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The effect of wavelet transform on OFDM system in modern cellular networks

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ABSTRACT

The performance of OFDM (Orthogonal Frequency Division Multiplexing) proved that it was an excellent technique for 4G.It provides good spectrum efficiency and it has excellent throughput in different situations. This technique can be improved to be suitable for 5G systems. Wavelet transform has many advantages that make it suitable and efficient approach to replace Fast Fourier Transform (FFT) in conventional OFDM systems. Wavelet transform is employed in modern cellular networks to remove the use of cyclic prefix, which leads to decreasing the bandwidth losses and the power of transmission. Wavelet based OFDM system is designed in order to overcome the drawbacks of OFDM system so that the proposed system is good candidate for next generation of wireless communications.

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1. INTRODUCTION

In spite of the fact that OFDM is playing an important role in current generation of wireless networks, it has drawbacks that must be enhanced. The properties of FFT spectrum are poor for high degree of spectral leakage and the transmission is inefficient which produces low data rate [1]. At the same time, OFDM has frequency offset in its signal, which makes the system more sensitive to the errors of synchronization [2]. Another, significant factor in OFDM system is cyclic prefix (CP) which is used to make delay spread of the channel longer than impulse response of the channel. CP reduces the power efficiency and throughput but on the other hand, CP is the main cause of minimizing inter-symbol interference (ISI) [3-4]. For these reasons, this work suggests applying Discrete Wavelet Transform (DWT) in the system instead of FFT since DWT isn't using CP and has low level of error i.e. low bit error rate (BER) [5]. Wavelet transform has the ability to extract information from data, images and audio signals [1]. It could also be said that, DWT gives more accurate information than FFT (as the results prove in this work).

2. ORTHOGONAL DISCRETE WAVELET TRANSFORM

Wavelet transform can be defined as a technique used to represent the functions and data; this signal processing and mathematical technique is used to represent real life signals with high level of efficiency [6]. Discrete wavelet transform has many advantages that make the researchers looking forward to use this technique in wireless communications. It has the ability of multi-resolutions, frequency spread and its wavelets have spatial localized nature [7].

DWT, which derived from Continuous Wavelet Transform (CWT), has two projections to provide its coefficients; they are coarse and fine projections. The coarse projection produces the coefficients $\alpha(J)$, together with the wavelet (finer projection) coefficients β(1), β(2), . . ., β(J) depending on J-level filter bank (octave band) [8-9].

On the other hand, the J-level orthogonal DWT of a sequence x is a function of ℓ ∈ {1, 2, . . . , J} as the following equation [8]:

$$a_k^{(j)} = < x_n, g_{n-2^J k}^{(J)} > n = \sum_{n\in Z} x_n\, g_{n-2^J k}^{(J)}, \tag{1}$$

$$\beta_k^{(\ell)} =< x_n, h_{n-2^\ell k}^{(\ell)} > n = \sum_{n\in Z} x_n\, h_{n-2^\ell k}^{(\ell)}, \ell \in \{1,2,\dots,J\} \tag{2}$$

On the other hand, IDWT is given by the equation [8]:

$$x_n = \sum_{k\in Z} \alpha_k^{(J)}\, g_{n-2^J k}^{(J)} + \sum_{\ell=1}^{J} \sum_{k\in Z} \beta_k^{(\ell)} h_{n-2^\ell k}^{(\ell)} \tag{3}$$

Note that $\alpha^{(J)}$ are the scaling coefficients while $\beta^{(\ell)}$ are the wavelet coefficients [8]. Consequently, $g^{(J)}$ is the scaling sequence and $h^{(\ell)}$ wavelets have the sequence of $\ell = 1, 2, \dots,$ J.

3. HAAR WAVELET TRANSFORM

Waveltet transform can be done using many types of filters such as Dmey filter and Haar filter. Haar wavelet transform is the simplest wavelet analysis and is based on square waves called Haar scaling function. This function has magnitude of 1 for time t=0 to t=1 as expressed in (1) [10] while the Haar transform matrix will be as (4).

$$(t) = \begin{cases} 1, for\ 0 \le t < 1 \\ 0\ otherwise \end{cases} \tag{4}$$

$$H_{2N} = \frac{1}{\sqrt{2}} \begin{bmatrix} H_N \otimes [1,1] \\ I_N \otimes [1,-1] \end{bmatrix} \tag{5}$$

H1 =one, IN is the identity matrix and the symbol ⊗ is the Kronecker product [10]. In this work Haar wavelet is used because of its simple analyses and it gives the best PAPR performance as mentioned in [11].

4. DISCRETE WAVELET ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (DWT-OFDM) SYSTEM

The proposed system in this work depends on the advantages of orthogonality and removing CP of DWT to improve the performance of OFDM. The main goal of this system is removing CP to increase the power efficiency and throughput and reduce the bit error rate as will be shown in the results.

The design is done though including Inverse Discrete Wavelet Transform (IDWT) instead of Inverse Fast Fourier Transform (IFFT) in the transmitter as shown in Figure 1. In the same way, the receiver side has Discrete Wavelet Transform (DWT) instead of Fast Fourier Transform (FFT) as illustrated in Figure 2.

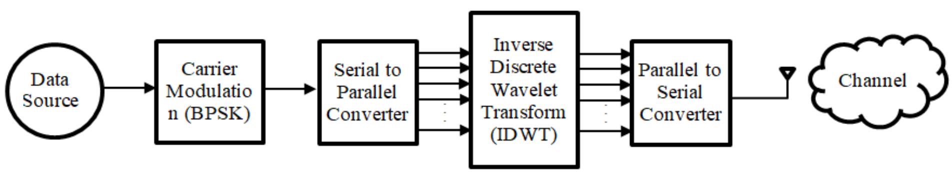

Figure 1. DWT-OFDM Transmitter Diagram

The bandwidth of DWT-OFDM system is fraction k of the total bandwidth as shown in the following equation [12]:

$$BW_{used} = k\widehat{F_s} \tag{6}$$

Where Fs is the sampling frequency [12]. While the spectral efficiency will be:

$$\eta = \frac{R_S}{BW_{used}} \frac{2^N - 1}{\hat{T}_S 2^{N_S}} \frac{1}{k\hat{F}_S} = \frac{1}{k} \frac{2^N - 1}{2^{N_S}} \quad (7)$$

Where Rs is the transmission symbol rate, N is the size of FFT and Ns is the number of scales. The following figure compares the spectra of DWT-OFDM and OFDM systems for the same coditions of sampling. Note that DWT-OFDM spectrum system is symmetrical if the cofficients of the filter are real, for this reason it is used in single band wirh same bandwidth of FFT which is not symmetrical [12].

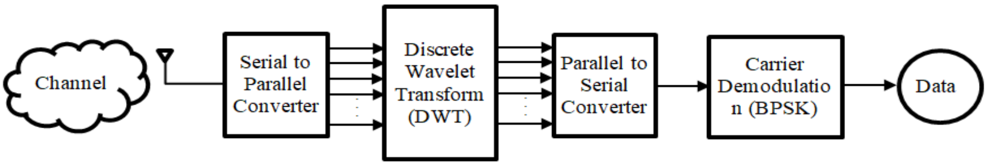

Figure 2. DWT-OFDM Receiver Diagram

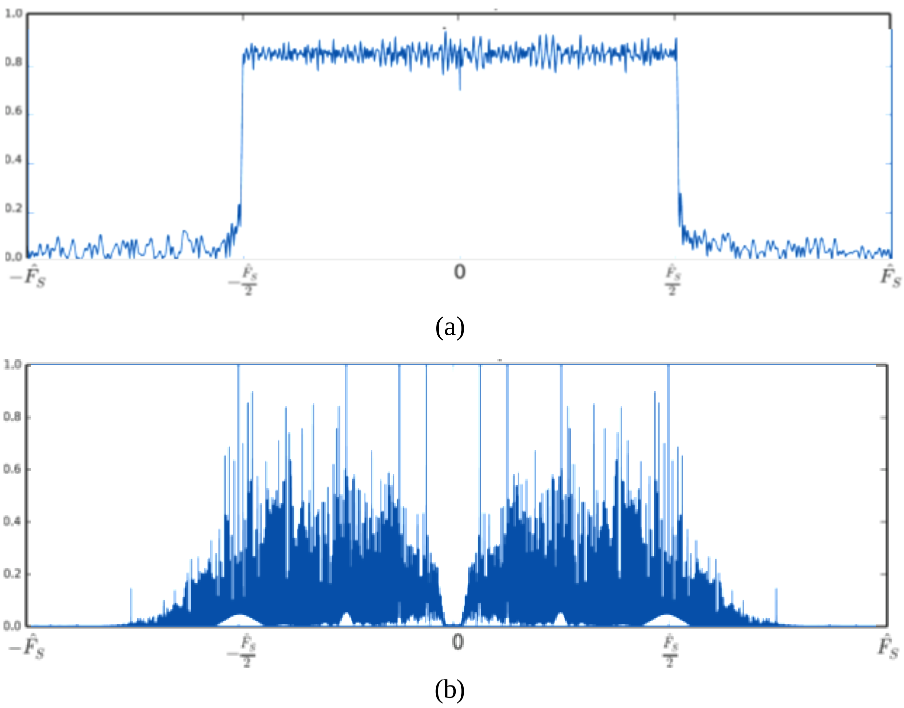

Figure 3. Spectra of systems in the same conditions of sampling (a) Fourier based spectrum, (b) Wavelet based spectrum [12]

5. RESULTS AND DISCUSSION

The simulation of OFDM system is performed on AWGN channel and the data is modulated using Binary Phase Shift Keying (BPSK). The performance of OFDM system, illustrated in Figure 4 confirms that the system is stable and the level of BER is acceptable but as mentioned before; the system has high sensitivity to synchronization and the cyclic prefix causes reduction in power efficiency and throughput.

The proposed system DWT-OFDM is suggested to reduce the errors of synchronization and on the other side, CP is not used in order to keep the efficiency and throughput on acceptable level. The performance of DWT-OFDM system with Haar filter is shown in Figure 5; it is clear that the level of BER is reduced and the system is still stable with the increasing of SNR level.

As a result, it is easy and acceptable to simulate and implement DWT with OFDM system, at the same time the errors is reduced and the efficiency of the proposed system is increased. In addition to that, the capability of transmission is increased because of removing the cyclic prefix from the system so DWT-OFDM system is stable and has better characteristics with lower level of bit error rate.

According to all the advantages of the proposed system above, this technique is an attractive solution for the drawbacks of OFDM system and it is a good candidate to the researchers for the coming generation of mobile communications.

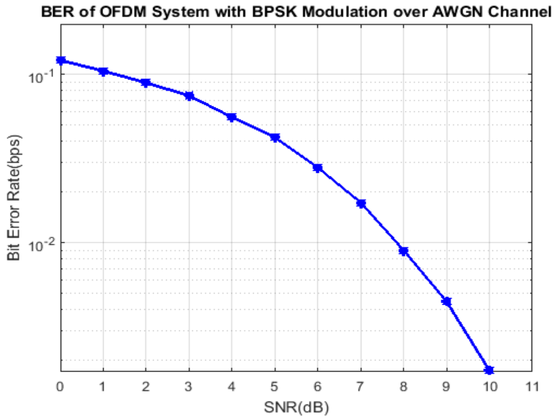

Figure 4. BER vs SNR for OFDM System

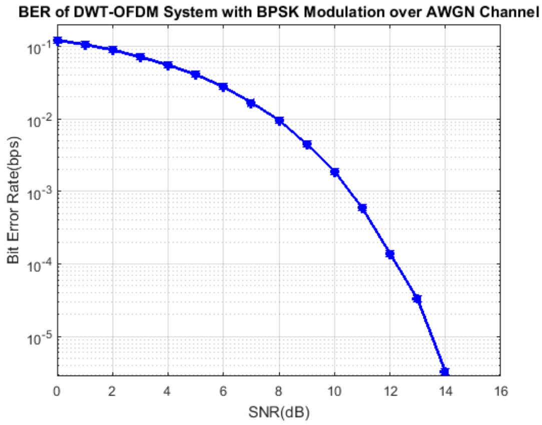

Figure 5. BER vs SNR for DWT-OFDM System

6. CONCLUTIONS

In this paper discrete wavelet transform is used to improve the drawbacks of OFDM signals and the results of the proposed sytem and OFDM are compared to confirm that DWT enhanced the throughput and efficiency of OFDM system. Moreover, omitting CP leads to reduction in the levels of BER. It can be seen from the above analysis that, the next step on this research must be analyzing the other parameters of the system performance as throughput, efficiency and PAPR to evaluate them and suggest solutions to pass any drawback in DWT-OFDM system

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