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Improving Bit Error Rate of MIMO-OFDM System Using Discrete Wavelet Transformation

Onebunne D. K.
Department of Electrical and Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria
Email: divine.onebunne1@gmail.com
Nwabueze C. A.
Department of Electrical and Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria
Email: canwabueze@gmail.com
Ekengwu B. O.
Department of Electronic Engineering, University of Nigeria, Nsukka, Nigeria
Email: bonaventure.ekengwu@unn.edu.ng
Odukwe P. C.
Department of Electrical and Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Nigeria
Email: promisco4life@gmail.com

ABSTRACT

This paper has developed a discrete wavelet transform (DWT) for multicarrier modulation in MIMO-OFDM system. The proposed system used additive Gaussian white noise (AGWN) and Rayleigh flat fading channel with respect to SNR using binary phase shift keying (BPSK). The algorithms for various scenarios of MIMO-OFDM system have been developed and simulated in MATLAB environment. The performance metric of the system was based on bit error ratio (BER) variation over values of signal to noise ratio (SNR) for different transmit and receive antennas including single input multiple output (SIMO) arrangement. The simulation results showed that the performance of DWT based MIMO-OFDM outperformed DFT based MIMO-OFDM. For the 2×1, 2×2, 2×3 MISO and MIMO systems, the DWT scheme offered reduced BER of 1.803e-05, 1.502e-05, and 1.413e-05 against 0.005847, 0.005361, and 0.005325 for the DFT scheme with respect to signal to noise ratio (SNR) at 10 dB. Generally, the results showed that using DWT scheme in OFDM for wireless communication system does not require an extra subcarrier to provide cyclic prefix function that serves as additional cost burden and reduces bandwidth.

Keywords – **Bit Error Rate, Discrete Fourier transform, Discrete wavelet transform, MIMO system, Transmission capacity**

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I. INTRODUCTION

The use of spectrum as a result of increasing number of users' equipment (or mobile users) using service such as audio, video and images is one of the problems facing wireless communication. Orthogonal Frequency Division Multiplexing (OFDM) is considered as one of the promising methods to increase spectral efficiency and as such provide better transmission capacity. The traditional or conventional OFDM that uses fast Fourier transform (FFT) or discrete Fourier transform (DFT) needs cyclic prefix (CP) to be inserted at the transmitter and removal of CP at receiver, which largely decreases spectral or bandwidth efficiency of wireless channel and impact severely on the transmission capacity. Discrete wavelet transform (DWT) are used as an alternative technique replacing FFT to increase the spectral efficiency since CP is eliminated. Also, to address the issue of multipath fading in wireless signal transmission, antenna diversity involving the use multiple input multiple output antennas is an appropriate option. Therefore, transmission capacity of MIMO-OFDM system can be improved using DWT to reduce Bit Error Rate.

Discrete Wavelet Transform (DWT) has been considered as alternative platform to conventional OFDM in which there is no need for cyclic prefix (CP) overhead due to the overlapping nature of DWT. In conventional OFDM, inter symbol interference (ISI) is mitigated using cyclic prefix (CP) and to increase the delay spread of the channel [1]. The conventional OFDM uses discrete Fourier transform (DFT). The DFT based OFDM has the disadvantages of increasing consummation of the bandwidth and reduces spectral efficiency [2].

In this paper, it is intended to use the DWT as multicarrier modulator instead of Discrete Fourier Transform (DFT) such that considering the scenario of having multiple antenna system allows increasing the transmission capacity and reducing bit error. Generally, DWT based MIMO-OFDM offers flexibility, improve in BER performance, mitigate interference, improve spectral efficiency since there is no use of CP, and perfect signal reconstruction.

II. EMPIRICAL REVIEW

In this section, related previous studies that are not more than a decade are reviewed. This is to align the present

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study to recent techniques and developments in wireless communication related to channel capacity/diversity improvement using FFT and or DWT based OFDM. The studies reviewed are highlighted.

Bouhlel et al. [2] simulated a DWT based MIMO-OFDM and FFT based MIMO-OFDM to study the performance of Bit Error Rate (BER) over AGWN and Rayleigh channel conditions with different modulation schemes comprising 4-QAM, 16-QAM and 16-QAM. The results obtained indicated that DWT MIMO-OFDM outperformed FFT MIMO-OFDM for different wavelet families in terms of BER. The study further showed that DWT based MIMO-OFDM with the HAAR wavelet under the BPSK modulation provided very good solution for wireless communication with minimum BER. However, the study only considered one MIMO system configuration that is two-input and two-output antennas with symbol length (or number of bits) equal 10^4, while the number of carrier frequencies (or FFT size) used was 64.

Parveen et al. [1] examined diversity technique based on DWT in OFDM system. The study surveyed various FFT base MIMO-OFDM and DWT based MIMO-OFDM techniques and observed that DWT provided better flexibility, improvement in BER, interference mitigation in DWT-OFDM system compared to FFT-OFDM system. The authors stated their intension to develop a technique to enhance DWT-OFDM with more convolution coding.

Vani and Bargade [3] investigated the BER performance of MIMO-OFDM system that uses discrete wavelet transform (DWT). The study only considered wireless communication over AGWN channel with QAM modulation technique. The number of bits or symbol length considered was 100 and the number of carrier was 96. There was no comparison with FFT-OFDM to ascertain the effectiveness of the proposed system.

Hreshee and Al-Gayem [4] combined convolutional coding (CC) and DWT to improve the performance of MIMO-OFDM by reducing the BER. The OFDM system was simulated and examined with three models consisting of single input single output (SISO) OFDM, multiple input single (MISO) OFDM and MIMO-OFDM. The study employed Rician and Rayleigh fading channels with Binary Phase-Shift Keying (BPSK) modulation technique and 64 number of carrier frequencies. The results obtained from simulation carried out in MATLAB revealed that the DWT based MIMO-OFDM system reduces the bit energy to the intensity of noise energy ratio (Eb/N_o) by 3.4dB and 4.6dB over Rayleigh and Rician channels respectively when BER is 10^{-3}.

Tan et al. [5] presented Discrete Wavelet Transform (DWT) based MIMO-OFDM simulation in MATLAB. The study carried out performance comparison of FFT based MIMO-OFDM and DWT based MIMO-OFDM in terms of BER. The performances were examined over AGWN and Rayleigh flat fading channels with 8-QAM, 16-QAM and 32-QAM and FFT size of 32. The number of symbols was 10^3. The simulation results indicated that DWT outperformed FFT in terms of BER reduction in MIMO-OFDM.

Somasekhar et al. [6] carried out performance investigations of DWT and traditional DFT MIMO-OFDM systems based channel estimation. The study considered two transmit and two receive antennas with Rayleigh fading channel and 128-number of subcarriers. The modulation technique used was 16-QAM. The results of the simulations conducted in MATLAB showed that with DWT SNR of 3dB was achieved at BER of 10^{-2}dB.

Tang et al. [7] proposed a Haar wavelet decision feedback channel estimation technique to improve data transmission rate and spectrum efficiency. The multipath channel models used in the study were China DTV Test 1st (CDT1) and China DTV Test 6st (CDT6), which are from field tests for digital television terrestrial broadcasting standard, and are both Rayleigh fading channels. The modulation scheme was QPSK with 512-number of subcarriers and OFDM block length of 10. The result of the simulations showed that SNR of about 0.95dB, 2.2dB, and 3.5dB respectively.

Sarowa et al. [8] presented performance analysis of various wavelets at different modulation schemes in OFDM to show in improvement in BER. The modulation techniques considered were 4-QAM, 16-QAM, and 64-QAM. The study was carried out for wireless communication over AGWN channel with 76-number of subcarriers, FFT size of 128, and number of symbol (or number of data) 100. The wavelet OFDM (WOFDM) performance was compared with that of conventional OFDM; the simulation results revealed that WOFDM significantly outperformed conventional OFDM in terms of BER. The authors stated thatthe BER performance of one type wavelet over another wavelet type OFDM depended on modulation level. Also as the spectral efficiency and data rate increased by 1.83 bps/Hz and 2.285 Mbps, the BER reduced up to 10 dB as the modulation level increased from 4-QAM to 64-QAM. This study did not consider the impact of fading channel such as Rayleigh and Rician over wavelet OFDM system.

Parveen [9] developed a wavelet based MIMO-OFDM to improve the performance and spectral efficiency. The modulation technique considered was QAM with various antenna models that are based on DWT such as SISO, MISO, and MIMO. Simulations were carried out in MATLAB for the various antenna diversity scenarios considered using different wavelets. The results obtained revealed that the Haar wavelets offered better performance compared to other wavelet transform by 2 dB (SNR) and at 0.001 (BER).

The empirical review showed that recent studies in wireless communication is moving towards the use of DWT to resolve the weakness associated with DFT by

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eliminating cyclic prefix effect that seems to reduce channel bandwidth thereby adversely impacting on transmission capacity. The DFT provides better BER as reported so far from the surveyed studies. However, an obvious pattern of study can drawn from literature reviewed that different antenna configuration of transmit antennas and receive antennas models were used in various studies conducted. This research has included different antenna configurations with DWT such as SISO-DWT, SIMO-DWT, and MIMO-DWT over AGWN and Rayleigh channels using BPSK. Convolution coding is also used to improve wireless system BER performance in this work.

III. MIMO BASED DWT SYSTEM DESIGN

This section will discuss DWT based MIMO (or simply MIMO-DWT) system including the block diagram design that describes the structure of the proposed system. Generally, the MIMO- DWT system consists of M_T transmit antennas, M_R receive antennas, N discrete wavelet transform (DWT) subcarriers shown in Fig. 1. The multicarrier technique for each transmit antenna is IDWT, while DWT acts as multicarrier scheme for each receive antenna.

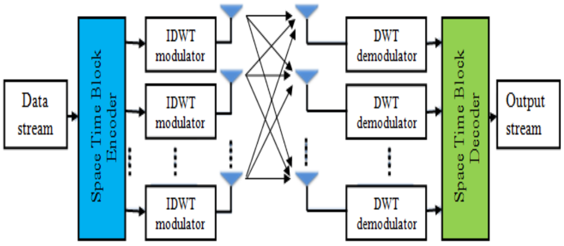

Fig. 1 MIMO based DWT system model

At transmit end of MIMO-DWT system, the STBC encoder encodes the incoming data stream (or symbol stream) and produces M_T code words. At each antenna, every N coded word is acted upon by an IDWT modulator scheme. The expression of the coded transmitted data symbols is given by:

$$s_k = \begin{bmatrix} s_k^0 & s_k^1 & s_k^2 & \cdots & s_k^{(N-1)} \end{bmatrix} \quad (1)$$

where s_k^i is the coded or the STBC encoder output transmitted data symbol from antenna k on i subcarrier such that $0 \le k \le M_T - 1$.

The transmission of all the output symbols from M_T IDWT modulator is performed at the same time from different transmit antennas. These symbols are transmitted through the MIMO channel. The coded transmitted data symbols are received by the receive antennas. Then the symbols are passed to through the DWT demodulator and after award to the STBC decoder.

The DWT based MIMO-OFDM system model with M_T transmit antennas and M_R receive antennas proposed in this paper is shown in Fig. 2. The use of space time block coding (STBC) technique can improve the diversity performance in MIMO system. Transmit diversity and power gain can be achieved using Space time block coding without forfeiting bandwidth. Alamouti encoder and decoder used for STBC technique in the proposed MIMO-OFDM system with DWT.

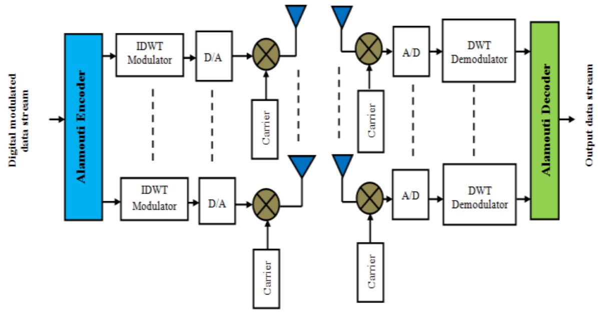

Fig. 2 Proposed Alamouti coded DWT system

3.1 Modulation Process

Modulation schemes considered in this work at the transmitter are binary phase-shift keying (BPSK). The BPSK modulation process is such that the carrier is directly phase modulated. That is, the phase of carrier is shifted by incoming binary data. A pair of signals $s_1(t)$ and $s_2(t)$ is used to represent the binary symbols in coherent BPSK. The mathematical expression is given by:

$$s_1(t) = \sqrt{\frac{2E_b}{T}} \cos(2\pi f_c t), \text{ for binary } 0 \quad (2)$$

$$s_2(t) = \sqrt{\frac{2E_b}{T}} \cos(2\pi f_c t + \pi), \text{ for binary } 1$$

$$= -\sqrt{\frac{2E_b}{T}} \cos(2\pi f_c t) \quad (3)$$

where $0 \le t \le T$, and E_b are the symbol duration and the transmitted energy per bit, f_c is the carrier frequency. Antipodal signals (that is signals 180 degree opposite to each other) space can be represented by the single basis function:

$$\phi(t) = \sqrt{\frac{2}{T}} \cos(2\pi f_c t) \quad (4)$$

Hence, the signals: binary 1is represented by $\sqrt{E_b}\,\phi(t)$ while binary 0 is represented by $-\sqrt{E_b}\,\phi(t)$. The block diagram of BPSK modulation is shown in Fig. 3.

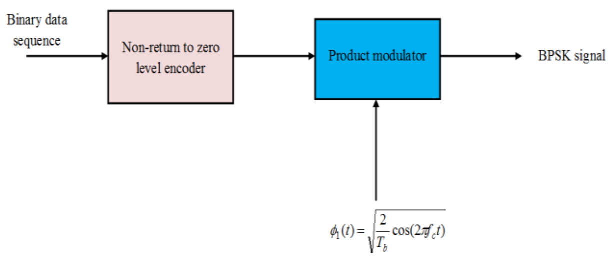

Fig. 3 Block diagram of BPSK modulation

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After the parallel to serial conversion of the DWT-OFDM signal, demapping takes place as shown in Fig. 4 using BPSK modulation. The phase shift in the received signal is detected by the BPSK receiver. The received signal is fed into the mixer circuit. The other input to the mixer circuit is driven by a reference oscillator synchronized to $\sin(2\pi f_c t)$, which is known coherent carrier recovery.

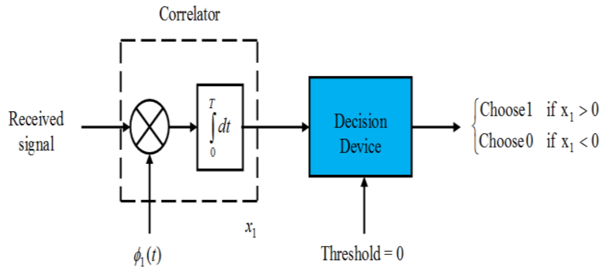

Fig. 4 Block diagram of BPSK demodulation

3.1 Performance and Simulation Parameters

It is necessary to consider the performance of any communication system based on certain parameters. In this work the proposed DWT based MIMO-OFDM system performance is measured in terms of bit error (BER) and the channel capacity (or data rate). The BER is defined as the number of bit errors per the overall bits transferred bits at a given period or duration. The BER of BPSK can be evaluated using:

$$P_b = Q\left(\sqrt{\frac{2E_b}{N_0}}\right) \quad \text{for BPSK} \qquad (5)$$

where P_b is the probability of error, Q is quality factor, and E_b/N_0 is the value of the SNR.

The capacity expresses the number of bits that can be transmitted over time. It is a measure of the rate at which the system can send data through the channel in bits per second (bps). The simulation parameters are listed in Table 1.

Table 1 Simulation parameters

Parameter	Specification
Number of data subcarrier (N) or FFT size	64
Type of modulation	BPSK
SNR	0-20 dB
Space time block coding (STBC)	Alamouti
Antenna configuration	Different configuration
Channel	AGWN/Rayleigh
Symbol length	10^6

IV. SIMULATION RESULTS

The simulation is of three scenarios: (a) The BER performance plots of DWT and DFT based multicarrier (OFDM) system with single input single output (SISO) antenna configuration. In this case, the SISO OFDM is examined considering OFDM symbol with guard band (or referred as null subcarriers) and without guard band. (b) The BER performance plots of DWT and DFT based OFDM system with single input multiple output (SIMO) antenna configuration. (c) The BER performance plots of DWT and DFT based OFDM system with multiple input multiple output (MIMO) configuration. That is simulation in terms of MIMO-OFDM based on DWT and MIMO-OFDM based DFT.

4.1 BER for DWT and DFT based OFDM System with SISO Antenna

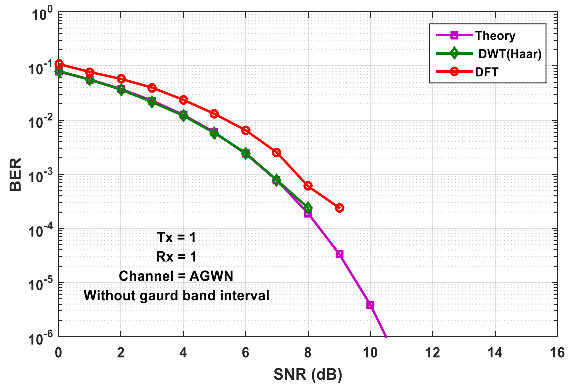

Fig. 5 BER of curves of SISO-OFDM based on DWT and DFT in AGWN channel

Figure 5 shows performance plots of BER against SNR for DWT and DFT based OFDM system and single carrier system (theory) using BPSK modulation in AGWN channel. Looking at the figure, it can be observed that DWT based OFDM BER offers less probability of error (BER) than DFT based OFDM over all values of SNR. Furthermore, it obvious from Fig. 5 that the BER for DWT based OFDM system is almost the same as the theoretical BER that is obtained from single carrier with BPSK modulation scheme. Table 2 shows numerical analysis of Fig. 1 in which the values of the BER yield by DWT, DFT and single carrier (theoretical) are listed against SNR.

Table 2 BER analysis of DWT and DFT based OFDM for SISO system

SNR (dB)	BER		
	Theory	DWT	DFT
0	0.07865	0.08083	0.1091
1	0.05628	0.05595	0.07752
2	0.03751	0.0366	0.05763
3	0.02288	0.02151	0.03984
4	0.0125	0.01208	0.02368
5	0.005954	0.005769	0.01304
6	0.002388	0.002464	0.00649
7	0.0007727	0.0007813	0.002524
8	0.0001909	0.0002404	0.000601
9	3.363e-05	-	0.0002404
10	3.872e-06	-	-

With respect to transmit capacity, the better performance in terms of BER offered by DWT based OFDM system than DFT based OFDM system can be attributed to the fact that the transmission capacity and utilization of bandwidth DWT based OFDM outperforms that of the DFT based OFDM because of the addition of cyclic prefix to DFT based OFDM symbol. While the DWT symbol contains 64 subcarriers such that each one carries one bit in BPSK technique without any extra subcarrier data, the DFT symbol on the contrary, contains 96 subcarriers with only 64 utilized for transmitting data and the remaining (32) are used to provide cyclic prefix extension. Thus for transmission capacity (expressed in bit/sec) the transmission time for one DFT-OFDM symbol will be larger than for one DWT-OFDM symbol. This way, the capacity in DWT-OFDM is better than in DFT-OFDM.

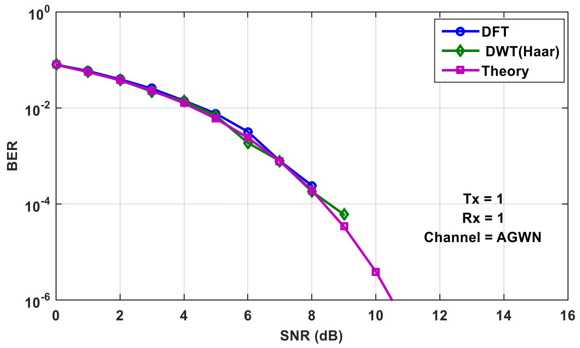

Fig. 6 BER of curves of SISO-OFDM based on DWT and DFT (with guard) in AGWN

Figure 6 represents the plot of the relationship between BER curves of DWT and DFT based OFDM systems, and for system with single carrier employing BPSK modulation against SNR in AGWN channel. In this case, a guard band is added to the DFT-OFDM system. It can be seen from the figure that probability of error for DWT-OFDM and DFT-OFDM are almost the same as the theoretical BER that is produced by single carrier for all values of SNR in BPSK modulation scheme. Nevertheless, the transmission capacity (bit/sec) that can be achieved in DWT-OFDM is better than that of DFT-OFDM because of the extra 32 subcarriers added to the DFT-OFDM symbols to provide cyclic prefix and 12 subcarriers used to provide guard band. Hence, unlike the DWT-OFDM symbol in which each uses 64 subcarriers to transmit data, every DFT-OFDM symbol uses 52 subcarriers out of 64 subcarriers to transmit data (12 are used as guard band). This means that for DWT-OFDM system, more available bandwidth is utilized so as to cause high-speed of data transmission and as such transmission capacity is increased. Table 4.2 shows the listing of the BER performance of DWT, DFT, and theoretical value obtained from single carrier modulation. Since DWT and DFT are both multicarrier, their transmit capacity is better than single carrier system as a result of the merits of multicarrier modulation.

Table 3 BER analysis of DWT and DFT (guard band) based OFDM for SISO system

SNR (dB)	BER		
	Theory	DWT	DFT
0	0.07865	0.08083	0.07963
1	0.05628	0.05595	0.05859
2	0.03751	0.03774	0.03930
3	0.02288	0.02187	0.02512
4	0.0125	0.0137	0.01412
5	0.005954	0.006851	0.0107572
6	0.002388	0.001863	0.0003185
7	0.0007727	0.0007813	0.0007813
8	0.0001909	0.0001803	0.000204
9	3.363e-05	6.01e-05	-
10	3.872e-06	-	-

The BER performances of DWT and DFT based OFDM systems with SIMO antenna configuration are presented in this subsection. Maximum ratio combiner (MRC) is used at the receiver of the SIMO system. The performance of the SIMO system is considered for antenna configurations: 1×2 and 1×3 in accordance to the two multicarrier transformation techniques (DWT and DFT). In the SIMO, maximum ratio combiner (MRC) is used at the receiver while introducing a Rayleigh flat fading channel since the data transmission involves multiple antenna system. The BER performance plots of the various SIMO arrangements are shown in Fig. 7 and 8. The numerical performances of the multicarrier transformation techniques are presented in Tables 4 and 5.

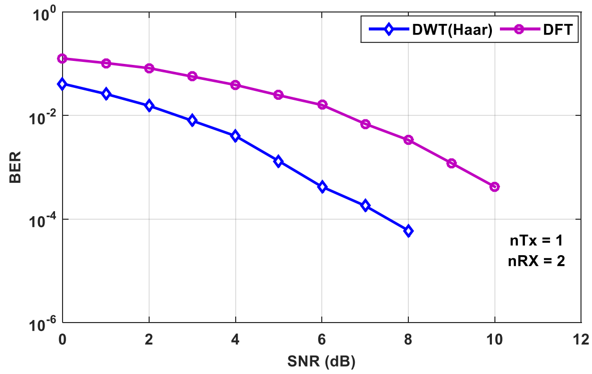

Fig. 7 BER performance of DWT and DFT based SIMO-OFDM system for 1×2

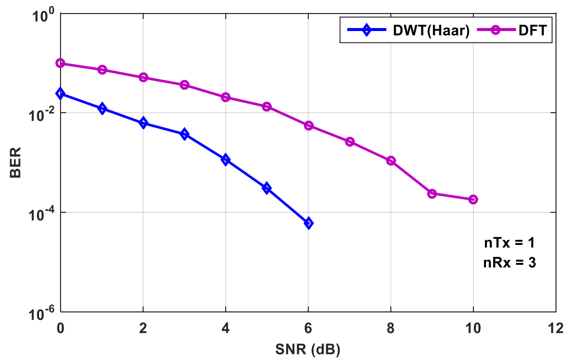

Fig. 8 BER performance of DWT and DFT based SIMO-OFDM system for 1×3

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Table 4 Analysis of BER for DWT and DFT based SIMO-OFDM system (1×2)

SNR (dB)	BER	
	DWT	DFT
0	0.04123	0.1267
1	0.02614	0.1034
2	0.01544	0.08239
3	0.007933	0.05661
4	0.004026	0.0390
5	0.001322	0.02464
6	0.0004207	0.01599
7	0.00001803	0.006911
8	6.01e-05	0.003365
9	-	0.001202
10	-	0.0004207

Table 5 Analysis of BER for DWT and DFT based SIMO-OFDM system (1×3)

SNR (dB)	BER	
	DWT	DFT
0	0.0241	0.09802
1	0.01226	0.07356
2	0.0619	0.0512
3	0.003726	0.0363
4	0.001142	0.02049
5	0.0003005	0.01334
6	6.01e-05	0.005589
7	-	0.002644
8	-	0.001082
9	-	0.0002404
10	-	0.0001803

The simulation results of the BER performance curves of DWT and DFT based MIMO-OFDM system in which number of transmit antennas is fixed at 2 while varying the number of receive antennas is shown in Fig. 9, 10, and 11. However, since the receive number of antennas are varied for fix multiple transmit number of antennas, a multiple input single output (MISO) case is also considered as shown in Fig. 9. Other simulation results involving multiple input multiple output are shown in Fig. 10 and 11. Table 6 through 8 are the lists of the numerical values of the BER curves of the various antenna arrangements for DWT and DFT based MIMO-OFDM system.

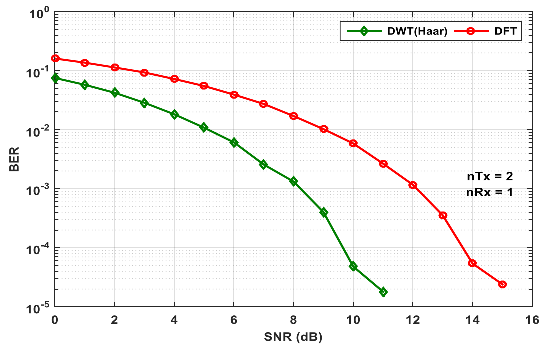

Fig. 9 BER performance of DWT and DFT based MISO-OFDM system

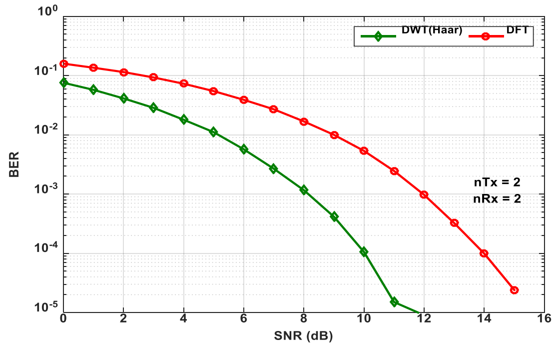

Fig. 10 BER performance of DWT and DFT based MIMO-OFDM system 2×2

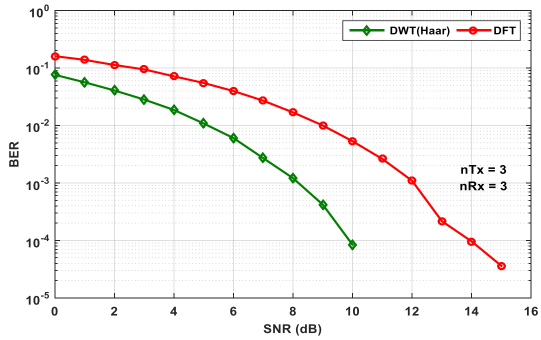

Fig. 11 BER performance of DWT and DFT based MIMO-OFDM system 2×3

Table 6 Analysis of BER for DWT and DFT based SIMO-OFDM system (2×1)

SNR (dB)	BER	
	DWT	DFT
0	0.07326	0.1608
1	0.05776	0.1369
2	0.0423	0.1135
3	0.02861	0.09335
4	0.01826	0.07233
5	0.01082	0.05507
6	0.006106	0.03931
7	0.002572	0.02733
8	0.001322	0.01705
9	0.0004026	0.01025
10	1.803e-05	0.005847

Table 7 Analysis of BER for DWT and DFT based SIMO-OFDM system (2×2)

SNR (dB)	BER	
	DWT	DFT
0	0.07258	0.1594
1	0.05757	0.1360
2	0.04126	0.1139
3	0.02858	0.09310
4	0.01800	0.07211
5	0.01009	0.05474
6	0.005703	0.03906
7	0.002468	0.02700
8	0.001163	0.01685
9	0.0004014	0.01001
10	1.502e-05	0.005361

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Table 8 Analysis of BER for DWT and DFT based SIMO-OFDM system (2×3)

SNR (dB)	BER	
	DWT	DFT
0	0.07058	0.1591
1	0.05648	0.1261
2	0.04070	0.1128
3	0.02828	0.09160
4	0.01786	0.07169
5	0.01008	0.05455
6	0.005078	0.03872
7	0.002014	0.02601
8	0.001214	0.01590
9	0.0004011	0.01000
10	1.413e-05	0.005325

In summary, the results or observations made from the simulation conducted in MATLAB environment to study the effect of DWT technique in the transmission capacity based on improvement of MIMO-OFDM system while comparing it with conventional (DFT based) MIMO-OFDM system in terms of BER performance over a range of values for SNR has been presented. The following findings are clearly observed from the simulation plots of BER curves for DWT and DFT presented in Fig.5 through Fig 11 and the numerical values obtained from the various plots in Table 2 through Table 8. First, as shown in Fig. 6, by inserting a guard band in DFT based OFDM system, its BER performance can become approximately the same as that of DWT. Nevertheless, this performance improvement in BER of DFT based MIMO comes at a cost in speed of data transmission. That is, while improving BER performance of DFT based OFDM with this strategy, there is a relative reduction in the transmitted data rate given that there are subcarriers that do not carry data. Next, using more receive antennas was observed to be a key factor. This is because from the simulations performed it was found that performance improvement in BER increases proportionally as the number of antennas at the receiver because of increase in diversity order and to the gain of the antenna arrangement wherein more antennas at receiver brings about more receive power.

V. CONCLUSION

The simulation results for the BER performance analysis carried out for either SISO, SIMO, or MIMO-OFDM system based on discrete wavelet transform (DWT) and discrete Fourier transform (DFT) in AGWN and Rayleigh flat fading channel with respect to SNR using BPSK have shown that DWT based OFDM system outperforms DFT based OFDM. The results obtained show that employing DWT as a transformation scheme in OFDM for wireless communication system does not require an extra subcarrier to provide cyclic prefix function that serves as additional cost burden and reduces bandwidth. Thus the use of cyclic prefix represents an overhead that reduces transmission capacity and since DWT does not use extra subcarrier for its transformation process when use in multicarrier modulation (OFDM), the available bandwidth is technically utilized and then helps in achieving higher transmitted data rate (improved transmission capacity).

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