Improving the Transmission Capacity Using Discrete Wavelet Transform as Multicarrier Modulation with Multiple Antennas

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Abstract —**The transmission through wireless channel suffers from many challenges due to the multipath effect that causes Inter Symbol Interference (ISI) problem. Multicarrier modulation (MCM) is proposed as solution to overcome the ISI. This research presents the Discrete Wavelet Transform (DWT) based multicarrier modulation as alternative platform of conventional OFDM in which there is no need for cyclic prefix overhead due to the overlapping nature of DWT. Simulation based analysis will be used to simulate the two multicarrier systems, DWT with Haar mother based multicarrier and the conventional OFDM, under the scenario of having multiple antennas system, with BPSK and QPSK as two modulation schemes in additive white Gaussian noise channel (AWGN). Based on the bit error rate performance and the transmission capacity, the DWT based multicarrier system was found to be superior to the conventional OFDM system.**

Keywords – DWT, OFDM, MCM, Sub-Band Coding, Filter Bank, OSTBC, MIMO.

I. Introduction

Multicarrier modulation (MCM) is an effective technique of wireless communication; unlike traditional single carrier systems it divides the bandwidth into independent narrow sub-band channels, and uses it to transmit parallel low data streams which are divided from the original high data stream [1][2]. The number of sub-channels is chosen to make the symbol time for each sub-stream much greater than the delay spread of the channel and to make the sub-stream bandwidth less than the channel coherence bandwidth to avoid the ISI [2]. Multicarrier modulation provides an efficient means to access and distribute multiple multiplexed data streams. This is potentially very attractive for high speed, broadband networks, which often multiplex multiple data sources during transmission [3]. The traditional multicarrier modulation scheme is the Orthogonal Frequency Division Multiplexing (OFDM) in which the Discrete Fourier Transform (DFT) is used to construct the orthogonal subcarriers. OFDM is emerged to combat the inter symbol interference (ISI), channel distortion and improve the spectral efficiency, ISI is eliminated in OFDM by added a cyclic prefix to the OFDM signal but this can decrease the bandwidth efficiency greatly [4]. In conventional OFDM transceiver the Inverse Fast Fourier Transform (IFFT) is applied at the transmitter side and the Fast Fourier Transform (FFT) is applied at the receiver side [5].

In order to get more improvement of transmission through wireless channel and to keep up with the rapid increase in demand of the wireless technologies such as Wi-Fi and the mobile communication, Discrete Wavelet Transform (DWT) have been considered as multicarrier modulation scheme. The Wavelet based OFDM as an alternative for conventional Fourier OFDM in order to reduce the level of ISI and inter-channel interference (ICI) powers was proposed in [6]. In wireless communication systems design the wavelets have found beneficial applicability, such as channel characterization, interference mitigation, modulation and multiplexing, multiple access communication, Ultra Wideband (UWB) communication, cognitive radio and networking [7]. The Discrete Wavelet Transform (DWT) is used in a variety of signal processing applications, such as video compression, Internet communications compression, object recognition and numerical analysis [8]. The power of the wavelet transform comes from the fact that the basic functions of the wavelet are localized in time (or space) and frequency, and have different resolutions in these two domains.

Multiple input multiple output (MIMO) technology is becoming very attractive technique in wireless communications because it achieves significant performance improvement in data throughput and spectral utilization of the bandwidth [2][12]. The diversity performance in MIMO system can be improved through the space time block coding (STBC) technique. Space time block coding can achieve transmit diversity and power gain without sacrificing the bandwidth [13][14].

The combination between multicarrier modulation and MIMO in one system combines the advantages of these two technologies in broadband wireless communications. The performances of STBC OFDM UWB systems that use two transmit and one or two receive antennas with Discrete Wavelets Transform (DWT) and conventional Fast Fourier transform (FFT) as two multicarrier modulation are investigated in [15].

In section II, the Discrete Wavelet Transform as multicarrier modulation is discussed including the Wavelet background and sub-band coding. In section III, the MIMO technology under STBC is discussed and the system model of MIMO-DWT is presented. The simulation parameters and results in terms of bit error rate (BER) are discussed in details in section IV.

II. Multicarrier Modulation Using DWT

A. Wavelet Background

Wavelet Transform (WT) is a mathematical function that is emerged as a new tool for multi-resolution decomposition of continuous time signal at different times and different frequencies (or scales) [5]. So the wavelet transform provides the time-frequency representation of the signal. In wavelet transform, higher frequencies are better resolved in time, and lower frequencies are better resolved in frequency. In this sense, the signal is multiplied with an orthogonal wavelet function, and the transform is computed separately for different segments of the time domain signal [9]. The continuous wavelet transform can be defined as in [5]:

$$\mathrm{CWT}_x^{\psi}(\tau, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{\infty} x(t)\psi^*\left(\frac{t-\tau}{s}\right) dt \qquad (1)$$

Where: CWT_x^{ψ} is the Continuous wavelet transform of the signal $x(t)$, $\psi(t)$ is the mother wavelet, τ represents the translation parameter which is corresponding to the time information in the signal and s represents the Scale parameter which is corresponding to the frequency information in the signal, Scale = 1/frequency.

The modified version of the wavelet transform is the discrete wavelet transform (DWT), in which the scaling as well as the translation variables are properly discretized. If the scaling variable " s " is discretized by 2^m and the translation variable " τ " by $2^m n$, where m and n are integers, then the DWT of a continuous-time signal $s(t)$ is expressed as [9]:

$$S_n^m = 2^{-m/2} \int s(t)\psi(2^{-m}t - n)dt \qquad (2)$$

Where: S_n^m represent the DWT coefficients at different scale and translation variables.

The Discrete Wavelet Transform can be regarded as a form of sub-band coding where the signal to be analyzed is passed through a series of filter banks [7].

B. Sub-band coding and filter bank theory

The process of splitting the full-band source signal into different frequency bands and encode each band individually based on their spectrum energies is called sub-band coding technique. The study of sub-band coding starts from the digital filter bank system, which is a group of filters that has different center frequencies. Two channel filter bank is the common and the efficient way to implement the discrete wavelet transform (DWT) [5][8]. Fig. 1, as an example, shows the structure of one level two channel sub-band filter bank.

Typically, the filter bank design has two stages which are used in signal transmission system. The first stage is called analysis stage which corresponds to the decomposition process in which the signal samples are reduced by two (down sampling). The second stage is called synthesis stage which corresponds to the interpolation process in which the signal samples are increased by two (up sampling).

The analysis stage consists of sub-band filter followed by down sampler whereas the synthesis stage consists of sub-band filter located after up sampler. The sub-band filter class used with the channel filter is perfect reconstruction Quadrature Mirror Filter (QMF) [8]. Since there are high pass " H_1 " and low pass " H_0 " filters at every level, the analysis stage has two output coefficients and they are called approximation coefficients which contain the low frequency information of the signal and detail coefficients which contain the high frequency information of the signal. The analysis stage of the multi-level two channels perfect reconstruction filter bank system is used for determining the DWT coefficients [5].

The process of reconstruction the source signal from the DWT coefficients is called the inverse discrete Wavelet transform (IDWT). For every level of reconstruction filter bank the approximation and details coefficients are up sampled and passed through low pass " G_0 " and high pass " G_1 " synthesis filters and then added.

Discrete Wavelet Transform is proposed as high performance digital signal processing technique for use in implementing multicarrier modulation. The block diagram design of multicarrier transceiver digital system based on DWT is shown in Fig. 2.

The system design comprise of an inverse discrete wavelet transform (IDWT) as modulator at the transmitter and a discrete wavelet transform (DWT) as demodulator at the receiver. The main and the important difference between the conventional OFDM and DWT multicarrier system is the elimination of the cyclic prefix blocks in the transmitter or in the receiver parts.

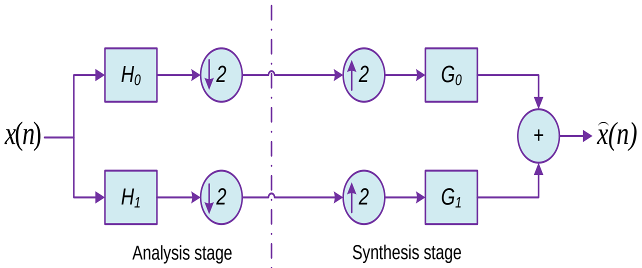

Figure 1. One level two channel sub-band filter bank.

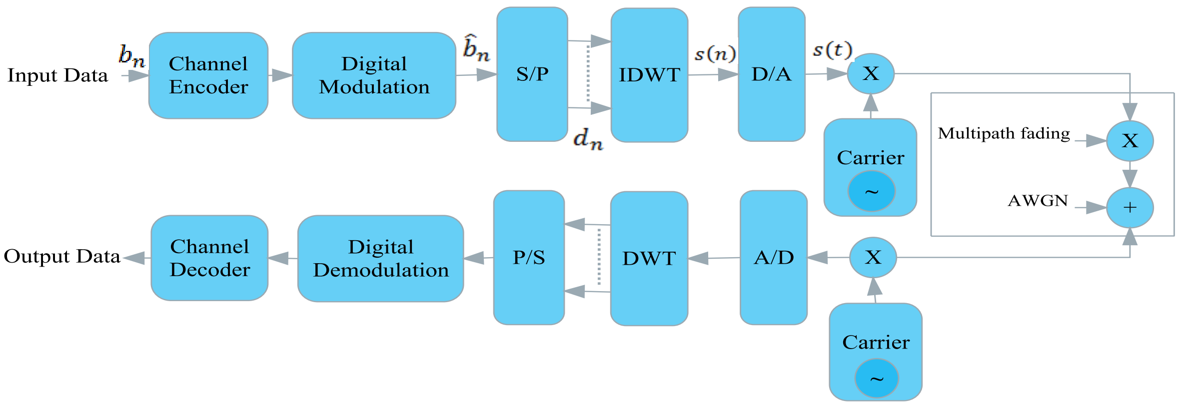

Figure 2. Wavelet based multicarrier modulation structure.

IDWT represents the key point of the multicarrier transmitter in which the orthogonal wavelet modulation is performed. Every wavelet basis is seen as a subcarrier and the transmitted symbols are multiplied by these subcarriers. The orthogonality of the individual basis function prevents inter symbol interference (ISI), furthermore, their mutual orthogonality prevents interference across scales [10]. The transmitted signal $s(t)$ can be expressed as:

$$s(t) = \sum_{m \in M} \sum_{n} S_n^m \, 2^{-m/2} \psi(2^{-m}t - n) \qquad (3)$$

Where: $\psi_{m,n}(t)$ is the mother wavelet and represent the basis wavelet functions (subcarriers) with compressed factor m times and shifted n times for each subcarrier, S_n^m is the data that is modulated onto the wavelets subcarriers at different scale, and M represent the number of frequency bands (or number of subcarriers).

At the receiver DWT is performed and the process is inversed. The orthogonality is the key feature that allows subcarrier separation at the receiver. The orthogonality property leads to make the wavelets orthogonal to each other on both their time position and their frequency localization (scale), such that:

$$\int \psi_{j,k}(t)\, \psi_{m,n}(t)\, dt = \begin{cases} 1 & \text{if } j = m \text{ and } k = n \\ 0 & \text{otherwise} \end{cases} \qquad (4)$$

Due to the overlapping nature of wavelets, the wavelet based multicarrier has very high spectral containment and therefore does not need a cyclic prefix to deal with the delay spreads of the channel [4]. Wavelet basis are more spectrally compact than traditional OFDM basis, they have less out of band energy. In other words, the side lobes of the OFDM spectrum, which is a sinc spectrum, contain an important amount of energy that create inter channel interference [11].

By not requiring the cyclic prefix, the available bandwidth would be more efficiently used, and hence high data rate can be achieved.

III. SPACE TIME BLOCK CODING UNDER MIMO SYSTEM

One very good way of achieving the capacity of MIMO wireless channels is to take help of space-time codes(STC). The code has been designed to use with multiple transmit antennas [12]. Space time block coding (STBC) is one approach of STC in which multiple copies of data are transmitted across multiple antennas at different times, thus compensate for fading and thermal noise.

The conceptual diagram of a MIMO system with orthogonal STBC technique is shown in Fig. 3. The system has M_T transmit antennas and M_R receive antennas. A space time encoder encodes the transmitted data. The $M_T$transmit antennas are used to transmit M_T parallel outputs simultaneously. STBC is a transmit diversity technique in which the transmitted streams are pre-processed before transmitted [14].

MIMO channel can be realized with multi-element array antennas, there is an individual channels between given pairs of transmit and receive antennas [14]. Assuming each link from the transmit antenna to the receive one can be modeled by flat fading for wireless mobile communication, then the channel matrix H describing a MIMO channel with M_T transmit and M_R receive antennas is given by [12]:

$$H = [h_{ij}] \qquad (5)$$

where the h_{ij} element is the fading attenuation coefficient for the path from transmit antenna i to receive antenna j. The received signal vector r can be represented as:

$$r = Hs + n \qquad (6)$$

Where: s is the transmitted signal vector and n is the additive noise vector.

At the receiver, the channel estimator is used to estimate the channel state information [12]. Maximal ratio combining (MRC) technique using maximum-likelihood (ML) decoder based on the minimum Euclidian distance is used to combine

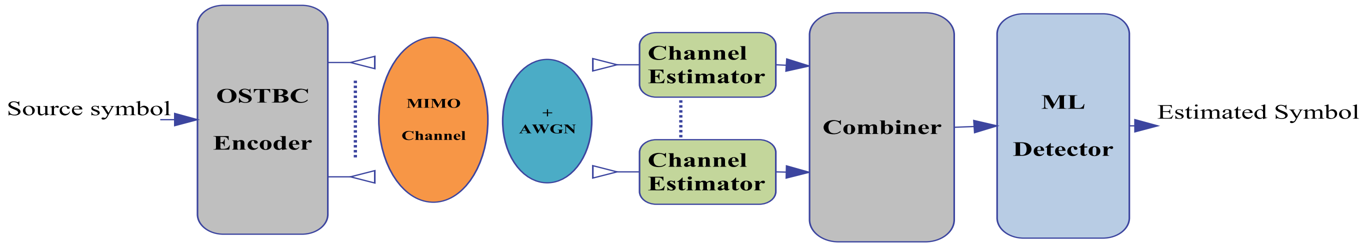

Figure 3. Conceptual diagram of MIMO-STBC system.

M_R received signals to find the most likely transmitted signal. Using MRC the receiver needs to demodulate all M_R receive signals and therefore increasing the effective which affects on the probability of error at the receiver [16].

Alamouti coding is the first and simplest orthogonal STBC, which uses two antennas for transmitting two symbols simultaneously in two successive time slots [12][16]. The encoder takes a block of two modulated symbols s_0 and s_1 in each encoding operation and maps them to the transmit antennas according to a code matrix given by [12]:

$$G_2 = \begin{bmatrix} s_0 & s_1 \\ -s_1{}^* & s_0{}^* \end{bmatrix} \tag{7}$$

In general, a space-time block code is defined by an $M_T \times p$ transmission matrix G in which M_T represents the number of transmit antennas and p represents the number of time periods for transmission of one block of coded symbols [14]. The entries of orthogonal matrix may be real or complex based on the signal constellations [12].

The rate of the code is defined as the number of the transmitted symbol, k, over the number of time periods for transmission of one block of coded symbol p [12][14]. The following matrices represent examples of orthogonal STBC design [17].

STBC with Four transmit-M_R receive antenna (Full code rate- real design) [17] :

$$G_4 = \begin{bmatrix} s_0 & s_1 & s_2 & s_1 \\ -s_1 & s_0 & -s_3 & s_2 \\ -s_2 & s_3 & s_0 & -s_1 \\ -s_3 & -s_2 & s_1 & s_0 \end{bmatrix} \tag{8}$$

STBC with five transmit-M_R receive antenna (Full code rate- real design) [17] :

$$G_{8\times5} = \begin{bmatrix} s_0 & s_1 & s_2 & s_3 & s_4 \\ s_1 & -s_0 & s_3 & -s_2 & s_5 \\ s_2 & -s_3 & -s_0 & s_1 & -s_6 \\ s_3 & s_2 & -s_1 & -s_0 & -s_7 \\ s_4 & -s_5 & s_6 & s_7 & -s_0 \\ s_5 & s_4 & s_7 & -s_6 & -s_1 \\ s_6 & s_7 & -s_4 & s_5 & s_2 \\ s_7 & -s_6 & -s_5 & -s_4 & s_3 \end{bmatrix} \tag{9}$$

The design of complex Half- rate orthogonal STBC is designed by concatenating the real STBC matrix with it is conjugate as follows [12]:

$$G_{2p\times M} = \begin{bmatrix} G_{p\times M_T} \\ G^*{}_{p\times M_T} \end{bmatrix} \tag{10}$$

Complex Orthogonal STBCs are given emphasis because they can be used for PSK/QAM modulation schemes and are more practical than real STBCs [16].

In general, the MIMO-DWT system is composed of M_T transmitting antennas, M_R receiving antennas, and N discrete wavelet transform (DWT) subcarriers as indicated in Fig.4. IDWT acts as multicarrier modulator for each transmitting antenna and DWT as demodulator for each receiving antenna. The coded transmitted data symbols can be defined as:

$$s_k = \begin{bmatrix} s_k^0 & s_k^1 & s_k^2 & \ldots. & s_k^{(N-1)} \end{bmatrix} \tag{11}$$

Where: s_k^i is the coded transmitted data symbol from antenna k on the i subcarrier, $0 \le k \le M_T - 1$.

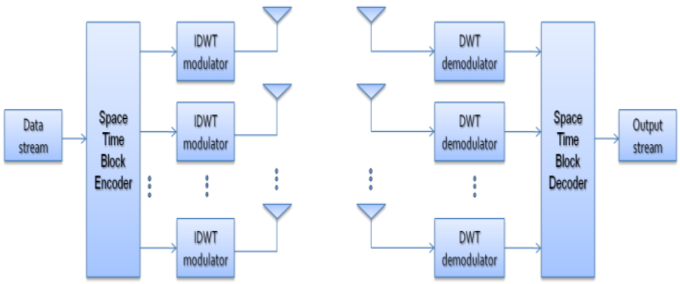

Figure 4. MIMO-DWT system model.

IV. SIMULATION RESULTS AND DISCUSSION

A. Performance and simulation parameters

Performance of communication systems including bit error rate (BER) and the capacity (or data rate) are two parameters that must be considered. The bit error rate (BER) is the number of bit errors divided by the total number of transferred bits. The capacity represents the number of bits that can be transferred per unit time, specified in bits per second (bps). Table I. summarize the simulation parameters that have been considered in our simulation DWT with Haar mother Wavelet is considered. Both the FFT and DWT based systems were implemented using MATLAB program.

TABLE I. SIMULATION PARAMETERS.

Parameters	Specification
Number of subcarriers (N)	64
Modulation type	BPSK, QPSK
E_b/N_o	0-15 dB
STBC scheme	Alamouti scheme Higher order STBC
MIMO configuration	Different configurations
Channel	AWGN
	Rayleigh for MIMO

B. Simulation results for single input single output (SISO) DWT based multicarrier and OFDM systems

The simulation results in terms of BER show the comparison between DWT based multicarrier and conventional OFDM (based FFT) systems in AWGN channel using BPSK and QPSK. Two cases for OFDM symbol have been considered in comparison with DWT system, OFDM symbol without guard band (null subcarriers) as shown in Fig. 5 and OFDM symbol with guard in which there are 12 null subcarriers (as in Wi-Fi) as shown in Fig. 6. In two cases, the cyclic prefix extension of length 16 subcarriers is associated with each OFDM symbol.

From Fig. 5, we can notice that the probability of error for DWT based multicarrier system is less than the probability of error of the conventional OFDM over all values of bit to noise energy ratio (E_b/N_o) under the two modulation schemes. Also we can notice that the BER for DWT is approximately the same as the theoretical BER that yields from single carrier with both modulation schemes that are used. For comparison, at E_b/N_o= 6 dB with BPSK, the probability of error in DWT system is 0.00252 and in OFDM system is 0.005801, whereas with QPSK, it is 0.0454 in DWT system and 0.07304 in OFDM system.

Fig. 6 shows the BER performance of DWT based multicarrier and OFDM in which the OFDM symbol has 12- null subcarriers. It is noticeable that the BER performance for DWT and OFDM systems are approximately the same as the theoretical BER that yields from single carrier with BPSK and QPSK.

In the two figures, we can notice that the QPSK needs twice the transmission power to achieve the same BER as in BPSK.

Table II shows the comparison between DWT based multicarrier and conventional OFDM in terms of capacity (the transmitted data measured bits per one multicarrier symbol) and the bandwidth utilization efficiency (the ratio between the length of subcarrier that carry data over the total multicarrier symbol length). It is noticeable that the achievable capacity when using DWT as multicarrier is superior the conventional OFDM whether the guard (null subcarrier) are present or not. The capacity is better when the QPSK scheme is used since each source symbol carry two data bits.

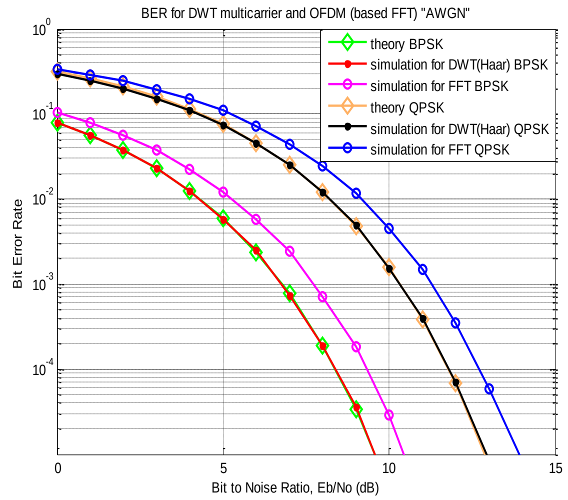

Figure 5. BER of Haar-DWT based multicarrier and conventional OFDM (without guard) using BPSK and QPSK in AWGN channel

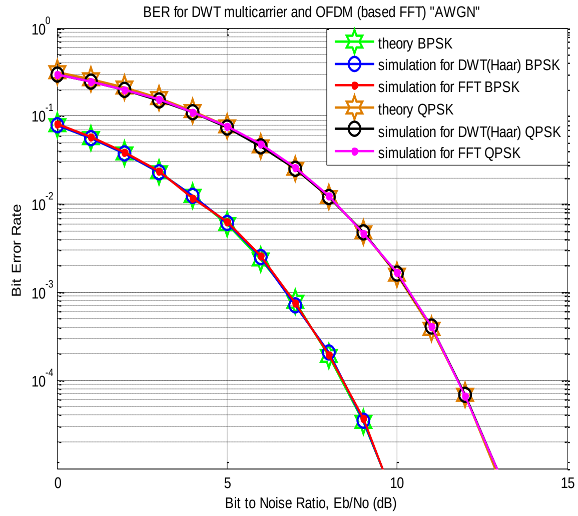

Figure 6. BER of Haar-DWT based multicarrier and conventional OFDM (with guard) using BPSK and QPSK in AWGN channel.

TABLE II. COMPARISON BETWEEN DWT AND OFDM SYSTEMS.

	OFDM		**DWT based multicarrier**
	Without guard	**With guard**	
Bandwidth utilization efficiency (η) / **Capacity (bits/ symbol)**	64 subcarrier for data. $\eta = \frac{64}{80}$	52 subcarrier for data. $\eta = \frac{52}{80}$	64 subcarrier for data. $\eta = \frac{64}{64} = 1$
BPSK	64	52	64
QPSK	128	104	128

C. BER performance of MIMO-DWT results

In this part we show the performance of DWT based multicarrier with MIMO technology. MIMO under complex STBC in Rayleigh flat fading channel will be considered. The comparison between MIMO-DWT and MIMO is discussed as well as between MIMO-DWT and MIMO-OFDM.

The BER performance versus bit to noise energy ratio of MIMO-DWT using BPSK under Alamouti STBC is shown in Fig. 7 and under STBC with five transmit-M_R receive antenna is shown in Fig. 8. It is noticeable that in the two figures there is improvements in BER when the number of receive antenna increase over all values of bit to noise ratio which is logically because when we receive the same signal more than once, and combine them at the receiver output, this causes to improve the E_b/N_o of the received signal. This improvement in E_b/N_o is due to increase in diversity order and to the array gain in which more receive antennas means receive more power.

In general, the multicarrier modulation improve the BER performance in wireless system. The combination of MIMO technology with multicarrier techniques is considered as a promising solution to enhance the data rate of future broadband wireless communication systems and improve the performance of the system. Fig. 9 compare between MIMO-DWT system and MIMO system in terms of BER with BPSK using 5×3 and 3×5 configurations.

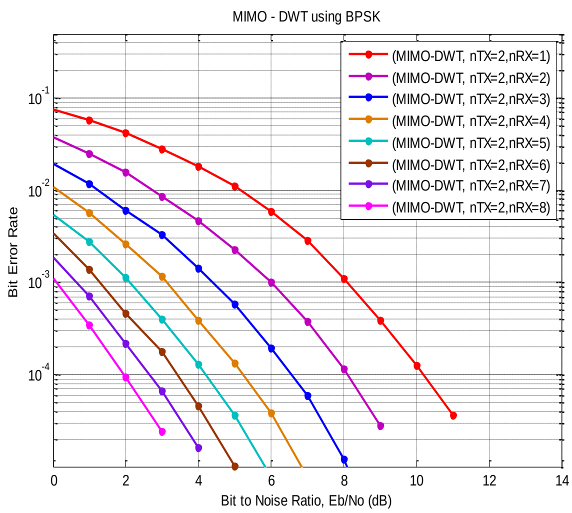

Figure 7. MIMO-DWT under Alamouti coding.

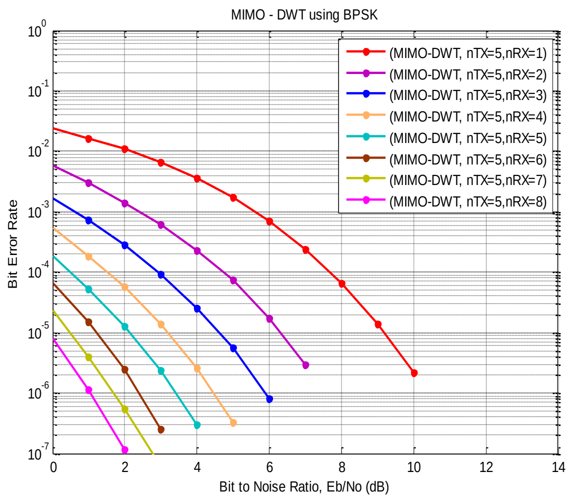

Figure 8. MIMO-DWT under STBC with five transmit-M_R receive antenna.

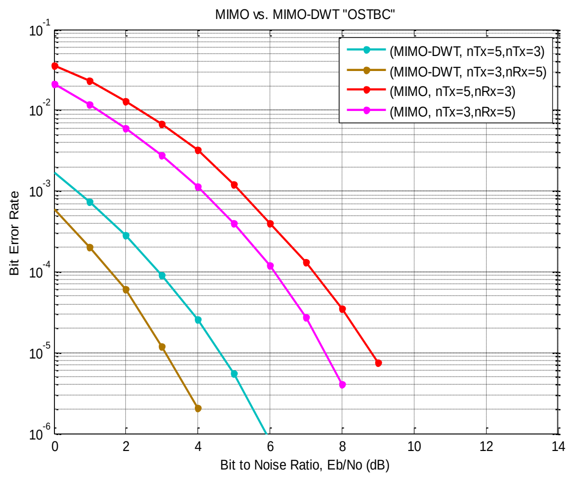

Figure 9. MIMO-DWT versus MIMO.

It is worth to point the improvement in the system when DWT is applied. At a certain signal-to-noise ratio in Fig. 9, there is a noticeable drop in the BER as an advantage of DWT based multicarrier with two configurations. For example, take 5×3 and looking at the point 5dB, we can notice that the BER with MIMO 1.21×10^{-3} and 5.538×10^{-6} with MIMO-DWT, the difference between these values is 0.001204462 which represent a good improvement.

Fig. 9 also shows the difference between 5×3 and 3×5 with MIMO and MIMO-DWT. We can notice that the BER with 3×5 is better than 5×3 in two systems. So that the increase in the number of receive antenna is preferable than increase in the number of transmit antenna.

Fig. 10 shows the BER performance of MIMO-DWT and MIMO-OFDM systems using BPSK under complex STBC. In this figure the 12 null subcarrier (guard band) is considered with OFDM symbol. It is noticeable that the two multicarrier systems have the same BER over all values of E_b/N_o and with all MIMO configurations approximately. However, the transmission capacity in MIMO-DWT is superior it in MIMO-OFDM since every DWT symbol carry 64 bit data whereas the OFDM symbol carry 52 bit data so that

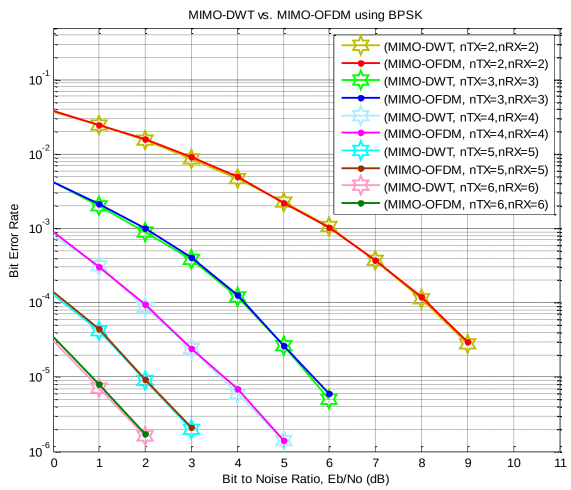

Figure 10. MIMO-DWT versus MIMO-OFDM using BPSK.

We can replace the conventional OFDM by DWT based multicarrier and achieve higher transmission capacity with MIMO technology. Fig. 10 also shows that less power will be needed for transmission if we move from 2×2 to 6×6 in the two multicarrier systems.

Applying QPSK instead of BPSK with MIMO-DWT system, has led to some important results, and has emphasized what we already know about the BER performance of both techniques. The performance of MIMO-DWT system under STBC with five transmit-M_R receive antenna in terms of BER with QPSK modulation is shown in Fig. 11. It is clear that we have a better performance when the number of receive antennas is increasing. If we compare between Fig. 8 and Fig. 11, we can find that the BER performance of BPSK is better than QPSK in MIMO-DWT system with all configurations of receive antenna.

Fig. 12 shows the comparison between MIMO-DWT and MIMO-OFDM with QPSK using 5×3 and 3×5 configuration. From this figure, we can notice that the BER is approximately the same in the two systems.

It is also noticeable from Fig. 12 that the BER performance of 3×5 is better than 5×3 in the two systems. For example, looking at the point 6dB, the drop in the BER between 3×5 and 5×3 is approximately 0.00015766.

In the following two figures, we show the BER performance of MIMO-OFDM system with and without guard. It is clear that from these two figures the BER performance of MIMO-OFDM with guard is better than without with two modulation schemes. For comparison, if we take 3×2 MIMO configuration and looking at the point 5 dB in Fig. 13, the BER of MIMO-OFDM with guard is 2.845×10^{-4} whereas the BER of MIMO-OFDM without guard is 6.543×10^{-4}, so there is drop in BER by 3.698×10^{-4} due to the use of guard. The drop in BER in Fig. 14 is by 5.646×10^{-3} with 3×2 MIMO configuration and at 5 dB.

The transmission capacity without guard is better than with guard since the 12-null subcarriers are used for carry data bits. But when we need reliable communication system we need less bit error rate, so that there is trade off in the conventional OFDM system. In DWT based multicarrier

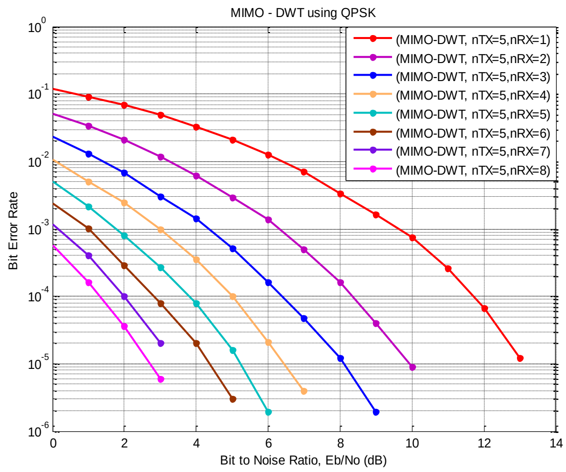

Figure 11. MIMO-DWT using QPSK under STBC with five transmit-M_R receive antenna.

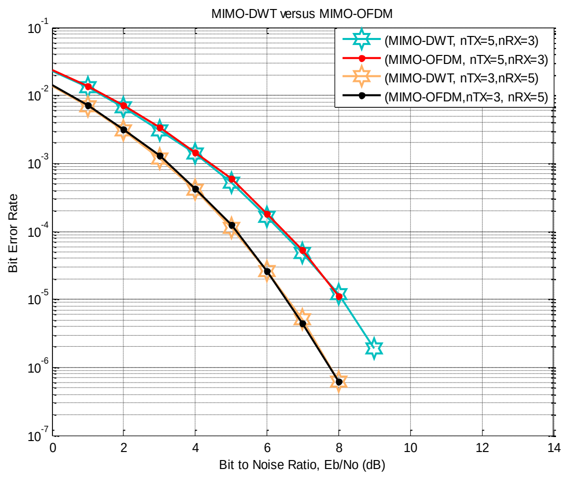

Figure 12. MIMO-DWT versus MIMO-OFDM using QPSK.

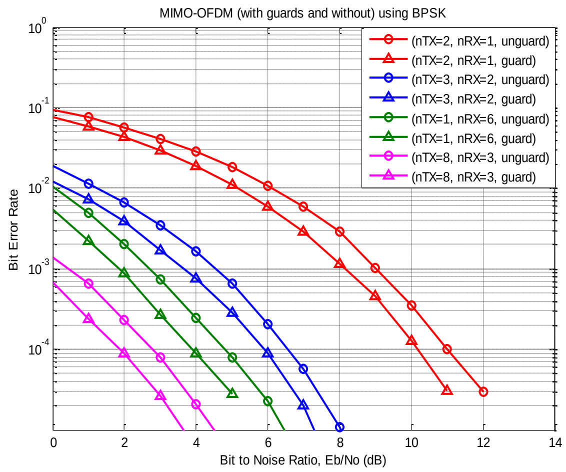

Figure 13. MIMO-OFDM with and without guard using BPSK.

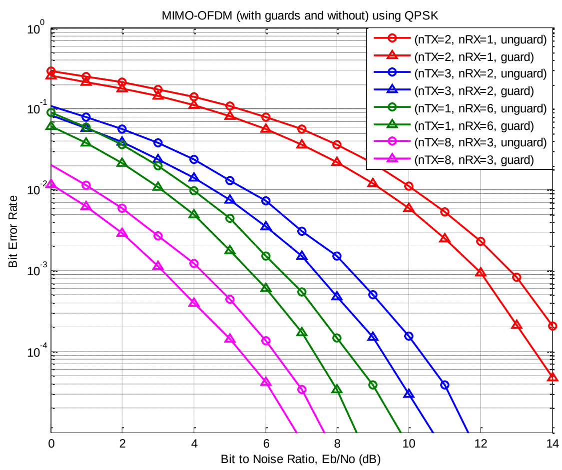

Figure 14. MIMO-OFDM with and without guard using QPSK.

system we do not add 12-null subcarriers and it is still superior to the conventional OFDM in terms of capacity and BER.

V. CONCLUCIONS AND FUTURE WORK

All the simulation results that we studied whether in SISO or in MIMO-MCM, we found that the performance of the discrete Wavelet transform with Haar mother (Haar-DWT) based multicarrier modulation is superior to the performance of conventional orthogonal frequency division multiplexing (OFDM) in terms of bit error rate and transmission capacity. Using the DWT as multicarrier modulator in wireless systems rather than using the conventional OFDM (based on FFT) does not need a cyclic prefix extension which represent an overhead, i.e, reduce the transmission capacity. In other words, in DWT the available bandwidth is wisely utilized and we achieve higher data rate. If we insert a guard band (null subcarriers) in conventional OFDM, then the BER performance OFDM and DWT is approximately the same. However, this improvement in BER in OFDM will reduce the data rate since there are subcarrier does not carry data.

MIMO technology improves the data rate in broadband wireless communication. The combination between MIMO and multicarrier modulation schemes improves the BER performance of wireless communications systems. Of course, MIMO with DWT as multicarrier is a very attractive technique for most of modern telecommunication systems that looking for achieve high data rate with small BER. Employing more antennas at the receiver side is the key factor, since it was noticed that the performance of BER increases linearly with the number of receive antennas due to increase in diversity order and to the array gain in which more receive antennas means receive more power. On the other hand, after a certain level of increase of the transmit antennas, there is no large improvement.

The BER performance of communication systems using binary phase shift keying (BPSK) is better than using Quadrature amplitude modulation (QPSK). However, the data rate with QPSK is superior to BPSK.

In order to develop this research, we propose the ideas that lead to adoption of this current work in several areas. First, Replacement the OFDM based technology such as Wi-Fi, WIMAX, cognitive radio and 4G mobile communication, by DWT based multicarrier. Second, study the performance of different mother Wavelets under different channel distributions.

REFERENCES

[1] K. Fazel, and S. Kaiser, Multi-Carrier and Spread Spectrum Systems, John Wiley & Sons Ltd, (2003).

[2] Andrea Goldsmith, Wireless Communications, Cambridge University Press, (2005).

[3] Stuart D. Sandberg, and Michael A. Tzannes, Overlapped Discrete Multitone Modulation for High Speed Copper Wire Communications, IEEE Journal On Selected Areas In Communications, Vol. 13, No. 9, December, (1995).

[4] Khaizuran Abdullah, Interference Mitigation Techniques for Wireless OFDM, Degree of Doctor of Philosophy, RMIT University, August (2009).

[5] All N. Akansu and Richard A. Haddad, Multiresolution Signal Decomposition Transforms, Subbands, and Wavelets, Academic Press,(2001).

[6] Rishabh Kasliwal, Nachiket Kale, and Piyush Nahar, EE678 WAVELETS APPLICATION ASSIGNMENT WAVELET OFDM.

[7] M. K. Lakshmanan, and H. Nikookar, a Review of Wavelets for Digital Wireless Communication, Wireless Personal Communications, Vol.37, (2006), pp. 387-420.

[8] Michael Weeks, Digital Signal Processing Using MATLAB and Wavelets, Georgia State University, 2007.

[9] Fuqin Xiong, Digital Modulation Techniques, Artech House, Inc,(2006).

[10] Fritz J., and Dolores H. Russ, M-Ary Orthogonal Modulation Using Wavelet Basis Functions, Degree Master of Science, Ohio University, November (2000).

[11] Marius Oltean, a Study of the Multi-Scale W-OFDM Transmission in Time Variant Channels, International Journal of Communications, Vol.2, (2008), pp.96-105.

[12] Abhay Kumar Sah, Sushobhan Nayak, Space-Time Codes for High Data-Rate Wireless Communication.

[13] A F Naguib, N Seshadri and A R Calderbank, Increasing Data Rate Over Wireless Channel, Signal Processing Magazine, IEEE, (2000), pp. 76 - 92.

[14] Branka Vucetic, Jinhong Yuan, *Space Time Coding*, John Wiley & Sons Ltd, (2003).

[15] Laith Ali Abdul-Rahaim, Design of Space Time Block Code Ultra-Wideband (UWB) System Based on Discrete Wavelets Transform, Electrical Engineering Department, Babylon University, Babylon, Iraq.

[16] Hamid Jafarkhani, *Space-Time Coding Theory and Practice,* Cambridge University Press, (2005).

[17] Vahid Tarokh, Hamid Jafarkhani, and A. R. Calderbank, Space–Time Block Codes from Orthogonal Designs, IEEE, Transactions On Information Theory, VOL. 45, NO. 5, July, (1999).