Speaker Verification over MIMO-OFDM Systems based on Artificial Intelligence Techniques

Omar R. Daoud, Qadri J. Hamarsheh, and Wael H. Al-Sawalmeh

***Abstract*—**In this work, an enhancement of a previously published work that tackles the use of automatic speaker verification (ASV) techniques in the Beyond Third generation (B3G) cellular systems has been proposed. The new proposition has been studied to overcome the effect of the Peak-to-Average Power Ratio (PAPR), which is a vital problem that found in the Orthogonal Frequency Division Multiplexing (OFDM) techniques, where a powerful combination between two main technologies; Multiple-Input Multiple-Output (MIMO) and OFDM has been developed to meet the rapidly increment in the users demand such as the ubiquitous transmission, imposing new multimedia applications and wireless services.

The work space has been divided into three main areas; firstly, reducing the ASV complexity by selecting the weight of the text independent speakers based on Self-Organizing Map (WSOM) Neural Network (NNT), secondly, using the Eigen values/vector extracting features techniques as a pre-processing one to enhance the orthogonality, and finally proposing a new algorithm to combat the effect of the PAPR in the MIMO-OFDM systems. In this algorithm, wavelets techniques have been used to Denoise the affected OFDM symbol by high PAPR values. After that and based on adaptive threshold method the local maxima and minima will be determined and replaced by the average of them and their surrounding neighbors; Denoise OFDM and Replace PAPR (DORP).

A system performance investigation process will be accomplished based on both of numerical method and MATLAB simulation. Moreover, a comparison has been made to check the validity of our proposition with our previously published work. Although, the achieved results show that the proposed work has lower PAPR values; an additional complexity has been added to transceiver's structure. Moreover, and as a result to the comparison with the conventional systems, the bit error rate (BER) performance has been improved for the same bandwidth occupancy. Our simulation results showed that around 28% extra reduction in PAPR over current values in the literature, it can be achieved depending on the system type. Moreover, two different investigation and verifications techniques have been used in this work; Gaussian mixture model based method (GMMWPE) and K-Means clustering based method (KMWPE). A promising verifications result has been showed for verifications rate; around 91% and for noise immunity.

***Keywords*—**MIMO, OFDM, Peak-to-Average Power Ratio, Self-Organizing map, Wavelet, Eigen vectors.

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I. Introduction

Over the last decade and due to the overwhelming huge data that the users' create, transmit and/or manage; a challenge has been made to the wireless communication systems vendors to ease such complexities This will produce advanced wireless techniques with high capacity and restrain the growth in the multimedia applications, internet access either wired or wireless and other needed applications in the new generation mobile systems. One of the main challenging issues is Speaker verification. It has been the topic of active research for many years, and has many important applications where propriety of information is a concern [1]. This is revealing that the speaker verification system is a difficult task. Typically, these intricacies contain the needed amount of speech for accurate verification and estimation; and the threshold estimation for acceptance and rejection [1-3]. Moreover, the unprecedented developments have been made to meet this rapidly increment in the users demand such as the ubiquitous transmission, imposing new multimedia applications and wireless services. An example of the technologies that have been developed to meet the increasing demand of reliability, coverage, the new services is the combination between two main techniques in cellular systems; Multiple-Input Multiple-Output -Orthogonal Frequency Division Multiplexing (MIMO-OFDM). This is to improve the system reliability and performance. For more improvement, a pre-processing technique has been introduced to increase the orthogonality among the tested data which is based on imposing the Eigen values/vector extracting features.

Orthogonal frequency division multiplexing has emerged as an efficient multicarrier modulation scheme for wireless, frequency selective, communication channels. Ease of implementation, high spectral efficiency, resilience to impulse noise and multipath are a few advantages of OFDM systems. It is a multi-carrier system which utilizes a parallel processing technique allowing the simultaneous transmission of data on many closely spaced, orthogonal sub-carriers. Inverse fast Fourier transforms (IFFT) and fast Fourier transform in a conventional OFDM system are used to multiplex the signals together and decode the signal at the receiver respectively. The system adds cyclic prefixes (CP) before transmitting the signal. The purpose of this is to increase the delay spread of the channel so that it becomes longer than the channel impulse response. The purpose of this is to minimize inter-symbol interference (ISI). However, the CP has the disadvantage of reducing the spectral containment of the channels. The main challenge of the new generation of wireless cellular systems is the reliability of providing data rate of around [4]. However, the peak-to-average power ratio (PAPR) is appears as a major drawback in the OFDM signal. This deficiency could be defined as a large envelope fluctuation. As a consequence, it limits the efficiency of the non-linear devices such as the power amplifiers, mixers, and analog to digital converters. Then they will operate at lower average power. This phenomenon results from the superposition of a large number of usually statistically independent subchannels that can constructively sum up to high peaks. As a result of this drawback, the signals envelop will be a Raleigh distributed in addition to a complex Gaussian process behavior. Various schemes have been developed to reduce high PAPR and classified as distortion and distortion-less methods in OFDM signals [5,6]. Those techniques reduce the PAPR at the expense of an increased, irreducible, symbol error rate at the receiver in addition to transmitting side information resulting in a reduced throughput. They are all based on adding time dependent blocks to the original OFDM frame to reduce its peak by changing some or all subcarriers (tones) in the frequency domain. To overcome these effects, several solutions have been introduced in [7-9] that used wavelet-based OFDM.

A core contribution of this work is developing a method of combating the PAPR, first proposed in [10], based onto two main parts; firstly, rebuild the FFT block using Wavelet Transforms (WT); secondly, develop a method to propose a new method of sending the average of surrounding samples instead of the affected sample by a high PAPR value. A comparison between the proposed work and the previously published work will evaluate and validate our work.

Inverse-WT (IWT) and wavelet transforms have been considered as alternative platforms for replacing IFFT and FFT [4, 11, and 12]. In order to avoid the extra CP data that reduced bandwidth, in [4, 13, and 14] presented the simulation approaches for a discrete wavelet transform based OFDM (DWT-OFDM) as alternative substitutions for FFT-OFDM. The results in terms of BER performance were also obtained for all of them. The DWT-OFDM system is superior to others, especially when the system uses bior5.5 or rbior3.3 wavelet family.

The overall DWT-OFDM is the same as FFT-OFDM; the only difference is in the OFDM modulator and demodulator. Also, the process of the S/P converter, the signal damper and the insertion of training sequence in DWT-OFDM system are the same as in the system of FFT-OFDM [15]. The main and important difference between FFT-OFDM and DWT-OFDM is that the DWT-OFDM system will not add a CP to OFDM symbol. Therefore, the data rates in DWT-OFDM can surpass those of FFT implementation.

In [16], further performance gains were made by looking at alternative orthogonal bases functions by proposing a fast computational method for a Discrete Multiwavelets Transform (DMWT) as alternative to conventional wavelet transform. The proposed DMWT in [16] has better performance in AWGN, Doppler shift and in selective fading channel.

A. Wavelet Packet Transform

A wavelet is a “small wavy function” of proficiently limited duration that has an average of zero. This wavelet is applied to develop the signal and the continuous wavelet transform (CWT) is obtained as a sum of all time signals multiplied by scaled and shifted version of the wavelet function. Nevertheless, it turns out that if we decide the scale and shifted version in a dyadic mode, i.e., based on powers of two, we can obtain a precise yet much more efficient transform. This is the discrete wavelet transform DWT. A more comprehensive form of the standard wavelet transform is the WT, which decomposes both the high and low frequency bands at each level. 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). This process can be repeated to partition the frequency spectrum into smaller frequency bands for obtaining different features while detecting the temporal information. It was indicated by many works that WP features have better presentation than the DWT [17].

The wavelet packet method is a generalization of wavelet decomposition that offers a richer signal analysis. Wavelet packet atoms are waveforms indexed by three naturally interpreted parameters: position and scale as in wavelet transform decomposition, and frequency. In the following, the wavelet transform is defined as the inner product of a signal $x(t)$ with the mother wavelet $\psi(t)$:

$$\psi_{a,b}(t) = \psi\left(\frac{t-b}{a}\right) \text{----------------(1)}$$

$$W_{\psi} x(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t)\psi * \left(\frac{t-b}{a}\right) dt \text{ ---------- (2)}$$

where a and b are the scale and shift parameters, respectively. The mother wavelet may be dilated or translated by modulating a and b. The wavelet packets transform performs the recursive decomposition of the speech signal obtained by the recursive binary tree. Basically, the WPT is very similar to DWT but WPT decomposes both details and approximations instead of only performing the decomposition process on approximations. The principle of wavelet packet is that, given a signal, a pair of low pass and high pass filters is used to yield two sequences to capture different frequency sub-band features of the original signal. The two wavelet orthogonal bases generated from a previous node are defined as

$$\psi_{j+1}^{2p}(k) = \sum_{n=-\infty}^{\infty} h[n]\psi_j^p(k-2/n) \text{---------------- (3)}$$

$$\psi_{j+1}^{2p}(k) = \sum_{n=-\infty}^{\infty} g[n]\psi_j^p(k-2/n) \text{--------------- (4)}$$

where $h[n]$ and $g[n]$ denote the low-pass and high-pass filters, respectively. In equations (3) and (4), $\psi[n]$ is the wavelet function. Parameters j and p are the number of decomposition levels and nodes of the previous node, respectively [18]. Fig. 1 shows the used wavelet packet at depth *J*, which will be used in the proposed work.

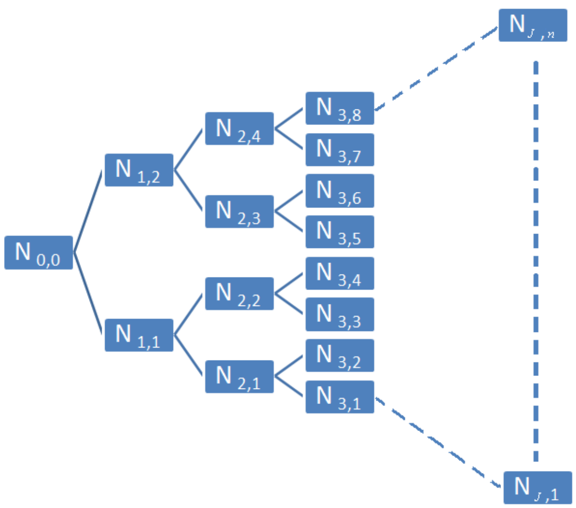

Fig. 1: Wavelet packet at depth *J*

In this section, the wavelet packets have been used to replace the even and odd parts in the FFT block. These parts have the main functionality, i.e. the fundamental principle of the FFT, which is clearly shown in Figure 2. Thus, the wavelet pockets defined as a general form of FFT with basis that is localized in both time and frequency. These basis are constructed using a special filters, namely Quadrature Mirror Filter (QMF) $h(n)$ and $g(n)$, that are satisfying some conditions and leading usually to low and high pass filters [19,20]. The QMFs $h(n)$ and $g(n)$ of length L are recursively used to define the sequence of basis functions ψ_n(t), called wavelet packet, which satisfy various orthogonality properties useful in calculating the discrete WPT. The latter takes at its input N numbers and produces N numbers at the output, similarly to a DFT operation. The inverse DWT (IDWPT) can be viewed as a synthesis operation representing the data symbols as a sum of shifted $\psi_j\,[k]$ waveforms. An alternate way to visualize wavelet packet transforms is by defining a set of operators ($H-1,G-1,H$ and G) based on $h(n)$ and $g(n)$ as follows [19]:

$$H\{x\}(2n) = \sum_{k\in Z} x(k)h(k-2n) \text{--------------------------(5)}$$

$$G\{x\}(2n) = \sum_{k\in Z} x(k)g(k-2n) \text{---------------------------(6)}$$

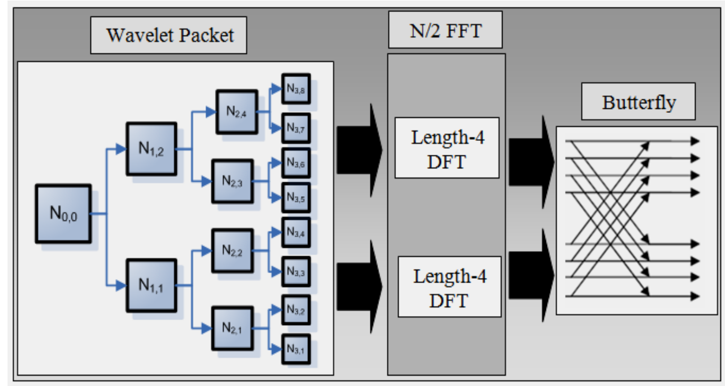

Fig. 2: Block diagram of wavelet packet based FFT (DWPT-FFT) at depth-3

Fig. 2 shows the block diagram of the proposed work. It consists of three main parts, namely wavelet packet; N/2 FFT; and Butterfly. This work is an extension of the previous published work in [10]. The DWPT-FFT could be represented based on the low and high filters; namely *h* and *g* as it is clearly shown below in (7).

$$F_N = \begin{bmatrix} A_{N/2} & B_{N/2} \\ C_{N/2} & D_{N/2} \end{bmatrix} \begin{bmatrix} F_{N/2} & 0 \\ 0 & F_{N/2} \end{bmatrix} [WP_N] \text{---------(7)}$$

Equations 5 and 6 define the low and high filter bank operators; *h* and *g* respectively. In equation 7, *AN/2* and *CN/2* has the same length of '*h*' and is defined as the length-N DFT of '*h* '. Moreover, *BN/2* and *DN/2* they are defined as length-N DFT for the high filter bank '*g*'. In our work, the wavelet packet is limited to the depth 3, thus the high pass and the low pass sub signals go through separate length-4 DFT, and then they are combined with butterfly operations as shown in Figure 2.

In this part, the computational complexity is also $O(N\log_2(N))$. However, the constant appears before $N\log_2(N)$ depends on the wavelet filters used [21]. And then a good tradeoff need to be found since the complexity of this implementation is based on some factors such as the input data, the used wavelet, and the used threshold to drop the insufficient data and to prune the butterfly operation.

B. PAPR Reduction Technique

Due to the coherence addition of N signals in the N-point IFFT stage to produce OFDM symbol, an occasionally production of a high peak power equal to N times the average power; namely Peak-to-Average Power ratio (PAPR).The, the PAPR could be defined as:

$$\text{PAPR}=10\log_{10}\left\{\frac{P_{peak}}{P_{avg}}\right\} \text{-----------------------(8)}$$

where, P_{peak} is the maximum power of an OFDM symbol, and P_{avg} is the average power. The PAPR can be reformulated as:

$$\text{PAPR}=\frac{|x(t)|^2}{\frac{1}{NT}\int_0^{NT}|x(t)|^2\,dt} \text{ ----------------------- (9)}$$

where T is the symbol duration, $x(t)$ is the OFDM symbol at time, t, which can be expressed as $x(t)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}X_n e^{j2\pi f_0 nt}$, $0 \le t \le NT$. X_n is the data modulating the n-th is sub carrier and f_0 is the nominal subcarrier frequency spacing. Moreover, the average power of the OFDM symbol presented in (9) can be written as:

$$P_{\text{avg}} = \sum\left\{|x_i(t)|^2\right\} = \frac{1}{T}\int_0^T |x(t)|^2\,dt \text{ ------------- (10)}$$

$$P_{\text{avg}} = \frac{1}{T}\int_0^T\left|\sum_{v=0}^{N-1} c_v e^{j2\pi\frac{v}{NT}t_v}\right|^2 dt \text{ ----------------- (11)}$$

$$P_{\text{avg}} = \frac{1}{T}\int_0^T(\sum_{v=0}^{N-1} c_v\cos(2\pi\frac{v}{NT}t_v))^2$$

$$+(\sum_{v=0}^{N-1} c_v\sin(2\pi\frac{v}{NT}t_v))^2\,dt \text{ ----------- (12)}$$

$$P_{\text{avg}} = \frac{1}{T}\int_0^T(\sum_{v=0}^{N-1} c_v^2)dt \text{ ----------------------- (13)}$$

where c_v is the magnitude of the modulated data. For simplicity, if BPSK modulation is used without any channel coding techniques, then $|\mathbf{c_v}|=1$, when $t \in [0, T]$. This can be substituted in (13). The result from this substitution leads to a direct relationship between the average power and the total number the IFFT points, N, which can be taken directly from

$$P_{\text{avg}} = N\,\frac{1}{\mathbf{T}}\int_0^{\mathbf{T}}\mathbf{c_v^2 dt} = N, \text{ ----------------------- (14)}$$

From (14) the average power is equal to the number of the BPSK-modulated orthogonal subcarriers. As already mentioned, the maximum peak amplitude is N, therefore, the maximum power of the OFDM symbol is N^2. As a result, from (8), the PAPR of uncoded BPSK will be $10\log_{10}(P_{\text{avg}})$ dB. Therefore, the PAPR will be decreased if the average power of the OFDM symbol is decreased.

In describing the algorithm steps of the proposed model, Figure 3 is divided into two main stages describing the steps of the proposed technique. In the first stage, the proposed technique begins with checking the OFDM symbol to see whether it is suffering from high PAPR values or not (this depends on the application itself; in our case the threshold is settled to be 10 dB based on mobile communication systems [10]). If the PAPR is within a set tolerance, "I" coded symbols generated through a Space Time Block Coder (STBC) will be transmitted through "I" number of antennae. If the PAPR, however, exceeds a predetermined acceptable threshold, the symbol will pass through LDPC coding block having first removed the guard interval. LDPC is one of the linear coding techniques which increase the symbol period in the time domain. The period of the affected symbol will be spread according to the chosen spreading rate, to be "I" times the original one, where "I" is the spreading rate. The second stage of the proposed technique deals with the new symbol and choosing the data with the lowest PAPR value. The spread symbol will be mapped to "I" parallel blocks, each of which has the same duration as the conventional symbol duration. The number of iterations that is needed to calculate the PAPR of each block, and choosing the lowest value is given by $[((I-1)N)+1]$

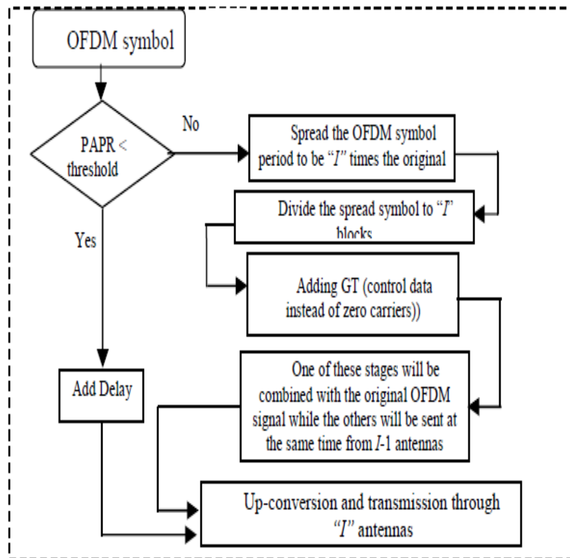

Fig. 3: The flowchart of the algorithm [10]

Thus, the proposed technique will add a first order complexity in according to the variable N. Due to the achieved spreading by using linear coding; these blocks will have a PAPR value less than the threshold value. Muck, *et. al.* demonstrated that it is possible to use the Zero Padding (ZP) at the end of the OFDM symbol to, instead of transmitting zeros, to transmit a deterministic control sequence [22]. In this work, this proposal is adopted to send a sequence to let the encoder know whether the symbol has been adapted due to excessive PAPR. After adding the control sequence, these new blocks will be transmitted through "I" number of antennae. Thus the total number of transmitting antennae depends on the value of "I" and the type of Alamouti STBC. As an example, if a 2X2 Alamouti STBC with a spreading rate of 2 is used, then the total number of antennae will be 4. The proposed technique here in this subsection adds a complexity to the MIMO-OFDM system of the first order while it is tackling the PAPR problem. This complexity added is the result of calculating the PAPR of each block and choosing the lowest value. The following formula shows the needed number of iterations {Iterations =

[((*I*-1)N)+1]}, where *I* is the spreading rate and *N* is the number of the IFFT points.

In this subsection, the DWT-OFDM performance will be showed based on both of reducing the PAPR ratio problem and defining the meaning of BER. In the BER part, it will be defined and compared with the conventional OFDM 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 (15)

$$\hat{S} = s_0 + s_1 \text{ --------- } (15)$$

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

$$SINR = \frac{E\left\{\left|s_o\right|^2\right\}}{E\left\{\left|s_1\right|^2\right\}} \text{ --------- } (16)$$

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 [22] which is based on Chernoff Union bound; the effective *SINR must accomplish* the following relationship

BER(SINR)=

$$BER_{WGN}\left(-\lambda \ln\left(\frac{1}{NQ}\sum_{q=1}^{Q}\sum_{n=1}^{N}\exp\left(\frac{-SINR_q}{\lambda}\right)\right)\right) \text{ -- } (17)$$

where *N* stands for the total number of subcarriers, *n* is the *n*th subcarrier=1;..; *N*, λ is a unique parameter based on the system level simulation, *Q* is the set of symbols that will be transmitted through certain number of antennas. Now, for the BER of WPT-OFDM systems, we can make use of the published work in [23,24] to show that the OFDM based WPT gives better BER than the OFDM based FFT.

In this paper, a new proposition of reducing the PAPR effect is introduced; by seeking the best features of the test data to be extracted and then entered the new OFDM structure. In this way, the redundant information is omitted by imposing the Eigen vector extracting feature and then we reducing the coherency among the transmitted signals. Moreover, the transmitted data will pass through FW-FDM instead of the FFT based OFDM. These modifications give the introduced work the power over the classical works proposed in the literature [5-9,16]. After that and before entering the stage of up conversion, the data will be processed via our proposed work. This will enhance the reliability of the system by reducing the number of affected OFDM symbols by the PAPR.

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

II. The MIMO-OFDM System Description

A. The MIMO-OFDM System Model Based DWPT

Fig. 4 shows the MIMO-OFDM architecture with and without the DWPT-FFT, where the proposed PAPR problem reduction technique is placed after the IFFT stages.

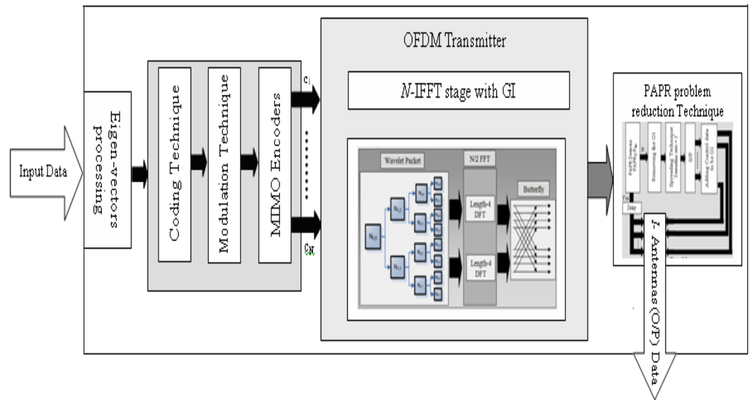

Fig. 4: The MIMO-OFDM system based DWPT block diagram

The main aim behind this work is to improve the MIMO-OFDM systems' performance, thus it is clearly that the OFDM transmitter block is divided into two parts; the conventional one, which is based on the IFFT and FW-FDM that is based on the wavelet packet as it is shown in Fig. 2.

For the sake of clarity, the system model will be limited to the use of an low-density parity check codes (LDPC) as a coding technique; Mary-Quadrature Amplitude Modulation (16,64) as modulation techniques together with a STBC MIMO encoder. A MIMO-OFDM modulator, consisting of the MIMO encoder and OFDM transmitter, processes the serial coded and modulated constellation symbols. This process became after the Eigen-vector process block, since this block reduces the coherency between the data signals and hence will improve the system performance. V-BLAST is used for increasing the overall throughput expressed in terms of bits/symbol, while applying either the IFFT or DWPT-FFT is to generate the OFDM symbols. The cyclic prefix will be added to the resultant data to form the OFDM symbol with a guard interval. 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. Thus we try to reduce the effect of these peaks by apply the PAPR reduction technique block after the IFFT/DIWPT-IFFT.

The novelty in our technique comes firstly from the manner of exploitation of the LDPC encoder as a means to deal with the PAPR, and secondly by dealing with the PAPR after the both IFFT stages. It is based on the LDPC coding technique, which reduces the PAPR by adding redundant data to reduce the OFDM symbol average power. These redundant data is added based on the coding rate. As an example, if the coding rate is 1/2 then the resultant data rate will be twice the original rate. The best combination between the original data and the redundant one will then be chosen to give the lowest PAPR to be sent, whilst the rest of data will be sent to be used at the receiver to recover the original data. The architecture of the receiver part is the inverse process of the transmitter.

B. The MIMO-OFDM System Model Based Denoise OFDM and Replace PAPR (DORP)

In this subsection, a new algorithm has been proposed as shown in Fig. 5 (a). Identifying and analyzing the peaks and valleys of OFDM. Signal detection algorithm has been implemented using MATLAB software

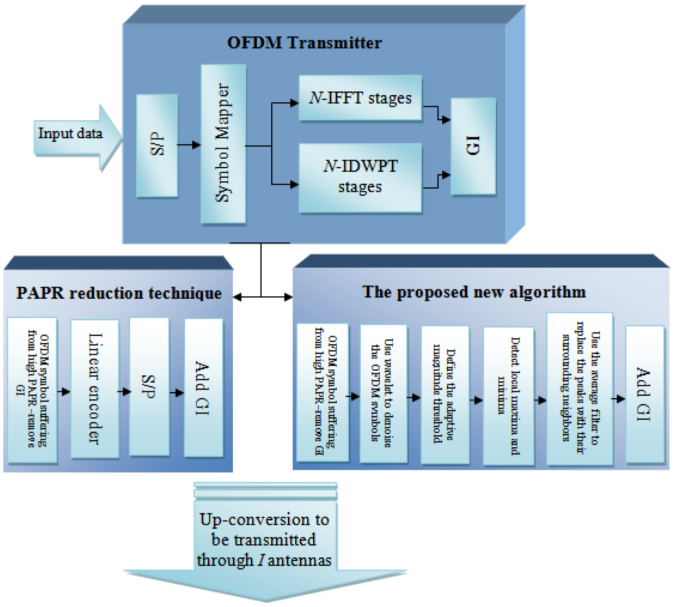

Fig.5 (a)

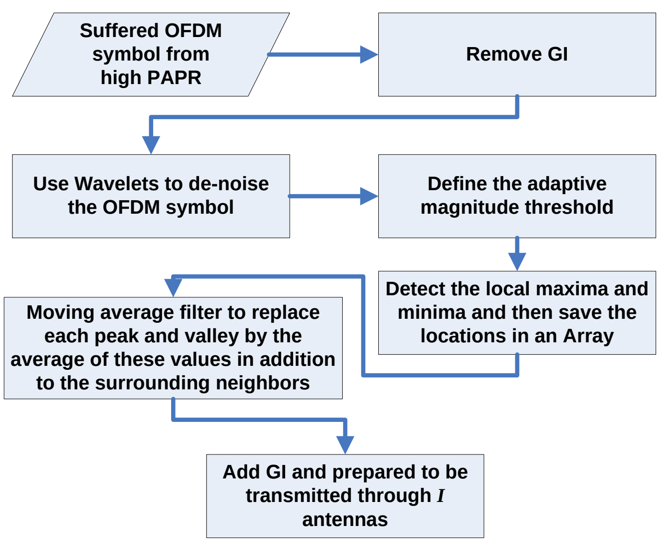

Fig.5 (b)

Fig. 5 (a) the block diagram of the proposed work, (b) the flowchart of the proposed algorithm

It can be summarized by the following steps, while the flowchart of this process is shown in Fig. 5 (b):

1. Read a segment of the OFDM signal.
2. Denoise the OFDM signal from additive white Gaussian noise (AWGN) using wavelets technique [25]. In this step the unwanted random addition to a wanted signal is removed using the following sub steps

a. Applying discrete wavelet transform DWT to the noisy signal.

b. Applying soft thresholding operator (wavelet shrinkage) [26] to highlight large values of wavelet coefficients which almost correspond to the OFDM signal and suppress small values which correspond to noise.

c. Applying inverse discrete wavelet transform IDWT to the thresholded wavelet coefficients to reconstruct a denoised OFDM signal.

3. Define an adaptive magnitude threshold required for peak detection algorithm using the following formulas [27]:

$$T = \frac{(max + abs\_avg)}{2} + (K * abs\_dev) \text{----- (18)}$$

where

max is the maximum value in the OFDM signal.

abs_avg is the average of the absolute values in the OFDM signal.

abs_dev is the mean absolute deviation.

K is a user defined constant (k=1).

The obtained threshold value is used to determine if each peak (valley) is significantly larger (or smaller) than the data around it.

4. Detect local maxima (peaks) and local minima (valleys), save these locations in an array(values and indices).

5. Use moving average filter for the found vector's points with their neighbors surrounding them in original OFDM signal and save the result into corresponding points of the original signal.

The results of this procedure are clearly found in Figure 6. Fig. 6.a shows the effect of denoisy the original OFDM signal. In this part, it is clearly shown the result of applying some denoisy methods; the maximum value has been reduced from 2.087 to 0.94495 and the minimum value also has been modified to be -1.3086 with a reduction ratio equals to 52%. In Fig. 6.b, the results of high peaks and valleys have been modified by imposing the proposed algorithm and its clearly shown that the maximum value has been improved to be 0.77712 with an enhancement ratio equals to almost 18%.

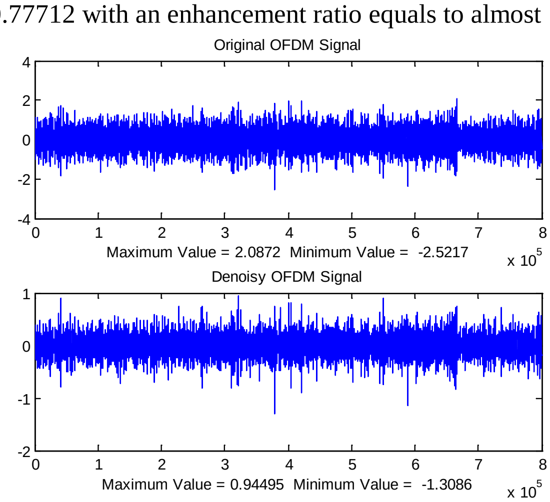

Fig. 6 (a)

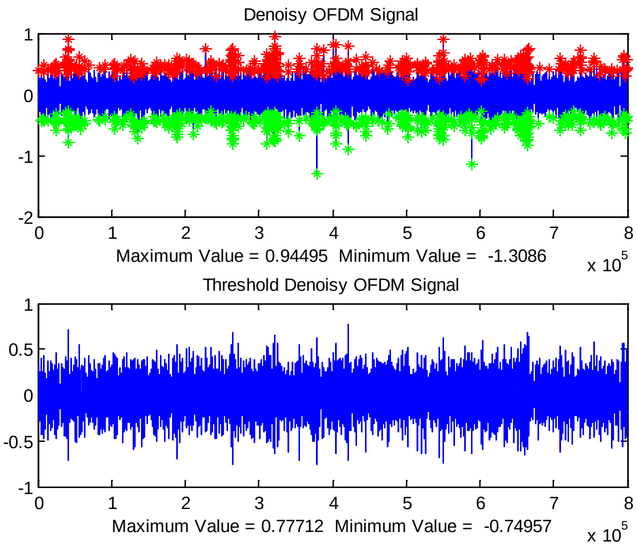

Fig. 6 (b)

Figure 6 The results of applying the new algorithm. 6.a The result of denoisy the OFDM signal 6.b the resultant OFDM signal after applying the proposed thresholding technique.

Next section describes the results from the simulation of the proposed work compared with the conventional techniques. The BER will be the key factor in differentiating the proposed work over the conventional ones in the literature, is in addition to the complementary cumulative distribution function (CCDF) curves; which is a performance metric independent of the transmitter amplifier. Given the reference level $PAPR_0 > 0$, the probability of a PAPR being higher than the reference value is the CCDF and is expressed as follows [6]:

$$CCDF(PAPR_0) = \Pr\{PAPR > PAPR_0\} \text{-----} \quad (19)$$

For practical reasons, the CCDF of PAPR is calculated based on the percentage of the OFDM/WPM frames for which PAPR exceeds the threshold $PAPR_0$. These results will be extracted from a Multipath condensed channel.

III. Simulation Results and Discussion

In this section the results of the comparison between the conventional MIMO-OFDM systems with the proposed one has been made. Thus, the conventional OFDM-based FFT transceiver has been simulated using MATLAB and its performance is compared with the one that is based on wavelet packet. We also compare the performance of the proposed system in identical channel conditions with the theoretical representation which is based on randomly generated data.

In order to verify the validity of our analytically derived technique, the MATLAB simulation program was performed with the following factors:

- Tested speech signals were recorded via PC-sound card, with a spectral frequency of 4000 Hz and sampling frequency 16000 Hz, over about 2s time duration. Each speaker recorded 10 times and they are classified as 4 females and 18 males of age 20 to 40 years participated in utterances recording. The recording process was provided in normal university office conditions. This is in addition to the theoretical data which is randomly generated to check the system effectiveness.
- Signal processing block, which is consists of two different parts; Analog to digital (A/D) conversion process and Eigen vectors process. Using A/D conversion program, the discrete speech signals are converted to binary digits stream. The program consists of the following main steps: shifting the speech signal by DC level equals to the maximum absolute value of the negative samples; the signal then normalized, nonuniform quantized using μ-low compression; and finally normalized quantized signal represented by binary bits.
- Two Channel coding rates 0.5 and 0.33,
- different modulation techniques (16QAM and 64QAM),
- IFFT size of 512,
- LDPC that has spreading rates of 2 and 3, column weight equals to 10, as well as the following values; m=64, n= 128, b=64, γ = 3 and $d_{\min}$ = 8.

Starting our investigation by comparing the effect of DORP on the system's performance with the one achieved previously by imposing the DWPT. Tab. 1 shows the promising performance of the proposed work; DORP comparing with DWT-OFDM, the OFDM based FFT and the PAPR combating techniques in the literature.

Tab.1 **P**erformance comparison between the proposed work and the used techniques in the literature for the spreading rate of 0.33

Mapping Techniques	**MIMO-OFDM systems' Performance P (PAPR>10 (dB)), (%)**						**Improvement percentage of using DORP over DWT-OFDM (%)**
	Without PAPR Reduction Techniques	*Clipping technique*	*PTS Technique*	*MIMO-OFDM based-FFT*	*DWT-OFDM*	*DORP*	
64QAM	28×10^{-2}	17×10^{-2}	11×10^{-2}	37.66×10^{-3}	25.7×10^{-4}	24.6×10^{-5}	**92**
16QAM	39×10^{-2}	30×10^{-2}	22×10^{-2}	18.3×10^{-3}	75×10^{-3}	40.8×10^{-4}	**57**

Using an intensive modulation technique; 64QAM, the MIMO-OFDM CCDF value has been reduced at the 20dB threshold around 96% for the DORP, which equals to 94.3% additional reduction over the work based on DWT-OFDM. Furthermore, when the modulation technique has been changed to be 16QAM, these reduction ratios have been slightly decreased. For the same threshold value, DWT-OFDM has around 84.6% reduction improvement over the conventional MIMO-OFDM. Moreover, using DWT-OFDM gives around 66% additional improvement for choosing OFDM-based FFT one.

The simulation results could be divided into three main parts; the one that shows the effect of imposing the Eigen vectors processing block to the system, the one that checks the MIMO-

OFDM system performance based on the BER, and the one that shows the CCDF curves.

Fig. 7 shows the effect of using an Eigen vector processing block. According to the results that are achieved in Fig.7, it is observed that the performance of the proposed could be improved when the coherency were reduced after imposing the Eigen vector processing block. In this part of our simulation, the Eigen vector processing block means that we will deal with the Eigen vectors of the speech signals instead of the original signals. Thus, not only the coherency is reduced but also redundancy as well. In this figure it is clearly shown that imposing the Eigen vector processing block will boost the system immunity since that the BER has been improved to be more closer to the theoretical result.

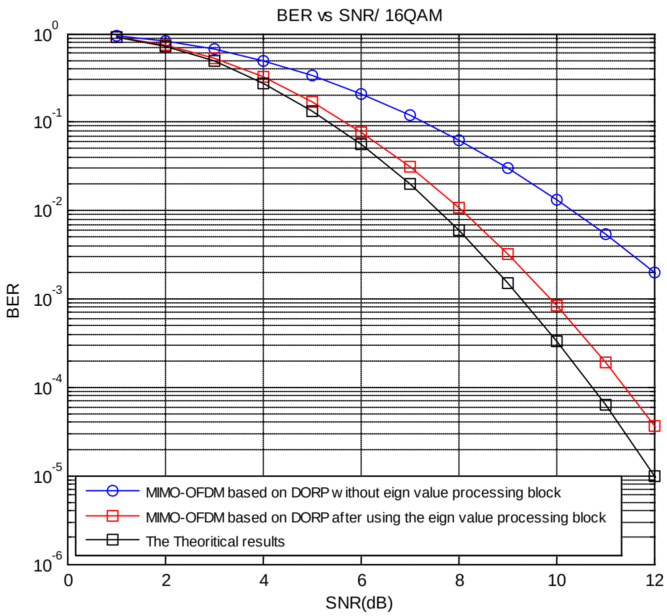

Fig. 7 Comparing the BER of the proposed work before and after imposing the Eigen vector processing block.

Fig.s 8 and 9 cover the second part of the simulation. Figure 8 shows the result of using the 64QAM for the MIMO-OFDM system for different spreading rates; I =0.5 and 0.33. In this Figure a comparison has been made among the one based on FFT, DWT-OFDM, the proposed work; DORP, and the one that is based on theoretical implementation (the tested data was randomly generated). Figure 9 has been divided at the same way of Fig. 8 unless that it shows the result of using 16QAM modulator.

Based on the simulation results in Fig. 8, the proposed algorithm gives promising results since it reduces the BER value at the threshold of 10dB from 3.01×10^{-1} to 1.3×10^{-1} which is somehow approximate to the theoretical result in part (a). Fig. 8.b gives the results of changing the spreading rate to be 0.33. In this case, the improvement of the BER has been increased to be 3.12×10^{-2}. However, Fig. 9 gives lower performance than the one achieved in Figure 8 due to the changing of modulation technique. Either in Fig. 9.a or Fig. 9.b, the proposed algorithm; DORP gives better performance than the previously published work that is based on DWT; DWT-OFDM. It is observed through these Fig.s that the use of higher order modulation techniques gives better BER than the lower order ones. In our case the 64QAM curves give better performance than the 16QAM ones. As an example for practical threshold of the MIMO-OFDM systems (10 dB), the curve of theoretical 64QAM MIMO-OFDM systems gives BER of 5.2×10^{-2} while this value was 1.8×10^{-1}.

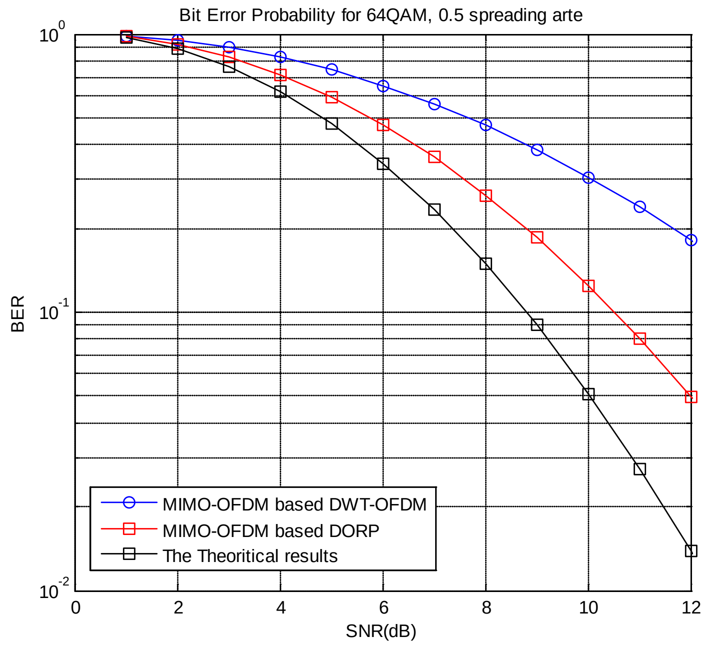

Fig.8.a

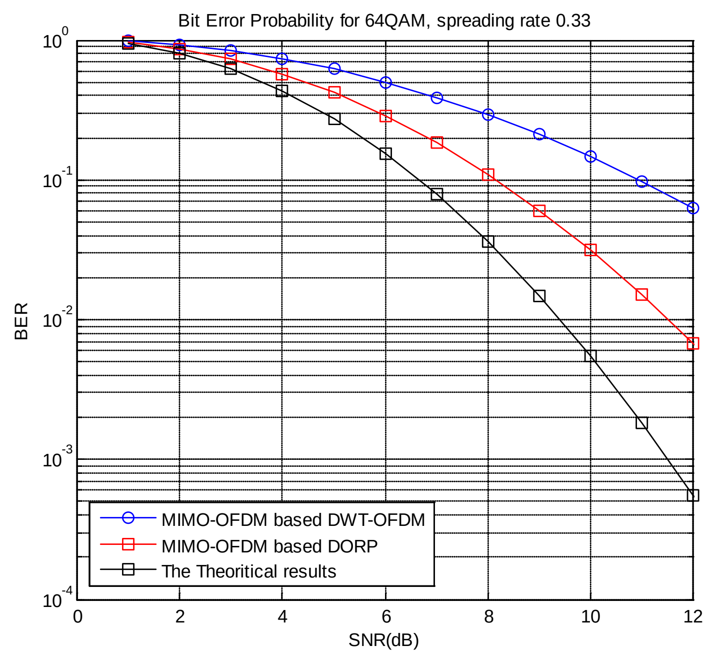

Fig. 8.b

Fig. 8 Comparison between the BER of the proposed work with the DWT-OFDM and the ones in the literature. In the figure the used modulation technique is 64QAM, this is in addition to the theoretical result. (8.a) I =0.5, (8.b) I= 0.33

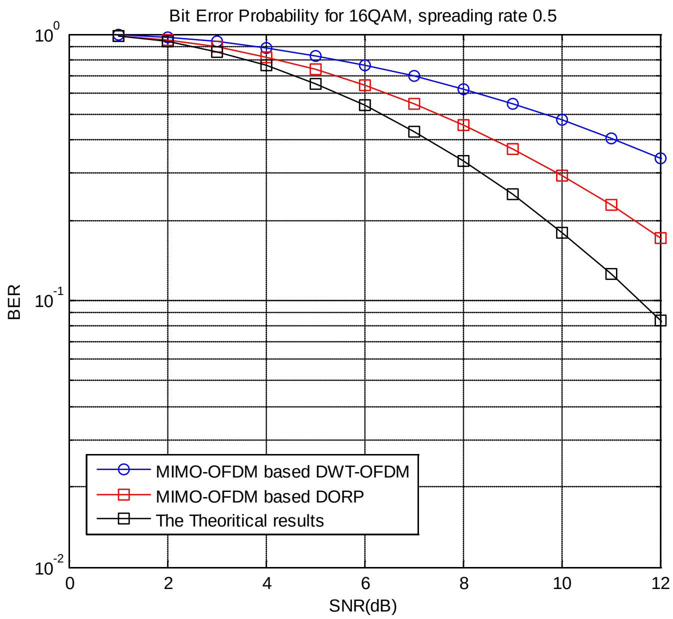

Fig. 9.a

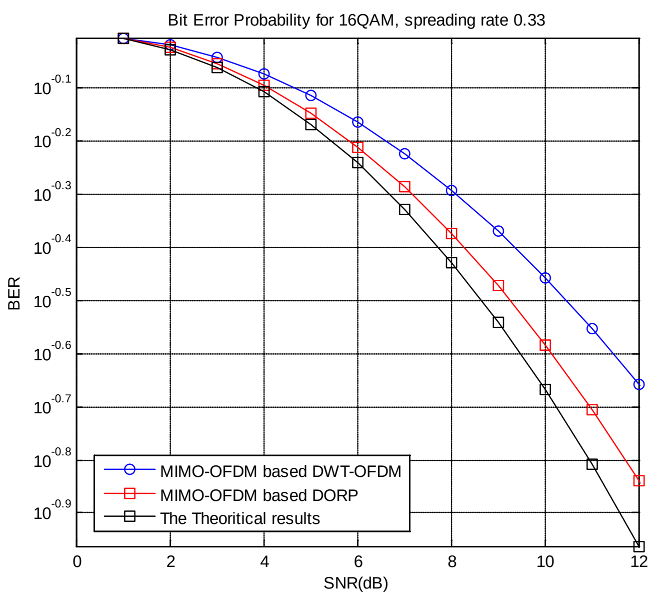

Fig. 9.b

Fig. 9 Comparison between the BER of the proposed work with the DWT-OFDM and the ones in the literature. In the figure the used modulation technique is 16QAM, this is in addition to the theoretical result. (9.a) I =0.5, (9.b) I= 0.33

Figures 10 and 11 show the last part of our simulation result which is based on the CCDF curves. These results check the performance of our system from reducing the PAPR problem point of view for two different modulation techniques; 64QAM and 16QAM, 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.

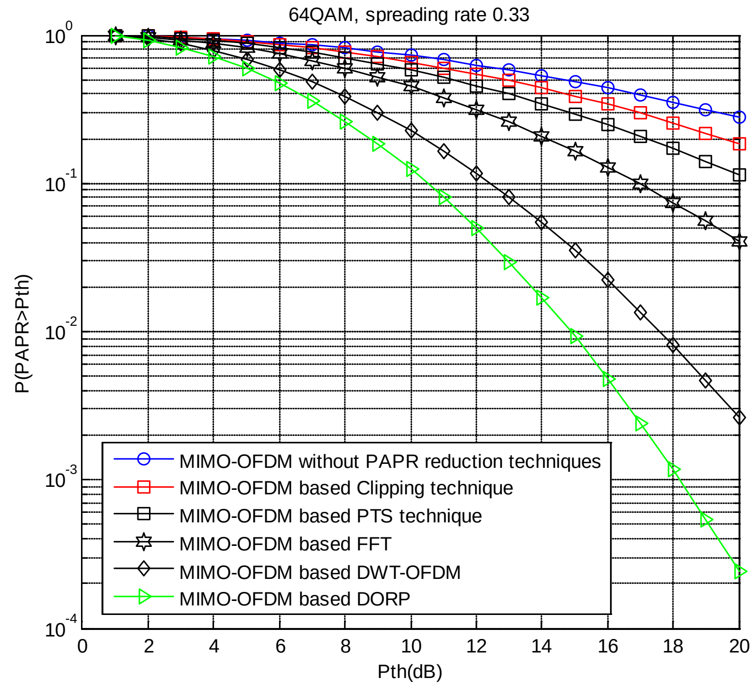

Figure 10 Comparison between the probabilities of PAPR values that exceed a certain threshold for the proposed work comparing to the conventional MIMO-OFDM system (for 64QAM modulation process).

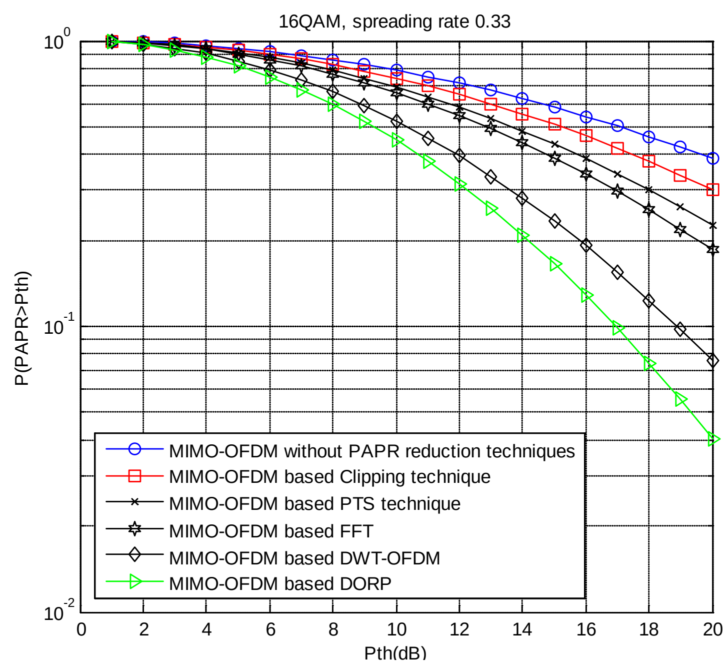

Figure 11 Comparison between the probabilities of PAPR values that exceed a certain threshold for the proposed work comparing to the conventional MIMO-OFDM system (for QPSK modulation process).

The CCDF curves in both figures confirm the reliability of the proposed work, not only from the BER point of view but also from combating the PAPR problem. Thus, the performance of the wavelet packet based OFDM is still better than that of the conventional OFDM. At 20 dB threshold, the CCDF curve for the conventional MIMO-OFDM system shows a reduction from 32×10^{-2} to 12×10^{-2}, while this value has been improved to reach 25×10^{-4} after using the wavelet packet based MIMO-OFDM systems. These values has been improved to be 23×10^{-5} after using the proposed algorithm; DORP. The same result has been achieved from Figure 11 when the modulation technique has been changed to be 16QAM; from this figure using the proposed work reduces the PAPR value from 3.9×10^{-1} to 40.1×10^{-3}.

IV. CONCLUSION

This paper has introduced DORP, which is a new proposition of designing the OFDM transceivers. This proposition is based on identifying and analyzing the peaks and valleys of OFDM signal. This algorithm is based on Denoise 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 70% of reducing the peaks production. The analytical derivation of the technique has been given which describes the theoretical functionality of the technique. Simulation results which are consisting of three different parts indicated that the new design could improve the MIMO-OFDM systems performance even in a condensed Multipath channel.

The wavelet packet based MIMO-OFDM system enhances the systems BER as well as combats the PAPR problem. Thus, improving the systems performance could be attained in terms of the two main factors; BER and PAPR. In addition, this improvement could be further increased after using the Eigen vectors of the tested signals instead of the original data. This is clearly observed from the simulation results, since they show that there was a further improvement (between 7% to 22%) in the BER performance. Moreover, a performance comparison between the proposed work and the used techniques in the literature has been made. From this comparison, the DWT-OFDM shows a potential and gives a performance improvement between 57%-92% for different modulation techniques.

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