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Design and Simulation of Wavelet OFDM with Wavelet Denoising on AWGN Channel

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Abstract: OFDM technique is widely used due to its high spectrum efficiency. Fast Fourier Transforms (FFT) has been used to generate the orthogonal sub-carriers. Implementation complexity of FFT based OFDM, has led to replace conventional FFT based OFDM by wavelet based OFDM. The main objective of this paper is to replace the conventional FFT based OFDM system with some orthonormal wavelets. Comparing with the conventional OFDM, it is found that the Haar and Daubechies-based orthonormal wavelets are capable of reconstructing the transmitted symbol at the receiver side and effect of noise is reduced using wavelet denoising for different SNRs on AWGN channel. In this paper, results are tabulated for transmitted symbols and reconstructed symbols after wavelet denoising& compared for an analysis. The scatterplot analysis of DWT-OFDM is also presented for different SNRs.

Kewords: Wavelet, DWT, Fourier, OFDM, SNR, AWGN

I. INTRODUCTION

OFDM system is one of the most promising technologies for current and future 4G wireless communications [1]. It is a multi-carrier transmission technique [2], which divides the available spectrum into many carriers, each one being modulated by a low rate data stream. Conventional OFDM system used IFFT and FFT to multiplex the signals in parallel with reduced complexity algorithm at the transmitter and receiver respectively. Many researchers have investigated the use of wavelet based to replace Fourier based OFDM and found out that the wavelet based has more advantages than Fourier based OFDM [3]-[6]. In paper [3], descriptions of Fourier based OFDM and Wavelet based OFDM and differences between them over the AWGN channel and Rayleigh channel presented. In paper[7], scatter plot analysis of wavelet OFDM is presented and symbol reconstruction is shown. In this paper, wavelet denoising applied on received symbols on AWGN channel. The transmitted and received symbols are presented for comparison. The results reveal that The DWT OFDM has potential to produce hardware complexity because it doesn't need a Cyclic Prefix and proposed system gives nearly perfect reconstruction.

The paper is organized as follows: The system model is described in Section II. Simulation and results are discussed in Section III. Concluding remarks appear in Section IV.

II. SYSTEM MODEL

The following diagram shows DWT based OFDM transceiver

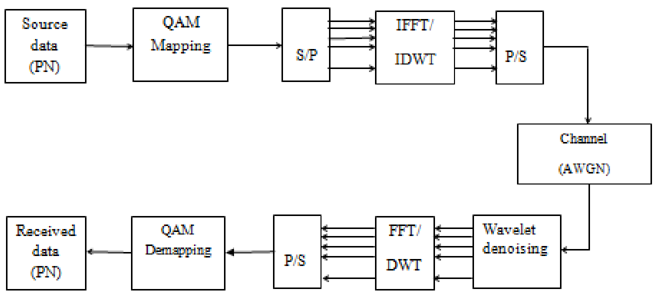

Fig.1 OFDM-DWT Transceiver

PN sequence generation:

In the simulation context, the most important reason for using PN sequences is for modelling data sources. By using a PN sequence generator almost all possible bit combinations having a given length can be produced over the shortest possible simulation length.

The connection vector establishes the performance characteristics of the generator and is defined by the polynomial,

$$g(D) = 1 + g_1 D + g_2 D^2 + \cdots g_{N-1} D^{N-1} + D^N \qquad \text{------(1)}$$

Modulation and Demodulation:

Modulation and Demodulation is done by using QAM

The predefined Look-up-table is used for converting bits into complex signal which are used to represent the QAM constellation points. The system is designed and simulated in MATLAB for 16QAM, 64QAM and 256QAM using MATLAB.

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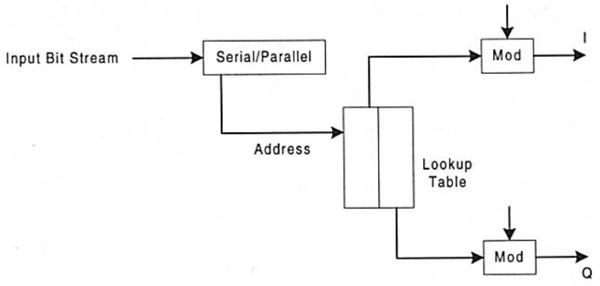

Fig.2 QAM Mapping

The constellation points are generated in such a way that, there should be a 1-Bit difference between two constellation points. The co-ordinates of i^{th} message point (a_i,b_i) are elements of L by L matrix as shown below.

$$(a_i,b_i) = \begin{bmatrix} (-L+1,L+1) & (-L+3,L-1) & \cdots & (L-1,L-1) \\ \vdots & & \ddots & \vdots \\ (-L+1,-L+1) & (-L+3,-L+1) & \cdots & (L-1,-L+1) \end{bmatrix} \quad \text{------ (2)}$$

IDWT-DWT:

The DWT is just a sampled version of CWT. The signals are analyzed in CWT using a set of basis functions which relate to each other by simple scaling and translation. While in the case of DWT, a time-scale representation of the digital signal is obtained using digital filtering techniques. The DWT is computed by successive low pass and high pass filtering of the discrete time-domain signal as shown in fig.3

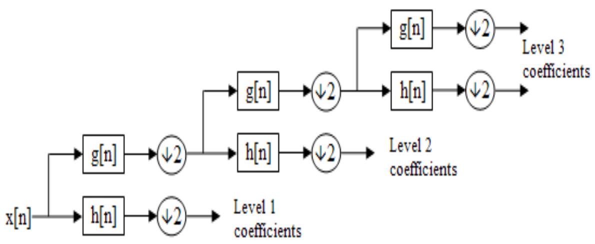

Fig.3 Structure of 3-Level wavelet decomposition

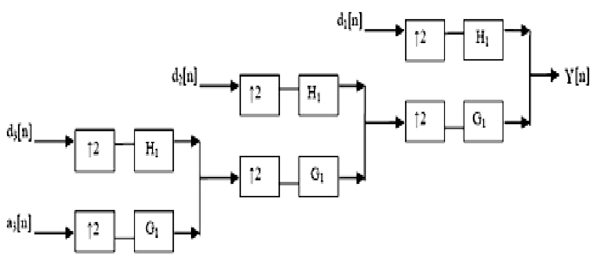

Fig.4 Three-levels wavelet reconstruction

The proposed method is simulated using Haar wavelets for IDWT and DWT with 3 levels of decomposition and reconstruction.

AWGN Channel:

Noise and interference are common transmission nuisances in wireless communication. Noise is modelled as Additive White Gaussian Noise (AWGN). In this channel, zero-mean white Gaussian noise is added to the transmitted signal x(t), so that the received signal r (t) can be represented as:

$$r(t) = x(t) + n(t) \quad \text{-------- (3)}$$

Where n (t) is a zero-mean Additive White Gaussian Noise process, with power spectral density $\frac{N_o}{2}$.

Wavelet Denoising:

The de-noising objective is to suppress the noise part of the signal r(t) and to recover x(t).

The de-noising procedure proceeds in three steps:

- *Decomposition:* Choose a wavelet, and choose a level N. Compute the wavelet decomposition of the signal s at level N.
- *Detail coefficients thresholding:* For each level from 1 to N, select a threshold and apply soft thresholding to the detail coefficients.
- *Reconstruction:* Compute wavelet reconstruction based on the original approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

III. SIMULATION & DISCUSSION

Simulation has been carried out to transmit symbols over wavelet based OFDM system over AWGN channels. The transmitted symbols for different SNR are examined for AWGN channel.

For performing the simulations, the flow chain shown in the Figure 1 is developed under a MATLAB 7.9.0 environment. The blocks are implemented by MATLAB instructions. The following is an overview of procedures to simulate the DWT-OFDM scheme shown above.

Transmitter:

Input signal: PN Sequence ($L=2^{10}-1$ =1023Bits)

Bit pattern Generation: Serial Bits is Converted into 4, 6 or 8 Bit Pattern Suitable for 16, 64 or 256QAM

Generating Look-up table: Look-up table contains complex values corresponding to a bit pattern.

QAM Encoder (16QAM, 64QAM, 256QAM): QAM constellation points are obtained by LUT method.

IDWT: Wavelet Decomposition using Haar Wavelets.

Time Domain conversion: Frequency domain signal is converted to time domain using IDWT and extract Real time signal.

Channel:

Channel Estimation: Finding AWGN channel Transfer Function (TF).

Convolving Received signal from Transmitter with Channel TF [Y = X * h].

Adding Noise to the Resulting signal [Y = X h + n].

Receiver:

Wavelet Denoising: Noise Cancellation of received signal from channel is done by wavelet filters.

De-Convolution [$X= Y H^T$]

Applying DWT: Wavelet Reconstruction using Haar Wavelets.

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QAM Decoder: Symbols are compared with desired Look-up table, produces corresponding complex signal.

The table 1 below shows difference between Denoised signal and the Transmitted signal for SNR=22dB for first 8 symbols.

Table 1: Difference between Denoised signal and the Transmitted signal for SNR=22db

4-Bit Pattern	Transmitted signal constellation	Received signal constellation after Denoising **(SNR=22db)**	DIFFERENCE	
			REAL	IMAGINARY
0000	-3.0000 +3.0000i	-3.0272 +2.8808i	0.0272	0.1192
0001	-1.0000 +3.0000i	-1.0804 + 2.9525i	0.0804	0.0475
0010	3.0000 + 3.0000i	3.1469 + 2.9503i	0.1469	0.0497
0011	1.0000 + 3.0000i	0.8712 + 3.1746i	0.1208	0.1746
0100	-3.0000 - 3.0000i	-2.9841 - 2.9337i	0.1592	0.0663
0101	-1.0000 - 3.0000i	-0.9514 - 3.0205i	0.0486	0.0205
0110	3.0000 - 3.0000i	3.0258- 3.0272i	0.0258	0.0272
0111	1.0000 - 3.0000i	0.5585 - 2.8909i	0.4415	0.1091

Scatter plot Analysis of DWT-OFDM:

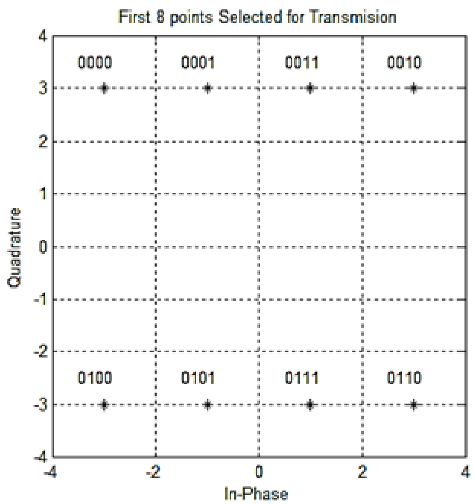

Fig.5. First 8 points selected for transmission

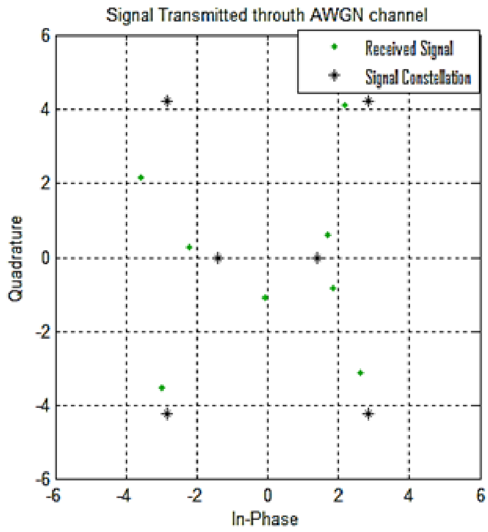

Fig.6. Scatter plot of noisy (AWGN) signalfor SNR=22db and transmitted signal on the same axes.

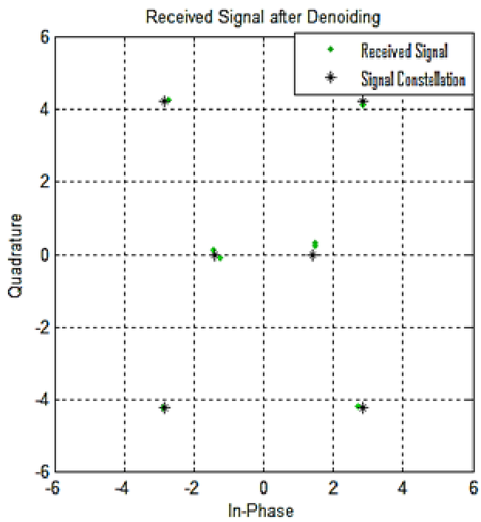

Fig.7. Scatter plot of Denoised signal, Symlets N=1 wavelet Filter

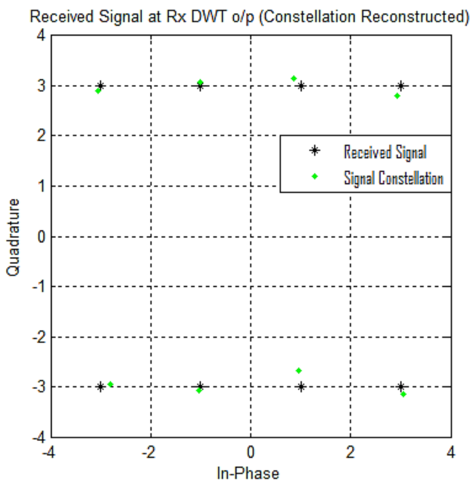

Fig.10. Scatter plot of signal after Wavelet Reconstruction

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System Configuration	OFDM	Simulation time
CPU=Intel Dual Core Processor RAM=2 GB OS=Windows 7	OFDM-DWT	1.4481 sec
	OFDM-FFT	4.5042 sec

As shown in above table, the elapsed simulation time for DWT-OFDM is less compared to FFT-OFDM. On the AWGN channel as the simulation results of the Scatter plot of the Denoised signal have indicated that OFDM with wavelet filter bases Symlets with minimaxi and Soft threshold at high SNR, reduced the probability of bit error rates at the receiver. The DWT OFDM has potential to produce hardware complexity because it doesn't need a CP.

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