Power Peaks Allocation based on Averaging-Adaptive Wavelet Transform

Qadri J. Hamarsheh¹, Omar R. Daoud²*, Mohammed M. Ali¹, Ahlam A. Damati³
¹ Department of Computer Engineering
² Department of Communications and Electronics Engineering
³ Department of Electrical Engineering
P.O.Box 1, Philadelphia University
Amman, 19392, Jordan
odaoud@philadelphia.edu.jo
* Corresponding Author

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.

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 signal characteristics), 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 be 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:

$$s(t) = \sum_{i = -N_s}^{N_s} \left[ \frac{d_i}{N_s} \right] e^{j2\pi f_c t + j2\pi \frac{3}{2}(i-1) f_c t} \epsilon(t-t_s) \right]$$

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].

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:

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

where, \( P_{peak} \) is the maximum power of an OFDM symbol, and \( P_{avg} \) 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 self-
programming, 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

<table>
<thead>
<tr>
<th>Functions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Type</td>
<td>FFB-P</td>
</tr>
<tr>
<td>Number of layers</td>
<td>3</td>
</tr>
<tr>
<td>Number of Neurons</td>
<td>512, 30, 512</td>
</tr>
<tr>
<td>Activation Function</td>
<td>Bipolar-Sigmoid</td>
</tr>
<tr>
<td>Training Function</td>
<td>Error B-P</td>
</tr>
<tr>
<td>Performance Function &amp; number of epochs</td>
<td>$10^{-3}$ and(24873, 16470)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Learning Parameter</th>
<th>MSE</th>
<th>Number of trained OFDM symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>$6.254\times10^{-5}$</td>
<td>100</td>
</tr>
<tr>
<td>0.01</td>
<td>$8.157\times10^{-5}$</td>
<td>100</td>
</tr>
</tbody>
</table>

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 $49\times10^{-2}$ to $12\times10^{-1}$. Furthermore, at 16dB threshold this enhancement has been considered and valuable since it reduces the BER from $15\times10^{-2}$ to $15\times10^{-7}$.
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.

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

\[ err\text{\_Diff} = reference\text{\_Signal} - noisy\text{\_Signal} \] (3)

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

\[ MSE = \frac{1}{N} \sum_{n=0}^{N-1} (x(n) - \bar{x}(n))^2 \] (4)

Where \( x(n) \) and \( \bar{x}(n) \) 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 :

\[ SNR = 10 \times \log_{10} \left( \frac{\sum_{n=0}^{N-1} x^2(n)}{\sum_{n=0}^{N-1} (\bar{x}(n) - \bar{x}(n))^2} \right) \] (5)

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

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

\[ PSNR = 10 \times \log_{10} \left( \frac{P}{\sum_{n=0}^{N-1} (\bar{x}(n) - \bar{x}(n))^2} \right) \] (6)

Where \( P \) specified by the user (for example: peak signal value), \( \bar{x}(n) \) and \( \bar{x}(n) \) 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

<table>
<thead>
<tr>
<th>De-noising parameters</th>
<th>Best results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solution 1</td>
</tr>
<tr>
<td>Decomposition Level</td>
<td>1</td>
</tr>
<tr>
<td>Threshold Selection Rule</td>
<td>rigrsure</td>
</tr>
<tr>
<td>Threshold Type</td>
<td>soft</td>
</tr>
<tr>
<td>Scaling Type</td>
<td>one</td>
</tr>
<tr>
<td>Wavelet Type</td>
<td>bior3.5</td>
</tr>
</tbody>
</table>

**Performance assessment methods**

| MSE                  | 9.46e-28     | 9.46e-28     |
| SNR                  | 312.98       | 312.98       |
| PSNR                 | 336.50       | 336.50       |
Our results show that Decomposition Level “1”, Threshold Selection Rule “rigrsure” or “heursure”, Threshold Type “soft”, Scaling Type “sln” 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 worst evaluated performance will be shown in figure 7.

![Wavelet-based Noise Reduction approach: Original Noisy OFDM Signal](image1)

**Figure 5** The best attained performance results (solution 1)

![Wavelet-based Noise Reduction approach: Original Noisy OFDM Signal](image2)

**Figure 6** The SAT results in [19].

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:

\[
\text{Thresh} = \frac{m + \text{avgabs} + \text{avgdev}}{k}
\]  

(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:

\[
\text{OFDM}_{\text{Mod}} = \frac{\text{OFDM}(n-1) + \text{OFDM}(n) + \text{OFDM}(n+1)}{3}
\]  

(8)

---

**Table 4** The worst attained performance results of SAAWT

<table>
<thead>
<tr>
<th>De-noising parameters</th>
<th>Worst results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solution 1</td>
</tr>
<tr>
<td>Decomposition Level</td>
<td>10</td>
</tr>
<tr>
<td>Threshold Selection Rule</td>
<td>sqtwolog</td>
</tr>
<tr>
<td>Threshold Type</td>
<td>soft</td>
</tr>
<tr>
<td>Scaling Type</td>
<td>sln</td>
</tr>
<tr>
<td>Wavelet Type</td>
<td>rbio3.1</td>
</tr>
</tbody>
</table>

**Performance assessment methods**

<table>
<thead>
<tr>
<th></th>
<th>Solution 1</th>
<th>Solution 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSE</td>
<td>268772.57</td>
<td>199216.45</td>
</tr>
<tr>
<td>SNR</td>
<td>-11.55</td>
<td>-10.25</td>
</tr>
<tr>
<td>PSNR</td>
<td>11.97</td>
<td>13.27</td>
</tr>
</tbody>
</table>
Where $M_{\text{Mod}}$ 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.

![OFDM Peaks Detection using Adaptive convolution-based approach](image)

**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.

<table>
<thead>
<tr>
<th>Input Data</th>
<th>CCDF (2%)</th>
<th>SAT additional reduction over literature (%)</th>
<th>CCDF performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional PAPR (dB)</td>
<td>20</td>
<td>8.3</td>
<td>75</td>
</tr>
<tr>
<td>Proposed Work (dB)</td>
<td>22</td>
<td>8</td>
<td>69</td>
</tr>
</tbody>
</table>

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 $1.5 \times 10^{-2}$ to around $6 \times 10^{-2}$. 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 $7 \times 10^{-6}$ and the Linear coding one has the probability $1.8 \times 10^{-6}$.

![Figure 9 PAPR combating proposed work comparison](image)
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](image)

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 $5.3 \times 10^{-2}$ to $9.3 \times 10^{-3}$. 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 $5.3 \times 10^{-2}$ to $9.3 \times 10^{-3}$.

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.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial support from the SRTD-II projects under the umbrella of the European Union support and from the Philadelphia University to build the project entitled “Energy Consumption Efficiency Management (ECEM)”, which is managed by the Higher Council for Science & Technology.


Qadri J. Hamarsheh has received the master degree of Computer Machines, Systems and Networks from the department of Computer Engineering, Lviv Polytechnic Institute in 1991. He obtained his Ph.D degree from Lviv National University “Lvivska Polytechnica”, Ukrima in 2001. Currently he is working as assistant professor of Computer Engineering, Philadelphia University-Jordon. He is in teaching since 2001. His areas of interest include Digital Signal Processing (DSP), Digital Image, Speech Processing, Object-Oriented Technology and Programming Languages, Internet Technology and Wireless Programming.

Omar R. Daoud has achieved the PhD in the field of Communication and Electronics Engineering at DMU/ UK 2006. He joined Philadelphia University in 2007 as Assistant Professor. His current work is about achieving the Quality of Service for the 4th Generation of the Wireless and Mobile Communication Systems by combining the advantages of the OFDM and the multiple antenna technology. He is the Assistant Dean in the Faculty of Engineering in addition to the Head of Communications and Electronics engineering department. Moreover, and in March 2012 he has promoted to the associate professor rank.

Mohammed M. Ali, received the BSc, MSc and PhD degrees in computer and control engineering from the university of Technology, Iraq in 1981, 1993, and 1998 respectively. He is currently an assistant professor in the department of computer engineering at Philadelphia University, Jordan. His research interest includes fuzzy logic, neural networks, image processing, and computer interfacing. He has 16 published papers related to real-time computer control applications.

Ahlam A. Damati has achieved the MSc in the field of Electrical Engineering/ Communications from The University of Jordan/ Jordan 2002. She had worked as a lecturer in different universities since 2003; UJ and GJU, while she joined Philadelphia University in 2014 as a lecturer in the Electrical Engineering department. Her research interests are in achieving the Quality of Service for the wireless new technologies based on a variety of digital signal processing techniques.