reduction (%)		
		No Coding	Based SLM	Based on [8]	Based on [9]	SLM	Convolutional Coding	Work [9]
16 QAM	Case study I	7.9	3.6	3.5	2.7	72.1	44.5	11
	Case study II		3.81	2.73	1.92	81.62	60	15
	Case study III		4.2	3.9	3.1	65.6	35.9	8
BPSK	Case study I	12.3	5.6	4.1	3.7	51.6	32.3	9.8
	Case study II		6.4	3.5	3.2	62	51.43	14
	Case study III		6.9	4.7	4.2	42.9	26.5	9

This work contains three case studies based on the entropy level of the DWT. Thus, a comparison among PD-EWT, our previously published work, and the SLM has been made. The results show that we can use just the first two detailed parameters where the decomposition status after that is not accepted. From this comparison, the PD-EWT shows extraordinary promising results in allocating and combating the high peaks. The achieved performance improvement for allocating and combating the effect of the PAPR is between 8%-81% over the limitations that have been taken into consideration. Moreover, the BER for the best scenario has been reduced to 36×10^{-2} from 48×10^{-2} that has been achieved in our previously work.

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