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Enhancing Transmission Capacity of Wireless Communication System Using Discrete Wavelet Technique

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A B S T R A C T

The conventional OFDM system that uses discrete Fourier transform (DFT) as multicarrier transform scheme has been able to eliminate ISI by adding a cyclic prefix to the OFDM signal. However, this comes with a cost because the extra subcarrier added to the original OFDM decreases bandwidth and as such reduces the transmission capacity of the system. A discrete wavelet transform (DWT) for multicarrier modulation in MIMO-OFDM system was examined as a promising solution. The system used additive Gaussian white noise (AGWN) and Rayleigh flat fading channel with respect to SNR using binary phase shift keying (BPSK) modulation scheme. The performance metric of the system was based on bit error ratio (BER) variation over values of signal to noise ratio (SNR) for fixed transmit and different receive antennas. The simulation results showed that the performance of DWT based MIMO-OFDM outperformed DFT based MIMO-OFDM. For MISO and MIMO systems arrangement considered. In general, the simulation analysis revealed that employing DWT scheme in OFDM for wireless communication system comes at no an extra subcarrier to provide cyclic prefix function. Therefore, the use of cyclic prefix represents an operating cost that minimizing transmission capacity and since DWT scheme does not use extra subcarrier for its transform 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).

Keywords: DFT, DWT, MIMO-OFDM, BER, BPSK

1. Introduction

There has been exponential increase in subscribers of wireless communications in recent years. Wireless communication systems use free-space (without material medium) for communications with one and another. As radio signals propagate in free-space, certain propagation obstacle mechanisms abound as a result of the surrounding environment such as scattering, diffraction, reflection, and others. Many challenges occur due to the impact of propagation mechanisms on wireless system. Over the years, many developments have been made towards addressing these challenges by improving the data rate or speed and capacity of wireless communication systems, while preserving quality of service (QoS).

In wireless system, the loss of signal takes place due to several factors such as multipath, obstacle along the path and inappropriate tuning between the transmitter and the receiver (Parveen et al., 2019). Diversity techniques are implemented to facilitate the reduction of signal loss in terms of bit to error ratio (BER) and thereby increase the channel capacity. Diversity technique is approach that involves improving SNR or BER by supplying the receiver with multiple independent replicas of the same signal using different frequencies, or different time points, or employing multiple antenna system.

One important approach that has the potential to increase spectral efficiency in wireless communication is to combine multiple input multiple output (MIMO) antenna with orthogonal frequency division multiplexing (OFDM), which is an important area of research (Bouhlel et al., 2015). This is called MIMO-OFDM system. The use of multiple antennas helps to improve the performance of system by reducing BER or improving signal to noise ratio (SNR) (Mietzner et al., 2009).

In conventional OFDM, inter symbol interference (ISI) is mitigated using cyclic prefix (CP) and to increase the delay spread of the channel (Parveen et al., 2019). 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 (Bouhlel et al., 2015). In order to overcome this drawback, a technique involving the use of discrete wavelet transform based MIMO-OFDM is presented in this paper.

2. Discrete wavelet in wireless communication

Wireless communication plays a significant role in day to day life. Besides communication, wireless technology has become an integral part of our daily activities. The transmission of data or information from one place to another witlessly is referred as wireless communication. This provides an exchange of data without any conductor through radio frequency (RF) and radio signals. The information is transmitted across the devices over some meters to hundreds of kilometres through well-defined wireless channels. The term wireless refers to communication without wires, and the medium used is called in wireless communication is called unguided medium (Islam and Jin, 2019). In order to transmit information (voice or data) using wireless communication, there is need for antenna. The antenna is the device which couples RF energy from one medium (that is wave guide, transmission line and others) to the other medium (that is air). We require two systems viz. transmitter and receiver to complete end to end wireless link. Wireless communication uses electromagnetic waves as medium for carrying the information through the channel between transmitter and receiver. The primary and important benefit of wireless communication is mobility. Apart from mobility, wireless communication also offers flexibility and ease of use, which makes it increasingly popular day – by – day. Wireless Communication like mobile telephony can be made anywhere and anytime with a considerably high throughput performance.

2.1 Transmission capacity

The process of improving the transmission capacity is one of the challenges that face the wireless system. The challenge comes from bandwidth and power limitations due to the regulations. The following equation which is called Shannon Capacity Theorem shows the relationship between the bandwidth of the channel with signal to noise ratio (SNR) and the capacity of system in additive Gaussian noise channel. For the purpose of simplicity, MIMO channel capacity can be represented by the approximated formula below (Idowu-Bismark et al., 2017).

$$C \approx m\log_2(1+\mathrm{SNR}) \quad (1)$$

where C is the capacity in bits per second and m is the channel bandwidth in Hz. Increasing the transmission capacity can be achieved by efficient utilization the available bandwidth and improvement SNR parameter.

Diversity techniques are used to improve SNR by supplying the receiver with multiple independent replicas of the same signal by using different frequencies or different time points or using multiple antenna system. MIMO and OFDM systems are techniques that utilize the bandwidth efficiently by mitigation the effect of ISI.

2.2 Parallel transmission techniques

Parallel transmission schemes: the principle of simultaneous transmission techniques of signals which are used to overcome ISI and to achieve high transmission data rate, either by using signal processing or antenna solutions. The system performance is improved by diversity technique. Some of the techniques are: frequency diversity, time diversity, polarization diversity, angle diversity, antenna/Spatial diversity (Parveen, 2020). Multiple antennas are used to send signals with information to the receiver to provide multiple independent fading paths in space diversity. Spatial diversity is widely used as it is simple, cost effective, easy to implement and also reduces fast fading and inter-channel interference effects in the wireless network system (Awon, 2012). For the implementation of Multiple input and multiple output (MIMO) wireless communication systems physical diversity techniques such as time, space, frequency and polarization have been thoroughly studied (Patil and Kokate, 2014). In wireless communication Space diversity is one of the diversity schemes which includes two or more antennas to improve the quality and reliability of the wireless link between the transmitter and receiver (Ghosh and Mehedi, 2018).

2.3 Discrete wavelet transform

Redundancy and impracticality those are the main drawbacks of CWT to be implemented easily, which is firstly obvious from the nature of CWT, and secondly the continuity status of the parameters of CWT equation (Akansu and Haddad, 2001). Hence, the sampling solution had taken effect on the parameter (s,τ) to obtain set of wavelet functions in discrete form under condition of overcoming the redundancy problem (Akansu and Haddad, 2001).

Discretizing the scaling variable s in the form of s_0^m and transformation variable τ in the form of $n\tau_0 s_0^m$ so that:

$$\psi_{mn} = s_0^{-m/2}\psi\left(s_0^{-m}t - n\tau_0\right) \quad (2)$$

This forms the basis of discrete wavelet transform (DWT), the coefficients of a continuous-time signal $s(t)$ using dyadic scaling $s_0 = 2$ and $\tau_0 = 1$ are defined as (Xiong, 2010):

$$\begin{aligned} d_{m,n} &= \{s(t), \psi_{m,n}(t)\} \\ &= 2^{-m/2}\int s(t)\psi(t^{-m}t - n)dt \end{aligned} \quad (3)$$

The signal $s(t)$ can be reconstructed from its DWT coefficients via the inverse DWT process as:

$$s(t) = \sum_{m}\sum_{n} d_{m,n}\psi_{m,n}(t) \quad (4)$$

The representation of the signal $s(t)$ using L-scales (or resolutions) requires two functions; they are called scaling and wavelet functions (Xiong, 2010). The scaling function families $\phi_n(t)$ are constructed by time-shifted versions of the so-called parent scaling function $\phi(t)$ at only one scale. From other hand, the wavelet function families $\psi_{m,n}(t)$ are defined for all L-scales (or resolutions) (Xiong, 2010). The $s(t)$ can be expressed in terms of $\phi_n(t)$ and $\psi_{m,n}$ given by:

$$s(t) = \sum_{n=-\infty}^{\infty}(c_{L,n})2^{-L/2}\phi(2^{-L}t-n) + \sum_{m=1}^{L}\sum_{n=-\infty}^{\infty}(d_{m,n})2^{-m/2}\psi(2^{-m}t-n) \quad (5)$$

where m, n, positive constant integers, $c_{L,n}$ and $d_{m,n}$ are the scaling (or averaging) coefficient and wavelet coefficient respectively. These coefficients are obtained by projection of the signal $s(t)$ onto the scaling and wavelet functions according to the following equations (Xiong, 2010):

$$c_{L,n} = \{s(t), \phi_{L,n}(t)\} = \int s(t)2^{-L/2}\phi(2^{-L}t-n)dt \quad (6a)$$

$$d_{m,n} = \{s(t), \psi_{m,n}(t)\} = \int s(t)2^{-m/2}\psi(2^{-m}t-n)dt \quad (6b)$$

The scaling function $\phi(t)$ is only orthogonal to its transformations, whereas the wavelet function $\psi(t)$ is orthogonal to its scaling and to the transformation of its scaling. For orthogonal wavelet system, the scaling functions and the wavelet functions are orthogonal to each other (Xiong, 2010), therefore:

$$\int \phi_{m,k}(t)\psi_{m,k}(t)dt = 0 \quad (7)$$

The scaled function $\phi(2t)$ can be used to represent the parent scaling function $\phi(t)$ and the mother wavelet function $\psi(t)$ as follows:

$$\phi(t) = \sqrt{2}\sum_{n} h_n\phi(2t-n) \quad (8a)$$

$$\psi(t) = \sqrt{2}\sum_{n} g_n\psi(2t-n) \quad (8b)$$

where h_n and g_n are called scalar function coefficient and wavelet function coefficient respectively. The relationship between these coefficients is given by:

$$g_n = (-1)^n h_{(1-n)} \quad (9)$$

The scaling function and the wavelet function are used to extract the low frequency and high frequency components in the signal $s(t)$ respectively.

2.4 Haar wavelet

Most standard wavelets are based on one mother wavelet, which is a function with some special properties. The Haar wavelet is the simplest and oldest type of mother wavelet functions, developed by Alfred Haar (Hubbard, 1996). The set of Haar functions is defined as a group of square waves with magnitude ±1at some intervals and zero elsewhere and can be written as:

$$\psi(t) = \begin{cases} 1, & 0 \le t \le 0.5 \\ -1, & 0.5 \le t \le 1 \\ 0, & \text{elsewhere} \end{cases} \quad (10)$$

The constant function is annihilated by the Haar wavelet, and Haar wavelet families are orthogonal. The scaling function corresponding to the Haar wavelet has the value 1 for 0 < t < 1, and 0 for all other values of t (Hubbard, 1996). Figure 1 shows the Haar scaling and wavelet functions.

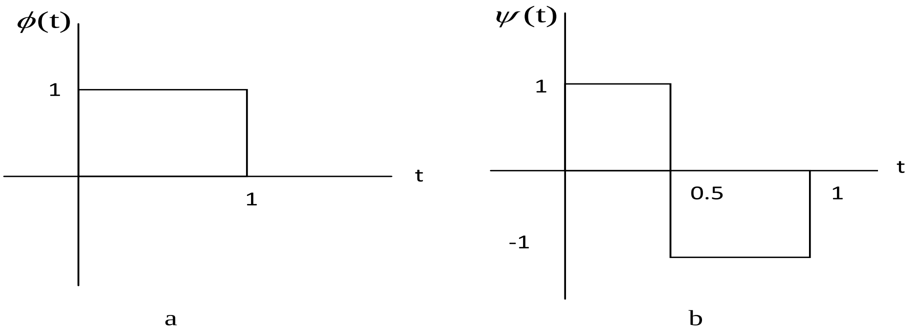

Fig. 1 - (a) Scaling Haar function; (b) Wavelet Haar function

2.5 Merits of using wavelets in wireless communication

In this section we will introduce a few features of wavelet transform. There are many features that motivate to use wavelet transform in wireless communication, such as:

1) Semi-arbitrary division of the signal space and multi-rate systems: Wavelet transform has the ability to create a different symbol length and bandwidth for the subcarriers.

2) Flexibility with time-frequency tiling: wavelets have also, the ability to arrange the time-frequency tiling in a case of minimizing the channel disturbances. In flexibly aligning the time-frequency tiling, the effect of noise and interference on the signal can be minimized. This can enhance the quality of service (QoS) of wireless systems (Lakshmanan and Nikookar, 2006, Prasad et al., 2011). With the promise of greater flexibility and improved performance against channel effects, wavelet based basis functions have emerged as strong candidates for MCM in wireless channels (Abdullah, 2010).

3) Waveform diversity: Wavelets give a new dimension to the physical diversities currently exist namely, space, frequency and time-diversity. Wavelet diversity which is similar to spread spectrum systems minimizes inter-cell interference (Lakshmanan and Nikookar, 2006, Prasad et al., 2011).

4) Sensitivity to channel effects: the performance of wavelet modulation scheme holds the promise of reducing the sensitivity of the system to harmful channel effects like inter-symbol interference (ISI) and inter-carrier interference (ICI) (Lakshmanan and Nikookar, 2006).

5) Flexibility with sub-carriers: wavelet transform allows for a configurable transform size and hence a configurable number of carriers. For instance, to reconfigure a transceiver according to a given communication protocol; the transform size could be selected according to the channel impulse response characteristics, computational complexity or link quality (Lakshmanan and Nikookar, 2006).

6) Power conservation: Wavelet-based algorithms have long been used for data compression. This added significance for mobile wireless devices, which are mostly energy starved, reduced volume of data means the power needed for transmission is also reduced (Lakshmanan and Nikookar, 2006).

Wavelets have found beneficial applicability in various aspects of wireless communication systems design including channel characterization, interference mitigation and de-nosing, modulation and multiplexing, multiple access communication, Ultra Wideband (UWB) communication, cognitive radio, and networking. 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 (Prasad et al., 2011).

3. Discrete wavelet transform based OFDM design

Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique that can be considered a transmultiplexer system that comprises synthesis and analysis parts. In this work, DWT is proposed as digital processing scheme for OFDM implementation capable of providing high performance. The orthogonality between the subcarriers in DWT is achieved by orthogonal wavelet filter banks. The block diagram design of DWT based OFDM as multicarrier transceiver digital system is shown in Fig. 2.

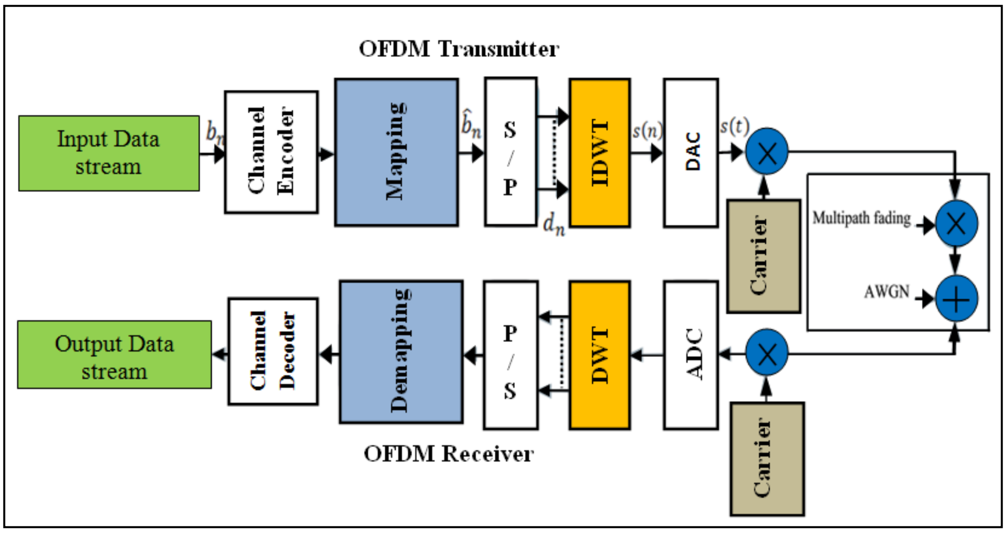

Fig. 2 – Block diagram of designed DWT based OFDM system

The block diagram of the DWT-OFDM system design consists of an inverse discrete wavelet transform (IDWT) at the transmitter, where mapping (or digital modulation) takes place and a DWT at the receiver, where demapping demodulation occurs. There are no cyclic prefix (CP) blocks at the transmitter and the receiver, which differentiates it from conventional OFDM, which is FFT (DFT) based. This is because wavelets have overlapping nature and as such DWT based OFDM has very high spectral containment and therefore no need for a CP to solve the problem of delay spreads of the channel. The transmitter, the DWT-OFDM channel and the receiver are discussed in the following subsections.

3.1 Transmitter

At the transmitter, input data stream or sequence of bits from data source is passed to channel encoder and after that mapping is performed to modulate the encoded data stream into stream of symbols. This stream of symbols is passed through a serial to parallel (S/P) converter, resulting to N lower data stream at dyadic sub rate of source rate. Subsequently, IDWT will be applied to the N-data stream and generating the sequence $s(n)$ at the data source rate. Then $s(n)$ is converted to analogue signal by digital to analogue converter (DAC) and is passed to the radio frequency (RF) modulation (represented by carrier block) and then to the wireless channel. Modulation schemes considered in this work at the transmitter are binary phase-shift keying (BPSK) .The processes at transmitter side are discussed as follows.

3.2 The DWT-OFDM channel

The transmitted signal is passed through wireless communication channel such as an Additive Gaussian Noise Channel (AGWN) or multipath (or Rayleigh) channel. Orthogonality between carriers is lost after the transmitted signal passes through a non-uniform channel resulting to interference. However, the amount of interference between carriers in wavelet systems is much lower than in Fourier systems since side lobes contain to a large extent less energy, so the Inter Carrier interference is reduced is wavelet based OFDM.

3.3 Receiver design

Demodulation of RF takes place at the receiver. The first process at the receive end is the conversion of the received signal $r(t)$ from analogue to digital as it passing through the ADC. The DWT scheme is applied to the sample points of the received signal $r(n)$ and produces the recovered data symbols $d(n)$. The sequence $d(n)$ is multiplexed using parallel to serial (P/S) converter. Demodulation or demapping, decisions and decoding process is carried out on the received signal symbols in a similar manner as any other digital communication system.

4. Results and discussion

The performance of the proposed Discrete Wavelength Transform (DWT) based MIMO-OFDM system to enhance transmission capacity is presented in this section. The analysis of the system is carried out in terms of BER. The curves of DWT and discrete Fourier transform (DFT) based OFDM (multicarrier) system with BER as a function of signal to noise ratio (SNR) are evaluated in MATLAB simulation environment. The simulation results are shown in Fig. 3 to 6.

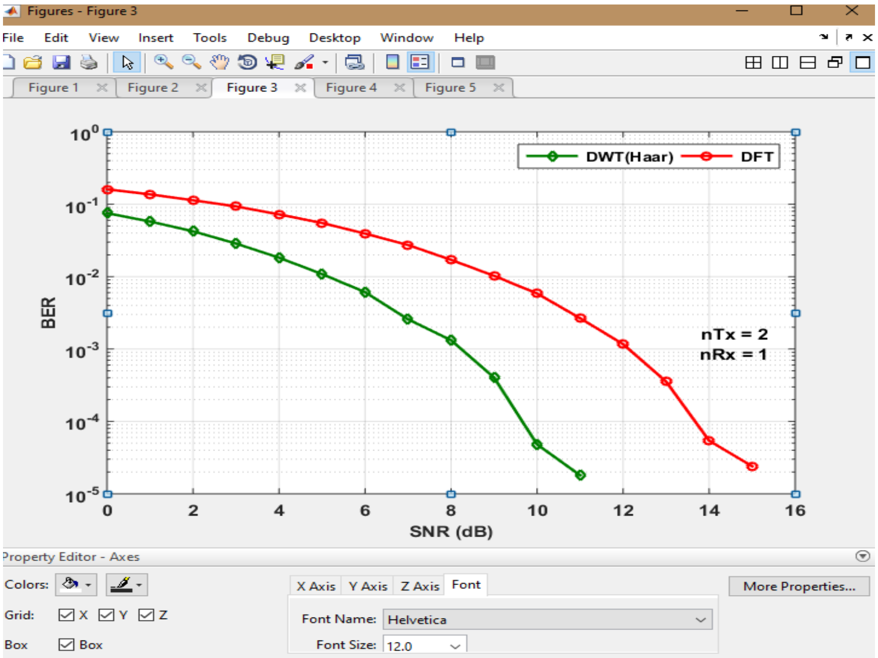

Fig. 3 – BER performance of DWT and DFT based MISO-OFDM system (2 X 1)

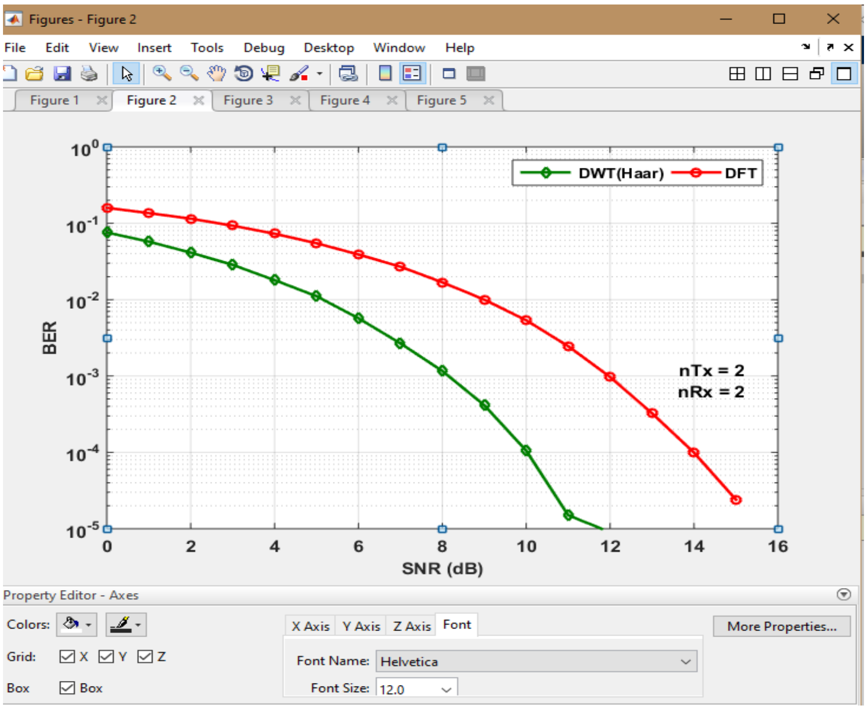

Fig. 4 – BER performance of DWT and DFT based MIMO-OFDM system (2 X 2)

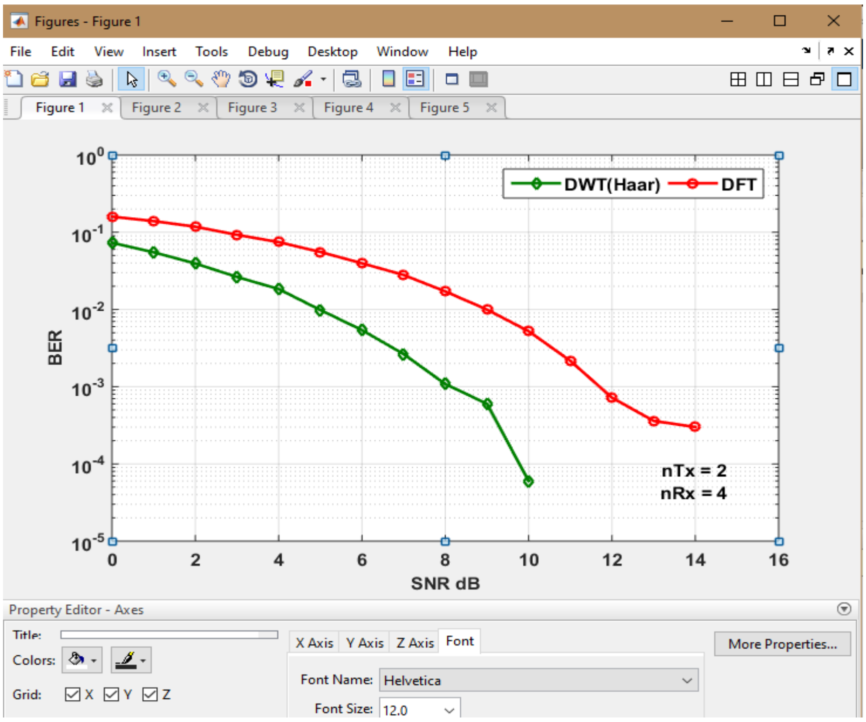

Fig. 5 – BER performance of DWT and DFT based MIMO-OFDM system (2 X 4)

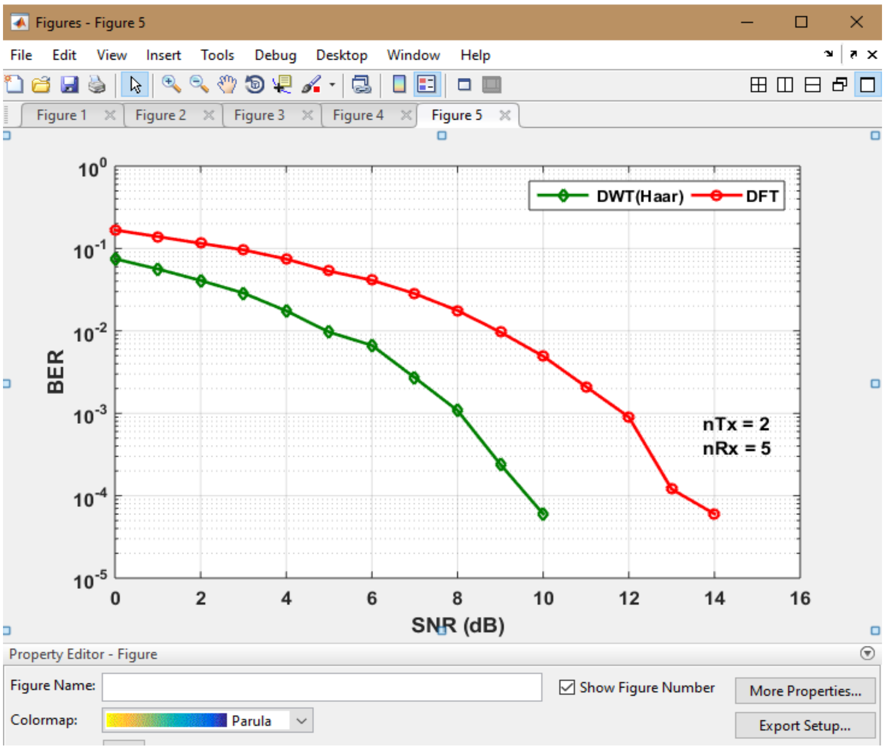

Fig. 6 – BER performance of DWT and DFT based MIMO-OFDM system (2 X 5)

The simulation results of the BER performance graph of DWT and DFT based MIMO-OFDM systems, with the transmit antenna fixed at 2 while varying the number of receive antennas. Nevertheless, since the receive number of antennas are varied for fix multiple transmit number of antennas, a multiple input single output (MISO) case was also considered during the simulation as shown in Fig. 3. Other simulation results due to multiple input multiple output are shown in Fig. 4 to 6. The simulation analyses performed for the various BER curves given fixed multiple transmit antennas; it can be seen from to Fig. 3 to 6 that the BER decreases as the number of receive antennas increases over all values of SNR which can be logically attributed to fact that when the same signal is received more than once, and are combined at the receive output, this results in SNR improvement of receive signal. In other words, there is improvement in SNR as a result of increase in antenna diversity and to array gain in which more antennas at the receiver means more power received. Generally, it can be seen from the numerical analysis that BER of 2×2 is less than that of 2×1, 2×4 is less than that of 2×2 and so on for both DWT based OFDM and DFT based OFDM. However, the performance analysis tables showed that DWT based OFDM system outperformed DFT based OFDM system in all cases.

Generally, it was observed that DWT technique offered better BER and data rate qualities than DFT at the same number of randomly generated data of BPSK modulation and the transmitter power. Hence, DWT based MIMO-OFDM is more efficient than conventional (DFT) MIMO-OFDM. The simulation of DFT alongside DWT was performed to validate the study and to show that DWT outperforms DFT and provides better transmission capacity. Hence, using DWT as a multicarrier modulation scheme in MIMO-OFDM will certainly improve transmission capacity and eliminate cost burden caused by extra subcarriers required to provide cyclic prefix as in DFT based MIMO-OFDM.

Acknowledgements

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