PERFORMANCE COMPARISON OF HAAR OFDM AND DAUBECHIES OFDM IN PRESENCE OF CARRIER FREQUENCY OFFSET (CFO) AND DOPPLER EFFECT

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ABSTRACT

Present day wireless communication systems demand for high data rates. Orthogonal frequency division multiplexing (OFDM) has emerged as a promising technology to provide these high data rates. OFDM is a digital modulation technique which divides the available spectrum into different sub bands. As a result data can be transmitted simultaneously using multiple subcarriers. Conventional OFDM is based on Fast Fourier transform. It uses Inverse Fast Fourier transform block at transmitter side and FFT block at the receiver side. Recent studies show that discrete wavelet transform can be used in the place of FFT as it provides better Bit Error rate performance. The major degradation factors that reduce the performance of conventional OFDM are Carrier frequency offset and Doppler Effect. This paper discusses the performance of DWT based OFDM in the presence of CFO and Doppler Effect. The paper compares the BER performance DWT OFDM using two wavelets, the Haar Wavelet and Daubechies wavelet. CFO and Doppler Effect are assumed to occur individually in the system. Simulations are carried out using MATLAB.

Keywords – DWT OFDM, Daubechies, FFT OFDM, Haar, OFDM

I. INTRODUCTION

OFDM has been widely used in communication systems to provide high data rates. It provides both modulation and multiplexing. It is a digital modulation scheme that provides multi carrier modulation that can transmit data parallel on closely spaced subcarriers. The sub carriers are orthogonal to each other. Because of the orthogonality among subcarriers and sharing of data among subcarriers, OFDM provide high bandwidth efficiency. It allows to digitally transmitting the data in the multipath fading environment without much distortion.

Conventional OFDM uses IFFT at the transmitter side for generating the orthogonal subcarriers. A cyclic prefix is added to the data symbols to combat the delay spread introduced by the fading environment and CP should have at least same size as channel delay spread. This will minimize the Intersymbol interference (ISI) among the symbols. At the receiver side, reverse operation takes place. CP is removed and data is passed to the FFT block to obtain the received signal in frequency domain.

Recent researches show that use of discrete wavelet transform instead of fast Fourier transform in OFDM systems provide better performance. DWT based OFDM uses IDWT block at the transmitter side and DWT block at the receiver side for reverse operation to take place. Wavelet transform OFDM provide all the benefits

as that of FFT OFDM .Unlike FFT OFDM wavelet system satisfies the orthogonality condition and achieves perfect reconstruction using orthogonal filters of the quadrature mirror filter (QMF) [1]. Because of the feature of DWT Inter Carrier lnterference can be avoided without using cyclicprefix (CP) is not needed .Different types of wavelets can be used depending upon the purpose. Of these Haar wavelet and Daubechies wavelet are used in the OFDM system in this paper.

As OFDM has emerged as indispensable technology, its performance has to be tested against the degrading factors. The primary degrading factors occurring in OFDM are Carrier Frequency Offset (CFO) and Doppler Effect[2], [3]. CFO defines the difference between the local oscillator frequencies in the transmitter and receiver side. CFO causes the loss of orthogonality between subcarriers and lead to ICI.Doppler Effect implies the shift occurring in the frequency of the receiver section due to channels random condition, which also leads to ICI.The paper discusses the effect of CFO and Doppler Effect on the performance of DWT OFDM using two wavelets, Haar and Daubechies.

The organization of paper is as follows. The succeeding section describes the system model of FFT OFDM and DWT OFDM. Third section explains the Haar and Daubechies wavelets. Fourth section deals with the effect of CFO and Doppler- effect over OFDM. Fifth section explains the simulation and results. Last section concludes the paper.

II. SYSTEM MODEL OF OFDM

The general block diagram of OFDM transceiver is shown in the Fig 1.
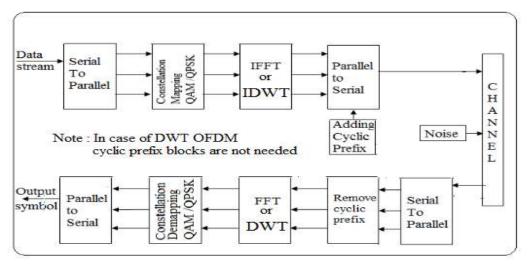

Fig 1 Block diagram of OFDM system

The serial stream of N numbers of data are converted into parallel stream. It is then processed by suitable modulation (QAM or QPSK or BPSK) to map the data with N subcarriers that are implemented using IFFT/IDWT [4] .In conventional OFDM, IFFT is used for the required frequency to time domain conversion. The output of IFFT is the sum of information signals in the discrete time domain as following:

$$X_k(n) = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X_m(i) e^{\left(\frac{j2\pi ni}{N}\right)} \qquad (1)$$

After IFFT, cyclic prefix is added to each symbol for avoiding both Inter Symbol interference (ISI) and Inter Carrier Interference (ICI).Cyclic prefix is added by extending the end of a symbol with its repetition .Digital

data is then converted to serial data and is transmitted over the channel. Using the Additive White Gaussian Noise (AWGN) channel, the received sequence is given by:

$$Y(n) = H[n]X(n) + w(n) \qquad (2)$$

Where H[n] is the transfer function of the channel and w (n) is the noise envelope of channel. In the recovery process, first the cyclic prefix is removed. Then the data is given to FFT block. The data recovered from the FFT block of receiver is expressed as:

$$Z_m((i) = \sum_{n=0}^{N-1} Z_k(n) e^{(-\frac{j2\pi i}{N})} \qquad (3)$$

In DWT OFDM, the IFFT block and FFT block are replaced by IDWT and DWT block respectively .Because of the peculiarity of DWT, even without using cyclic prefix, ICI can be avoided. So the block representing addition and deletion of cyclic prefix is not needed in DWT OFDM. Cyclic prefix is the redundant data that reduces actual data rate. So by avoiding cyclic prefix data, both data rate and efficiency can be improved [5].

Mallet algorithm or subband coding is used to compute DWT [4].Here the data sequence is given to a series of high pass filters and low pass filters as shown in the Fig 2. Low pass filter (G_0) provides approximate coefficients$a_n$known as scaling function. Likewise High Pass Filter (H_0) produces detailed coefficients d_n known as wavelet function. In this algorithm, successive filtering operations are performed on the scaling function only. As a result, one scaling function and n number of sets of wavelet functions are available at the final stage. The filtering function also involves a down sampling procedure.

In IDWT computation, reverse operations of DWT takes place. Here the filtering in reverse order with upsampling is involved. After constellation mapping, N parallel data streams are available at the transmitter side .By using these data, orthonormal wavelet carriers can be generated.
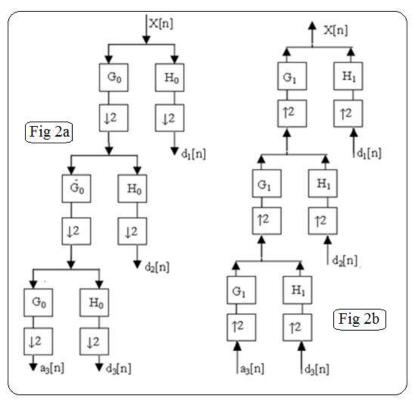

Fig 2 Computation of a) DWT b) IDWT

For accomplishing this task, parallel data should be converted to serial data & should be denoted as a vector. Then this vector is converted to parallel matrix by vector transposing (Fig 3). It is then followed by upsampling

and low pass filtering to get approximate coefficients which denotes the actual data. To get wavelet coefficients, the same procedures are done with zero padding and vector transposed output is high pass filtered.
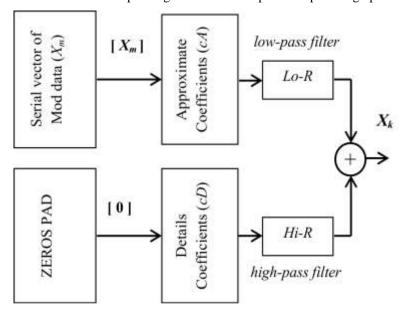

Fig 3 IDWT block in transmitter

At the receiver side, DWT process is involved for data recovery. The filters G_0 and H_0 known as analysis filter, used for this purpose should have matching characteristics with that of synthesis filters G_1 and H_1, in the IDWT block of the transmitter. For perfect reconstruction the analysis and synthesis filters needs to satisfy the conditions below [6]:

$$G_0(-z)G_1(z) + H_0(-z)H_1(z) = 0 \tag{4}$$

$$G_0(z)G_1(z) + H_0(z)H_1(z) = 2z^{-d} \tag{5}$$

Equation 4 is used for making output free of aliasing and equation 5 makes output free of distortion. For keeping the orthogonality condition, the following equation should be satisfied:
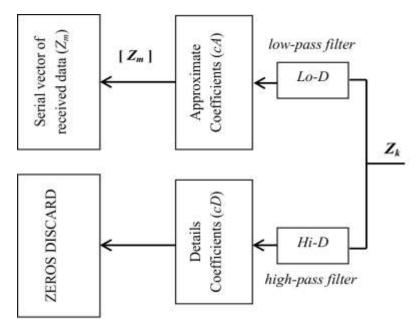
$$H_0(z) = z^{-N}G_0(-z^{-1}) \tag{6}$$

Fig 4 DWT block in receiver

The series of filtering on the signal produces approximate coefficients and some sets of detail coefficients. After summing up all the sets, the detail coefficients required are obtained. Finally, approximate and detail coefficients are vector transposed (Fig 4) and output got will be in parallel format of required data. After serially converting it, the data symbols are demapped and zeros are discarded

III. HAAR AND DAUBECHIES WAVELET

3.1 Haar Wavelet

Haar Wavelet is the simplest of all wavelets [7].Mathematically, discrete Haar wavelets can be represented as Haar transform. It defines as a sample for all supplementary wavelet transform .A discrete signal is decomposed into two subsignals of half its length using the transform. One signal is running average, while other is a running difference. Advantages of Haar wavelet transform include the following [8].

- Conceptually simple
- Fast
- Memory Efficient
- Exactly reversible without the edge effects

Haar transform possesses its own limitations, which make some applications difficult. While calculating each of the averages for the next level and each set of coefficients, Haar transform does an average and difference on a pair of values. After that algorithm is shifted over by two values and performs another average and difference on next pair. All high frequency changes will be reflected by the high frequency coefficient spectrum. Haar window consists of two elements only. A big change from an even to odd value cannot be reflected in the high frequency coefficients. As a consequence, this transform cannot be used in compression and audio signal processing. The mother wavelet function and scaling function of Haar transform is given by as:

$$\Psi(x) = \Phi(2x) - \Phi(2x-1)$$

$$where$$

$$\Phi(x) = \begin{cases} 1, & if \quad 0 \le x < 1 \\ 0, & elsewhere \end{cases}$$

(7)

3.2. Daubechies Wavelet

Daubechies wavelet transform is named after its inventor, the mathematician Ingrid Daubechies. Daubechies wavelet transforms are defined in same way as Haar wavelet transform such that running averages and differences via scalar products with scaling signals and wavelets. The only difference lies in how the scaling and wavelet functions are defined. This paper uses the Daubechies D4 transform. It has four wavelet and scaling coefficients.

The scaling function coefficients are given by:

$$h_0 = \frac{1+\sqrt{3}}{4\sqrt{2}}$$

$$h_1 = \frac{3+\sqrt{3}}{4\sqrt{2}}$$ (8)

$$h_2 = \frac{3-\sqrt{3}}{4\sqrt{2}}$$

$$h_3 = \frac{1-\sqrt{3}}{4\sqrt{2}}$$

Scaling function is applied to input data at each step of wavelet transform. If data has N values, scaling function produces N/2 smoothed values.

The wavelet function coefficients are given by:

$$g_0 = h_3$$

$$g_1 = -h_2$$

$$g_2 = h_1 \hspace{8cm} (9)$$

$$g_3 = -h_0$$

Wavelet function is applied to input data at each step. If data set has N values, wavelet function calculates N/2 differences. Daubechies wavelet has balanced frequency responses and nonlinear phase responses. As this uses overlapping windows, high frequency coefficient spectrum reflects all high frequency changes. Thus they are useful in compression and noise removal of audio signal processing. [8].

IV. CFO AND DOPPLER-SHIFT EFFECT ON OFDM

The received signal at the front end of the OFDM receiver in the ideal case is given in the equation 2.Ideal case means there is no CFO and Doppler-effect. It is not practical [2],[6].

In the presence of CFO, the received sequence is given as:

$$Y(n) = H[n]X(n)\frac{\sin(\pi\epsilon)}{N\sin(\pi\epsilon/N)}e^{j\pi\epsilon(N-1))}+$$

$$\sum_{m=0,m\neq n}^{N-1}H[m]X(m)\frac{\sin[\pi(m-n+\epsilon)]}{N\sin\left[\frac{\pi(m-n+\epsilon)}{N}\right]}e^{\left[\frac{j\pi(m-n+\epsilon)(N-1)}{N}\right]}+\omega(n) \quad (10)$$

Where ϵ is the normalized frequency offset given as $\frac{f_0}{\Delta f}$. In the above equation, the first part $\frac{\sin(\pi\epsilon)}{N\sin(\pi\epsilon/N)}$ is the attenuation factor of the amplitude and $e^{j\pi\epsilon(N-1))}$ value of phase shift that the signal experience.

Likewise, Doppler- effect also contributes to the change in carrier frequency. Consider that an OFDM system employed mobile system has a velocity of 'v' because of the frequency shift in carrier frequency. This is known as Doppler-effect [3]

$$f_d = f_0\frac{v}{c}cos\alpha \hspace{6cm} (11)$$

Where f_0 represents the carrier oscillator frequency, c is the velocity of light in free space, α is the angle exists between the velocity vector and the direction of electromagnetic waves. As a result of this frequency shift, inter carrier interference occurs and its coefficient between k^{th} and I^{th} carrier is given as:

$$S(k-l) = \frac{\sin(\pi(k+\varepsilon-l))}{N\sin(\frac{\pi}{N}(k+\varepsilon-l))} e^{(j\pi(1-\frac{1}{N})(k+\varepsilon-l))}$$
(12)

The ICI caused by the carrier frequencies mismatch leads to the loss of orthogonality between the sub carriers and as a result performance is degraded more strongly. This paper shows the BER performance of Haar wavelet OFDM and Daubechies OFDM in the presence of CFO and Doppler- effect, considering both occurring individually.

V. SIMULATION DETAILS

Simulation of Haar wavelet OFDM and Daubechies wavelet OFDM is done using Matlab.When simulating the oscillator's mismatch at both transmitter and receiver, the mobile unit is considered to be in standstill condition. Such that the Doppler-effect is ignored. Likewise, performing simulation for Doppler-effect, mismatch of oscillator is not considered. In DWT OFDM the filter banks are selected in such a way that it satisfies the condition for perfect reconstruction and renders required orthogonality. Simulation parameters are given below:

- Modulation: BPSK
- No of subcarriers:256
- Frame length:1000
- Channel: AWGN
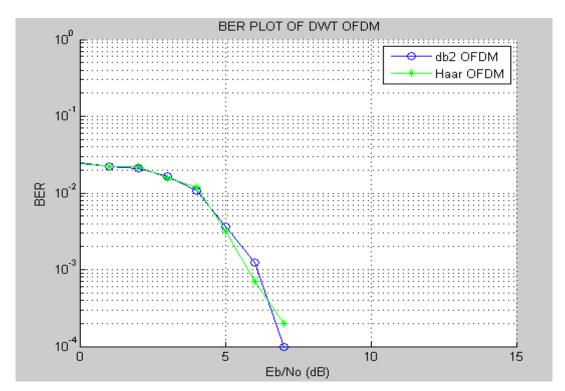- Wavelet used : Haar wavelet & Daubechies wavelet (D4 or db2)

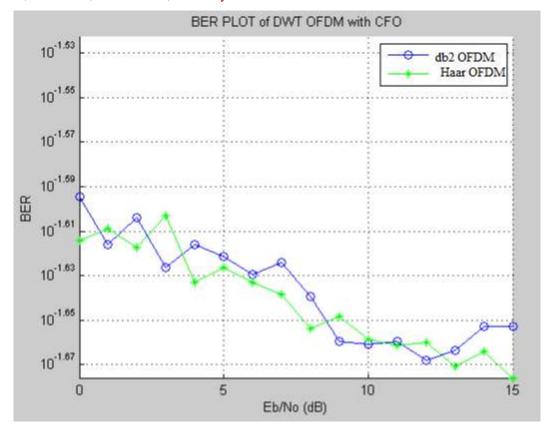**Fig 5 .BER plot of Haar OFDM and db2 OFDM**

Fig 6 BER plot of Haar OFDM & db2 in presence of CFO

VI. CONCLUSION

OFDM can be implemented more effectively using Discrete Wavelet Transform instead of Fast Fourier Transform. Spectral containment of channels can be improved by using this transform, as they are not using cyclic prefix (CP).Wavelet based OFDM has orthonormal base properties and reconstruction properties. This paper simulated two types of wavelet OFDM, one using Haar wavelet and other using Daubechies wavelet using MATLAB software. The performance of both OFDM is compared in the presence of the degrading factors, Carrier Frequency Offset (CFO) and Doppler-effect. Haar OFDM shows similar BER performance as that of Daubechies 4 (db2) OFDM. In the presence of degrading factors, Haar OFDM shows slight better performance than Daubechies OFDM.

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