ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 5, May 2014

Performance Analysis of Convolutional Interleaved DWT based OFDM system

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Abstract: Discrete Wavelet Transform (DWT) is broadly considered as an efficient approach to replace FFT in the conventional OFDM systems due to its better time-frequency localization, bit error rate improvement, interference minimization, improvement in bandwidth efficiency and many more advantages. In this paper, the DWT based OFDM system with Convolutional encoding is introduced and its BER performance is compared with the DWT-OFDM system without encoding in both AWGN and Rayleigh channel. Simulation results show that the DWT-OFDM system with encoding outperforms the DWT-OFDM system without encoding and BER is significantly improved over higher values of SNR in both the channels.

Keywords: Discrete Wavelet transform (DWT), Discrete Wavelet based OFDM (DWT-OFDM), Convolutional Encoding

I. INTRODUCTION

The rapidly growing technology has made it possible for the communication systems to transfer data almost everywhere on this planet. But the limited bandwidth allocated to a large number of users restricts the bandwidth availability to the users. This scenario creates a technological challenge to develop the data transmission schemes which are bandwidth efficient. Multicarrier modulation is such a scheme that transmits the data by dividing the serial high data rate streams into a number of low data rate parallel data streams [1]. Orthogonal Frequency Division Multiplexing (OFDM) is a kind of multi-carrier modulation, which divides the available spectrum into a number of parallel subcarriers and each subcarrier is then modulated by a low rate data stream at different carrier frequency [2]. The conventional OFDM systems make use of IFFT and FFT at the transmitter and receiver respectively but DWT-OFDM or wavelets based OFDM is an alternative approach to this conventional FFT based OFDM system.

A wavelet means a small waveform of limited duration unlike the sine waves which do not have limited duration. Another difference between wavelets and sine waves is that sine waves are smooth, regular and predictable but wavelets are irregular and asymmetric. The wavelet transform is an effective tool used in various signal processing applications such as image and video compression, numerical analysis, object recognition and many more. It is an efficient method for signal analysis in joint time-frequency domains [3]. Wavelet transform is implemented using a pair of filters i.e. a low pass filter and a high pass filter. Wavelets possess better orthogonality as well as localization in both time and frequency. DWT-OFDM uses wavelet carriers at different time and frequency resolutions which make the wavelets flexible. Wavelets are also superior in minimizing the intersymbol interference (ISI) as well as inter carrier interference (ICI). Due to the time overlapping nature of wavelets, the use of cyclic prefix is not required in case of DWT-OFDM which improves the bandwidth efficiency [4].

In communication systems, when the signal is transmitted over the channel, noise and unwanted interferences are introduced which leads to the distortion of transmitted signal. Error control coding techniques are used to get rid of such channel distortions. The original data sequence is appended with redundant bits to increase the reliability of the system. Convolutional codes are very powerful error correcting codes which finds their applications in digital video, satellite communication and mobile communication [5]. In this paper, the Convolutional codes are used in DWT based OFDM system which improves the bit error rate performance of the system. The purpose of this paper is to compare the BER performance DWT-OFDM with and without Convolutional encoding and channel models used are AWGN channel and Rayleigh channel. The rest of the paper is organized as follows: Section II gives an overview of Wavelet transform. Section III describes the DWT based OFDM systems with Convolutional encoding. Section IV and V describes Convolutional codes and bit interleaving respectively. Channel models are presented in section VI. In section VII, the simulation results are presented. Finally, section VIII concludes the work.

II. WAVELET TRANSFORM

In DWT, the signal is decomposed into approximation and detail information by successive high-pass and low-pass filtering of the original time domain signal. This decomposition is done to analyse the signal at different frequency bands with different resolutions. The original signal x[n] is passed through a low-pass filter g[n] to obtain approximation coefficients and a high-pass filter h[n] to obtain detail coefficients as shown in figure 1.

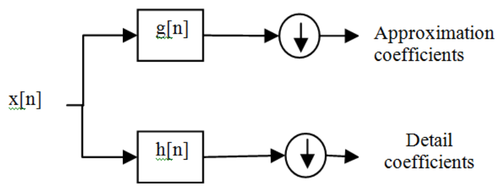

Fig. 1 Wavelet decomposition

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 5, May 2014
ISSN (Online) : 2278-1021
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DWT-OFDM uses wavelet carriers at different scales (j) and positions on the time-axis (k). These functions are generated by the translation and dilation of a unique function, known as the 'wavelet mother' denoted by $\psi(t)$ and is given by equation (3),

$$\psi_{j,k}(t) = 2^{-\frac{j}{2}}\psi(2^{-j}t - k) \quad (1)$$

The scale index (j) and time location index (k) affects the orthogonality of the subcarriers and exhibits better time-frequency localization as compared to the complex exponentials used in FFT based OFDM systems [6]. The orthogonality is achieved if it satisfies the following condition, according to equation (4),

$$\langle \psi_{j,k}(t), \psi_{m,n}(t) \rangle = \begin{cases} 1 & if\ j = m, k = n \\ 0 & otherwise \end{cases} \quad (2)$$

The scaling function $\varphi(t)$ is used to obtain a finite number of scales and is generated using equation (3),

$$\varphi_{j,k}(t) = 2^{\frac{j}{2}}\varphi(2^{j}t - k) \quad (3)$$

Higher the value of j, higher is the resolution. The lower resolution function, denoted by $\varphi(t)$can be represented as the weighted sum of shifted versions of some scaling functions at next higher resolution i.e. $\varphi(2t)$, given by equation (4),

$$\varphi(t) = \sum_k h(k)\sqrt{2}\,\varphi(2t - k) \quad (4)$$

To better describe the important features of a signal, another set of functions given by $\psi_{j,k}(t)$ is defined which is also represented in terms of the scaling function, given by equation (5) as follows,

$$\psi(t) = \sum_k g(k)\sqrt{2}\,\varphi(2t - k) \quad (5)$$

The set of $g(k)$ coefficients are known as the wavelet function coefficients.

III. WAVELETS BASED OFDM (DWT-OFDM) USING CONVOLUTIONAL ENCODING

The block diagram of wavelets based OFDM is shown in figure 2.

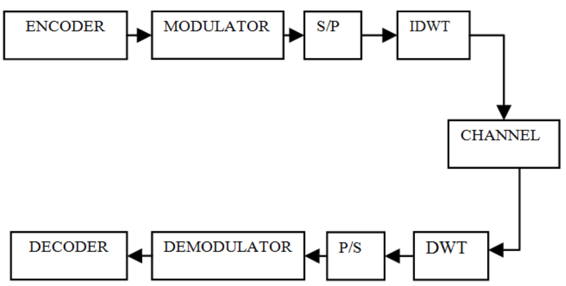

Fig. 2 Block diagram of encoded DWT-OFDM

The data generator first generates a serial random data bits stream. This data stream is passed through the encoder which consists of Convolutional encoder followed by the bit interleaver. The bits are first interleaved with help of convolution encoder and interleaver and then the data is processed using modulator to map the input data into symbols based on the modulation technique used [7]. The DWT-OFDM symbol can be represented as equation (3),

$$s(t) = \sum_{j \leq J}\sum_k w_{j,k}(t)\psi_{j,k}(t) + \sum_k a_{J,k}\varphi_{J,k} \quad (3)$$

This symbol is clearly the weighted sum of wavelet and scale carriers which is similar to the Inverse Wavelet Transform (IDWT). In DWT-OFDM, the input data is processed same as in FFT-OFDM but the advantage in this case is that the cyclic prefix is not required because of the overlapping nature of wavelet properties. The data is processed in the IDWT block, whose output can be given as equation (4),

$$d(k) = \sum_{m=0}^{\infty}\sum_{n=0}^{\infty} D_m^n\, 2^{\frac{m}{2}}\psi(2_k^m - n) \quad (4)$$

Where k is the number of subcarriers ($0 \leq k \leq N-1$), D_m^n are the wavelet coefficients which represents the signal in scale and position on time-axis and $\psi(t)$ is the wavelet function with compressed factor m times and shifted n times for each subcarrier [8]. At the receiver side, the process is reversed. The output of discrete wavelet transform (DWT) is represented by equation (5),

$$D_m^n = \sum_{k=0}^{N-1} d(k) 2^{\frac{m}{2}}\psi(2_k^m - n) \quad (5)$$

The description of DWT-OFDM transmitter and receiver is given in the following section:

A. DWT-OFDM transmitter

On the transmitter side, the digital modulator maps the serial data bits into OFDM symbols X_m in the similar way as in FFT-OFDM within the parallel N data streams represented by $X_m\,(i)$ where ($0 \leq i \leq N-1$). Each data stream $X_m\,(i)$ is passed through serial to parallel converter to create a vector. Then the transpose of this vector is taken to obtain the approximation coefficients which are also known as scaling coefficients. Thus the signal is upsampled and low-pass filtered to achieve the low frequency signals. In the similar way, the vector generated from the zeroes padding signal is convolved with the high-pass filter which contains the detailed coefficients or wavelet coefficients. The values of these approximation and detailed coefficients depend on the wavelet family which is used. The MATLAB command $[X] = idwt(cA, cD, 'wname')$ is used to simulate the signal on the transmitter side where $'wname'$ represents the wavelet family used in simulation.

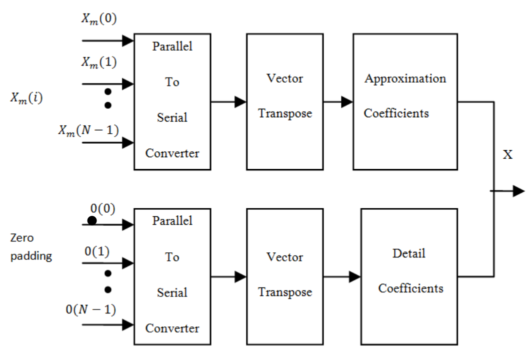

Fig. 3 DWT-OFDM transmitter

B. DWT-OFDM receiver

The DWT-OFDM receiver is shown in Fig. 4. It performs the exact reverse process of the transmitter. MATLAB

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940
International Journal of Advanced Research in Computer and Communication Engineering
Vol. 3, Issue 5, May 2014

command $[cA; cD] = dwt(Y;' wname')$ is used to simulate the received signal where $wname$ represents the wavelet family used in simulation. The received data Y is decomposed into two parts and then sent to the low-pass and high-pass filters to obtain the approximation and detailed coefficients respectively. Only the output cA of the LPF is passed through the demodulator and the output cD of the HPF is discarded. Before demodulation, the transpose of data is taken and then passed through a serial to parallel converter. cD is discarded because it contains only zeroes elements and does not carry any useful information. The original data is recovered at the output of the demodulator [9].

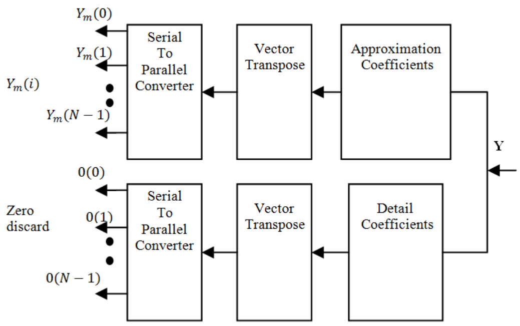

Fig. 4 DWT-OFDM receiver

IV. CONVOLUTIONAL ENCODING

Convolutional codes are very efficient error correcting codes which are complicated yet possess powerful error correcting capabilities. In Convolutional codes, a block of n bits generated by the encoder depends on the block of k message bits as well as on the preceding (N-1) blocks of message bits. Convolutional codes are defined in terms of three parameters (n, k, K) where n is the number of encoded bits or the output bits, k is the number of message bits and K is constraint length which donates the time span of bits affected by each input bit. k/n is termed as the code rate [10]. The encoder for generator polynomial (171,133) with code rate ½ is shown in figure 5.

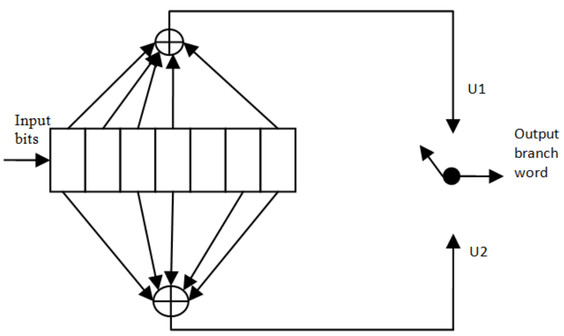

Fig. 5 Convolutional Encoder

V. BIT INTERLEAVING

In order to maximize the diversity in a fading channel, the error correction coding coupled with interleaver is used. It separates the adjacent coded symbols farther than the coherence time of fading process by creating large Euclidean distance between the code words of a convolution code. The burst errors occurring in the channel or caused by the detector on the receiver side are dispersed by a de-interleaver at the receiver. A random interleaver is used in this system and a pseudo-random permutation is selected, which is assumed to be known both at the transmitter and the receiver and is used to reorder the coded symbols [11].

VI. CHANNEL MODELS

A. *AWGN*

The Additive White Gaussian Noise Channel is the simplest mathematical model for channel realization when the thermal noise is assumed to be the only source of disturbance at the receiver side. The AWGN channel simply adds the white Gaussian noise to the signal which is transmitted through it. Thus, the received signal $r(t)$ is represented as the sum of transmitted signal $s(t)$ through AWGN channel and the white Gaussian noise $n(t)$ added to it, i.e.

$$r(t) = s(t) + n(t) \qquad (6)$$

Also, the noise sample follows the Gaussian distribution and its probability density function with variance σ^2 is given by equation (7),

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-m)^2}{2\sigma^2}} \qquad (7)$$

B. *Multipath Rayleigh channel*

When a signal is transmitted through a Rayleigh channel, its power is assumed to vary randomly according to the Rayleigh distribution. The Rayleigh distribution is represented by the radial component of the sum of two Gaussian random variables which are uncorrelated. The Rayleigh fading channel is considered to model the effect of propagation environment on the radio signals such as in wireless devices. Rayleigh fading model is mostly used when the line of sight is not present between the transmitter and the receiver [12].

VII. RESULTS AND DISCUSSION

Simulation is carried out for DWT-OFDM system with and without encoding for both AWGN as well as Rayleigh channel by taking SNR in the range 0 to 40 dB and 4-QAM modulation technique is used. The number of samples is 1000 and the number of subcarriers i.e. N is 64. The BER comparison with DWT-OFDM with and without encoding in AWGN channel is represented by Fig. (6).

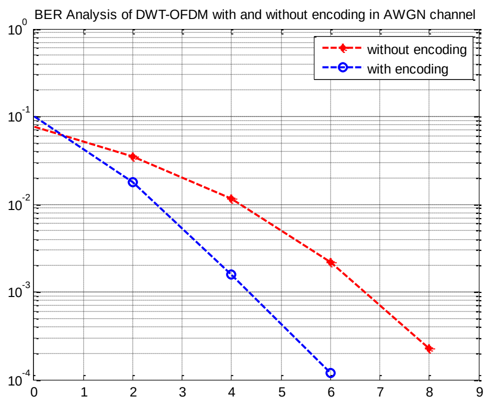

Fig. 6 BER comparison in AWGN channel

ISSN (Online) : 2278-1021
ISSN (Print) : 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering
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The BER is significantly improved by using encoded DWT-OFDM system as compared to DWT-OFDM system without encoding. Further, the BER for both the systems in Rayleigh channel is compared. The BER of encoded DWT-OFDM system is significantly improved over the higher SNR range in Rayleigh channel. BER comparison for DWT-OFDM with and without Convolutional encoding in Rayleigh channel is given in fig. (7),

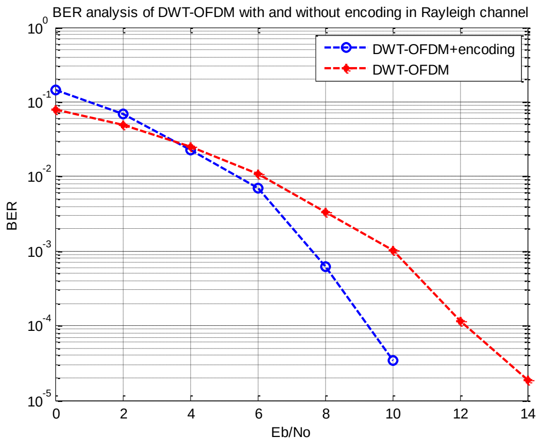

Fig. 7 BER comparison in Rayleigh channel

VIII. CONCLUSION

MATLAB simulation for the DWT-OFDM system with and without Convolutional encoding is presented for both AWGN and Rayleigh channel. DWT has come up as an effective technique to be used in multicarrier modulation because of its good time-frequency localization properties, ICI and ISI suppression and flexibility. Moreover, the cyclic prefix is not used in DWT based OFDM system. The simulation results show that when the DWT-OFDM system is used with Convolutional encoding, the BER performance of the system is improved in AWGN as well as Rayleigh channel. This is because the Convolutional codes are very effective in removing the burst errors and distortions caused by the channel. Moreover, the BER performance of the system is affected by the outage probability. Outage probability is the probability when the required data rate is not supported by the specific channel due to variable SNR. The Convolutional encoding coupled with bit interleaving reduces the outage probability at higher SNR. Thus, the DWT-OFDM system with encoding outperforms significantly at higher values of SNR.

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