Wavelet Transform Effect on MIMO-OFDM System Performance

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Abstract— **Although latest generations for mobile communications systems have provided flexible expansion in system capacity, they faced great challenge in performance enhancement especially in the presence of bad fading channel conditions. In this paper a modified MIMO OFDM system will be introduced that is capable of mitigating fading channel distortion even in its worst conditions. In most recent researches *Wavelet Transform* (WT) was applied in stead of OFDM technology but in this paper both WT and OFDM technologies were applied together in order to have more performance enhancement. MIMO technology and various channel equalization techniques such as phase equalization (PE) and maximal ration equalization (MRE) will be applied in the proposed system for the purpose of performance enhancement. Obtained results from proposed system simulation showed acceptable BER performance at low SNR.**

Index Terms— **OFDM, MIMO, Wavelet Transform, Phase Equalization, and Maximal Ratio Equalization**

I. Introduction

THE greatest enemy for all wireless communication systems is the distortion caused by multi- path fading channel. Actually the reason for this harmful effect is the time variation of multi-path fading characteristics in both time domain and frequency domain. Many candidate modifications were inserted into wireless communication systems, digital systems in specific, in order to mitigate fading channel distortion such as *Orthogonal Frequency Division Multiplexing* (OFDM) technology. In OFDM technology data symbols modulate group of subcarriers with orthogonal frequency sub- bands. The bandwidth of these sub-bands is smaller than single carrier total band (i.e. the total band of data symbols after modulating single carrier) therefore fading characteristics seen by each sub- carrier will be flat fading type.

In spite of showing satisfying performance, OFDM is still constrained by certain limitation which is the central frequency around to which all sub-bands will be shifted. This is done through RF modulation process which is considered the last stage in all wireless communication systems. Therefore, ordinary OFDM system may show optimum performance in certain channel condition whereas the same system performance may degrade when channel conditions change.

In this paper we have 1introduced modification to classical OFDM technology where WT is inserted in OFDM transmitter in order to introduce many versions for central carrier frequency providing some sort of frequency diversity that is capable of mitigating time variant fading channel.

The wavelet transform (WT) is one of several mathematical tools that is useful in the analysis and design of systems and signals. Its representation basically involves the decomposition of the signals in terms of small wave components called wavelets as shown in figure 1 which displays simple example for WT output of fourth level. Wavelet theory is employed in many fields and applications such as signal and image processing, communication systems, and many other signal processing areas. The wavelet transform has proven to be very efficient and effective in analyzing a very wide class of signals and phenomena. It has the ability to compact the signal energy into few large coefficients. The original signal can be reconstructed perfectly from these few coefficients while suppressing the other coefficients without losing most of the features of the signal. [1 – 4].

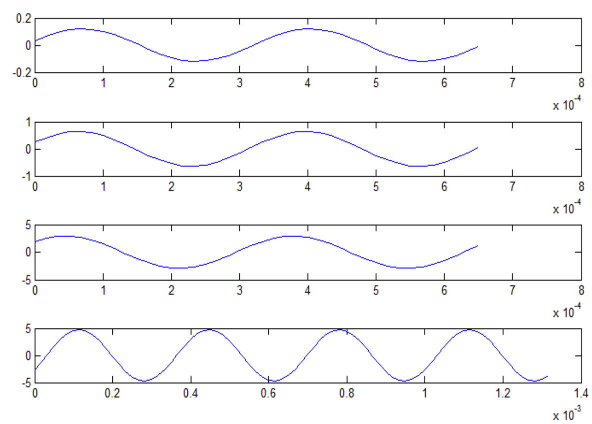

Fig. 1 "WT output in case of fourth level"

From another point of view the wavelet analysis procedure is to adopt a wavelet prototype function, called an *analyzing wavelet* or *mother wavelet.* Because the original signal or function can be represented in terms of a wavelet expansion (using coefficients in a linear combination of the wavelet functions), data operations can be performed using just the corresponding wavelet coefficients. And if you further choose the best wavelets adapted to your data, or truncate the coefficients below a threshold, your data is sparsely represented. This sparse coding makes wavelets an excellent tool in the field of data compression. Other applied fields that are making use of wavelets include astronomy, acoustics, nuclear engineering, sub-band coding, signal and image processing, neurophysiology, music, magnetic resonance imaging, speech discrimination, optics, fractals, turbulence, earthquake-prediction, radar, human vision, and pure mathematics applications such as solving partial differential equations. [5]

MIMO technology has a great history in performance enhancement in all mobile communication systems for all its generations. As well known, MIMO systems provides many versions for the same transmitted data symbol at the receiving end each version experiences different fading channel characteristics. Therefore it will be very rare to have deep fading effect over all received data versions simultaneously. Each antenna element in the MIMO system operates on the same frequency and therefore doesn't require extra bandwidth. The used of MIMO has been proposed multiple times for use in the high- speed packet data mode of third generation mobile systems [6]. Because of all reasons mentioned before, we had to insert MIMO technique into the proposed system in order to optimize its performance.

In this paper modified MIMO OFDM system based on Wavelet transform scheme will be handled and evaluated in the presence of Rayleigh fading channel. Subsections of this paper are arranged as follows; in subsection 2 transmitter model of the proposed system will be described in details. Receiver model for the proposed system will be displayed in subsection 3. Subsection 4 will display and analyze results obtained from proposed system simulation by the aid of computer software (MATLAB 7.10 code). In the last subsection, briefed conclusion for the whole work will be handled.

II. Transmitter Model

Stages for the proposed system transmitter shown in figure 4 will be described in details in the coming points:

(a) Data source:

What ever was the form of message to be transmitted (voice, image, video, or text) it is required to represent this message in form of binary stream of data denoted by $\underline{d} \in \{0\ ,1\}$ with total length *L* bits. Remember that it is the first stage at any digital communication transmitter.

(b) Digital Mapping:

This is also called *baseband modulation* stage in which the digital form of the output symbol is determined dependant on the applied modulation technique. For example when BPSK is applied as modulation technique, the output symbols obtained after digital mapping stage could be denoted by $\underline{S} \in \{\pm 1\}$ with one symbol – to – one bit correspondence. Whereas, when QPSK is applied, the modulated output symbols will be $\underline{S} \in \{\pm j\ , \pm 1\}$ with one symbol – to – two bits correspondence. By considering L_S as the length of the output data symbols, $\therefore L_S = \frac{L}{\log_2(M)}$ where *M* is the number of constellation points applied in the modulation technique.

(c) Serial – to – Parallel Conversion and IFFT:

This is considered the main stage in OFDM transmitter where data symbols vector $\underline{S}$ with length L_S will be divided into groups each with length *N* and this is the function of S/P converter. After that the operation of IFFT will take place in order to make the *N* data symbols modulate *N* subcarriers with frequency shift $\Delta f = \frac{1}{NT_S}$ where, T_S is the symbol duration.

The output time domain sequence obtained after IFFT operation could be described as follows:

$$s_l = \frac{1}{N}\sum_{k=0}^{N-1} S_k\, e^{j(2\pi/N)kl} \quad ,\ l = 0\ ,\ 1\ ,\ 2, \ldots , N-1 \quad \ldots \ (1)$$

(d) Wavelet Transform:

The simplest method for WT representation could be achieved by a set of FIR filters. The synthesis discrete wavelet transform constructs a signal as the sum of $V = 2^J$ waveforms. Those waveforms can be built by *J* successive iterations each consisting of filtering and up- sampling operations. Noting $\langle .\ ,.\rangle$ representing convolution operation, the algorithm can be written as follows [7]:

$$\begin{cases} \varphi_{j,2v}[k] &= \langle h_{lo}^{rec}[k]\ ,\ \varphi_{j-1,v}[k/2]\rangle \\ \varphi_{j,2V+1}[k] &= \langle h_{hi}^{rec}[k]\ ,\ \varphi_{j-1,v}[k/2]\rangle \end{cases} \quad \ldots \quad (2)$$

With $\varphi_{0,m}[k] = \begin{cases} 1 & for\ k = 1 \quad \forall m \\ 0 & otherwise \quad \forall m \end{cases}$

Where *j* is the iteration index $1 \le j \le J$ and *v* is the waveform index $0 \le v \le V-1$. Using usual notation in discrete signal processing, $\varphi_{j,v}[k/2]$ denotes the upsampling by two version for $\varphi_{j,v}[k]$. Figure 2 contains both Wavelet Transformation applied at the transmitter and Inverse Wavelet Transformation applied at the receiving end. Blocks denoted by h_{hi}^{dec} and h_{lo}^{dec} represent decomposition high pass and low pass filters respectively. Whereas, blocks denoted by h_{hi}^{rec} and h_{lo}^{rec} represent reconstruction high pass and low pass filters respectively.

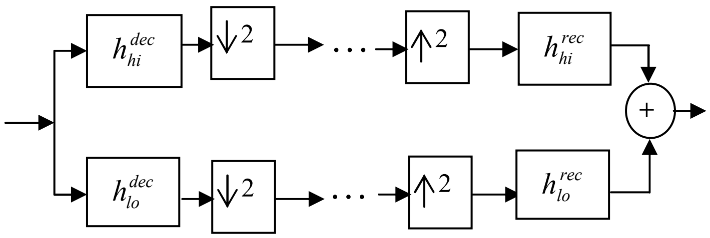

Fig. 2 "Wavelet Transformation and Inverse Transformation Block diagram"

In the proposed system multi- level WT were applied which is simply successive repetition for single level WT shown in figure 2 as displayed in figure 3

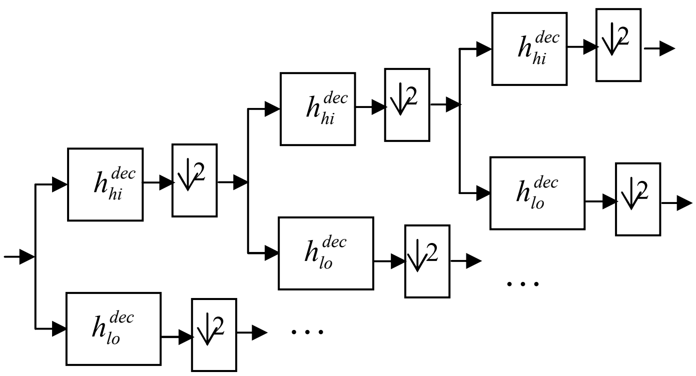

Fig. 3 "Multi- level Wavelet Transformation Block diagram"

(e) Multiple antenna RF terminals:

In the last stage of the proposed system transmitter, the output time domain sequence given in equation (1) will modulate sinusoidal carrier with central frequency f_o so that the final transmitted sequence will be as follows:

$$s_l(t) = \frac{1}{N}\sum_{k=0}^{N-1} S_k e^{j(2\pi(f_o + l\,\Delta f))}, \qquad \ldots \quad (3)$$

$$l = 0, 1, 2, \ldots, N-1$$

Finally the N items of the sequence given in equation (3) will be emitted through N_t transmitting antennas simultaneously.

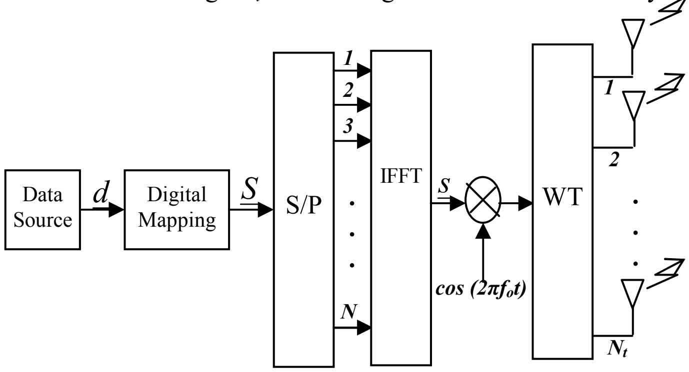

Fig. 4 "Transmitter Model for Proposed MIMO OFDM System"

III. RECEIVER MODEL

Receiver stages shown in figure 5 are simply reverse sequence for corresponding stages in the transmitter model. Therefore, we will explain some stages in the receiver model that were not mentioned in the transmitter model subsection.

(a) Receiving Antennas with Combining Scheme:

The first stage in the proposed system receiver consists of N_r receiving antennas. Remember also there are N_t transmitting antennas inserted as the last stage in the transmitter. Therefore, there will be $N_t N_r$ versions for every transmitted data symbol obtained at the receiving end so it has to be combined in one decided symbol. Actually, there are many combining schemes applied in MIMO systems receivers. In our system we have selected *equal gain combining* in which all received symbols are summed (at every signaling interval) then divide by $N_t N_r$.

(b) Channel Equalization:

In order to enable receiving end to make channel equalization process in efficient way, training sequence should be send before real data transmission (i.e. before transmission of every data symbols frame each contains N data symbols). It was found that the most effective training sequence is simply a unit vector with length N denoted by Xp given as follows:

$$Xp = diag\left(\begin{bmatrix}1 & 1 & \cdots & 1\end{bmatrix}\right) \quad \ldots \quad (4)$$

When training sequence has the form given in equation (4) it is also called *preamble* or *pilot* vector. When transmitting this preamble vector, received vector can give rough estimation for channel coefficients in frequency domain which is described as follows:

$$(C_{ij})_{est} = Xp\ C_{ij} + N_{ij} \quad \ldots \quad (5)$$

Where; C_{ij} and N_{ij} are fading channel and AWGN coefficients vectors respectively in the path between transmitting antenna i and receiving antenna j each vector contains N coefficients.

After that actual data symbols will be transmitted and it is supposed to unchanged channel conditions. Therefore channel equalization process is simply omitting estimated channel vector from received data vector. Estimation for transmitted data sequence could be obtained from this process with acceptable probability of error. In this paper two channel equalization schemes were examined; *phase equalization* (PE) and *maximal ratio equalization* (MRE)

A. In PE scheme equalized data vector is given as follows:

$$\underline{S}_{ij}\Big)_{eq} = \underline{\tilde{S}}_{ij}.conj\left(C_{ij}\right)_{est} \quad \ldots \quad (6)$$

B. In MRE scheme equalized data vector is given as follows:

$$\underline{S}_{ij}\Big)_{eq} = \underline{\widetilde{S}}_{ij} \cdot \frac{conj\left(C_{ij}\right)_{est}}{\left|\left(C_{ij}\right)_{est}\right|} \quad \ldots \; (7)$$

Where; $\underline{\widetilde{S}}_{ij}$ is the received data vector transmitted by transmitting antenna i and received by receiving antenna j obtained at the output of P/S converter.

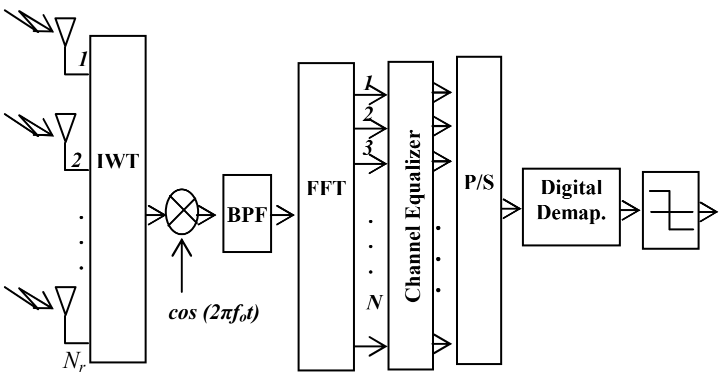

Fig. 5 "Receiver Model for Proposed MIMO OFDM System"

IV. Simulation Results

By the aid of MATLAB 7.10 code, proposed system has been simulated in order to evaluate its performance. Simulation results will be displayed in form of set of curves and tables that illustrate BER performance versus variation in the SNR under many system conditions. Actually three parameters effect will be analyzed in the coming subsections; the effect of Wavelet transform levels number, the effect of equalization technique, and the effect of transmitting and receiving antennas number.

A. Effect of Number of Wavelet Transform Levels

Before displaying effect of WT levels number, let's first compare between OFDM performance with its performance when combined with WT. Figure 6 includes BER performance versus variation in the SNR at four system forms; the first case represents OFDM only system without WT whereas the rest three cases represent OFDM combined with WT system at three values for WF levels L, at L = 2, 3, and 4. Actually, WT insertion into OFDM system has no positive effect except when the number of levels is greater than 2 levels and this is clearly illustrated at figure 6. As mentioned before, the number of WF levels represents number of sinusoidals versions introduced by WT that will be modulated by each data symbol after that. Therefore it is logic that when the number of levels increases, the performance of the system will be enhanced. As illustrated in figure 6 the lowest BER is obtained at L = 4 w.r.t. L = 2 and 3 cases. For example at SNR = 4 dB, obtained BER at L = 4, 3, and 2 are (1.3×10^{-6}), (2.8×10^{-4}), and (0.0169) respectively. Whereas when OFDM technology is applied only in the proposed system, then obtained BER at the same SNR was 0.0012.

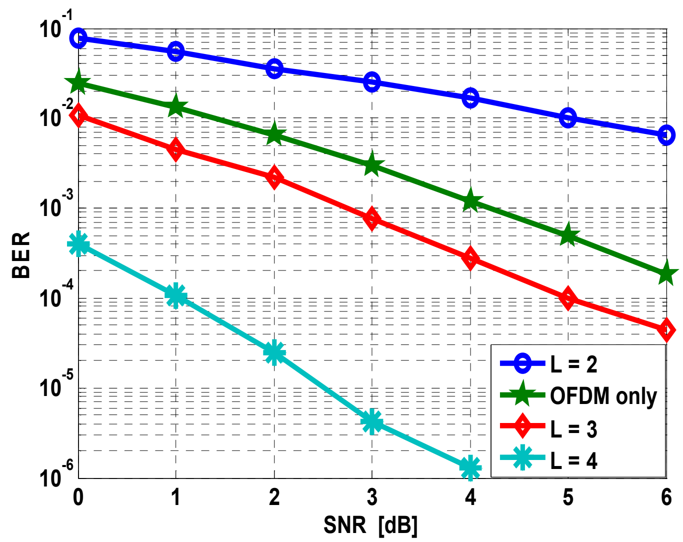

Fig. 6 "BER performance at N = 32, BPSK modulation technique, MRE, N_t = 1 and N_r = 1"

B. Effect of Modulation and Equalization Techniques

It is necessary when considering any digital communication system to focus on suggested modulation technique and its effect on proposed system performance. Figure 7 displays BER performance versus variation in SNR comparing among three modulation techniques; QPSK, DBPSK, and BPSK. As expected, BPSK modulation technique will result in the lowest BER w.r.t. other two techniques. Also channel equalization stage is essential in all wireless communication systems therefore it effect is also considered in this figure where two channel equalization schemes are considered; *maximal ratio equalization* (MRE) and *phase equalization* (PE). As illustrated in figure 7, MRE resulted in better performance when compared with PE. Table 1 contains an example of obtained BER in the six cases displayed at figure 7 obtained at SNR = 6 dB.

TABLE 1: "BER AT SNR = 6 DB PICKED FROM CURVES SET OF FIGURE 7"

	Maximal Ratio Equalizer	Phase Equalizer
QPSK	0.0027	0.0043
DBPSK	8.3×10^{-5}	1.46×10^{-4}
BPSK	4.7×10^{-5}	6.25×10^{-5}

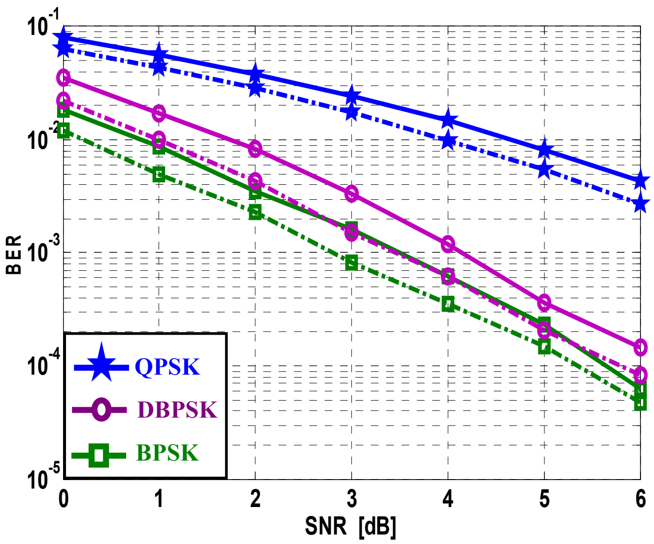

Fig. 7 "BER performance for OFDM transceiver with WF with L = 3, N = 128, N_t =1 and N_r = 1. Solid line represents phase equalizer and dashed line represents maximal ratio equalizer"

C. Effect of MIMO Structure

One of the basic schemes applied for performance improvement in the proposed system is the MIMO technology. Therefore simulation results should include the effect of MIMO structure on the system performance represented by the number of both transmitting and receiving antenna (N_t and N_r respectively). Figure 8 displays BER performance versus variation in SNR in four different cases of N_t and N_r combination. As Expected, by increasing both N_t and N_r , lower BER could be obtained at receiving end. As illustrated in figure 8, by applying (N_t x N_r) = (1 x 1), (2 x 1), (3 x 1), and (2 x 2) BER = (0.005), (2.73 x 10^{-4}), (1.95 x 10^{-5}), and (8.68 x 10^{-7}).

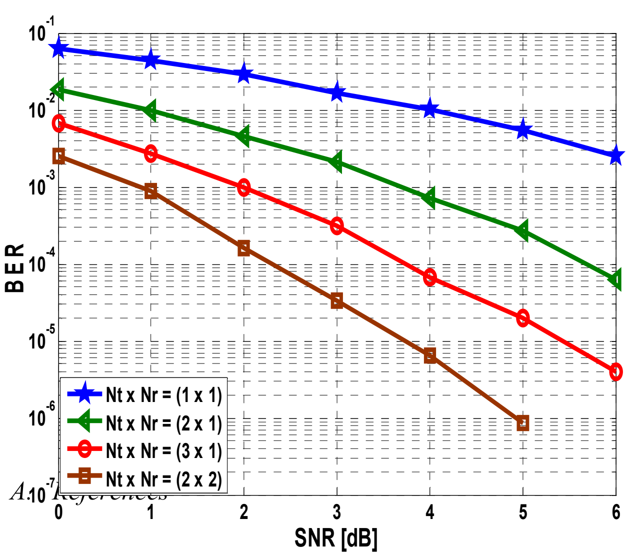

Fig. 8 "BER performance for OFDM transceiver with WF with N = 64, QPSK modulation technique and maximal ratio combiner"

V. CONCLUSIONS

Orthogonal frequency division multiplexing system has a great history of acceptable performance efficiency but sometimes bad fading channel conditions become stronger than OFDM technology capabilities. Therefore it was necessary to find new solution for OFDM system enhancement under worst multi path fading channel characteristics. In this paper wavelet transform is combined with OFDM technology for that purpose. By the aid of wavelet transform many versions of RF carrier will be transmitted so that when deep fading is applied over one carrier frequency it will be very rare to find the same fading conditions over the rest frequencies. Never forget classical modifications applied into any wireless communication which are MIMO technology and channel equalization which are considered vital stages in the recent generations for mobile communication systems. Simulation results have shown satisfactory BER performance at low SNR level. For example at SNR = 4 dB, BER was order of 10-6 using two transmitting antennas and two receiving antenna which means that this system will be efficient for heavy packet transmission corresponding to voice, video, or multimedia communication systems.

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