Power Peaks Allocation based on Averaging-Adaptive Wavelet Transform

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Abstract—a One of Orthogonal Frequency Division Multiplexing deficiency has been taken into consideration in this work. A proposition has been made to tackle the Peak to Average Power Ratio (PAPR) problem. The proposed work will be based on a special averaging adaptive wavelet transformation (SAAWT) process. It will be compared with two main works that has been published previously; a neural network (NN)-based and a special averaging technique (SAT)-based.

In the NN work, the learning process makes use of a previously published work that is based on three linear coding techniques. The proposed work (SAAWT) consists of three main stages; extracting the needed features, de-noising and the optimization criterion. SAAWT has an enhancement over the SAT that will take the noise clearance enhancement into its consideration. It uses 136880 different combinations of de-noising parameters that are experimentally computed to get the most efficient result with respect to the MSE, SNR and PSNR values.

A MATLAB simulation-based of such works has been made in order to check the proposition performance. In this simulation, both of the BER and CCDF curves have been taken into consideration. Furthermore, the bandwidth and channel behaviors have been remain constant. Moreover, two kinds of data have been imposing to this simulation; a random data that is generated randomly by making use of the MATLAB features and a practical data that have been extracted from a funded project entitled by ECEM.

From the previously published work the SAT shows promising results in reducing the PAPR effect reached up to 75% over the work in the literature and over the NN-based work. Under the cost of increasing complexity, SAAWT gives further reduction over the SAT reaches up to 6%. This drawback will be examined in the future work.

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I. Introduction

ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM) is considered as one of the main topics that is taken into consideration in order to enhance the wireless systems reliability during the last decades.
This is in order to achieve a promising data rates either for the downlinks or the uplinks physical transmissions, especially after the rapid growth in using the mobile phone applications [1, 2].

Along the last decades, the researchers got from the benefits of OFDM technology and are adopted widely in the recent wireless communications technologies; especially in the wide band systems and standards, where the Mobile data traffic expected to increase by 11 times by 2018. [3, 4]

However, the Peak-to-Average Power ratio problem is considered as one of the major drawbacks that limits the efficiency of OFDM technology. The sensitivity to the nonlinear behavior especially with none constant envelops plays a vital role in affecting the powerfulness of using OFDM. Thus a spectral regrowth in adjacent channels and deformation of the signal constellation could happen. Accordingly and in order to minimize the PAPR values, many solutions were found in the literature. This will prevent the limitations in using the nonlinear devices without back-off levels, especially the power amplifiers and mixers; such as multiple signal representations, neural networks, neuro-fuzzy, selective mapping, partial transmit sequence, coding, clipping, filtering and travelling wave tube amplifiers[1,5-12].

Furthermore and to enhance the OFDM systems robustness, Multiple-Input Multiple-Output (MIMO) technology has been proposed to be combined with the OFDM techniques. MIMO technology also has a number of powerful advantages including the ability to increase the system capacity and improving the communication reliability via the diversity gain. The capacity of MIMO channels scale linearly with respect to the minimum available transmitter and receiver antennas [11, 13].

In this work, we are motivated to compare a new proposition based on a special averaging technique with the previously published work based on NN in [2]. In [2], the NN were imposed and trained based on our previously attained results in [11-13], this is in order to attain the goal of maximum amplification [14]. The NN will intelligently choose the best combination that reduces the PAPR ratio values in the transmitted OFDM signal. As a result of imposing the NN, slight enhancement has been attained at the 10 dB threshold for the BER; since it has been reduced to be 2.5×10^{-2} from 1.1×10^{-2} [2]. Furthermore, the MIMO technology has been imposed in order to enhance the system's capacity by introducing the use of Vertical Bell Laboratories Layered Space-Time (V-BLAST) techniques [15].

The special averaging technique will be divided into three main stages and it will make use of the test data has been collected from a funded work by the European Union (SRTD-II) and Philadelphia University; entitled by Energy Consumption Efficiency Management-Phase I (ECEM). Therefore, the wireless systems based MIMO-OFDM performance will be checked based on the bit error rate (BER) that is based on the Chernoff Union Bound and the complementary cumulative distribution function (CCDF) curves. These three stage will consist of a pre-processing stage (check the noise removal effect and to enhance the input signal characteristics), detecting the odd peaks stage (derivatives theorem, magnitude sign selection, template matching process, adaptive thresholding process), and the post processing stage (moving averaging filter).

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

II. MIMO-OFDM System Description

In order to fulfill the requirements of this work, the MIMO-OFDM system's parts will cover the followings; 2/3 turbo encoder, 64 QAM, and a V-BLAST MIMO encoder. V-BLAST is used for increasing the overall throughput expressed in terms of bits/symbol, while applying the IFFT to generate the OFDM symbols [2, 15]. As a consequence for the coherent addition after the IFFT, a huge peak value may appear [1-12].

In this work, a comparison between two main proposed work will accomplished; consequently the work based on NN and will be described in subsection A, the proposed work that is based on a special averaging technique will be covered in subsection B.

In this configuration, the transmitted OFDM signal consists of a sum of 64 QAM modulated subcarriers and is shown in [1] as:

$$s(t)=\sum_{i=-\frac{N_s}{2}}^{\frac{N_s}{2}-1}\left[d_{\left(i+\frac{N_s}{2}\right)}e^{\left(j2\pi\left(f_c-\frac{i+0.5}{T}\right)(t-t_s)\right)}\right],\ t_s\le t\le t_s+T \quad (1)$$

Here, d_i can be considered as a complex input symbol resulted from the modulation stage, the carrier frequency of the *i-th* subcarrier is depicted in f_c, the OFDM symbol duration is defined as T and the starting time of one OFDM symbol is t=t_s.

A. NN-Based proposed work

Figure 1 shows the main parts of the MIMO-OFDM transmitter stages with the addition the NN part [2].

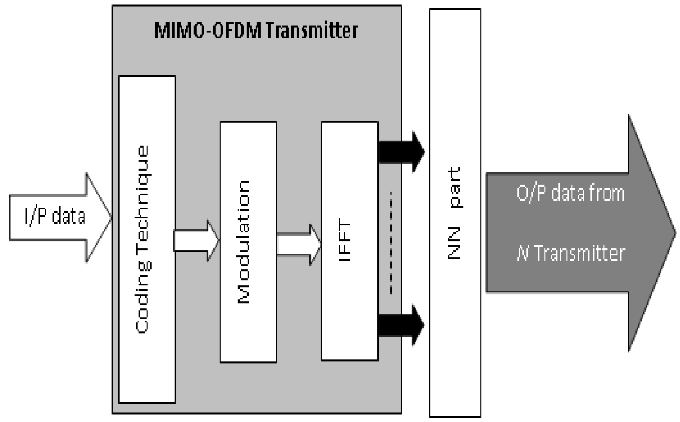

Figure 1. AN MIMO-OFDM-Based NN Transmitter

It shows that the NN part has been imposed after the IFFT stage. This is due to that the same phase addition will increase the probability of PAPR appearance [1, 2]. A high peak power equals to N times the average power occasionally appears as a result of this addition process. Thus, the PAPR definition can be written as:

$$\text{PAPR} = 10\log_{10}\left\{\frac{P_{peak}}{P_{avg}}\right\} \quad (2)$$

where, Ppeak is the maximum power of an OFDM symbol, and Pavg is the average power.

From [11], a conclusion has been drawn that the PAPR will decrease if the average power of the OFDM symbol is decreased. This mathematical derivation was the basis of our previously published work to combat the effect of the PAPR drawback on the MIMO-OFDM systems. Imposing the NN can improve MIMO-OFDM systems performance; as it is the simplest way of linearization for RFPA. This is due to the NN ability of simultaneous BW linearization [16].

Intelligent controllers are generally self-organizing or adaptive and are naturally able to cope with the significant changes in the plant and its environment. As processes increase in complexity, they become less amenable to direct mathematical modeling based on physical laws, since they may be, distributed, stochastic, nonlinear and time-varying.

Research into intelligent systems integrates concepts and methodologies from a range of disciplines including neurophysiology, artificial intelligence, optimization and approximation theory, control theory and mathematics. This integration of research fields has led to an emergent discipline, frequently referred to as connectionism or neuron science that inherently incorporates distributed processing concepts organized in an intelligent manner. Connectionist or neurons systems, unlike conventional techniques and selfprogramming, appear to be stochastic or fuzzy, heuristic and associative. An approximation to the desired mapping is constructed in intelligent or learning systems [17].

ANNs or simply NNs go by many names such as connectionist models, parallel distributed processing models, and neuromorphic systems, whatever the name, all these models attempt to achieve good performance via dense interconnection of simple computational elements. Computational elements or nodes used in neural net models are nonlinear and typically analog. The simplest node sums N weighted inputs and passes the results through a nonlinear function [2, 17, 18].

From this work, very promising results have been extracted as shown in Figure 2. The structure of the used NN can be found in Table 1 as:

Table 1 NN structure

Functions	**Description**
Network Type	FFB-P
Number of layers	3
Number of Neurons	512, 30, 512
Activation Function	Bipolar-Sigmoid
Training Function	Error B-P
Performance Function & number of epochs	10^{-3} and(24873, 16470)

As mentioned previously, the previous achieved result in combatting the PAPR [11-13] has been used in the learning process of the NN part. This is in to model the MIMO-OFDM system based on multipath fading channels. The achieved results are depicted in Table 2 [2].

Table 2 Back-propagation based Powell-Beale conjugate gradient

Learning Parameter	**MSE**	**Number of trained OFDM symbols**
0.1	6.254×10^{-5}	100
0.01	8.157×10^{-5}	100

Based on the results in [2], it can be concluded that the NN work has a slight improvement over the previously achieved results in [11-13]. From the complexity point of view, this enhancement comes in addition to the simplicity of the system structure, i.e. the NN simplifies the complexity of the work in addition to boost the performance enhancement by combatting the PAPR intelligently. In addition to the CCDF results, Figure 2 depicts a slight modification in the system's performance from the BER point of view; at 10 dB threshold as an example the BER has been reduced from 49×10^{-2} to 12×10^{-3}. Furthermore, at 16dB threshold this enhancement has been considered and valuable since it reduces the BER from 15×10^{-2} to 15×10^{-7}.

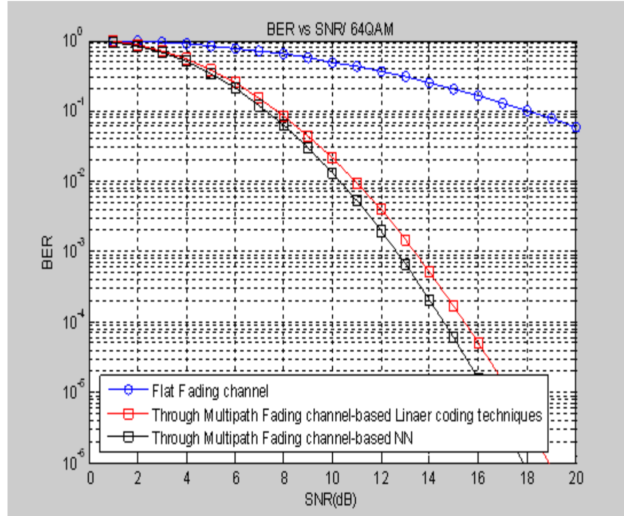

Figure 2 BER vs. SNR curves for the NN based work [2]

B. Special Averaging Technique-Based Proposed work

In [19], the SAT work has been clearly described and depicted in Figure 3 below.

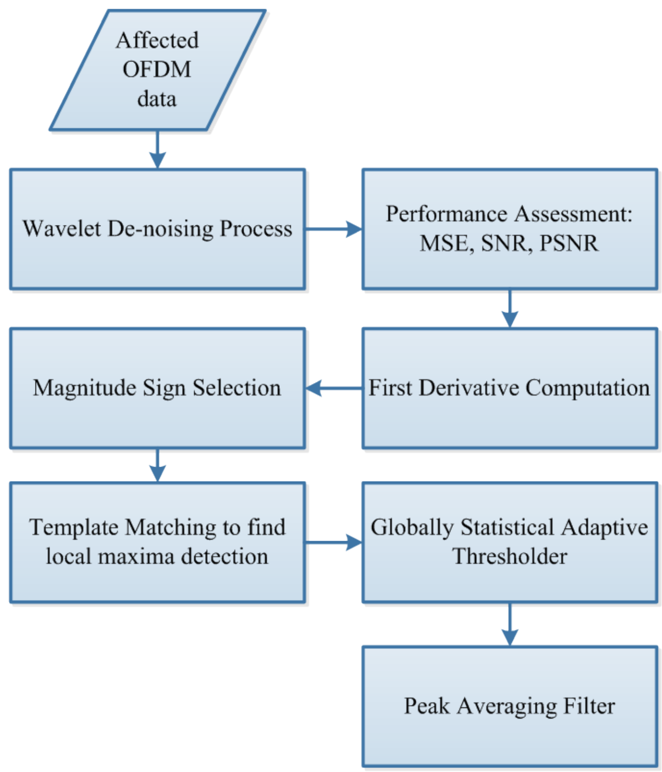

Figure 3 The flowchart of the proposed algorithm

In Figure 3, the work divided into three main stages. The procedure of these stages is as follows [19]:

1) The Pre-processing stage: Signal noise removal stage making use of Biorthogonal, Daubechis, Symmlet, Coiflet and Haar wavelets families.
2) The main Process stage: Detecting the unwanted power peaks
3) The Post-processing stage: Averaging process.

Figure 4 depicts the results of the proposed procedure for detecting the large peaks and thresholding them below a predefined threshold; In this Figure, the red stars defining the peaks above certain threshold [19].

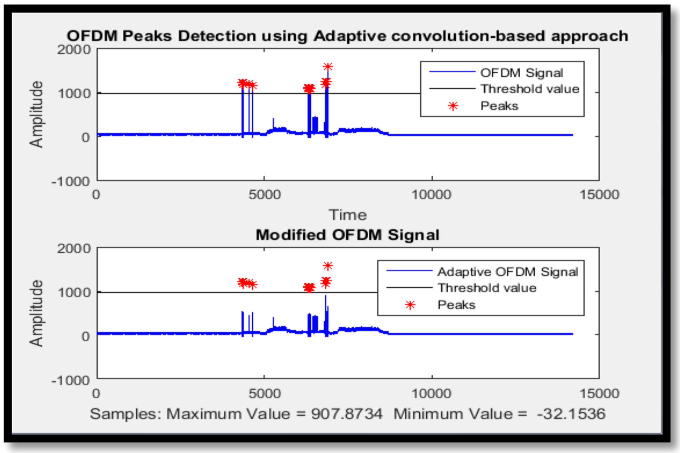

Figure 4 OFDM peaks detection using adaptive convolution-based approach

C. *Special Averaging Adaptive Wavelet Transform work*

The SAAWT work is a modified version of SAT [19] and differs in the de-noising step that was found in the preprocessing stage. Here and after reading the affected signals, 13680 different combinations of de-noising were used. These parameters were experimentally computed in order to get the best result with respect to the Mean-squared error (MSE), Signal-to-Noise ratio (SNR) and Peak Signal-to-Noise ratio (PSNR) values properly.

By making use of the available functions in [20], the used de-noising parameters were limited to the followings:

- Several families of known wavelets are tested and evaluate (57 types), they include:
  - Orthogonal and compactly supported wavelets like Haar, Daubechies (dbN), symlets (symN), coiflets (coifN).
  - B-splines biorthogonal wavelets like biorNr.Nd and rbioNr.Nd.
- Threshold selection algorithms: 'minimax', 'universal', Rigrsure and, 'Heursure' threshold estimation techniques.
- Soft and hard thresholding rules.
- Different multiplicative threshold rescaling types: 'one', 'sln' and 'mln'.
- Wavelet decompositions are performed at different levels from the first level to the tenth one.

After the de-noising step, the performance evaluation has been taken a place in this work. This is attained by optimizing criteria has been used in order to quantify the possibly found errors after the de-noising process. This will help in characterizing the OFDM signal quality; compared to the original one (the smoothed reconstructed and denoised versions). The following three factors will limit the use of such de-noising factors based on (3); namely MSE, SNR and PSNR; where the difference between referenced signal and the noisy signal is defined as

$$\text{err\_Diff} = \text{reference Signal} - \text{noisy Signal} \qquad (3)$$

- Due to its computational simplicity, the MSE is commonly used and expressed as:

$$\text{MSE} = \frac{1}{N}\sum_{n=0}^{N-1}\left(x(n) - \tilde{x}(n)\right)^2 \qquad (4)$$

Where $x(n)$ and $\tilde{x}(n)$ are respectively the clean and the denoised signals. It is found in [20] as "immse".

- The SNR is used to measure the performance of the de-noising method by calculation of the residual SNR, which is generally stated in a logarithmic scale; decibels (dB); and measured with respect to actual signal power. Furthermore, when it is chosen above 3dB, it is generally enough to get the visible corruption. Thus, it is usually the most important measure rather than the power of noise. It can be expressed as :

$$\text{SNR} = 10 * \log_{10}\left(\frac{\sum_{n=0}^{N-1} x^2(n)}{\sum_{n=0}^{N-1}\left(\hat{x}(n) - \bar{x}(n)\right)^2}\right) \qquad (5)$$

Where both of $x(n)$, and $\bar{x}(n)$ were defined earlier, and $\hat{x}(n)$ refers to the mean value of $x(n)$.

- Another useful metric value is the PSNR and can be described as :

$$\text{PSNR} = 10 * \log_{10}\left(\frac{P}{\sum_{n=0}^{N-1}\left(\hat{x}(n) - \bar{x}(n)\right)^2}\right) \qquad (6)$$

Where P specified by the user (for example: peak signal value), $\bar{x}(n)$ and $\hat{x}(n)$ denoted as above. As found in [20], the needed MATLAB function is "psnr".

Table 3 shows the best attained performance values for the proposed SAAWT, where the worst ones are depicted in Table 4.

Table 3 The best attained performance results of SAAWT

De-noising parameters	Best results	
	Solution 1	Solution 2
Decomposition Level	1	1
Threshold Selection Rule	rigrsure	heursure
Threshold Type	soft	soft
Scaling Type	one	one
Wavelet Type	bior3.5	bior3.5
Performance assessment methods		
MSE	9.46e-28	9.46e-28
SNR	312.98	312.98
PSNR	336.50	336.50

Table 4 The worst attained performance results of SAAWT

De-noising parameters	Worst results	
	Solution 1	Solution 2
Decomposition Level	10	10
Threshold Selection Rule	sqtwolog	minimaxi
Threshold Type	soft	soft
Scaling Type	sln	sln
Wavelet Type	rbio3.1	rbio3.1
Performance assessment methods		
MSE	268772.57	199216.45
SNR	-11.55	-10.25
PSNR	11.97	13.27

Our results show that Decomposition Level “1”, Threshold Selection Rule “rigrsure” or “heursure”, Threshold Type “soft”, Scaling Type “one” and Wavelet Type “bior3.5” are the best options for better de-noising process that fit between an original signal and the denoised one.

In figure 5, the best evaluated performance results deducted from table 3 were depicted. These results can show easily the enhancement of the achieved results over the SAT ones that found in [19] and shown below in figure 6. Furthermore, the SAAWT wort evaluated performance will be shown in figure 7.

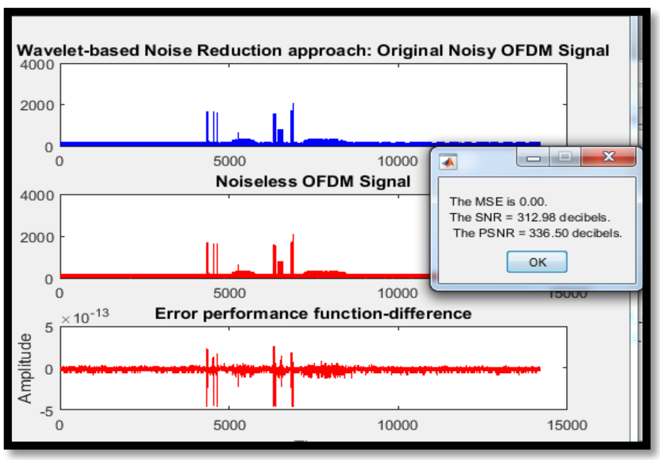

Figure 5 The best attained performance results (solution 1)

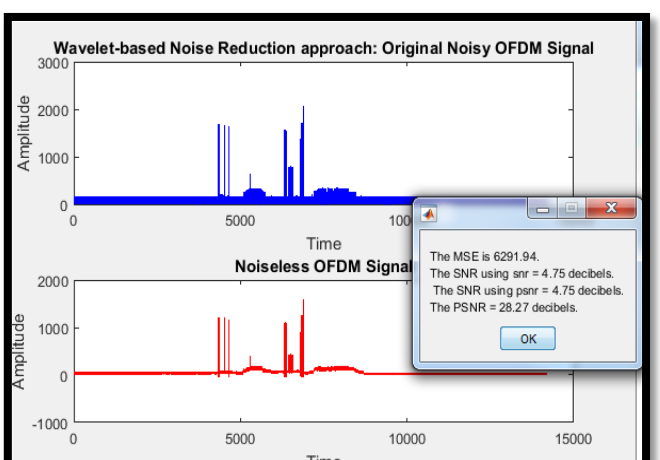

Figure 6 The SAT results in [19].

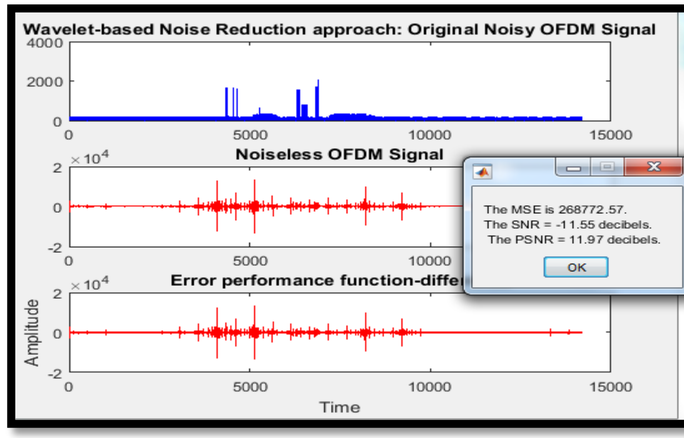

Figure 7 The worst attained performance results (solution 1)

After the first stage, preprocessing stage, the same SAT procedure [19] will be applied as follows:

1) Calculate the first numerical partial derivatives of the noiseless OFDM (difference between successive samples of a signal) to search for a local maxima and look for an increasing-decreasing (positive-negative) pair in the differences.
2) Magnitude Sign Selection process will be applied. The magnitude of differences is irrelevant, only the sign is needed here to create a simple pattern [1, -1]. This will be used in the searching process (The sign indicates the trend of increasing, decreasing or being constant).
3) Template matching using discrete convolution: in this searching process, the [-1, 1] pattern is used as sliding kernel window and convolved with signed data (the kernel window is slid along the input). In the output result of this process, the value of 2 appears only if the pattern matches exactly and its corresponding peak value.
4) Global Statistically Adaptive Thresholder is used to detect thresholded peaks in OFDM signal , the value of thresholder depends on all values of the input signal, and it's measured adaptively with respect to the descriptive statistics (maximum, mean and standard deviation values) and the constant adaptive parameter k as stated in the following equation:

$$\text{Thresh} = (\text{m} + \text{avgabs} + \text{avgdev}) / \text{k} \qquad (7)$$

The quality of the thresholding process can be controlled by the adaptive parameter k: small k causes the threshold value to be increased and we can adaptively select an appropriate and a suitable threshold value for the given signal.
5) Peaks’ moving averaging filter is used to replace the peak values with the averaging values surrounding them in the OFDM signal and construct the modified OFDM signal suitable for transmission. This is represented by the following difference equation:

$$OFDM_{Mod} = \frac{OFDM(n-1)+OFDM(n)+OFDM(n+1)}{3} \qquad (8)$$

Where M_{Mod} is the modified OFDM signal, $OFDM$ is the OFDM signal and n is the sample number.

6) Different moving average structures (Simple, Exponential, Weighted etc.) could be used. The achieved results are depicted in Figure 8 and show the original OFDM Signal, the threshold value, and the new thresholded results of SAAWT.

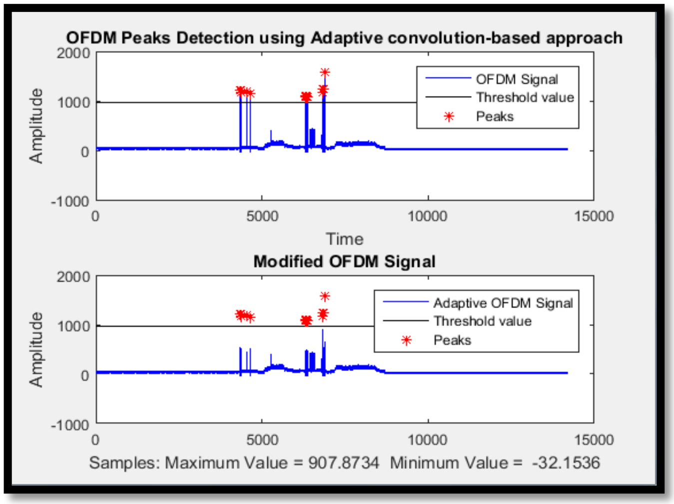

Figure 8 The SAAWT peaks detection result.

III. Simulation Results and Discussion

Comparison between the previously published work based on the NN, the SAT work and the new work; SAAWT has been made. In order to accomplish this target, a MATLAB-based simulation has been performed to imitate both of block diagram in Figure 1 and the flowchart of Figure 3. The results of this simulation will compare the OFDM performance based on the different two proposed techniques keeping in mind the two main factors; BER and CCDF. This is in addition to taking into consideration identical channel conditions with the theoretical representation. Furthermore, real signals will be extracted from the funded project by both of European Union under the SRTD-II and Philadelphia University. This is in addition to the theoretically initiated data. The system parameters were chosen to cover the following:

- 512 subcarrier
- 64-QAM modulation technique
- 2/3 inner coding rate
- 1/4 Guard interval duration
- V-BLAST MIMO coding technique

This is in addition to keep in mind the NN structure settings that shown previously in Table 1 and Table 2, which they were extracted experimentally in previous work [2].

Figures 9 and 10 show the simulation results based on CCDF curves and the BER ones, respectively. These results cover the comparison between the different three works. Furthermore and in order to check its performance, Table 5 shows a comparison that has been made with previously published work. From the achieved results, the OFDM system QoS has been checked and verified from both of two different kinds of data.

Table 3 The Simulation results of the proposed technique compared to the literature work for a 64-QAM modulation technique.

Input Data	CCDF (2%)		SAT additional reduction over literature (%)			SAAWT performance CCDF (2%)
	Conventional PAPR (dB)	Proposed Work (dB)	Clipping	SLM	PTS	
Theoretical	20	8.3	75	53.3	20	7.8
ECEM	22	8	69	54	21	7.76

It is clearly shown that there is a huge improvement achieved from the proposed work; at a probability of 2% the PAPR has been reduced to around 8 dB instead of 20 dB. Moreover and comparing to the work in the literature, the attained improvement falls in the range of 20% to 75% more enhancements over the three of them. The best values were over the clipping technique and the worst were over the PTS technique.

Figure 6 shows the CCDF comparison between the NN based work and the special averaging technique based work. These curves contain the thresholds that the probability of the PAPR will not exceed. The limitation for such simulation as mentioned earlier. Figure 6 shows that a very promising results especially after exceeding the 12 dB threshold. It is clearly shown that before 12 dB there is an enhancement; however it cannot reflect the imposed work weight; as an example at 8 dB the probability comes between 1.5×10^{-2} to around 6×10^{-2}. At 16 dB threshold, the probability of using the SAT gives exceeds the 10^{-7}, while the NN based work does not exceed the probability of 7×10^{-6} and the Linear coding one has the probability 1.8×10^{-5}.

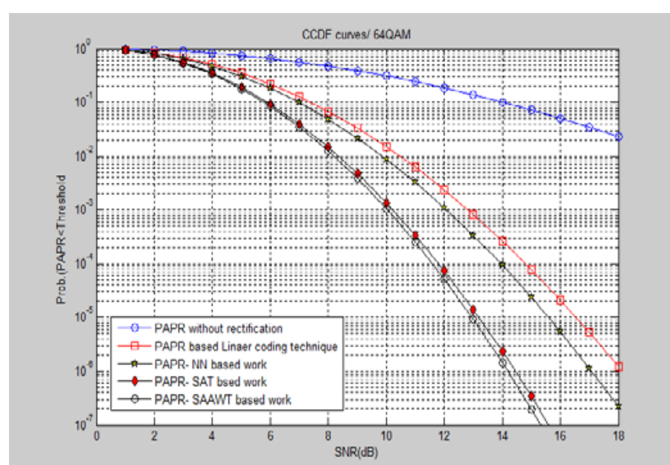

Figure 9 PAPR combating proposed work comparison

It is clearly shown from Figure 9 that the SAAWT gives a slight modification over the SAT one with respect to the CCDF curves.

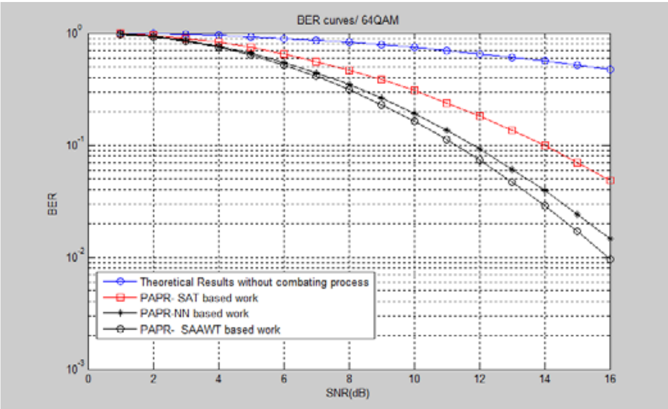

Figure 10 BER curves comparison

Figure 10 shows that the SAAWT enhances the BER values of work. The enhancement values somehow exceed the best results achieved in [19] for the work based on the NN. Here, the BER at 16 dB as an example is enhanced from 5.3×10^{-2} to 9.3×10^{-3}. Thus the enhancement ratio exceeds the 72% [19] to be around 75%.

IV. Conclusion

In this paper, a new work has been proposed based a modified version of a previously published work, namely Special Averaging Adaptive Wavelet Transform (SAAWT). In order to validate its efficiency, a comparison has been made with the SAT work, the work based on the NN and with the literature.
From the achieved results, the OFDM system QoS has been checked and verified from both of two different kinds of data. It is clearly shown that there is a huge improvement achieved from the proposed work; at a probability of 2% the PAPR has been reduced to around 7.76 dB instead of 20 dB. Moreover, the best values were over the clipping technique and the worst were over the PTS technique. Furthermore, at At 16 dB threshold, the probability of using the SAAWT gives a slight enhancement over the attained SAT results, which exceeds the 10^{-7}. This is in addition to extra enhancement of the BER that exceeds the NN work values and reduces the BER at 16 dB from 5.3×10^{-2} to 9.3×10^{-3}.
As a conclusion from the previous results, the proposed works have proved their reliability in overcoming the effect of PAPR. This is in addition to that the use of NN reduces the added complexity at the receiver side since there is no need to send a control data that has been sent in the previously published work.

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