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Sniffer Mobile Robot Performance Enhancement-Based Averaging-Adaptive Wavelet Transform Method

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Abstract— This work concerns of reducing the effect of a drawback of some wireless systems that were sensitive to the peak power signals, namely peak-to-average power ratio (PAPR) problem. It is considered as a vital disadvantage of the Multiple-Input Multiple-Output-Orthogonal Frequency Division Multiplexing (MIMO-OFDM)-based wireless systems. The effect of a new proposition called special averaging adaptive wavelet transformation (SAAWT) will be studied over Sniffer Mobile Robot (SNFRbot) wireless system. This proposition will check the SNFRbot performance and measure its capability of reducing the PAPR. Furthermore, two previously published works will be used to validate our proposition; Neural Network-based, special averaging technique-based. In addition, it compares the attained results with literature techniques such as selective mapping (SLM), Clipping technique, and partial transmit sequence technique (PTS). The SNFRbot based MIMO-OFDM performance is checked based on both of the Bit Error Rate (BER) and Complementary Cumulative Distribution Function (CCDF) curves. This is true in the light of the limitation of bandwidth and channel behaviors constants. This will be attained by making use of two kinds of data; randomly generated data and practically collected data that have been extracted from a funded project entitled energy consumption: efficiency and management (ECEM). As a result, the proposed work, namely special averaging adaptive wavelet transformation (SAAWT), shows promising results to enhance the SNFRbot performance. The SAAWT-based work is compared to five other works and shows powerfulness in combatting the PAPR; the achieved enhancement falls in the range between 20% and 83.89%. BER enhancements combat the channel effects, where it achieves a 65.5% over the SAT-Based work and 42% over the NN-Based work. Furthermore, the enhancement of the SAAWT over literature work falls in the period between 46.3% and 55.1%.

Keywords— Linear codes, MIMO-OFDM, Moving average filter, Neural network, Special averaging techniques, Wavelet.

I. INTRODUCTION

Many different applications have used the latest technologies in order to enhance their performance and reliability. Users' demand on wireless systems rapidly grows [1]-[3]. A hybrid model of two powerful techniques namely Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Out (MIMO-OFDM) has been studied thoroughly in the literature. The combination between the MIMO and the OFDM will improve the whole modulation process and permit data rates to exceed the threshold of 100 Mbps for the downlink process and 30 Mbps for the uplink. It enhances robustness to multipath fading and simplification of the channel equalization. Furthermore, it achieves extraordinary data-rates even in a rich scattering environment [4]-[11].

In this work, a modification has been done in order to enhance our previously published work in [3], [12]. In [13], a comparison has been performed among different techniques proposed to allocate the odd peaks that could arise after the fast Fourier transform stage in the OFDM block. The odd peaks phenomenon is known as the Peak to Average Power Ratio (PAPR). It could affect systems' performance especially the ones that have nonlinear components such as power amplifiers, mixers and converters; it causes such signal deficiencies as intermodulation in the energy being generated at frequencies outside the allocated bandwidth, spectral

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spreading and changing in signal constellation. The average signal power must be kept low in order to prevent the transmitter amplifier on broadcasting and Broadband Radio Access Network (BRAN). Accordingly, and in order to minimize the PAPR values, many solutions were found in 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], [9], [14]-[16].

The work based on a special averaging adaptive wavelet transformation (SAAWT) process has been compared to both 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 SAAWT consists of three main stages: extracting the needed features, de-noising and the optimization criterion. SAAWT enhances the SAT that will take noise clearance enhancement into consideration. It uses 136880 different combinations of de-noising parameters that are experimentally computed to get the most efficient result with respect to the Mean Square Error (MSE), Signal to Noise Ratio (SNR) and Power-SNR (PSNR) values. According to the previously published work, the SAT has the potentials to reduce 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 reached up to 6%. This drawback will be examined in the future work [13]. These three main techniques will be applied in order to enhance the Sniffer Mobile Robot (SNFRbot) system performance. It requires a specific combination of wireless communication, user interface and signal processing techniques to assist human in everyday tasks. Moreover, the proposed work, which is SNFRbot based, is a smart robot monitoring dangerous areas, supplying the administrator with vital information and, in some cases, playing the co-administrator role. This monitoring is accomplished by sending live videos through Multi-Input Multi-Output–Orthogonal Frequency Division Multiplexing (MIMO-OFDM) modems to the administrator. The administrator should notify the SNFRbot that the situation on hand is under control; otherwise, it will act as a co-administrator to give temporary solutions [3], [12].

The results of this work are based on the bit error rate (BER), the Chernoff Union Bound and the complementary cumulative distribution function (CCDF) curves.

The rest of the paper is organized as follows: the SNFRbot structure will be given in Section II; the introduced structure of the wireless system based on MIMO-OFDM model is defined in Section III; the simulation results are presented in Section IV; and the last section summarizes the conclusion.

II. SNFRBOT STRUCTURE-BASED MIMO-OFDM

As mentioned in [3], [12], the SNFRbot structure consists of four main layers; the input layer, the hardware/software (HW/SW) layer, the transmission layer and the administration layer. The input layer of the SNFRbot deals with the sensing and recording issues; i.e. monitors the safety requirements in the surrounding environment. Thus, if any sudden accident happens that causes a high deadly gas concentration or a high temperature in the surroundings, the video camera mode will be activated to send live video to the administrator. The configuration of it is hardware and software will be completed through the second layer. Thus, environmental conditions will be satisfied and reconfigured in this layer, such as its speed. Furthermore, transmission processes will be completed in the third layer. In order to enhance the SNFRbot performance, this layer should be reconstructed; and the internal systems should be modified. Then, our target is to enhance the transmission layer configuration, where the MIMO-OFDM stages were inserted. In this layer, we can modify the MIMO-OFDM stages by imposing another block in-between; this will be responsible for enhancing MIMO-OFDM performances. The prototype has approximately been around 6×10^{-3} m^3 size. It consists of five main parts:

- Motor drive
- MIMO-OFDM modem designed using field-programmable gate array (FPGA)
- Microcontroller
- Power supply
- Sensors/Video camera

In order to finalize the modem, the authors make use of the Xilinx supported facilities and the developed environment that are found in [17], [18]. The Integrated Synthesis Environment (ISE) tool chain will be used to emulate the proposed work design and check its behaviours and performances. Furthermore, the ISE environment provides a behavioural simulator that allows the performance of the design to be post-synthesis examined, i.e. complete with all of the routing delays and imperfections that would be present in the physical instantiation of the design in an actual FPGA [3]. The four layers have been successively implemented to the ISE by making use of the Verilog HDL to be evaluated and tested. This is in addition to the needed synchronization, timing and handshaking additional blocks that are used to ensure the smooth flow of the transport data between the proposed layers. The whole evaluation and utilization process is shown in the generated report by the ISE tool chain once the entire design has been implemented. Furthermore, it determines the overall needed size and required structure of the used FPGA. The generated utilization report shows that the inclusive implementation was fit comfortably with an in-used memory space that does not exceed the 90% of the used Xilinx XC2S150 part; one of the Spartan 2E series.
As mentioned earlier, our target is to enhance system performance through the third layer. It consists of three different stages: the OFDM stage, the MIMO-stage, and the imposed proposed work stage. The imposed proposed work will have one of the following: NN-based, SAT-based and SAAWT-based.
The OFDM stage will consist of a turbo encoder with a coding rate of 0.5, mapping stage using either 16-QAM or 64-QAM techniques, a 256-point IFFT stage. The generated transmitted signal from each antenna is expressed as [1]:

$$x(t)=\sum_{k=-\infty}^{\infty}\sum_{i=0}^{N-1}d_i(k)\exp(j2\pi f_i(t-kT_s))\,f(t-kT_s) \tag{1}$$

In (1), the modulating symbol is defined by d_i. f_i stands for the *i-th* carrier frequency; and T_s is the OFDM symbol duration. This work seeks to enhance systems performance by combatting the PAPR problem. Mathematically, the PAPR could be written as [1]:

$$\text{PAPR}=10log_{10}\left\{\frac{P_{peak}}{P_{avg}}\right\}=\frac{\left|x(t)\right|^2}{\frac{1}{NT}\int_0^{NT}\left|x(t)\right|^2dt} \tag{2}$$

P_{peak} is the maximum power of an OFDM symbol; P_{avg} is the average power; T is the symbol duration; *x(t)* is the OFDM symbol at time *t*. For simplicity purposes, if the used modulation technique is BPSK, the absolute value of the modulated symbol will equal 1. This assumption concludes that the resultant average power will equal to the total number of input signals *N*. The maximum power of the OFDM symbol is N^2 [8]. Thus, the signal $x(t)$ will be implemented using the Verilog HDL to be utilized and checked by the ISE. This is in order to pass through the second stage that is responsible for detecting the high PAPR values. After detecting those values, the proposed work will be used to remedy such a drawback before it is transmitted through the MIMO stage, which uses the V-BLAST MIMO encoder. V-BLAST is used for increasing the overall throughput expressed in terms of bits/symbol.

III. THE PROPOSED WORK TO COMBAT THE PAPR DRAWBACK

This section describes the three different works proposed to combat the PAPR problem. They will be imposed after the IFFT stage in the OFDM stage. These propositions will be described in the following subsections.

A. NN-Based Work

As in [19], due to its ability of the simultaneous bandwidth (BW) linearization, the NN is considered the simplest method of linearization especially for RFPA. 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 on 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. 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 [3], [19]. The used NN-based work structure is described in Table 1; the achieved BER curves results will be depicted in Fig. 1.

In order to fulfill the learning process, the previously attained results in [2], [3], [8], [12], [13], [16] will be used to test data for the learning process. Fig. 1 depicts the BER results that have been attained after using the NN-based proposed work. A slight modification has been attained in the previously published work. This helps simplify the system’s structure complexity, i.e. the NN simplifies the complexity of the work and boost performance enhancement by combatting the PAPR intelligently. For a used 64-QAM, the BER has been enhanced between 97.55%-to-99.9% for the 10dB to 16dB SNR interval.

TABLE 1
NN-BASED WORK STRUCTURE AND LEARNING PROCESS RESULTS

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)
Number of Trained OFDM Symbols		100
Learning Parameters	0.1	MSE= 6.254×10^{-5}
	0.01	MSE= 8.157×10^{-5}

B. SAT-Based Work

The adaptive convolutional approach is the basis of the SAT-based work. The following procedure shows the basic three stages of SAT:

- Cleaning the signal by removing the noise and making use of some wavelet families, namely Biorthogonal, Daubechis, Symmlet, Coiflet and Haar wavelets. The cleaning process is based on three main factors, namely mean square error (MSE), signal to noise ratio (SNR) and the peak SNR (PSNR).
- Odd peaks detecting process by making use of local maxima idea and its relation with derivatives theorem, sign selection (where the sign indicates the trend of increasing, decreasing or remaining with no changes), template matching process making use of the discrete convolution idea (the used pattern is [-1,1]), and adaptive thresholding process [13].
- Finally, the post processing stage that deals which thresholds the founded peaks by making use of the moving averaging filters (AF), such as simple-AF, exponential-AF and Weighted-AF. The moving averaging filter is described in (3) as in [13]:

$$OFDM_{n_{mod}} = (OFDM_{n-1} + OFDM_n + OFDM_{n+1})/3 \tag{3}$$

where $OFDM_{n_{mod}}$ is the modified OFDM sample; $\{\ldots\}_{0\leq n\leq N-1}$ is the number of OFDM sample; $OFDM_n$ is the affected OFDM sample.

The results of the SAT-Based work are clearly depicted in Fig. 2, where Fig. 2a shows the cleaning stage results; and Fig. 2b shows the results of the thresholding and the averaging filter processes.

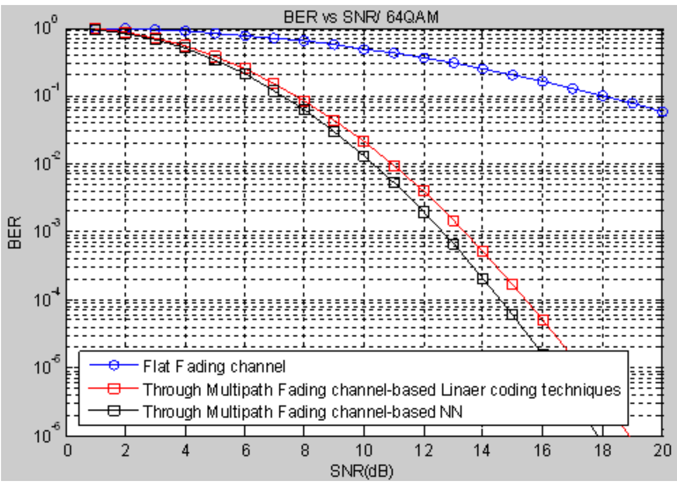

Fig. 1. NN-based work BER curves [2]

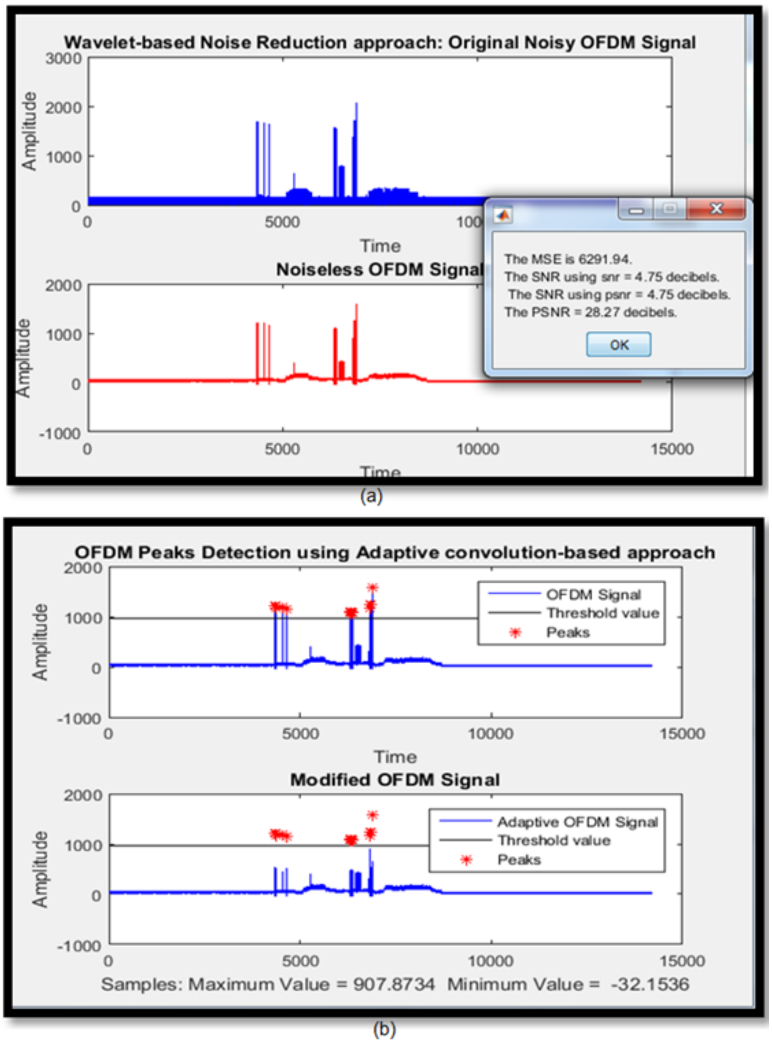

Fig. 2. a) Noise removal using SAT-based work, b) Odd peaks detected using SAT-based work [13]

It is clearly shown that in Fig. 2a the wavelet-based noise removal approach enhances the resultant signal shape; the MSE is 6291.94; the SNR is 4.75dB; and the PSNR is 28.27dB.

C. SAAWT-Based Work

The SAAWT work is a modified version of SAT and differs in the noise removal step that was found in the pre-processing stage. The rest of processes are similar. Thus, after reading the affected signals, 13680 different combinations of noise removals were used. These parameters were experimentally computed in order to get the best result with respect to the same previously mentioned parameters: MSE, SNR and PSNR.

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

- Several families of known wavelets were tested and evaluated (57 types), including the orthogonal and compactly supported wavelets (Haar, Daubechies (dbN), symlets (symN), coiflets (coifN)) and the B-splines biorthogonal wavelets (biorNr.Nd and rbioNr.Nd).
- Different thresholding algorithms such as ‘minimax’, ‘universal’, Rigrsure and, 'Heursure' threshold estimation techniques.
- Soft and hard thresholding rules.

- Different multiplicative threshold rescaling types such as 'one', 'sln' and 'mln'.
- Wavelet decompositions were performed at different levels from the first level to the tenth.

Table 2 shows the attained SAAWT performance values in the best and worst cases; these results were extracted from the results depicted in Fig. 3. It shows easily the enhancement of the achieved results over the SAT ones that are shown in Fig. 2a.

TABLE 2
THE PARAMETERS THAT GIVES THE BEST AND WORST SAAWT PERFORMANCE RESULTS

De-Noising Parameters	Best Results		Worst Results	
	Solution 1	Solution 2	Solution 1	Solution 2
Decomposition Level	1	1	10	10
Threshold Selection Rule	rigrsure	heursure	sqtwolog	minimaxi
Threshold Type	soft	soft	soft	soft
Scaling Type	one	one	sln	sln
Wavelet Type	bior3.5	bior3.5	rbio3.1	rbio3.1
Performance Assessment Methods				
MSE	9.46e-28	9.46e-28	268772.57	199216.45
SNR	312.98	312.98	-11.55	-10.25
PSNR	336.50	336.50	11.97	13.27

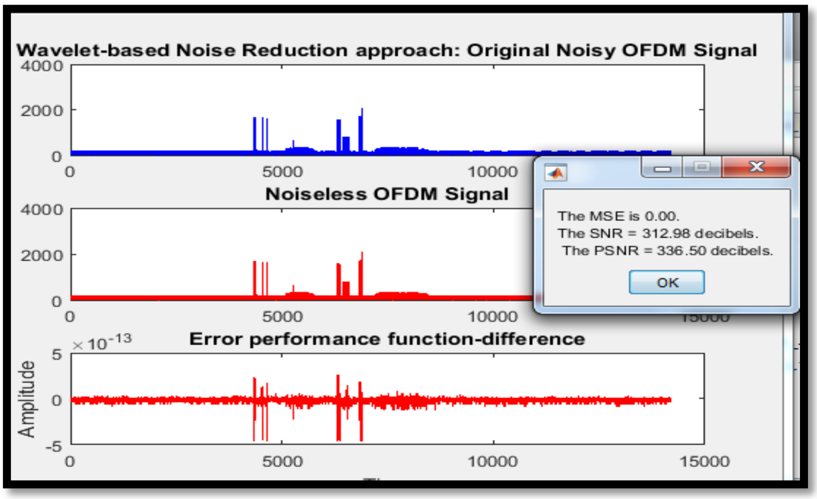

Fig. 3. The best attained performance results (solution 1)

IV. SIMULATION RESULTS AND DISCUSSION

While the efficiency of the three proposed works has been tested in the previous section, this section deals with the SNFRbot performance after imposing them in the thirst layer, i.e. inside the MIMO-OFDM stage. Fig. 4 describes the structure of the MIMO-OFDM stage with the imposed proposed work stage. A MATLAB simulation has been performed in order to test the SNFRbot performance based on the different works proposed. It is clearly shown that the position of the proposed work is between the OFDM stage, i.e. after the Fast Fourier Transform (FFT), and the MIMO stage.

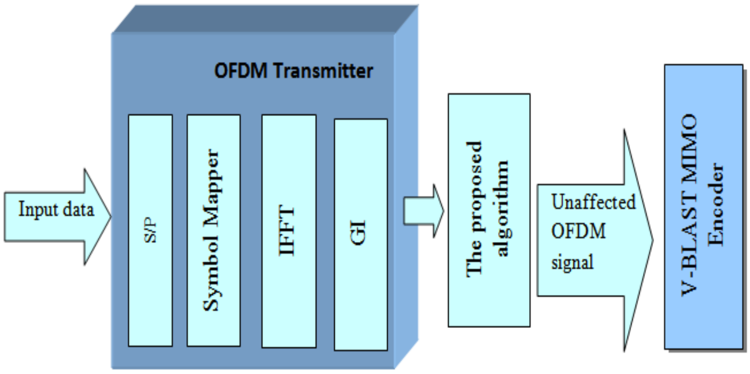

Fig. 4. SNFRbot MIMO-OFDM enhanced block diagram

Fig. 4 shows the process of the input data that will be passed through a modified MIMO-OFDM transmitter. These blocks are divided into three main parts: the OFDM transmitter, the proposed algorithm block and the MIMO stage block. The OFDM stage consists of four main blocks: the serial-to-parallel block, the mapping block (modulation stage), the IFFT stage and the guard interval that has been used to overcome the effect of either the inter symbol interference (ISI) or the inter carrier interference (ICI). In the middle stage, the proposed algorithm could be either of the proposed work namely, NN, SAT and SAAWT. Finally, processing will be accomplished with the MIMO encoder, namely Vertical-Bell Laboratories Layered Space-Time (V-BLAST), which is used in order to enhance system capacity.

The MATLAB program is limited to 256 subcarriers, two different modulation techniques, namely 16-QAM and 64-QAM, a Turbo encoding stage with a coding rate of ½, the used OFDM guard intervals equals to 0.25 of the symbol length, and a MIMO encoder-based V-BLAST. In addition, the tested input data will be generated as an independent and identically distributed (i.i.d.) random variables.

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. The BER will be the key factor in differentiating the proposed work from the conventional ones and the CCDF curves. The BER part will be defined and compared to the conventional work. It is known that either wrong detection or noisy channels causes burst error which needs special protection. The BER defines the relationship between the bit error probabilities and the *SINR*. Thus, a mapping function could be defined through the link level simulation with the needed channel. Furthermore, CCDF is a performance metric independent of the transmitter amplifier; given the reference level $P_{th}>0$, the probability of a PAPR being higher than the reference value is the CCDF. For practical reasons, the CCDF of PAPR is calculated based on the percentage of the OFDM/WPM frames for which PAPR exceeds the threshold P_{th}. These results will be extracted from a Multipath condensed channel.

To check the performance of our proposed work, this work has been firstly compared to the literature. The result of this comparison at 2% CCDF is depicted in Table 3, while the whole CCDF curves comparison is shown in Fig. 5.

Based on Table 3, system performance has been enhanced to overcome the PAPR ratios. Table 3 shows that our proposed three works have better values than the literature. The worst enhancement range when using the 16-QAM has been achieved for the NN-based work and falls in the range of 11.1%-to-41.8%. The SAAWT-based work gives the best enhancement range and achieves an extra 41.25% over the NN-based work and 21.6% over the SAT-based work.

TABLE 3
THE 2% CCDF RESULTS OF THE PROPOSED TECHNIQUES COMPARISON

Modulated Input Data	64-QAM	16-QAM
Conventional PAPR, dB	27	34
SLM, dB	21	27.5
PTS, dB	16.7	21
Clipping, dB	14.5	18
NN-Based Work, dB	12	16
SAT-Based Work, dB	10.3	12
SAAWT-Based Work, dB	9	9.4

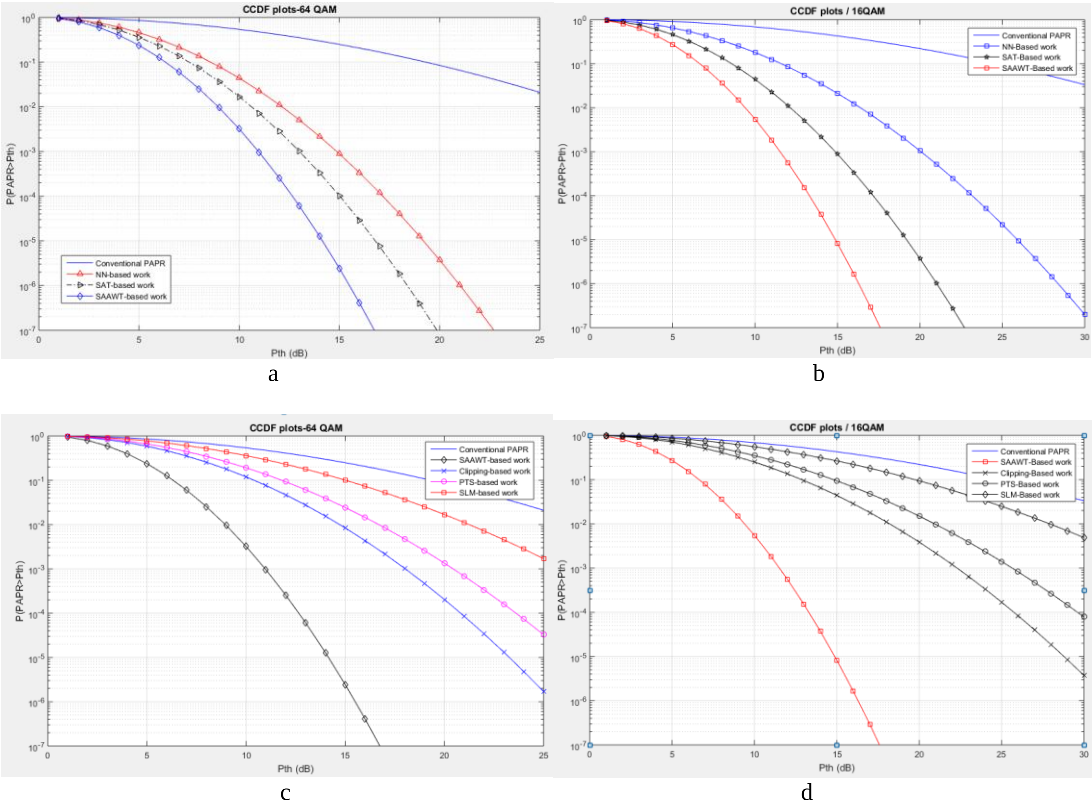

Fig. 5. CCDF curves comparisons: a) Comparing the proposed work with our previously published work-based 64-QAM, b) Comparing the proposed work with our previously published work-based 16-QAM, c) Comparing the proposed work with the literature-based 64-QAM, d) Comparing the proposed work with the literature-based 16-QAM

Furthermore, the SAAWT-based work has an enhancement of 72.3% over the conventional systems. After changing the modulation technique to be 64-QAM, system performance improves; the SAAWT-based work performance falls in the range of 46.1%-to-66.6%. Thus, the achieved results show that the proposed algorithm demonstrates promising results over the archived results in the literature.

The second part of the checking criterion is clearly depicted in Fig. 6 for the different used modulation techniques; 16-QAM and 64-QAM, respectively.

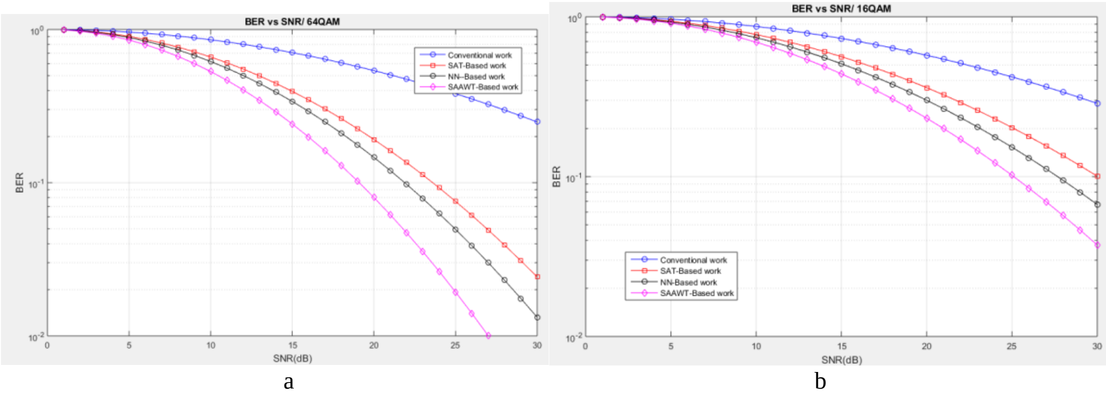

Fig. 6. BER curves: a) based 64-QAM, b) Based 16-QAM

In both Fig. 6a and Fig. 6b, the proposed work gives better results in combatting channel effect. It is clearly shown that the 64-QAM based results are better than the 16-QAM based ones; at 30dB, the conventional work BER is around 2.9×10^{-1} for the 16-QAM based work, while this value is enhanced to be 2.3×10^{-1} by the 64-QAM. Furthermore, in a comparison among the proposed three works, the proposed SAAWT work gives the best results for the SNFRbot for the used modulation techniques. At 20dB in Fig. 6a, the SAAWT reduces the BER of the conventional work from 5.4×10^{-1} to 8.7×10^{-2}. Thus, the enhancement ratio is about 83.89%. Comparing the SAAWT results to the other two proposed works gives extra 65.5% enhancement over the SAT-Based work and 42% over the NN-Based work. These results are quite better than the ones achieved in Fig. 7; by using the 16-QAM modulation technique. At the same threshold value, the SAAWT reduces the BER of the conventional work from 6.2×10^{-1} to 1.2×10^{-1}. Thus the enhancement ratio is reduced to about 61.6%. This reduction is also projected to the comparison with the other two proposed works; the SAAWT results give extra 43.6% enhancement over the SAT-Based work instead of the 65.5% that is achieved in Fig. 6a. Also, the achieved enhancement is reduced to almost 20% over the NN-Based work.
The SAAWT-based work worst scenario is compared to the work in literature; SLM, PTS and the clipping techniques are depicted in Fig. 7.

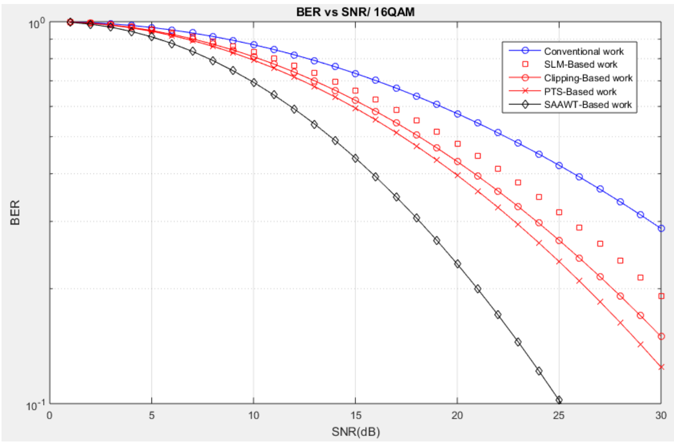

Fig. 7. BER curves based 16-QAM compared to literature

The SNFRbot system performance has been checked based on a comparison between the SAAWT-based work and three different works that have been found in the literature. As mentioned earlier, at 20dB, the SAAWT shows an enhancement of 61.6%% over the conventional work. Furthermore, the enhancement of the SAAWT over literature falls between 46.3% and 55.1%.

V. CONCLUSIONS

In this paper, three propositions have been proposed to enhance the performance of SNFRbot work. This is in order to combat the effect of high PAPR problem in OFDM systems. These propositions cover the SAT-based work, the NN-Based work and the SAAWT-based work.
The enhancement performance is checked based on two main criteria: the CCDF curves and the BER curves. Furthermore, a comparison has been made between the proposed work and three different works from the literature, namely, SLM, PTS and the Clipping technique. Moreover, two main modulation techniques have been used: 16-QAM and 64-QAM.
The proposed work shows a performance improvement over literature work in CCDF and BER curves. Simulation results show that the use of SAAWT-based work gives the best system performance; it gives a CCDF enhancement range and achieves an extra 41.25% over NN-based work and 21.6% over the SAT-based work. Furthermore, the SAAWT-based work has an enhancement of 72.3% over conventional systems. After changing the modulation technique to be 64-QAM, system performance has improved; the SAAWT-based work performance has fallen in the range of 46.1%-to-66.6%. Also, the SAAWT reduces the BER of the conventional work in a ratio range of about 61.6%-to-83.89%. The best enhancement ranges between 65.5% over the SAT-Based work and 42% over the NN-Based work. Furthermore, enhancement of the SAAWT over literature work ranges between 46.3% and 55.1%. According to the previous results, the proposed works have proved their reliability in overcoming the effect of PAPR. The use of NN reduces the added complexity at the receiver side since there is no need to send control data that has been sent in the previously published work.

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