Performance Evaluation of DWT based Multicarrier Systems over Frequency Selective Channels

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Abstract— In this work, the performance of DWT based OFDM is studied and compared it with conventional FFT based OFDM over frequency selective channels in different test environments. The Bit Error Rate (BER) estimation is done to evaluate the performance of both the systems. In DWT based OFDM, different wavelet families such as haar, daubechies, coiflet and biorthogonal were used with different levels of decomposition. The simulation results show that in all channels, DWT based OFDM requires less SNR value to achieve the minimum BER of 10^{-3}, when compared to conventional FFT based OFDM. Therefore, DWT based OFDM can be used in place of FFT based OFDM with high bandwidth efficiency.

Keywords- Multicarrier modulation, OFDM, FFT based OFDM, DWT based OFDM, BER, Frequency selective channel

I. INTRODUCTION

Wireless communication is the fastest growing sector of communication industry [1]. Over wireless channels, Multicarrier modulation is the most popular technique for broad band communication, which deals with non-flat broadband channels by splitting up the channel into a large number of flat narrow band sub-channels. One form of multicarrier modulation is Orthogonal Frequency Division Multiplexing (OFDM), which uses orthogonal subcarriers to carry the data over parallel sub-channels. The conventional FFT based OFDM improves the spectral efficiency, data rate and capacity without increasing the power, cost and bandwidth of the system [2].

The conventional FFT based OFDM has many limitations like high Peak to Average Power Ratio (PAPR), which affects the linear operation of power amplifier, highly sensitive to carrier frequency offsets, doppler shift, synchronization problems [3]. In FFT based OFDM, use of cyclic prefix to combat ISI decreases the efficient use of spectrum. In frequency domain, FFT based OFDM has high side lobes which leads to high interference. Therefore, Discrete Wavelet (DWT) based OFDM is used as an alternate method to overcome the drawbacks of conventional FFT based OFDM [4]-[9].

In DWT based OFDM, Cyclic Prefix (CP) is not used, as it has the ability to combat ISI .Without CP, DWT-OFDM increases bandwidth efficiency [10]. The spectrum of DWT based OFDM has low side lobes, which leads to less interference. It has many other advantages like multi resolution analysis, time and frequency domain localization and preservation of orthogonality [11], [12].The performance of DWT based multicarrier systems over frequency selective channels is little studied. In this paper, we have evaluated BER performance of haar, daubechies, coiflet and biorthogonal wavelet based OFDM and compared it with conventional FFT based OFDM over frequency selective channels.

This paper is organized as follows: Section II describes the DWT based OFDM system and a brief review of wavelets employed; Section III specifies the parameters used for simulation; Section IV discusses the results and performance analysis of both conventional FFT based OFDM and DWT based OFDM over frequency selective channels; Section V summarizes conclusion.

II. DWT BASED OFDM

Discrete wavelet based OFDM system differs from conventional FFT based OFDM by replacing IFFT and FFT by IDWT and DWT respectively, i.e. fourier bases are replaced by orthogonal wavelets. The block diagram of DWT based OFDM is shown in Fig. 1.

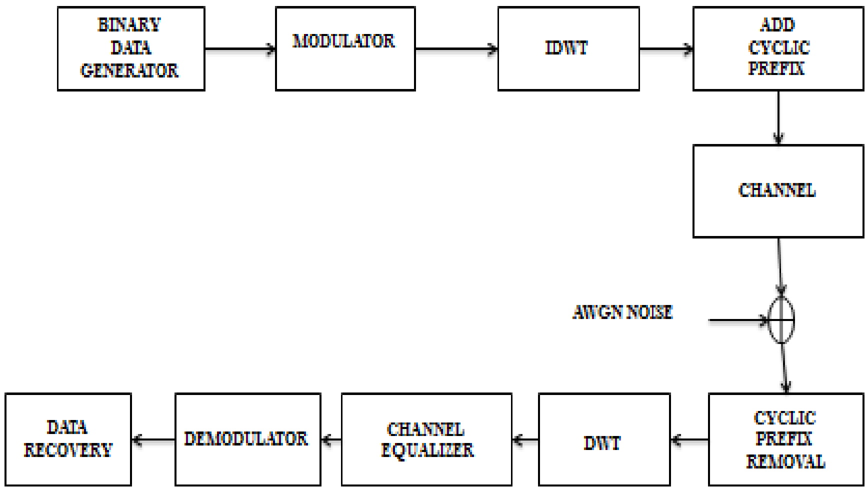

Fig. 1. Block diagram of DWT-OFDM

In transmitter part, the random binary data is generated which is passed through M-ary QAM modulator and serial to parallel converter to produce N parallel QAM symbols $X_m(i)$. These symbols and zero pads are passed through IDWT in which each symbol and zero pad is converted into serial representation (XX).The vector transpose is used to transpose XX into CA and CD for symbols and zero pads respectively. Then CA and CD are filtered by approximated coefficients (i.e. LPF) and detailed coefficients (i.e. HPF) respectively. The output of transmitter block is transmitted signal X_k as shown in Fig. 2. This transmitter part is called synthesis filter. The output of IDWT block [13] is

$$x(n) = \sum_{m=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} X(m,k) 2^{m/2} \Psi(2^m n - k) \tag{1}$$

At receiver side, DWT and M-ary QAM demodulator is used to recover the transmitted data from received signal U_k. The receiver part is also called analysis filter. The output of DWT block [13] is

$$X(m,k) = \sum_{n} x(n) 2^{m/2} \Psi(2^m n - k) \tag{2}$$

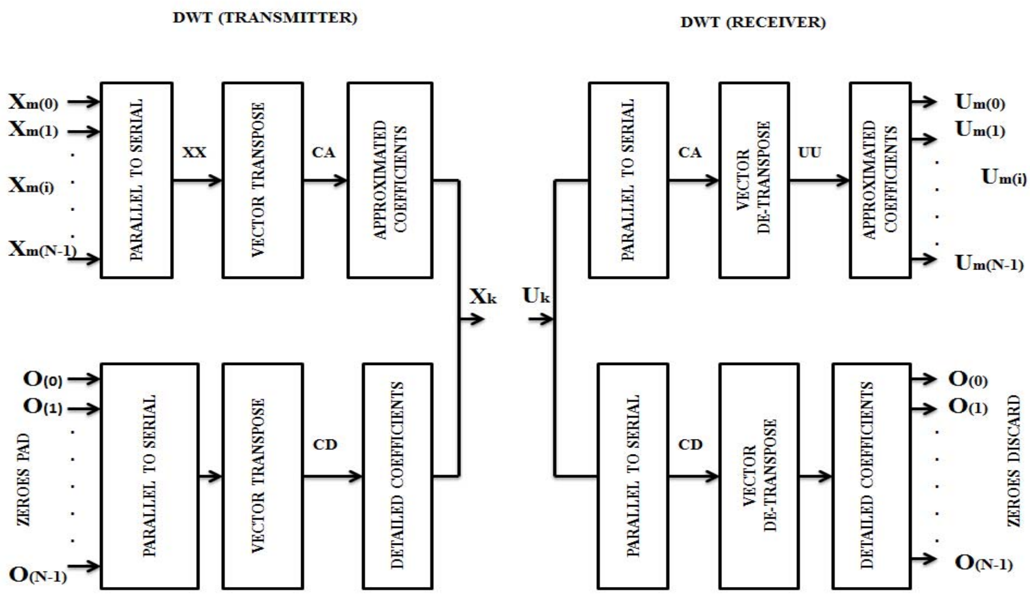

Fig. 2. DWT transmitter and receiver [14]

DWT has less complexity of O(N) when compared to the FFTs O(N$\log_2$N) [12]. A wavelet is a small wave with finite energy concentrated around a point which is used for multi-resolution analysis. In this work, the performance of wavelet based OFDM is analysed by using some of the most widely used wavelet families such as haar, daubechies, coiflets, biorthogonal. A brief description of each of these families [15] is given below:

1) *Haar Wavelets:* They are the most simple and flexible wavelet. They have a compact support, which means the wavelet function Ψ has values in a finite range. Haar wavelet is widely used for analysing the signals with sudden transitions and avoids the loss of information, when they are applied.

$$\text{Wavelet function, } \Psi(t)=\begin{cases}1, 0\le t<\frac{1}{2}\\ -1, \frac{1}{2}\le t<1\\ 0, otherwise\end{cases} \quad (3)$$

$$\text{Scaling function, } \Phi(t)=\begin{cases}1, 0\le t<1\\ 0, otherwise\end{cases} \quad (4)$$

2) *Daubechies Wavelets*: They are asymmetric and orthogonal wavelets. Daubechies wavelets are widely used because they are compactly supported with external phase and largest number of vanishing moments for a given support width. Db1 wavelet is same as haar wavelet.

3) *Coiflet Wavelets*: They are orthogonal and quasi-symmetric wavelets. Coiflets are widely used because they are compactly supported with largest number of vanishing moments for both wavelet function (Ψ) and scaling function (Φ) for a given support width.

4) *Biorthogonal Wavelets*: They have a compact support so the loss of information is avoided, when they are applied. Biorthogonal wavelets are widely used because they exhibit the linear phase property needed for signal reconstruction and their coefficients are symmetrical in nature.

III. Simulation Parameters

The performance comparison of FFT based OFDM and DWT based OFDM over frequency selective channels were done using MATLAB software. In this work, for both the systems we have used 4-QAM modulator because the bandwidth efficiency of QAM is high, when compared to other modulation techniques. We have taken 64 subcarriers for FFT based OFDM and we have employed four different wavelet families such as haar, daubechies, coiflet and biorthogonal in DWT based OFDM. The different frequency selective channels considered for simulation are indoor channel A, indoor channel B, vehicular channel A, vehicular channel B, pedestrian channel A and pedestrian channel B. Their channel impulse response models are shown in Table I.

TABLE I. ITU Channel Models [16]

CHANNEL	RELATIVE DELAY (ns)	AVERAGE POWER (dB)	DOPPLER SPECTRUM
Indoor channel A	[0,50,110,170,290,310]	[0,-3.0,-10.0,-18.0,-26.0,-32.0]	Flat
Indoor channel B	[0,100,200,300,500,700]	[0,-3.6,-7.2,-10.8,-18.0,-25.2]	Flat
Vehicular channel A	[0,310,710,1090,1730,2510]	[0,-1.0,-9.0,-10.0,-15.0,-20.0]	Classical
Vehicular channel B	[0,300,8900,12900,17100,20000]	[-2.5,0,-12.8,-10.0,-25.2,-16.0]	Classical
Pedestrian channel A	[0,110,190,410]	[0,-9.7,-19.2,-22.8]	Classical
Pedestrian channel B	[0,200,800,1200,2300,3700]	[0,-0.9,-4.9,-8.0,-7.8,-23.9]	Classical

IV. RESULTS AND DISCUSSION

In this section, BER performance of both conventional FFT based OFDM and DWT based OFDM with different decomposition levels of wavelet is achieved and analysed for different frequency selective channels.

A. Comparison of FFT and DWT based OFDM over Indoor Channel A

In indoor channel A, it is noticed that for low SNR values (i.e. upto 8 db) FFT- OFDM performs better than DWT-OFDM but for high SNR values (i.e. above 8 db) DWT-OFDM outperforms FFT-OFDM as shown in Fig.3.At 10^{-3} BER, Db1 performs better than FFT-OFDM by SNR of about 9 db, bior 1.1 by about 10 db, haar by about 11 db and Coif1 by about 12 db. Among all wavelet families employed here in this paper, coiflet wavelet based OFDM has less BER values.

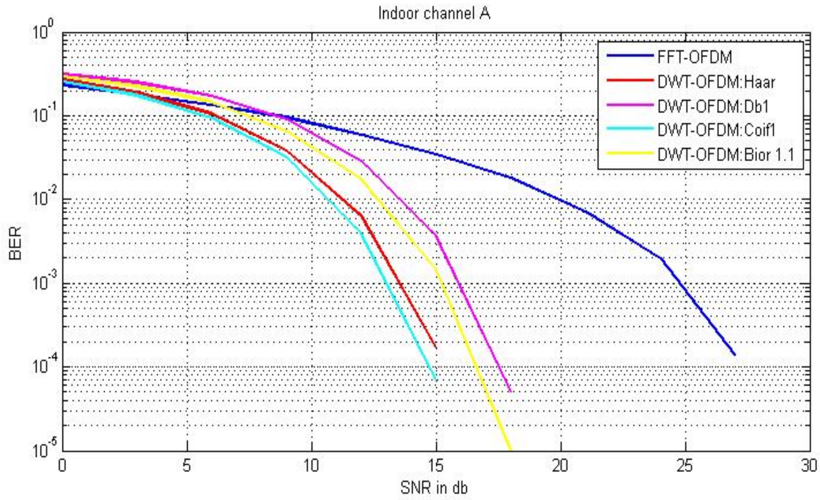

Fig. 3. Indoor channel A

B. Comparison of FFT and DWT based OFDM over Indoor Channel B

From Fig. 4, it is noticed that Bit Error Rate of DWT-OFDM is less than the FFT-OFDM over indoor channel B. Daubechies wavelet performs better than all the other wavelet families employed here. At BER of 10^{-2}, Db1 wavelet has SNR of about 11 db, whereas FFT-OFDM has SNR of about 16 db, which is more when compared to DWT-OFDM. The performance of haar and db1 wavelet based OFDM are found to be nearly equal.

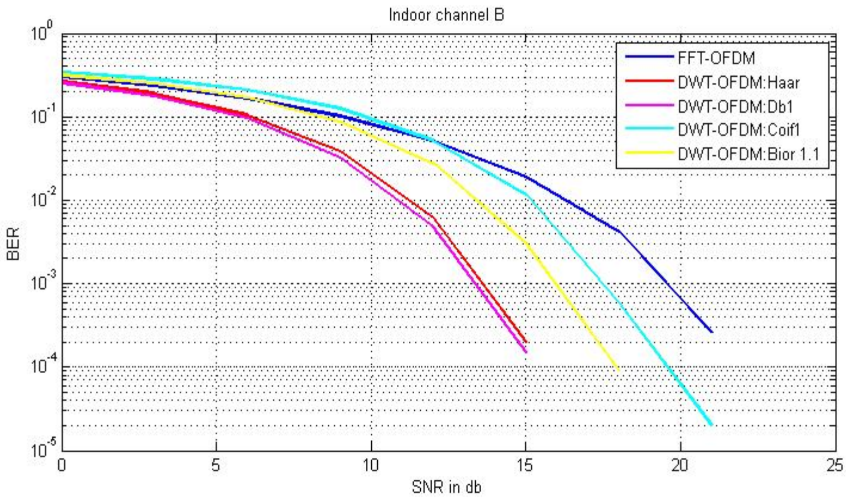

Fig. 4. Indoor channel B

C. Comparison of FFT and DWT based OFDM over Vehicular Channel A

Fig. 5 depicts that DWT based OFDM performs better than FFT based OFDM over vehicular channel A. But for SNR values below 10 db, FFT-OFDM gives better performance than coiflet wavelet based OFDM. At BER of 10^{-2}, both daubechies and biorthogonal wavelets have SNR value exactly equal to 10 db which gives less bit error rate when compared to FFT and other wavelets based OFDM discussed in this paper.

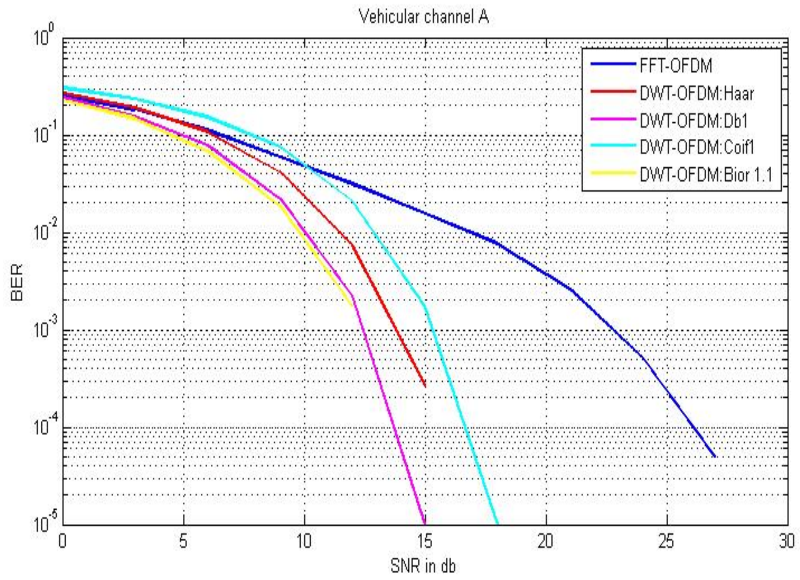

Fig. 5. Vehicular channel A

D. Comparison of FFT and DWT based OFDM over Vehicular Channel B

In vehicular channel B, DWT-OFDM gives better performance than FFT-OFDM as shown in Fig. 6.The performance of coiflet and daubechies wavelet based OFDM are nearly equal and found to be better than FFT by about 5 db at 10^{-3} BER. The performance of haar and biorthogonal wavelet based OFDM are nearly equal and found to be better than FFT by about 6 db at 10^{-3} BER, which is better than all the other wavelet families discussed in this paper.

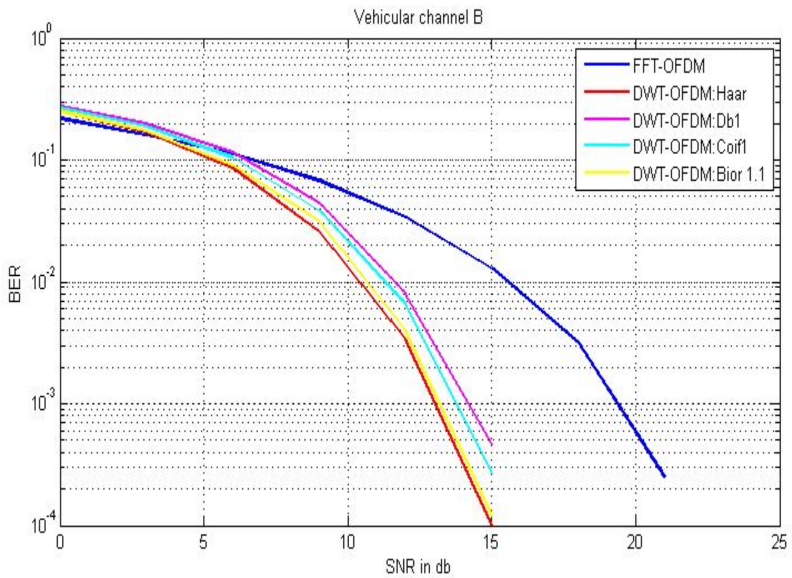

Fig. 6. Vehicular channel B

E. Comparison of FFT and DWT based OFDM over Pedestrian Channel A

In pedestrian channel A, daubechies wavelet has less BER than FFT-OFDM and all the other wavelet based OFDM used here. As shown in Fig. 7, the bit error rate is 10^{-3} in DWT-OFDM (Db1) at SNR=12 db, whereas the same BER is given by FFT-OFDM only above 20 db.

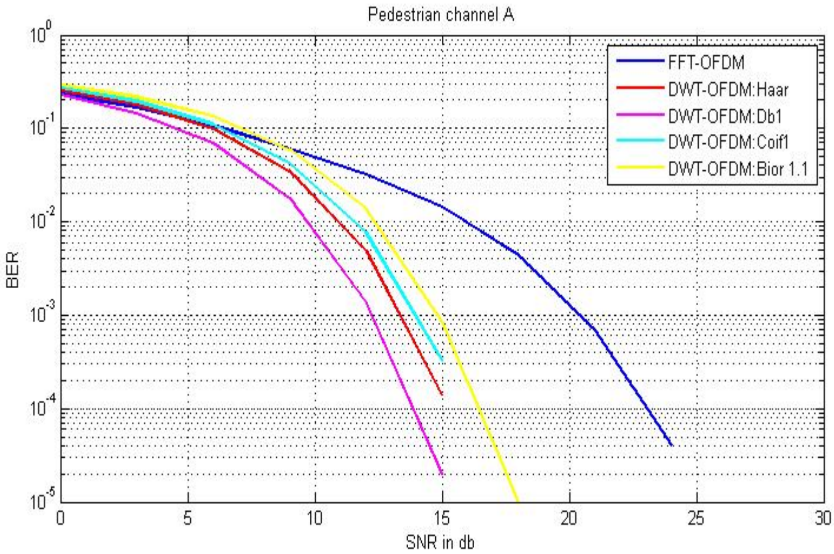

Fig. 7. Pedestrian channel A

F. Comparison of FFT and DWT based OFDM over Pedestrian Channel B

As shown in Fig. 8, the BER values of FFT- OFDM is more when compared to DWT-OFDM. At 10^{-3} BER, Db1 performs better than FFT by SNR of about 11 db. In pedestrian channel B, Daubechies wavelet based OFDM gives less BER than all the other wavelets employed here for discussion.

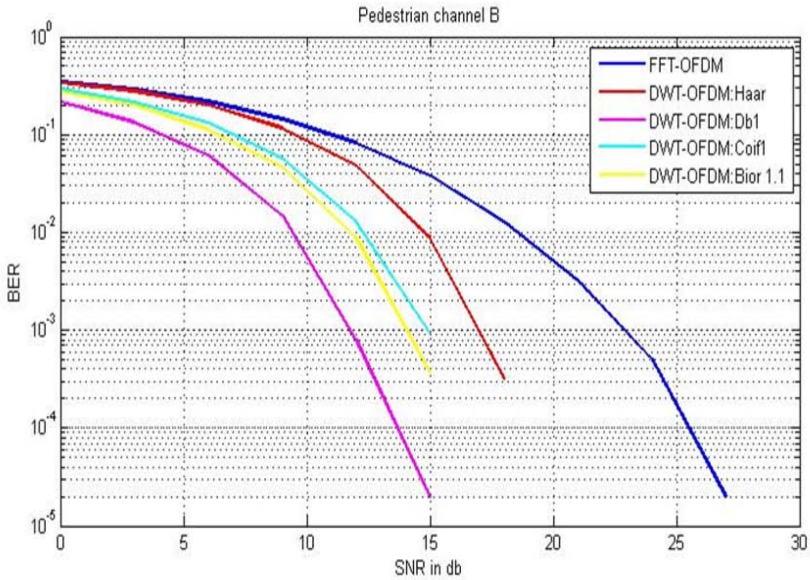

Fig. 8. Pedestrian channel B

G. Comparison of different decomposition levels of DWT based OFDM

The BER performance of different decomposition levels of DWT based OFDM has been simulated for all the above channels and wavelets. For instance, we present below the representative result for haar and biorthogonal wavelet over indoor channel A to demonstrate the improvement in performance with increase in wavelet decomposition levels. From Fig. 9, it is noticed that at 10^{-3} BER haar wavelet with 4 decomposition levels performs better than levels 1, 2, 3 by SNR of about 7 db, 6 db, 4 db respectively over indoor channel A. Similar to haar wavelet, biorthogonal wavelet gives better performance with increase in decomposition levels as shown in Fig. 10. At 10^{-3} BER, biorthogonal wavelet with 4 decompostion levels has SNR of about 12 db which is found to be less than all the other lower levels of wavelet decomposition.

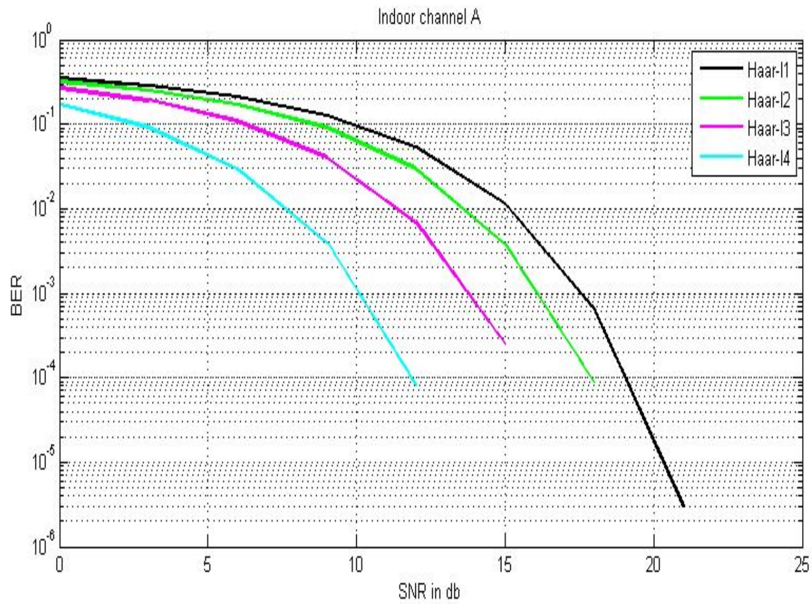

Fig. 9. Different decomposition levels of Haar wavelet

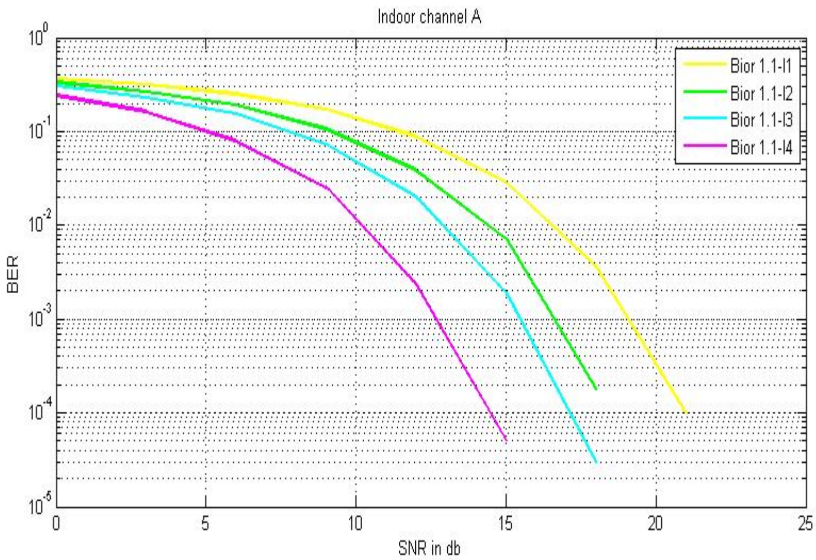

Fig. 10. Different decomposition levels of Biorthogonal wavelet

From the above results, it is summarized that the BER values of DWT based OFDM is less, when compared to FFT based OFDM and it is found that as SNR increases BER decreases in all cases. In indoor channel A, at 10^{-3} BER coiflet wavelet outperforms FFT by SNR of about 12 db. Daubechies wavelet performs better in indoor channel B than FFT by about 6 db at 10^{-3} BER. In vehicular channel A, at 10^{-2} BER both biorthogonal and daubechies wavelets perform better than FFT by SNR of about 7 db. Both haar and biorthogonal wavelets are found to be better than FFT by about 5 db at 10^{-3} BER. In both pedestrian channel A and B, daubechies wavelet performs better than FFT by SNR of about 9 db and 11 db at 10^{-3} BER respectively. The performance of DWT based OFDM is improved further by increasing the number of wavelet decomposition levels.

V. CONCLUSION

In this paper, DWT based OFDM performance is investigated and evaluated with different wavelet families such as haar, Daubechies, coiflet, biorthogonal over frequency selective channels. It is also compared with conventional FFT based OFDM and the results obtained show that DWT based OFDM performs better than FFT based OFDM with less BER. Wavelet based OFDM is also simple to implement with less complexity and efficient bandwidth than FFT based OFDM. In future, DWT based OFDM can be combined with diversity techniques and channel coding to improve the performance of the system. This system can also be implemented by optimizing the choice of wavelets and the number of decomposition levels with energy compaction to reduce the power transmission.

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