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A Comparative Study of FFT and Wavelet-Based OFDM Techniques for MIMO Wireless Systems over Fading Channels

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) combined with Multiple Input Multiple Output (MIMO) antenna systems has become a fundamental technology in modern wireless communications, particularly in 4G and beyond. OFDM enables high data rate transmission within limited bandwidth, while MIMO systems provide spatial diversity to effectively mitigate the effects of channel fading. Conventional OFDM systems are primarily based on the Fast Fourier Transform (FFT). However, the increasing demand for higher performance in next-generation wireless systems has led to the exploration of alternative techniques such as Discrete Wavelet Transform (DWT)-based OFDM.

In this work, a comparative performance analysis of FFT-OFDM and DWT-OFDM is presented. The study is further extended to evaluate their performance in MIMO systems under Rayleigh fading channel conditions. Haar wavelet is employed for the implementation of DWT-OFDM, and simulations are carried out using MATLAB. Performance metrics such as error rate and spectral efficiency are considered for evaluation. The results demonstrate that DWT-OFDM, both as a standalone system and in combination with MIMO, outperforms conventional FFT-based OFDM in terms of overall system performance.

Keywords: OFDM, MIMO, DWT, FFT

1. Introduction

Nowadays wireless application demands very high data rate with limited bandwidth resource. A modulation system that suits with tailor-made perfection is OFDM. In this scheme the channel is made up of multiple flat fading sub channels to combat frequency selective fading. Since the sub carriers of the channel overlaps with each other the efficient usage of spectrum is ensured. Orthogonality should be maintained among sub carriers to avoid Inter Symbol Interference (ISI). To ensure this cyclic prefix (CP) is added, which is nothing but extending the symbol size with the same information[1]. CP nullifies ISI, betterments synchronisation, but all at the cost of reduced throughput. Conventional OFDM which uses IFFT/FFT, the usage of CP is unavoidable. Newly evolving DWT based OFDM doesn't need CP and renders increased throughput. Apart from eliminating CP DWT OFDM has many advantages. This paper presents the comparative analysis of the FFT OFDM and DWT OFDM for various levels of subcarriers. Also, it evaluates the BER (Bit Error Rate) performance of both the schemes individually partnered with MIMO systems in simulated fading channel.

The rest of the paper is organised in the following manner. Section II describes about the conventional FFT based OFDM. DWT based OFDM is discussed in section III, Fourth section deals with the comparative analysis. Section V tells about the MIMO OFDM basics and the next compares both the OFDM schemes in conjunction with MIMO. The last section is for conclusions.

2. Conventional FFT based OFDM

OFDM is a multi-carrier system in which orthogonal subcarriers are used to transmit multiple symbols. For this (refer figure 1) the serial data stream should be converted into N number of parallel data stream. N refers to the number of sub carriers. Constellation mapping is used to produce digitally modulated data of QAM, QPSK or BPSK. The usage of IFFT / FFT is justified here because it makes the conversion process very simple. Otherwise at the transmitter / receiver side the system needs N number of sinusoidal multipliers [2] The mathematical expression of the data available in the N numbers of data streams after IFFT block is given by,

$$X_{k(n)} = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X_m(i) e^{(j2\pi ni/N)} \qquad (1)$$

Cyclic prefix is added to the IFFT output in order to avoid ISI. It is done by extending the end of a symbol with its repetition. The resulting output signal is transmitted in the channel. At the receiver end the reverse process happens and the symbols are retrieved.
The frequency domain output at the FFT block is given by,

$$D_{m(i)} = \sum_{n=0}^{N-1} D_{k(n)} e^{(-j2\pi ni/N)} \qquad (2)$$

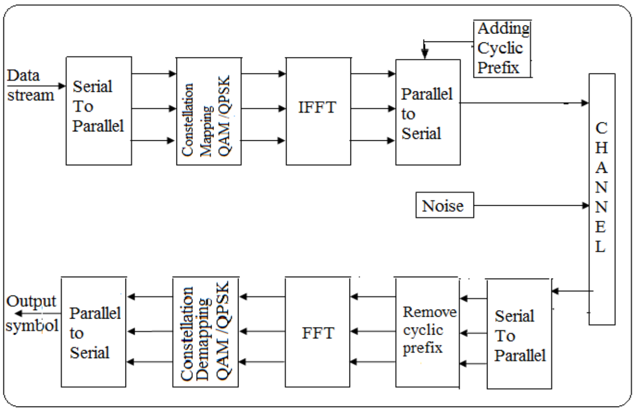

Figure 1: Block diagram of FFT based OFDM

3. DWT based OFDM

The DWT OFDM is constructed using wavelet carriers obtained from mother wavelet $\psi(t)$ is given by the expression

$$\psi_{i,l}(t) = 2^{-i/2}\psi(2^{-i}t - l) \qquad (3)$$

Where, l is the time location of the wavelet carrier and i is the scaling index.

As a result of applying translation (shifting process) and dilation (compression) over the mother wavelet, the wavelet carriers are generated. Comparing FFT (which gives only spectrum details), these wavelet carriers can provide time-frequency localisation. The more desired property in our case is Orthogonality, can be achieved by creating members of the wavelet family as per the equation below.

$$\langle \psi_{i,l}(t), \psi_{m,n}(t) \rangle = \begin{cases} 1, i=m \,\&\, l=n \\ 0 \text{ otherwise} \end{cases} \qquad (4)$$

IDWT / DWT is computed using Mallat's Algorithm [3] in which the discrete time domain signal undergoes series of Low pass and High pass filtering.

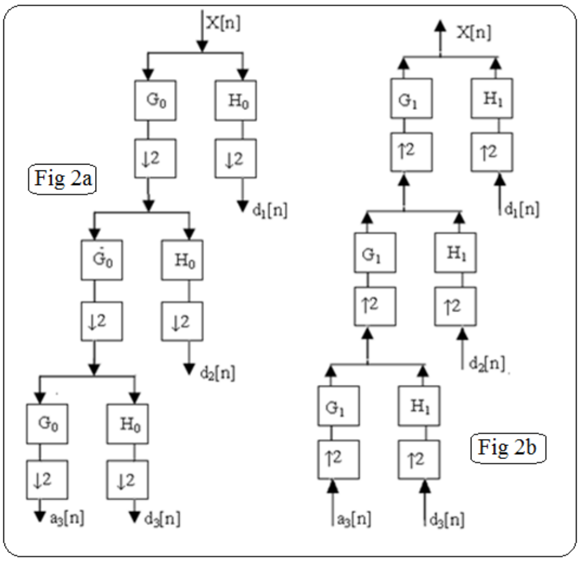

Figure 2: Computation of a) DWT b) IDWT

As shown in Figure 2, for computing DWT, X (n) is applied to G_0 and H_0, LPF and HPF respectively. The information produced by the LPF is approximate a(n) and by HPF is detailed information d(n). (Because of this at high frequencies time resolution is good and at low frequencies, frequency resolution will be good.) The output is down- sampled and again applied to a set of filters. This process is repeated for three stages. Finally by concatenating all the coefficients DWT is computed. For IDWT the reverse process of DWT is done. In this case symbols are first up-sampled and applied to the filters. This computation method is used to build IDWT / DWT block in the DWT OFDM transceiver.

Except two things, the DWT OFDM system is as same as fig 1.

1. It will not have cyclic prefixing and removing.
2. It will be replacing IFFT / FFT block with IDWT / DWT block that is shown in fig 3.

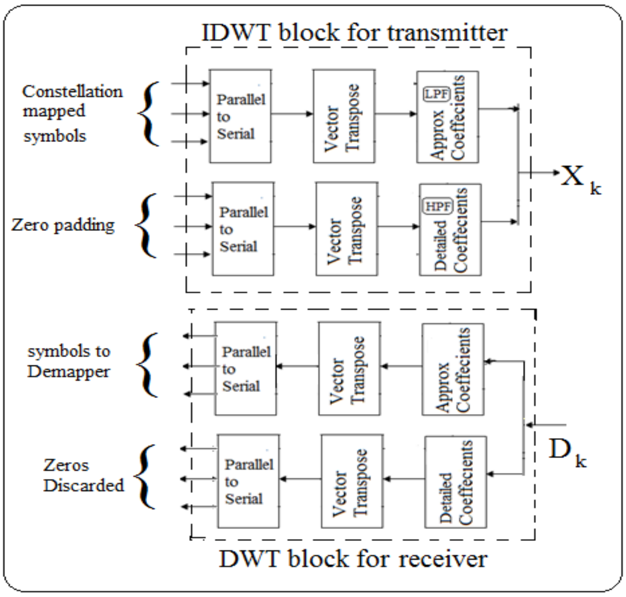

Figure 3: IDWT/ DWI blocks for DWT OFDM transceiver

In the transmitter side after constellation mapping N parallel data streams are available. Using these data wavelet subcarriers with orthonormal (orthogonal and also normal) properties should be constructed. To implement the task, initially the parallel data stream is converted to serial and represented as a vector. Then the vector is converted to parallel matrix by vector transposing. After that up-sampling and Low pass filtering is done to get approximate coefficients, which represents data. On the other hand to get the wavelet coefficients, same procedure is followed with zero padding, and the vector transposed output is High pass filtered. Due to this zero padding, most of the symbols in the midway becomes zero and hence the mean power of the DWT OFDM is comparatively very low than that of FFT OFDM.[4] In the receiver side the reverse process that means DWT takes place. In this case, two sets of outputs generated. One with symbols to be de –mapped. Other set is of zeros-discarded.

4. Comparative analysis of FFT-OFDM and DWT-OFDM

Comparison of BER performance of FFT OFDM and DWT OFDM is carried over in MATLAB. Rayleigh channel is used as simulation environment. The parameters for simulations are as listed below.

Table 1: Simulation Parameters

Parameters	FFT OFDM	DWT OFDM
Modulation	QPSK	
Constellation size	4	
Data Length	varied Ref fig 4,5 and 6	
Block size	varied Ref fig 4,5 and 7	
Number of FFT points	Equal to block size	
Cyclic Prefix	Rounded of to 10% of block size	Not Applicable

From the simulation results it is obvious that for any given condition the DWT OFDM is always the better performer. Also it infers that for the same data length if the block size is increased the BER performance increases (compare figure 4 and 5), and for the same block size if the data length decreased the BER performance decreases (Compare figure 5 and 6).

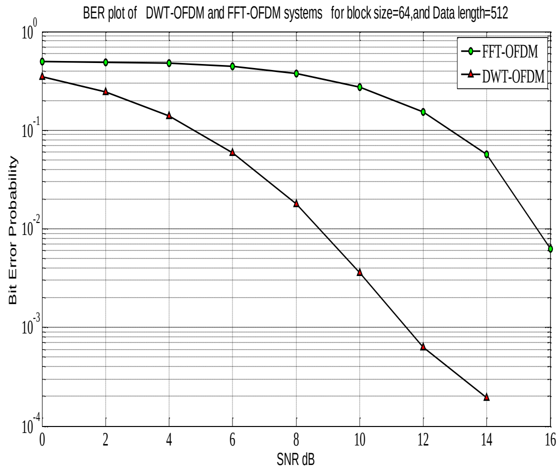

Figure 4: Simulation for block size 64 & Data length 51

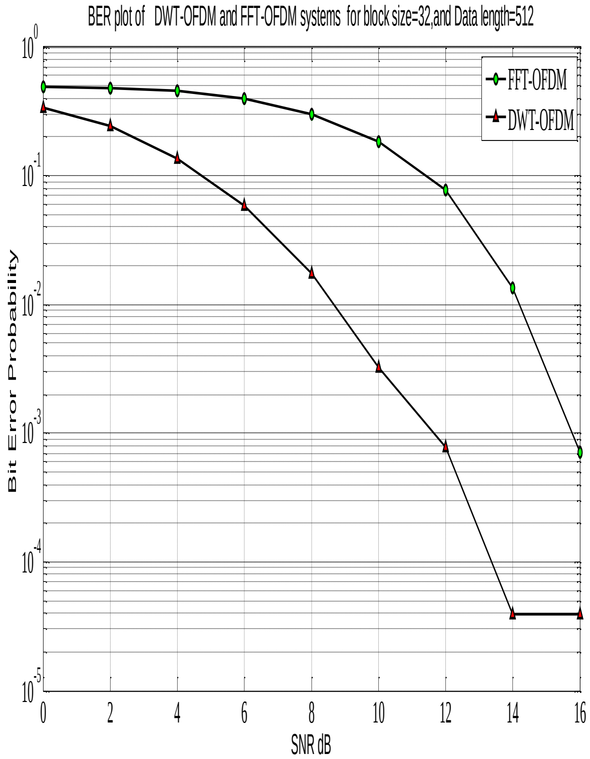

Figure 5: Simulation for block size 32 & Data length 512

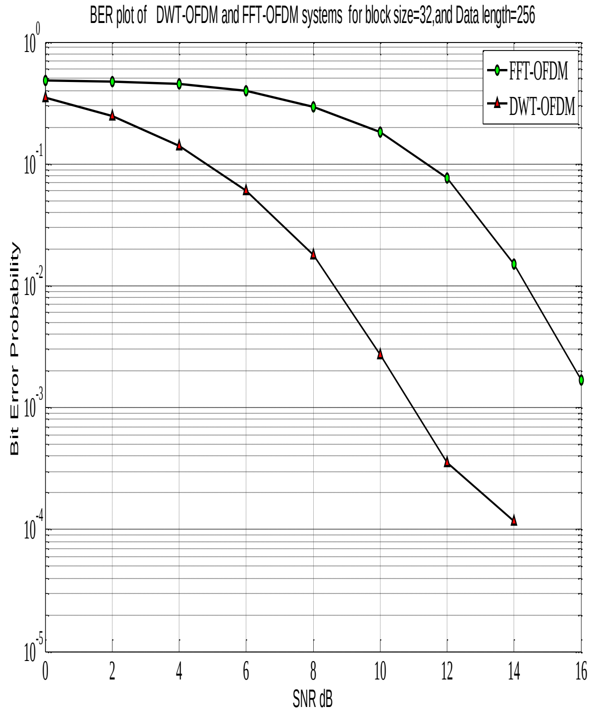

Figure 6: Simulation for block size 32 & Data length 256

5. MIMO OFDM Systems

The OFDM systems discussed so far is of single transmitting antenna and single receiving antenna.

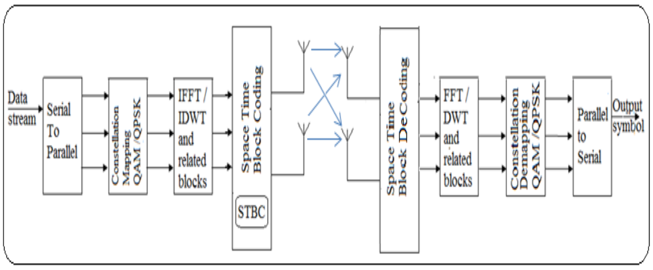

Figure 7: MIMO OFDM system using STBC coding

Suppose if the same information is simultaniously transmitted with more than one transmitting antenna and simultaniously received by more than one receiving antenna then the system is reffered to as MIMO systems. A simple 2 x 2 MIMO system (based on [5],[6]) is shown in fig 7. In transmitter side it generates OFDM signal using IFFT or IDWT. According to that successive related blocks will change. The generated OFDM symbols are coded using Space Time Block Coding (STBC) techniqe. The output of the coder is simultaniously fed to the two antennas for transmitting. This raises the diversity gain and hence the effeciency of the system highly increased. In the receiver side reverse process is carried over and the signal gets demodulated.

6. DWT OFDM MIMO Vs. FFT OFDM MIMO

MIMO OFDM system with STBC coding is simulated using MATLAB. 2 x 2 MIMO system is created with QPSK modulation of constellation size 4.

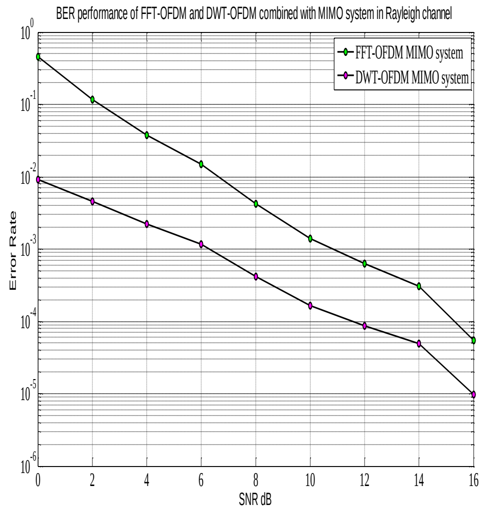

Figure 8: BER Plot of DWT- OFDM MIMO Vs. FFT- OFDM MIMO

The BER plot shown in fig 8 is generated for the block size 8 and the number of bits equal to 2048 (means 1024 x 2). Rayleigh channel is used for simulation.

7. Conclusion

From the simulated results and plots it is very clear that the DWT OFDM as it is or together with MIMO systems performing very well. Symptoms are indicating that FFT OFDM will be replaced by DWT OFDM in the long run. Even though the simulated results are promising some hopes, the computational complexity, compactness of the receiver, power lasting capacity, Quality Of service and lot more things needs to be considered as implementation factors and each of them is a wide area for further research.

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