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PERFORMANCE COMPARISON OF OFDM SYSTEM BASED ON DMWTCS, DWT, AND FFT USING QAM MODULATION TECHNIQUE

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is a popular modulation technique that is widely utilized in many wireless communication systems. Traditional OFDM based on fast Fourier transform (FFT) involves the use of a rectangular window; consequently, high side lobes are created. Hence, OFDM based on discrete multiwavelet critical sampling transform (DMWTCS) is proposed in this paper. DMWTCS is more flexible in terms of data rate and has much lower side lobes than OFDM based on FFT. Given that the multiwavelet can overlap both in time and frequency domains and eliminates the need for a cyclic prefix, OFDM based on DMWTCS has higher bandwidth efficiency than OFDM based on FFT. In this paper, the performance of OFDM based on DMWTCS is compared with that of traditional OFDM based on FFT and OFDM based on discrete wavelet transform (DWT) through the use of various quadrature amplitude modulation (QAM) constellation points, such as 4-QAM, 8-QAM, and 16-QAM. These systems are examined in additive white Gaussian noise (AWGN), flat fading, and frequency-selective fading channels through MATLAB software. Simulation results reveal that the performance of the proposed system is better than that of the other two systems in all types of channels.

Keyword: OFDM, multiwavelet transform, critical sampling processing, QAM.

INTRODUCTION

The demand for high-speed mobile wireless communication is rapidly increasing. Orthogonal frequency division multiplexing (OFDM) technology promises to be a key technique to achieve high data capacity and spectral efficiency requirements for wireless communication systems in the near future. OFDM is a special form of multicarrier transmission where all subcarriers are orthogonal to one another [1]. The principle of OFDM involves splitting a wideband signal at a high symbol rate into several low-rate signals by dividing the input data stream into parallel sub-streams, with each stream being modulated on a set of sub-channels at different orthogonal carrier frequencies [2]. A frequency selective wideband channel is transformed into a group of nonselective narrowband channels in this technique; thus, large delay spreads are prevented by preserving orthogonality in the frequency domain [3].

OFDM is widely applied in different wireless communication standards, such as digital audio/video broadcasting, ETS1 HIPERLAN/2 standard, IEEE 802.11a standard for wireless local area networks (WLAN), and IEEE 802.16a standard for wireless metropolitan area networks (WMAN), because of its robustness to multipath fading and its capability to provide high bandwidth efficiency and high data rate transmission [4, 5].

Fast Fourier transform (FFT) is utilized to reduce implementation complexity and satisfy the required orthogonality between subcarriers [6]. A significant disadvantage of FFT is that it involves the use of a rectangular window, which creates high side lobes and results in increased sensitivity of the OFDM system to inter-carrier interference (ICI) and narrowband interference (NBI). Moreover, the pulse shaping function utilized to modulate each subcarrier extends to infinity in the frequency domain. This condition degrades performance and creates high interference [7]. Inter-symbol interference (ISI) and ICI can be eliminated by adding a cyclic prefix (CP) into each OFDM symbol, which is a copy of several samples from the end of the OFDM symbol, and appending them to the beginning of the OFDM symbol; however, spectrum efficiency would be reduced [7].

Studies conducted in recent years aimed to enhance the performance of the OFDM system by reducing ISI and ICI and improving spectrum efficiency by reducing bandwidth waste, which is produced by adding CP. These studies were performed by replacing FFT with other transform methods. The authors of [8] observed that ISI and ICI, which are caused by the loss of orthogonality among subcarriers, can be reduced in OFDM systems by replacing FFT with discrete wavelet transform (DWT). The authors of [9] investigated the performance of the OFDM system based on a wavelet with different families, such as Haar, Daubechies, bi-orthogonal, and reverse bi-orthogonal wavelets. They found that the Haar wavelet provides a very good platform for wireless communication with minimum bit error rate (BER), ISI, and peak average power ratio (PAPR). Furthermore, the authors of [10] reported that OFDM systems become flexible, robust to narrowband interference, and spectrally efficient by replacing FFT with discrete wavelet packet transform (DWPT). Reference [11] presented OFDM systems that employ

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slantlet transform (SLT) instead of FFT to reduce the level of interference and therefore improve the bandwidth efficiency of OFDM by removing the need for a guard interval (GI).

Multiwavelet is a new concept proposed recently [12]. Multiwavelet, which is a natural extension of wavelet, is designed to be simultaneously symmetric, orthogonal, and have short supports with high approximation power, which cannot be achieved simultaneously by wavelet using only one scaling function [12]. The idea is to increase the number of scaling functions to raise the approximation power rather than use one scaling function. Multiwavelet enhances the performance of many wavelet applications, such as image coding and denoising [12, 13]. Given its features, multiwavelet is suitable for OFDM systems.

In this study, discrete multiwavelet critical sampling transform (DMWTCS) is utilized for OFDM systems to achieve better BER performance than conventional OFDM using FFT and DWT. The main objective of this study is to compare the performance of OFDM based on DMWTCS with that of two other systems through the use of various quadrature amplitude modulation (QAM) constellation points in a wireless channel.

The rest of this paper is organized as follows. A brief introduction of multiwavelet transform is presented in section 2. The proposed system for OFDM based on DMWTCS is presented in section 3. The simulation results are discussed in section 4, and the conclusions are presented in section 5.

MULTIWAVELET TRANSFORM

Multiwavelet has two or more scaling and wavelet functions, whereas wavelet has one scaling and one wavelet function. The multiwavelets studied to date consist of two scaling and two wavelet functions. Multiwavelet scaling and wavelet functions can be represented by the following equations [14].

$$\phi(t) = \sqrt{2}\sum_{k=-\infty}^{\infty} H_k\,\phi(2t-k) \qquad (1)$$

$$\psi(t) = \sqrt{2}\sum_{k=-\infty}^{\infty} G_k\,\phi(2t-k) \qquad (2)$$

where H_k and G_k are the filter coefficients of scaling and wavelet functions, respectively. $\sqrt{2}$ maintains the norm of the scaling and wavelet functions with a scale of two. For multiwavelets, both H_k and G_k are matrices for each integer k.

Figure-1 shows a 1-level of analysis/synthesis for 1D discrete multiwavelet transform (DMWT). Blocks H and G are low- and high-pass analysis filters, and $\tilde{H}$ and $\tilde{G}$ are low- and high-pass synthesis filters.

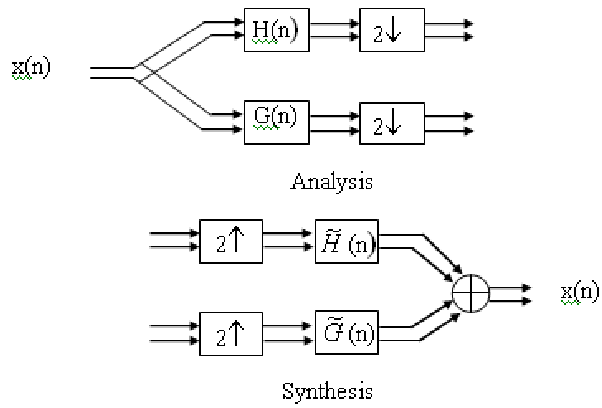

Figure-1. Analysis and synthesis stages of 1D single-level DMWT.

An important difference between multiwavelets and wavelets is that each channel in the filter bank has a vector-valued input and a vector-valued output (as shown in Figure-1). A scalar-valued input signal must be converted into a suitable vector-valued signal. This conversion is called preprocessing [15]. The aim of preprocessing is to affiliate the given scalar input data stream with duration N with two vectors to begin the multiwavelet transformation process. Preprocessing is a mapping process implemented with a pre-filter in the analysis stage. Naturally, a matching post-filter operation occurs in the synthesis stage; this operation exactly reverses the effects of the pre-filter. Two methods of preprocessing to compute DMWT, namely, repeated row and critically sampled, are available for use. In repeated row preprocessing, the input stream is repeated with the same stream multiplied by a constant [16]. Repeated row preprocessing doubles the input data symbols. In critically sampled preprocessing, the two vectors are obtained by preprocessing the given input stream [17]. Critically sampled preprocessing based on second-order approximation preprocessing can be summarized as equations (3) and (4), where every two rows generate two new rows [17].

a) For odd rows

$$\begin{aligned}\text{new odd row} &= (10/8\sqrt{2})[\text{same odd row}]+\\ &(3/8\sqrt{8})[\text{next even row}]+\\ &(3/8\sqrt{2})[\text{previous even row}]\end{aligned} \qquad (3)$$

b) For even-rows

$$\text{new even row} = [\text{same even row}] \qquad (4)$$

When processing the first odd row, the previous even row in equation (3) should be zero. Critically sampled preprocessing maintains the same data rate of input symbols; therefore, it was proposed in this work.

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Similar to wavelet analysis, multiwavelet analysis has many types. Geronimo, Hardian, and Massopust proposed a useful multiwavelet filter called GHM. GHM filter offers a combination of orthogonality, symmetry, and compact support, which are important in signal processing [18]. In the GHM system, H_k consists of four scaling matrices, namely, H_0, H_1, H_2, and H_3, as shown in equation (5). G_k consists of four wavelet matrices, namely, G_0, G_1, G_2, and G_3, as shown in equation (6) [18].

$$H_0=\begin{bmatrix}\frac{3}{5\sqrt{2}} & \frac{4}{5}\\ \frac{-1}{20} & \frac{-3}{10\sqrt{2}}\end{bmatrix}, H_1=\begin{bmatrix}\frac{3}{5\sqrt{2}} & 0\\ \frac{9}{20} & \frac{1}{\sqrt{2}}\end{bmatrix}, H_2=\begin{bmatrix}0 & 0\\ \frac{9}{20} & \frac{-3}{10\sqrt{2}}\end{bmatrix}, H_3=\begin{bmatrix}0 & 0\\ \frac{-1}{20} & 0\end{bmatrix} \quad (5)$$

$$G_0=\begin{bmatrix}\frac{-1}{20} & \frac{-3}{10\sqrt{2}}\\ \frac{1}{10\sqrt{2}} & \frac{3}{10}\end{bmatrix}, G_1=\begin{bmatrix}\frac{9}{20} & \frac{-1}{\sqrt{2}}\\ \frac{-9}{10\sqrt{2}} & 0\end{bmatrix}, G_2=\begin{bmatrix}\frac{9}{20} & \frac{-3}{10\sqrt{2}}\\ \frac{9}{10\sqrt{2}} & \frac{-3}{10}\end{bmatrix}, G_3=\begin{bmatrix}\frac{-1}{20} & 0\\ \frac{-1}{10\sqrt{2}} & 0\end{bmatrix} \quad (6)$$

PROPOSED SYSTEM MODEL

The proposed OFDM based on the DMWTCS system model is shown in Figure-2. The transmitter accepts serial binary source information and converts it into low-rate sequences via serial to parallel conversion. These low-rate sequences are mapped to provide sequences of channel symbols. This process converts data to the corresponding value of M-ary constellation, which is a complex word (i.e., real and imaginary parts). The training sequence (pilot sub-carriers) is then inserted. N-point inverse discrete multiwavelet critical sampling transform (IDMWTCS) is applied to the signal to achieve orthogonality between subcarriers. Zeros are inserted in several bins of IDMWTCS to make the transmitted spectrum compact and reduce the adjacent carriers' interference. Finally, the data are sent to the receiver over the channel after being converted to a frame structure (serial data stream). The frame structure consists of modulated data and the pilot signal, which is utilized for estimation and compensation.

Given that CP is not added to OFDM symbols in the proposed system, the data rates in OFDM based on DMWTCS are therefore higher than those in traditional OFDM based on FFT.

At the receiver side, the inverse operations are performed in a reverse order to yield the correct data stream. The received signal is converted to a parallel version via serial to parallel conversion. N-point DMWTCS is performed, and the zero pads are removed. The training sequence is then utilized to estimate the channel frequency response as follows:

$$H(k)=\frac{Received\ \ Training\ \ Sample(k)}{Transmitted\ \ Training\ \ Sample(k)}, k=1,2,....,N \quad (7)$$

The channel frequency response obtained in equation (7) is employed to compensate the channel effects on the data. Estimated data can be obtained with the following equation:

$$Estimate\ \ data(k)=H^{-1}(k)*Received\ \ data(k),\ k=1,2,.....,N \quad (8)$$

Finally, the output of the channel compensator passes through the signal demapper, and the type of signal demapper is the type used in the transmitter.

Fast computation for single-level DMWTCS can be accomplished through the following steps.

a) The length of input vector N should be of a power 2.
b) The GHM filter coefficients given in equations (5) and (6) are utilized to generate the transformation matrix (W) with size $N/2*N/2$, which is provided in equation (9).

$$W=\begin{bmatrix}H_0 & H_1 & H_2 & H_3 & 0 & 0 & \cdots & 0 & 0 & 0 & 0\\ 0 & 0 & H_0 & H_1 & H_2 & H_3 & \cdots & 0 & 0 & 0 & 0\\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots\\ H_2 & H_3 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & H_0 & H_1\\ G_0 & G_1 & G_2 & G_3 & \vdots & \vdots & \cdots & 0 & 0 & 0 & 0\\ 0 & 0 & G_0 & G_1 & G_2 & G_3 & \cdots & 0 & 0 & 0 & 0\\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \vdots\\ 0 & 0 & 0 & 0 & 0 & 0 & \cdots & G_0 & G_1 & G_2 & G_3\\ G_2 & G_3 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & G_0 & G_1\end{bmatrix} \quad (9)$$

Given that H_i and G_i are 2*2 matrices, an $N*N$ transformation matrix is obtained after substituting the GHM filter coefficients in equation (9).

c) Preprocessing of the input signal through critically sampled preprocessing based on second-order approximation is implemented by applying equations (3) and (4) to odd and even rows of input stream, respectively, to generate two new rows.
d) Transformation of input vector is accomplished by applying matrix multiplication to the $N*N$ constructed transformation matrix (W) via the $N*1$ preprocessing input vector.

To illustrate the computation of DMWTCS, we let X be input vector $X=[1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6\ \ 7\ \ 8]^T$, where T refers to the transpose process. For an 8*1 input signal, X, a 4*4 transformation matrix, W is constructed by using GHM low- and high-pass filters.

$$W=\begin{bmatrix}H_0 & H_1 & H_2 & H_3\\ H_2 & H_3 & H_0 & H_1\\ G_0 & G_1 & G_2 & G_3\\ G_2 & G_3 & G_0 & G_1\end{bmatrix}$$

For second-order approximation preprocessing, equations (3) and (4) are utilized for odd and even rows. The result is

$$P=[1.1490, 2.0000, 3.7123, 4.0000, 6.2756, 6.0000, 8.8388, 8.0000]^T$$

Transformation of the input vector is implemented as follows:

$$[Y]=[W]*[P]$$

$$Y=[3.6625, 5.1265, 11.2125, 7.9549, -0.5303, -0.1125, -3.3588, -3.5125]^T$$

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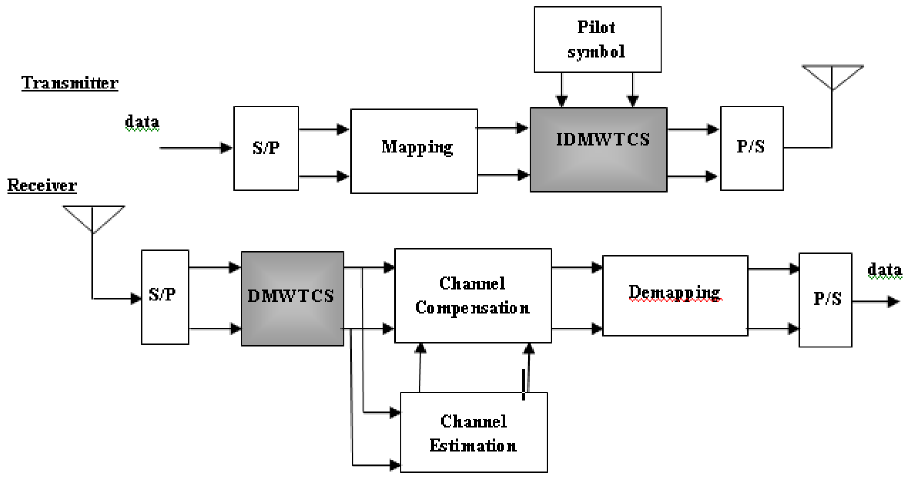

Figure-2. Transceiver of the proposed system.

SIMULATION RESULTS

The proposed OFDM-DMWTCS system was simulated with MATLAB (V7.8), and its BER performance was compared with that of OFDM-DWT and OFDM-FFT systems under 4-QAM, 8-QAM, and 16-QAM. Haar wavelet [19] was employed for DWT because of its simplicity. The BER against bit energy to noise power spectral density ratio (E_b/N_o) of these systems was analyzed in AWGN, flat fading, and frequency-selective fading channels. The fading channel was considered a Rayleigh fading channel modeled as Jake's model [20]. Channel effect was assumed to be constant on each packet frame. Therefore, block-type pilot channel estimation [21] was employed. Table-1 shows the parameters and their values in the system utilized in the simulation.

Table-1. Simulation parameters.

Parameter	Value
System bandwidth	10MHz
Number of transmitted bits	100,000
Number of DMWTCS, DWT, FFT points	64
Number of CP	16, used in OFDM-FFT only

Figures 3, 4, and 5 present the performance of the proposed system (OFDM-DMWTCS) compared with that of OFDM-DWT and OFDM-FFT systems in the AWGN channel using 4-QAM, 8-QAM, and 16-QAM, respectively. The Figures show that OFDM-DMWTCS performs much better than the two other systems (OFDM-DWT and OFDM-FFT) in all types of modulation because the orthogonality between subcarriers in DMWTCS is more significant than that in DWT and FFT. For example, as shown in Figure-3, BER = 10^{-4} resulted in 1.8 dB and 15.6 dB improvement for the proposed system compared with the OFDM-DWT and OFDM-FFT, respectively. Although using a higher constellation point is better for high data rate transmission, it results in noise enhancement because the points on constellation mapping become very close to one another; thus, the transmission becomes less robust to errors. Performance is reduced as the number of constellation mapping points increase from 4 to 16.

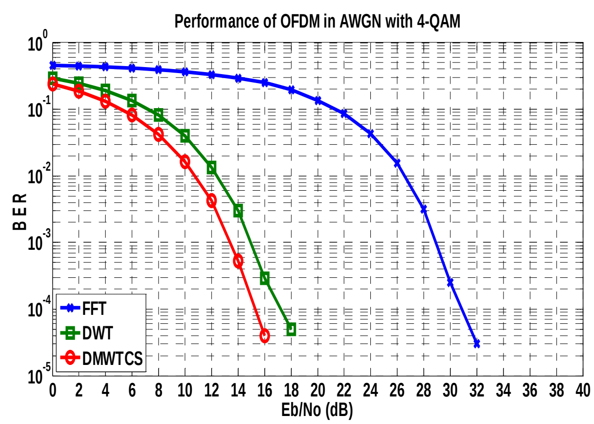

Figure-3. BER performance of DMWTCS, DWT, and FFT-OFDM for 4-QAM modulation in the AWGN channel.

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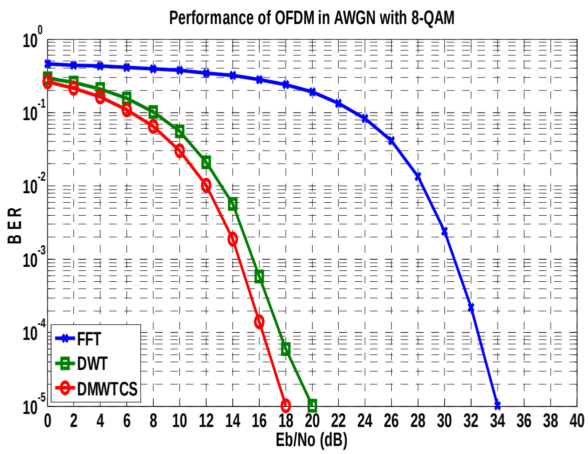

Figure-4. BER performance of DMWTCS, DWT, and FFT-OFDM for 8-QAM modulation in the AWGN channel.

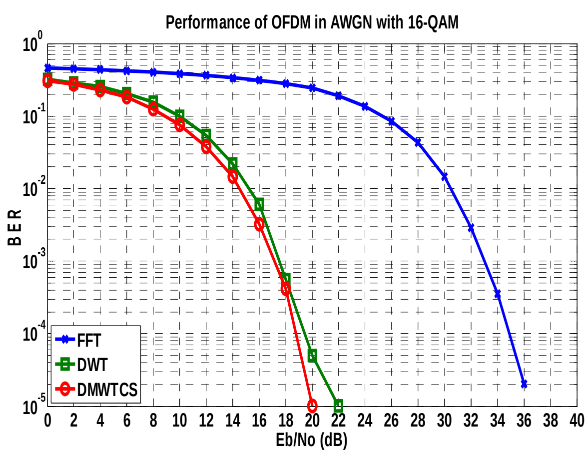

Figure-5. BER performance of DMWTCS, DWT, and FFT-OFDM for 16-QAM modulation in the AWGN channel.

Figures 6, 7, and 8 show the performance of the proposed system in comparison with that of the two other systems in a flat Rayleigh fading channel as well as AWGN using 4-QAM, 8-QAM, and 16-QAM, respectively. The Doppler frequency considered was 10 Hz (slow fading). The performance of the proposed system is superior to that of the other systems in all types of modulation. For instance, as shown in Figure-6, the proposed system has BER of 10^{-4} at E_b/N_o = 17.8 dB. OFDM-DWT has the same BER at E_b/N_o = 19 dB, and OFDM-FFT has the same BER at E_b/N_o = 33 dB.

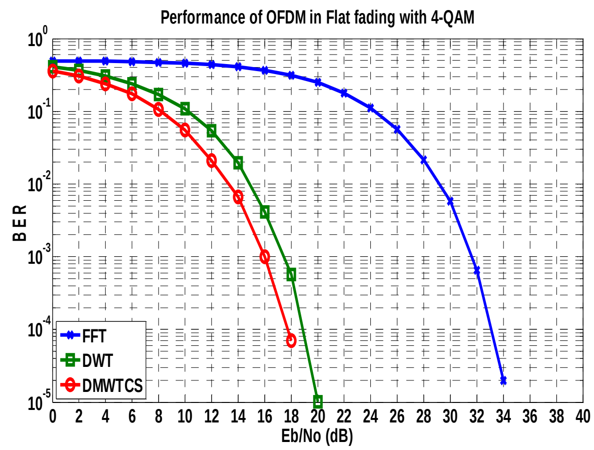

Figure-6. BER performance of DMWTCS, DWT, and FFT-OFDM for 4-QAM modulation in the flat fading channel.

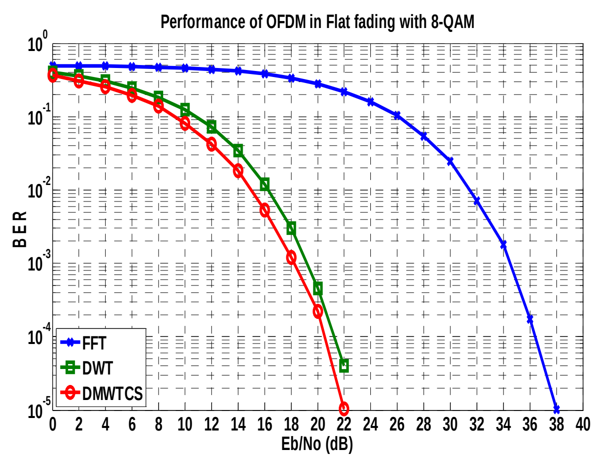

Figure-7. BER performance of DMWTCS, DWT, and FFT-OFDM for 8-QAM modulation in the flat fading channel.

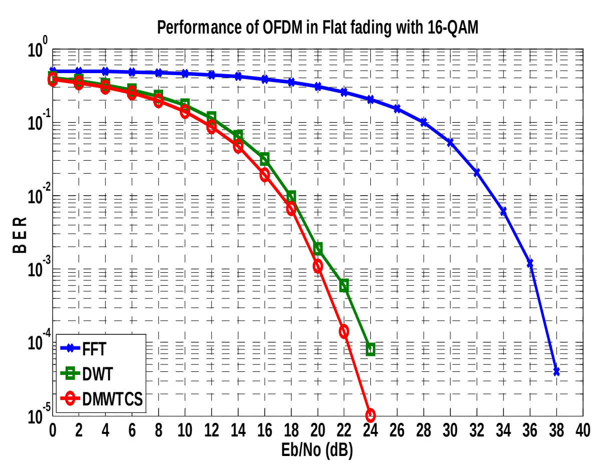

Figure-8. BER performance of DMWTCS, DWT, and FFT-OFDM for 16-QAM modulation in the flat fading channel.

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The comparison of the performance of the three systems in a frequency-selective Rayleigh fading channel and AWGN using 4-QAM, 8-QAM, and 16-QAM is illustrated in Figures 9, 10, and 11, respectively. Two paths were selected; the second path has a path gain of -10 dB and a path delay of 8 samples. Obviously, as seen in Figures 9 and 10, the proposed system is more robust in the frequency-selective fading channel compared with OFDM-DWT and OFDM-FFT. Figure-11 shows that the BER performance of OFDM-DMWTCS and OFDM-DWT becomes constant after a certain value of E_b/N_o. For OFDM-DMWTCS, the BER becomes constant at 6 $*10^{-3}$ after E_b/N_o of approximately 35 dB. For OFDM-DWT, the BER becomes constant at $8*10^{-3}$ after E_b/N_o of approximately 34.5 dB. Figure-11 indicates that the BER curves of OFDM-FFT decrease with the increase in E_b/N_o. Hence, in the frequency-selective fading channel and 16-QAM modulation, OFDM-DMWTCS and OFDM-DWT do not outperform OFDM-FFT in all the E_b/N_o values. OFDM-DMWTCS is better than OFDM-FFT up to approximately E_b/N_o = 35 dB, whereas OFDM-DWT is better than OFDM-FFT up to approximately E_b/N_o = 34.5 dB. After these values, OFDM-FFT outperforms the other two systems because CP that already exists in OFDM-FFT eliminated ISI; thus, no ISI occurred in OFDM-FFT. In the case of OFDM-DMWTCS and OFDM-DWT, no CP exists; hence, ISI occurred and resulted in the loss of orthogonality between sub-carriers and the occurrence of ICI.

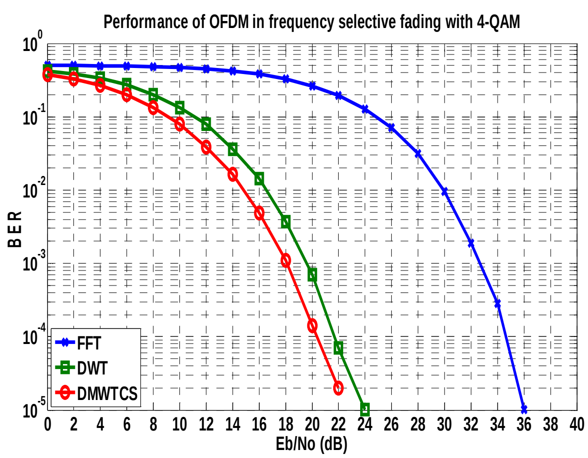

Figure-9. BER performance of DMWTCS, DWT, and FFT-OFDM for 4-QAM modulation in the frequency-selective fading channel.

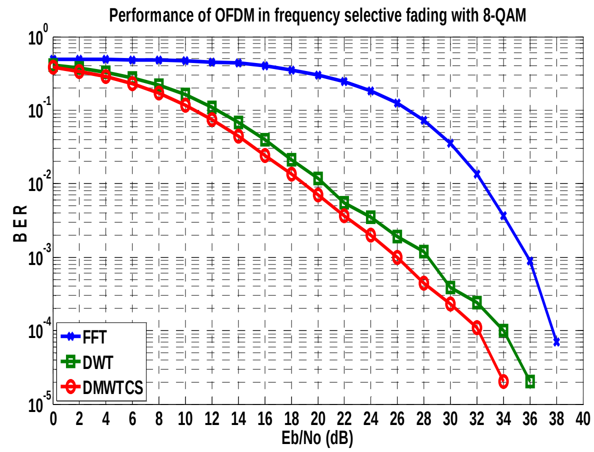

Figure-10. BER performance of DMWTCS, DWT, and FFT-OFDM for 8-QAM modulation in the frequency-selective fading channel.

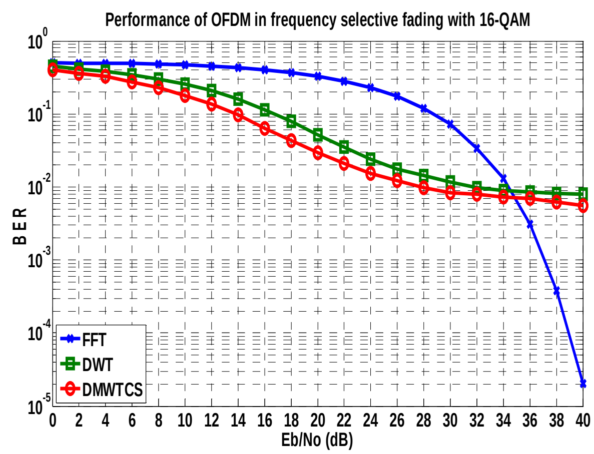

Figure-11. BER performance of DMWTCS, DWT, and FFT-OFDM for 16-QAM modulation in the frequency-selective fading channel.

CONCLUSIONS

An OFDM system based on DMWTCS was proposed and compared with OFDM based on DWT and traditional OFDM based on FFT through the use of various QAM constellation points, such as 4-QAM, 8-QAM, and 16-QAM. The performance of the systems was tested and compared in three types of channels, namely, AWGN, flat fading, and frequency-selective channels. The comparison of different constellation points for the systems indicates that although using a high M-ary constellation achieves high data rate transmission, doing so enhances noise and degrades the performance of the proposed system. Thus, the trade-off between data rate and the amount of noise at the receiver must be considered.

Simulation results indicated that the proposed system is better than OFDM-DWT and OFDM-FFT in AWGN and flat fading channels and in all type of QAM constellation points mentioned above. In the frequency-selective fading channel, the proposed system is better than the other two systems at 4-QAM and 8-QAM. At 16-QAM the BER performance of OFDM-DMWTCS and OFDM-DWT is better than that of OFDM-FFT until a certain value of E_b/N_o. After this value, OFDM-FFT outperforms OFDM-DMWTCS and OFDM-DWT because CP already exists in OFDM-FFT. CP eliminates ISI. Thus, no ISI occurred in OFDM-FFT. By contrast, no CP exists in OFDM-DMWTCS and OFDM-DWT; thus, ISI occurred, destroyed the orthogonality between sub-carriers, and led to the occurrence of ICI. Hence, more equalization complexity should be utilized with the proposed system to achieve high data rate in the frequency-selective fading channel.

Finally, the proposed system can be utilized as an alternative to conventional OFDM. OFDM based on DMWTCS has higher bandwidth efficiency than OFDM based on FFT because of the good orthogonality of DMWTCS. ISI and ICI are reduced. Thus, the use of CP in the proposed system is unnecessary.

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