Improving MIMO-OFDM Performance with Convolutional Coding and Discrete Wavelet Transform

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***Abstract*—This paper presents a new way to improve the performance of MIMO-OFDM (multiple input multiple output - orthogonal frequency division multiplexing) by reducing the Bit Error Rate (BER) using both Convolutional Coding (CC) and discrete wavelet transform (DWT). In this Paper, OFDM system was simulated and studied with three models, SISO-OFDM, MISO-OFDM and MIMO-OFDM. The final system (MIMO-OFDM) has been improved by using CC at a coding rate 1/2 and using a DWT instead of FFT and then using both CC and DWT. The communication channels used in the study are Rician and Rayleigh fading channels and the modulation technique is Binary Phase-Shift Keying (BPSK) with 64 number of carrier frequencies. The results showed that the use of both convolutional coding and discrete wavelet transform in the MIMO-OFDM system reduces the bit energy to the intensity of noise energy (Eb/N_0) by 3.4 dB as the Rayleigh fading channel is used and 4.6 dB as the Rician fading channel is used when BER=10^{-3}. The results were obtained by modeling in the MATLAB program.**

***Index Terms*—BPSK, convolutional coding, discrete wavelet transform, MIMO, OFDM**

I. Introduction

The signal transmitted over the wireless channel suffers from the multipath phenomenon. The receiver receives multiple copies of the signal, each with a different path, and each copy of the signal suffers from attenuation and phase shifting that differ from other copies. When these different versions are compiled at the receiving point, the quality of the signal may be low, which poses a challenge of how to reduce this phenomenon. The second challenge is to ensure a high speed of data transfer with limited bandwidth available [1].

The Multiple Input Multiple Output (MIMO) system is used to provide high-speed and high-reliability wireless communication system without any increase in available beam width and no increase in transmission capacity. The MIMO system uses more than one antenna at both the transmitter and the receiver. The propagation with a multipath phenomenon in communication systems requiring a high data rate which makes the channel frequency-selective and the receiver design is very complex. The Orthogonal Frequency Division Multiplexing (OFDM) system divides the frequency-selective channel into N partial flat-frequency channels [1].

Wireless mobile communications have evolved historically from the first generation when this system provided the audio-service only [2]. The second generation of digital mobile communication systems had better performance because it uses the Time Division Multible Access (TDMA) or Frequency Division Multible Access (FDMA) technologies, but it was limited by the width of the band [1]. The third generation then appeared to enhance the data rate, but with the continuous development of multimedia applications that has made the user data rate insufficient. Therefore, the MIMO-OFDM system can meet these requirements [3].

MIMO-OFDM has recently attracted significant attention due to its improvement in increasing the speed of data transfer and the reliability of this data. There have been many previous studies that have dealt with each technique individually and the ways of improving it's work [2], also there are studies on the overall system (MIMO-OFDM) [3]-[7] that have improved its performance, and here is a review of the main contributions in this fields:

In 2019, Dw *et. al.*, concluded that OFDM based on Discrete Wavelet Transform (DWT) with its channel modeling presents a better performance than conventional OFDM specially for the indoor Visible Light Communication systems. The challenge of these systems was its complexity which answered by using Pulse Amplitude Modulation 4-PAM for their proposed system Discreet Wavelet Transform OFDM (DWT-OFDM) [3].

In [4], the MIMO-OFDM system was studied and simulated using a Rayleigh fading channel with Binary Phase Shift Keying (BPSK) modulation type and using Convolutional Coding (CC) at a 1/2 coding rate. The results showed that the system has high reliability and this reliability increases by increasing the number of antennas used in transmission or reception. The results also showed that increasing the number of carrier frequencies reduces the reliability of the system because

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the overlap between partial carriers increases by increasing the number of carrier frequencies.

The performance of the MIMO-OFDM system was studied in [5] by using different modulation methods and with the Rayleigh fading channel. The results showed that when the Bit Error Rate (BER) $=10^{-3}$, the case of using unequal transmission power at the transmission antennas (the first transmission antenna has more power than the second transmission antenna) will achieve a transmission power-saving of 1.33 dB, comparing with the case of using equal transmission power. The results also showed that the use of antenna selection technology with MIMO-OFDM makes the power-saving of 1.25dB comparing with the case that without antenna selection.

A comparison was made between OFDM with fast Fourier transform (FFT) and OFDM with Discreet Wavelet Transform (DWT) in [6] by using multiple modulation methods through the Additive White Gaussian Noise (AWGN) communication channel. The results showed that when the BER$=10^{-3}$, the use of DWT in OFDM achieves a transmission power-saving about 1.2dB comparing with the traditional OFDM system in which FFT is used. This study did not discuss the MIMO system.

The performance of the MIMO-OFDM system was studied and improved in [7] by using turbo coding with a 2/3 coding rate. The modulation method used in this study was the quadreture amplitued modulation QAM-16 through an AWGN communication channel. The results showed that when BER$=10^{-3}$, the use of turbo coding in the MIMO-OFDM system achieves a transmission power-saving of 4dB comparing with the non-coded MIMO-OFDM system. This study did not discuss the fading channels Rayleigh and Rician.

II. Research Importance and Objectives

The MIMO-OFDM system forms the core of the 4G mobile communications systems by achieving a high data rate with increased reliability in data transmission. Therefore, the main goal of this work is to enhance reliability in data transfer for the MIMO-OFDM system without increasing bit energy to the intensity of noise energy (E_b/N_0) ratio. At this point, BER was studied for this system and then both convolutional coding and discrete wavelet transform were adopted with the MIMO-OFDM system to obtain an enhanced BER values.

III. Research Methodology

A. *Space Time Block Coding (STBC)*

This system exploits the multiple antennas structure at the transmitter to achieve spatial diversity. Alamouti has designed the transmission diversity technology for systems that have two transmitting antennas, which require simple linear processes at both the transmitter and the receiver. The coding and decoding processes are carried out on two sets of the modulated codes, therefore, modulation must be done at first [6].

Assume that (x_1 and x_2) are two modulated symbols enter the Space-Time Block Coding (STBC). These two symbols (x_1 and x_2) transmitted during respective intervals (t_1 and t_2) in single antenna systems, but in STBC, during the first interval (t_1), the symbols (x_1 and x_2) are transmitted through the first and second antennas respectively and during the second interval (t_2), the symbols (x_1^* and x_2^*) are transmitted through the first and second antennas respectively. In the following section, two different situations can be explained:

The status of a single receiving antenna: Fig. 1 shows a transmission and reception system that uses STBC, two antennas at the transmitter and a single antenna on the receiver with channels connecting the transmitter to the receiver.

The receiving signals at the antenna during the first interval (t_1) and the second (t_2) are expressed respectively as [6]:

$$y_1 = h_1 x_1 + h_2 x_2 + n_1 \quad (1)$$

$$y_2 = -h_1 x_2^* + h_2 x_1^* + n_2 \quad (2)$$

where n_1 and n_2 represent the noise of channels (h_1 and h_2) respectively, y_1 and y_2 represents the two received signals through the first time interval (t_1) and the second time interval (t_2) respectively, x_1 and x_2 represent the two modulated symbols enter the STBC, x_1^* and x_2^* represent the complex conjugate of the two symbols (x_1 and x_2) respectively.

At the receiver, the decoding equations are given in (3) and (4):

$$\hat{x}_1 = h_1^* y_1 + h_2 y_2^* \quad (3)$$

$$\hat{x}_2 = h_2^* y_1 - h_1 y_2^* \quad (4)$$

The case of two antennas in the reception: Fig. 2 shows a transmission and reception system that uses STBC, with two antennas at the transmitter and two antennas at the receiver with the channels connecting the transmitter to the receiver.

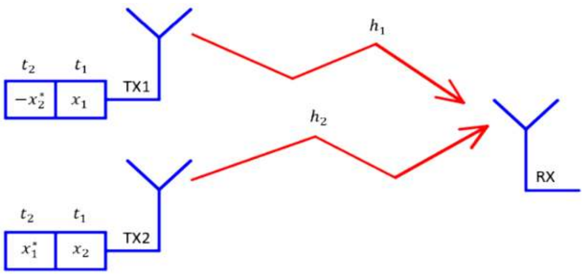


Fig. 1. A transmission and reception system that uses STBC, two antennas at the transmitter and a single antenna at the receiver [6].

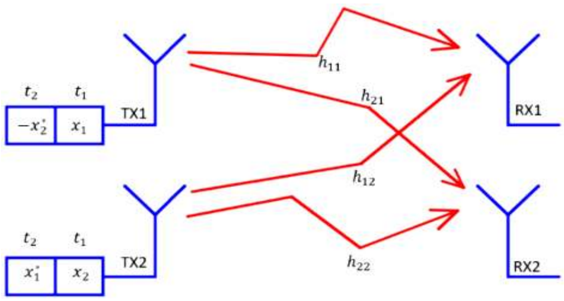


Fig. 2. shows a transmission and reception system that uses STBC, with two antennas at the transmitter and two antennas at the receiver [6].

Eqations (5) and (6) represent the receiving signals during the first-time interval (t_1) on the first receiving antenna and the second receiving antennas respectively. While equivalents (7) and (8) represent the receiving signals during the second time interval (t_2) on the first and second receiving antennas respectively [6].

$$y_{11} = h_{11}x_1 + h_{12}x_2 + n_{11} \tag{5}$$

$$y_{21} = h_{21}x_1 + h_{22}x_2 + n_{21} \tag{6}$$

$$y_{12} = h_{12}x_1^* - h_{11}x_2^* + n_{12} \tag{7}$$

$$y_{22} = h_{22}x_1^* - h_{21}x_2^* + n_{22} \tag{8}$$

At the receiver, the decoding equations are given by:

$$\hat{x}_1 = h_{11}^* y_{11} + h_{21}^* y_{21} + h_{12} y_{12}^* + h_{22} y_{22}^* \tag{9}$$

$$\hat{x}_2 = h_{12}^* y_{11} + h_{22}^* y_{21} - h_{11} y_{12}^* - h_{21} y_{22}^* \tag{10}$$

B. *Orthogonal Frequency Division Multiplexing OFDM*

The signal transmitted in single-carrier systems uses all available bandwidth, while in multi-carrier frequency systems, the available spectrum is divided into a number of narrow and orthogonal domains. Fig. 3 shows the block diagram of the OFDM system. The principle of multi-carrier transmission is based on the spreading of data that have high transfer rate to be transmitted through a large number of frequency carriers each of low transfer rate and this process is called a serial to parallel transformation. This parallel-data is then converted to the digital modulation formula (BPSK) by modulating each partial field with a partial frequency carrier using Inverse Fast Fourier Transform (IFFT). The Cyclic Prefix (CP) is then inserted by taking a copy of the last part of the OFDM code and placing it in the beginning of the code. The cyclic prefix interval must be greater than the maximum delay caused by the channel to prevent both the Inter Symbol Interference (ISI) and the Inter-Carrier Interference (ICI). At the receiving terminal, an opposite operation to what happened at the transmitter is utilized, where the cyclic prefix is removed firstly, then an FFT process, demodulation operation, and finally the process of converting the parallel sequence to serial sequence [8]-[10].

The most important characteristic that distinguishes OFDM is that inter-carrier guard bands are not required between adjacent subcarriers, where there will be no overlap between these carriers because of their orthogonality. Orthogonal means that the top of subcarriers is associated with the zero value of the next subcarriers [10], [11].

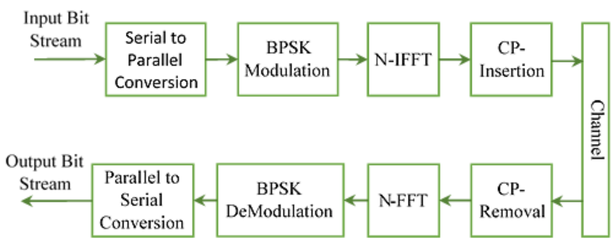


Fig. 3. Block diagram of the OFDM system [8].

C. *Rayleigh and Rician Fading*

The signal is faded due to the multi-path receiving of the signal. There is no dominant parameter in the Rayleigh fading type created from the line of sight (LOS) for the receiving signal, where there is no direct line of sight between the transmitter and the receiver. In the Rician fading, there is a strong and dominant parameter resulting from LOS where there is a direct line of sight between the transmitter and the receiver [12]. The K parameter in this type of fading is defined as the ratio of LOS path ability to the ability in other paths [12], [13]. In this study, K will be considered as 3dB.

D. *Convolutional Coding*

Channel encoding is defined as a technique in which additional bits are added to the original bits, and these additional bits are used to protect the transmitted data from the effects of the communication channel (attenuation, fading, noise, etc) [14], [15]. Channel encoding can be either to detect the error or to correct the error [14].

In this paper, a forward error correction (FEC) has been used to correct the error based on receiving data and choose bypass coding to improve MIMO-OFDM system performance. Fig. 4 shows the convolutional encoder, where there are three parameters that define convolutional coding:

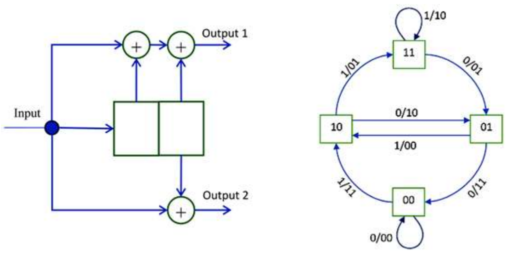
1 Code rate: The ratio between the number of input bits (k) to the number of output bits (n). In this study, the coding rate is equal to 1/2, which means that each input bit is matched by two output bits.

2 Constraint length: The number of stages in which the input bit remains in the convolutional code and in this study the constraint length = 3.

3 Generator polynomial: Determines how to connect the input sequence to the registrar to form the output.

$$G_1(D) = 1 + D + D^2 \tag{11}$$

$$G_2(D) = 1 + D^2 \tag{12}$$



(a) (b)

Fig. 4. Convolutional coding, (a) Block diagram (b) status diagram [16].

Fig. 5 shows the status chart of the convolutional coding, where each node represents the status of the coder, i.e. the digital content of memory elements, each branch represents the state of transition to another state according to the current input box, and the branch shows the two exit boxes corresponding to the current input box from a specific state [16].

The decoding process is carried out by using Viterbi's algorithm. Fig. 3. shows the block diagram of the MIMO-OFDM system with the convolutional coding that is applied before the modulation [17], [18].

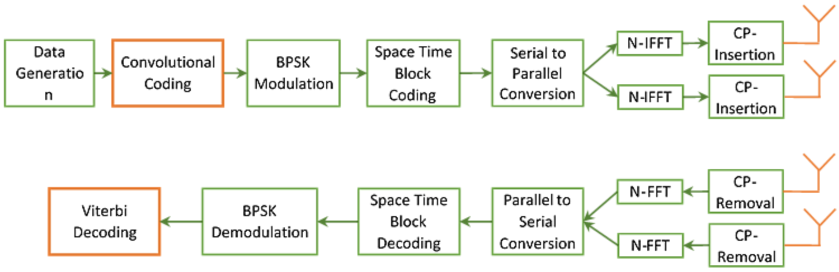


Fig. 5. MIMO-OFDM scheme with convolutional coding [18].

E. MIMO-OFDM Using Wavelet Transforms

In the wireless communication systems, an OFDM technique is used for high data transmission. OFDM with MIMO configuration used to increase the diversity gain or system capacity. In the OFDM, processing speed is increased with using IFFT and FFT which also reduces the complexity at transmitter and receiver.

Wavelet transform is one of the most appropriate methods for non-stationary signals and concentrated around a central point in time and frequency. The wavelet representation shows a multi resolution expression of a signal with localization in both time and frequency [19]. The signal is decomposed into a set of basis functions using wavelet transforms. DWT is a discrete wavelet transform and it uses any wavelet transform for discrediting into samples. Wavelet transform offers high side lobes suppression ratio, so that DFT/IDFT replaced in this work with DWT/IDWT and the final system will be MIMO-OFDM-DWT.

Wavelet transform has several advantages such as good consumption of spectrum, flexibility, and less interference. Hence, Wavelet transform used with MIMO-OFDM and proposed in the system [9], [10].

F. Proposed MIMO-OFDM-DWT System

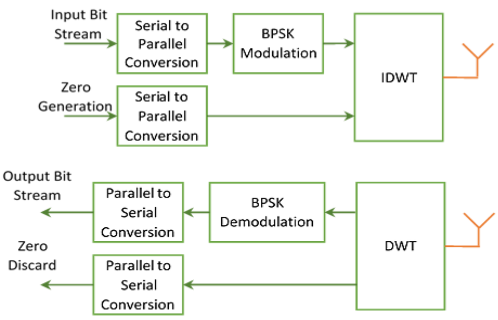


Fig. 6. Block diagram of SISO-OFDM-DWT [20].

Predicting the length of the channel's pulse response is particularly difficult especially in wireless applications. The length of the cyclic prefix increases by increasing the length of this response. This significantly reduces the spectral containment of the channel. OFDM-DWT also has a stronger ability to suppress ICI and ISI, so there is no need to add a cyclic prefix to the system. Fig. 6 illustrates the OFDM-DWT system [10], [20].

G. The Algorithm of the Proposed Model

The algorithm steps of the proposed model (MIMO-OFDM-DWT system shown in Fig. 7 are described below:

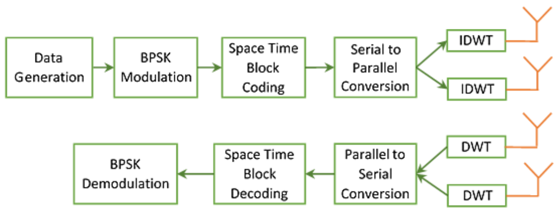


Fig. 7. Block diagram of MIMO-OFDM-DWT

Step 1: Assign the initial values then generating and coding the evaluated data.

Step 2: Convert the input bit stream from serial to parallel.

Step 3: Modulate the signal according to the BPSK.

Step 4: Perform the IDWT operation to convert the wave into the time domain. The signal or image extension mode is set for discrete wavelet and wavelet packet transforms. IDWT requires two parts of input data which are called the first approximate factors and the second detailed factors. The modulated data using BPSK represents the approximate part and the zeros represent the detailed part.

Step 5: In the receiver, extract the corresponding bandwidth for the parallel input data using DWT. The first half of the output data of the DWT represents the desired receiving signal that is demodulated, and the second half represents the unwanted factors that are cancelled.

Step 6: Calculated the BER for different wavelet transforms based on the received signal.

IV. Results and Discussion

Firstly, the BER was studied according to the E_b/N_0 parameter of the OFDM system with cases (1×1) SISO-OFDM, (2×1) MISO-OFDM and finally (2×2) MIMO-OFDM in the transmitter and receiver terminals. These cases were studied to evaluate their effect on the BER with two types of channels which are Rician fading channel and Rayleigh fading channel.

Fig. 8 to Fig. 11 shows the comparison between the classical OFDM-FFT with MISO and MIMO OFDM-FFT. From the cases shown in these figures, it can be noted that BER is decreased with increasing the number of antennas and with increasing E_b/N_0.

In the case of the MIMO-OFDM system which is shown in Fig. 10 (Rayleigh fading channel), it is noted that, when E_b/N_0 =15dB, the decreasing in the BER will be less than other E_b/N_0 values. At this point, the number of received error bits is 32 out of 640000 transmitted bits, while at E_b/N_0 =14dB the number of received error bits is 44 bits out of 640000 bits. That means the difference is only 12 bits.

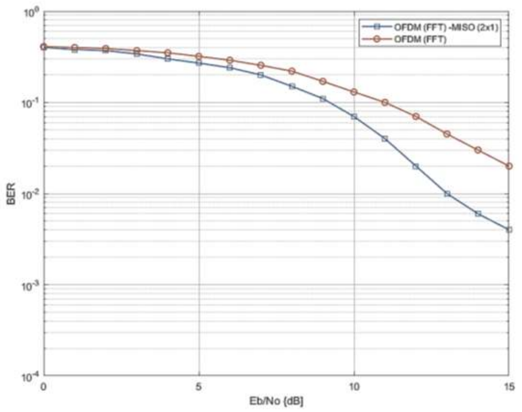


Fig. 8. Comparison between OFDM-FFT and MISO-OFDM-FFT through Rayleigh fading channel.

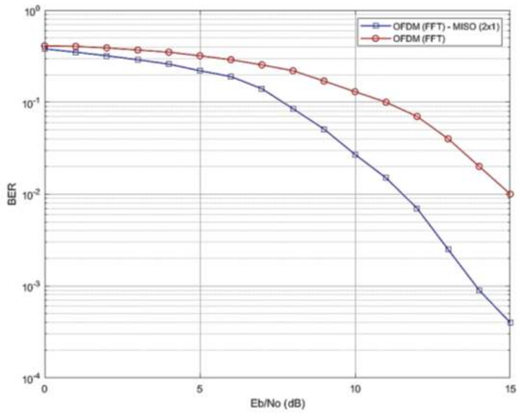


Fig. 9. Comparison between OFDM-FFT and MISO-OFDM-FFT through Rician fading channel

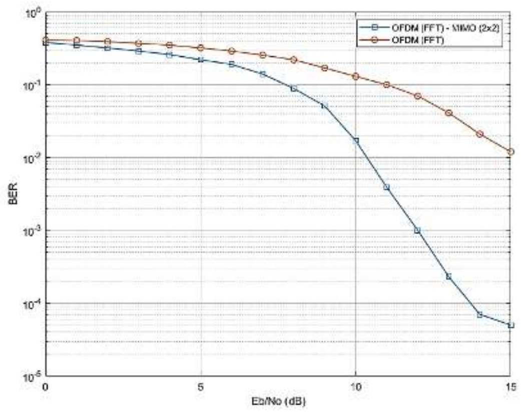


Fig. 10. Comparison between OFDM-FFT and MIMO-OFDM-FFT through Rayleigh fading channel.

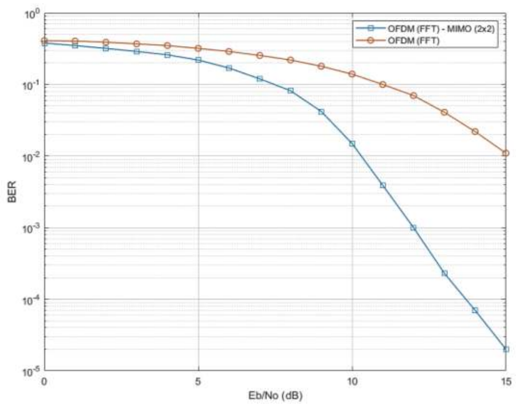


Fig. 11. Comparison between OFDM-FFT and MIMO-OFDM-FFT through a Rician fading channel.

From Fig. 11 (Rician fading channel), it is clear when E_b/N_0 =15dB, the number of received error bits is 13 out of 640000 transmitted bits, while at E_b/N_0 =14dB the number of received error bits is 43 bits out of 640000 bits. That means the difference is 30 bits.

Secondly, the effect of adding the convolutional coding (CC) to the MIMO-OFDM system is considered. In this case the results illustrate lower BER. Fig. 12 and Fig. 13 show the comparison between (2×2) MIMO-OFDM-FFT and (2×2) MIMO-OFDM-CC with the same two types of channels (Rician fading channel and Rayleigh fading channel).

Due to decreasing the number of received error bits with 640000 bits we had to use more bits (double) in the transmitter to confirm the calculations and the new number of bits used here is 1280000 bits

Fig. 12 (Rayleigh fading channel) illustrates the case of the MIMO-OFDM-CC system. It can be seen that the lower value of the BER occure at E_b/N_0=15dB. At this point, the number of received error bits is 4 out of 1280000 transmitted bits, while at E_b/N_0=14dB the number of received error bits is 22 bits out of 1280000 bits. That means the difference is 18 bits.

From Fig. 13 (Rician fading channel) it can be noted that, when E_b/N_0 =15dB, the number of received error bits is 2 out of 1280000 transmitted bits, while at E_b/N_0 =14dB, the number of received error bits is 19 bits out of 1280000 bits. That means the difference is 17 bits.

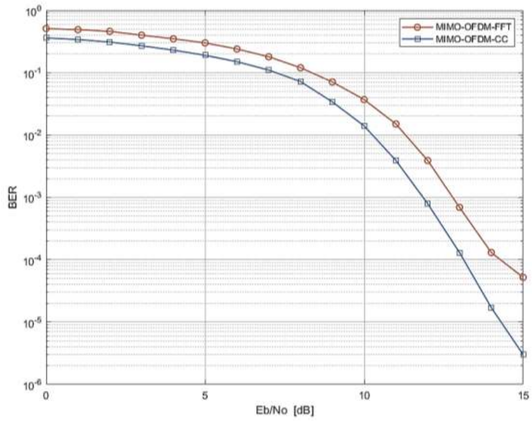


Fig. 12. Comparison between MIMO-OFDM-FFT and MIMO-OFDM-CC through Rayleigh fading channel.

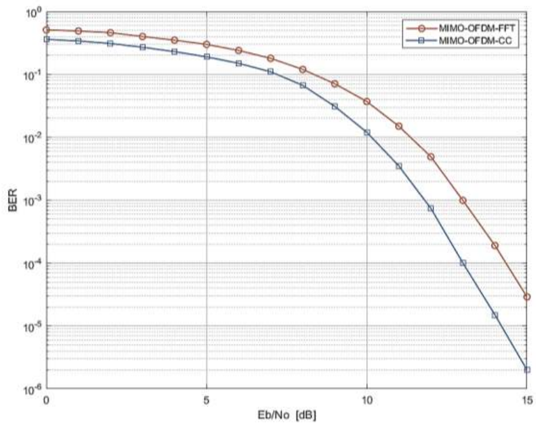


Fig. 13. Comparison between MIMO-OFDM-FFT and MIMO-OFDM-CC through a Rician fading channel.

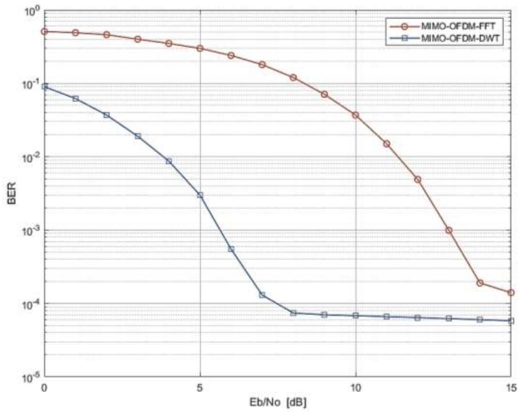


Fig. 14. Comparison between MIMO-OFDM-FFT and MIMO-OFDM-DWT through Rayleigh fading channel.

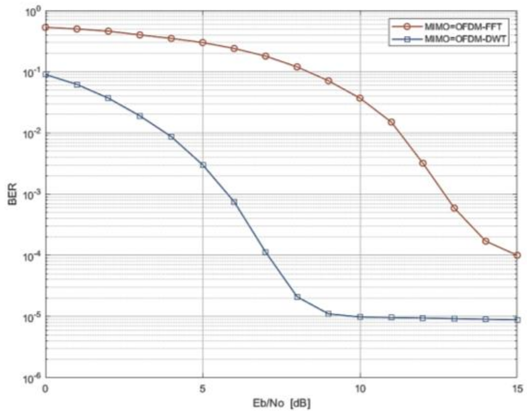


Fig. 15. Comparison between MIMO-OFDM-FFT and MIMO-OFDM-DWT through a Rician fading channel.

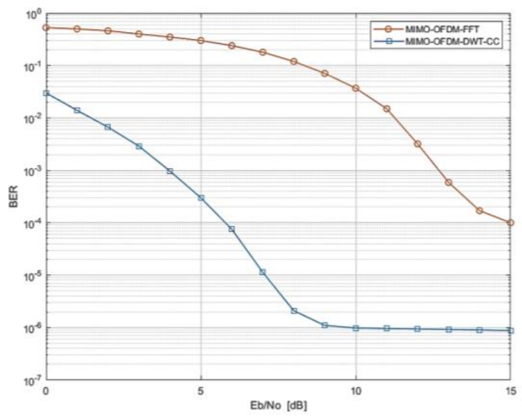


Fig. 16. Comparison between MIMO-OFDM-FFT and MIMO-OFDM-DWT-CC through Rayleigh fading channel.

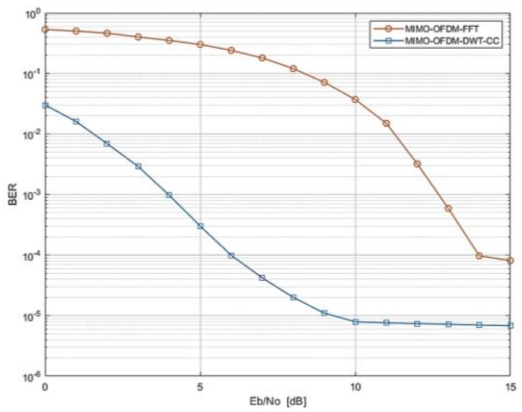


Fig. 17. Comparison between MIMO-OFDM-FFT and MIMO-OFDM-DWT-CC through a Rician fading channel.

TABLE I: SUMMARY OF RELATED WORKS

Reference and year	BER	SNR (dB)
Manik, *et al*., (2012) [5]	10^{-2}	10 - 30
Shakir & Hreshee, (2013) [7]	10^{-3}	5
Dahiya *et al*., (2013) [8]	10^{-3}	4
Vani & Bargade (2019) [21]	5.19×10^{-3}	12

In the third case, the use of DWT instead of FFT in the MIMO-OFDM system further reduces BER than the previous case in which convolutional coding was added to the MIMO-OFDM. Fig. 14 and Fig. 15 show the comparison between (2×2) MIMO-OFDM-FFT and (2×2) MIMO-OFDM-DWT with the Rayleigh and Rician channels.

In the Fourth case, the use of DWT in addition to the convolutional coding instead of FFT in the MIMO-OFDM system makes BER decrease significantly at small values of E_b/N_0, to achieve the best performance of the MIMO-OFDM system. Fig. 16 and Fig. 17 illustrate a comparison between (2×2) MIMO-OFDM-FFT and (2×2) MIMO-OFDM-DWT-CC through Rayleigh fading and Rician fading channels.

The results show that using both of convolutional coding and discrete wavelet transform in the MIMO-OFDM system reduces E_b/N_0 by 3.4 dB in the case study of the Rayleigh fading channel and by 4.6 dB when the Rician fading channel is adopted at BER $=10^{-3}$.

As shown in Table I, researchers have used various techniques in terms of DWT and convilutional coding, and have evaluated their proposed methodologies under various SNRs.

By comparing these results with the results of this paper, it can be observed that the above combination (MIMO-OFDM-DWT-CC) achieves better system performance than using antenna selection technology that has achieved a transmission power-saving of only 1.25 dB when BER$=10^{-3}$. By using unequally transmitted power technique at the transmission antennas, a transmission power-saving of only 1.33 dB is achieved when BER $=10^{-3}$. On the other hand, the use of turbo coding has achieved a saving of 4dB, with the AWGN communication channel which is better than the Rayleigh and Rician fading channels because it effects on the transmitted signal by noise only without fading.

V. CONCLUSIONS

After considering the MIMO-OFDM system with both convolutional coding and DWT, the following conclusions are drawn. Firstly, increasing the number of transmitting and receiving antennas directly increases the reliability of MIMO-OFDM system, while the use of convolutional coding with the MIMO-OFDM system reduces the BER. Secondly, using DWT instead of FFT with MIMO-OFDM also reduces BER and is better than the case of using convolutional coding. In addition, the use of both convolutional coding and DWT together with the MIMO-OFDM system makes BER=0 when E_b/N_0=9dB, in the case of the Rayleigh fading channel and when Eb/N_0=10dB in the case of the Rician fading channel. Therefore, these techniques could potentially enhance the system performance.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Saad Hreshee and Qais Al-Gayem conceived and designed the analysis and conducted the research; Hreshee collected the data and performed the analysis and wrote the paper; all authors had approved the final version.

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