Performance Analysis of Modified SV-Model Based DWT-OFDM Diversity for UWB System

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Abstract— **Any UWB system faces major challenges in achieving wide coverage without affecting the system performance. In recent generation communication system OFDM is used to cater for increased data rate of wireless medium with good performance. Diversity techniques play an important role in achieving higher performance level under imperfect channel condition. Recently DWT (Discrete Wavelet Transform) is adopted in lieu of FFT (Fast Fourier Transform) for frequency transform. This paper proposes a DWT-OFDM Diversity to achieve better performance in terms of SNR and bit error rate (BER) for modified SV model based UWB channel. The performance of different discrete wavelets are analyzed and compared with FFT based OFDM. The result indicates better BER performance in case of lower order wavelet.**

Keywords- DWT; OFDM; SV Mode;, UWB; FFT; SNR; BER; ISI.

I. INTRODUCTION

Ultra Wide Band (UWB) technology demonstrates a great promise for high speed short range wireless communication. UWB system faces major challenges in achieving the desired performance and coverage due to low power transmission. OFDM technique promises better performance for the UWB system due to certain diversity advantage. In Orthogonal Frequency Division Multiplexing (OFDM), the signal itself is first split into independent channel, modulated by data and further re-multiplexed to create OFDM carrier. As the subcarriers in OFDM are orthogonal, it allows for simultaneous transmission of multiple sub-carriers in a compact frequency space without interference. OFDM can provide large data rates even under channel impairment. Efficient compact spectral utilization can be achieved in OFDM scheme with help of minimally separated sub-carriers [5]. Similarly OFDM scheme converts a broadband frequency selective channel into parallel flat fading narrow band sub channel.

In order to mitigate the problem of ISI (Inter symbol interference) caused by complex multipath wireless channel a cyclic prefix (CP) [4] is added to each symbol in OFDM system. The cyclic prefix causes ripples in the power spectral density of the UWB signal [2]. On the other hand wavelet based modulation satisfies orthogonality criterion. We can derive benefits of OFDM even when traditional sinusoid carriers of FFT based OFDM are replaced with suitable wavelets. Wavelet based system have better to immunity to impulse and narrow band noises as compared to FFT OFDM[2,4].

In addition to this, wavelet based OFDM does not require any CP, leading to increase in spectral efficiency, reduced complexity and better symbol rate. Discrete wavelet transform (DWT) are being considered as an alternative platforms for replacing IFFT and FFT [15, 16]. It utilizes low pass filter and high pass filter operating as Quadrature Mirror Filters (QMF) which satisfies perfect reconstruction and ortho-normal properties. The purpose of this paper is to demonstrate the diversity advantage provided by use of DWT in lieu of FFT in OFDM system. DWT has been introduced as a highly efficient and flexible method for sub-band decomposition of signal.

Section II presents the traditional FFT OFDM and wavelet OFDM whereas Section III describes the system and channel model. In Section IV simulation environment with result are discussed. Section V concludes the paper.

II. FFT OFDM AND WAVELET OFDM

A. FFT-OFDM

OFDM system is used as modulation method that divides a given bandwidth into multiple smaller sub-bands. In time domain, an N-point FFT OFDM system can be represented as:

$$s[n]=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} S_k\, e^{j2\pi nk/N}, \quad n=0,1,2,\ldots\ldots N-1 \qquad (1)$$

Where s[n] is the discrete form of s(t), N is the number of sub channels, $\frac{1}{\sqrt{N}}$ is a scaling factor with n as the index of the prevalent subcarrier. S_k is the BPSK mapped input symbol of k^{th} sub-channel. The number of FFT points used is same as the number of narrowband sub-channels over which the input symbols are multiplexed. Each of the resulting narrowband sub-channels is modulated by the mapped input bits. Cyclic prefix (CP) at least equal to the length of the channel response, L is pre-appended to each OFDM symbol to contest ISI. To account for the CP, Equation 1 can be expressed as:

$$s[n]=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} S_k\, e^{j2\pi nk/N}, -N_g \leq n \leq N-1 \quad (2)$$

In Equation 2, N_g denotes the length of CP pre-appended to every OFDM symbol.

B. Wavelet – OFDM

The discrete wavelet transform (DWT) can be used to study multicarrier systems as in [9]. It represents signals in time-frequency domain such that the signal exists neither purely in frequency domain nor purely in time domain. For a mapped input symbol S_k to be transformed by the DWT, the time domain output can be realized from [10];

$$s[n] = \sum_k \sum_{m=0}^{M-1} S_{k,n}\, \varphi_{m,n}(t) \quad (3)$$

where $S_{k,n}$ represents the n^{th} symbol which modulates the m^{th}-waveform of the k^{th}-constellation. $\varphi_{m,n}(t)$ represents the complex orthogonal DWT basis function similar to the traditional OFDM as:

$$\varphi_{m,n} = \begin{cases} 1 & n = m \\ 0 & elsewhere \end{cases} \quad (4)$$

Where m and n are scales and shifts respectively. If n is the index of each discrete wavelet symbol s[n] of the continuous time symbol $s(t)$, then the wavelet transform is defined as [11]:

$$\Psi_{k,a}(t) = e^{j\pi t^2} \quad (5)$$

Now, let a continuous wavelet function is expressed as:

$$\Psi_{k,a}(t) = \frac{1}{\sqrt{k}}\Psi\left(\frac{t-a}{k}\right) \quad (6)$$

where k and a are the scaling and shifting parameters respectively and $\Psi(\cdot)$is called the mother wavelet. Then, from Equations 5 and 6 the resulting continuous transform can be represented as:

$$S_{CWT}(\tau,k) = \frac{1}{\sqrt{k}}\int_{-\infty}^{\infty} exp\left[i\pi\frac{(t-\tau)^2}{k^2}\right]s(t)dt \quad (7)$$

Equation 7 has the advantage of time and frequency diversities unlike the FFT transform that has only frequency diversity advantage. In fact, it has been explored that orthogonal wavelet-based OFDM is more robust to ICI and ISI problems than the FFT-based OFDM [12-14]. Absence of CP in wavelet OFDM unlike that in FFT OFDM, provides for additional 25% spectral efficiency.

I. SYSTEM AND CHANNEL MODEL

A. FFT OFDM Model

The OFDM system model described below is utilized for both FFT-OFDM and DWT-OFDM. The input binary data is generated randomly as bit stream b. It is processed using BPSK modulator to map the input data into symbols X_m. These symbols are now passed through IFFT block to perform IFFT operation to generate N parallel data streams. Its output in discrete time domain is given by,

$$X_{k(n)} = \frac{1}{\sqrt{N}}\sum_{i=0}^{N-1} X_m(i) e^{\left(\frac{j2\pi ni}{N}\right)} \quad (8)$$

The cyclic prefix is now appended to transformed output (X_k). The cyclic prefix (CP) is added before transmission, to moderate ISI effect. This OFDM symbol is passed through standard UWB channel. At the receiver, the reverse operation is carried out to obtain the original data back. The CP is removed and processed in the FFT block and finally passed through demodulator for data recovery. The output of the FFT in frequency domain is given by,

$$Y_{m(i)} = \sum_{n=0}^{N-1} Y_{k(n)} e^{\left(\frac{-j2\pi ni}{N}\right)} \quad (9)$$

B. DWT OFDM Model

In DWT OFDM, at the transmitter the input data b maps on to BPSK modulator, thereby converting data b_k into symbols $X_{m(i)}$. Each $X_{m(i)}$ is first converted to serial representation having a vector XX which will next be transposed into CA. Then, the signal is up-sampled (zero padding) and filtered by the LPF coefficients or approximated coefficients. Since our aim is to have low frequency signals, the modulated signals XX perform circular convolution with LPF filter whereas the HPF filter also perform the convolution with zeroes padding signals CD respectively. Note that the HPF filter contains detailed coefficients or wavelet coefficients. This data is given as an input to IDWT block wherein a particular wavelet is chosen for simulation. At the receiver, DWT and PSK demodulator (BPSK) are used to recover back the data.

C. Channel Model

This model starts with physical realization that rays arrives in clusters. The cluster arrival times are modeled as Poisson arrival process with some fixed rate Λ, Within each cluster subsequent rays also arrives according to Poisson process with another fixed rate λ. Each cluster consists of rays i.e. λ << Λ

Let arrival time of l^{th} cluster be T_l, l= 0, 1, 2, ...

Let the arrival time of k^{th} ray measured from beginning of the l^{th} cluster be $\tau_{k,l}$, k = 0,1,2, ...

For the first cluster $T_0 = 0$ and for the first ray within l^{th} cluster $\tau_{k,l} = 0$.

Hence $\tau_{k,l}$ and T_l are independent inter-arrival exponential probability density function.

$$p\,(T_l|T_{l-1}) = \Lambda \exp[-\Lambda\,(T_l - T_{l-1})], \qquad l > 0$$

$$p\,(\tau_{k,l}|\tau_{(k-l),1}) = \lambda \exp[-\lambda\,(\tau_{k,l} - \tau_{(k-l),1})], \quad k > 0, l > 0$$

The amplitudes of k^{th} path within the l^{th} cluster obeys Rayleigh distribution. Whereas the clustering of the multipath arrivals, S-V model uses two Poisson process to describe multipath channel. The first Poisson process describes the arrival of the cluster, and second process describes the arrival of rays within that cluster.

- T_l = the arrival time of the first path of the l-th cluster;
- $\tau_{k,l}$ = the delay of the k-the path within the l-th cluster relative to the first path arrival time, T_l;
- Γ= cluster arrival rate;
- λ=ray arrival rate, i.e., the arrival rate of path within each cluster.

Therefore, $\tau_{0,l} = T_l$ The distribution of cluster arrival time and ray arrival time are given by

Let the gain of k^{th} ray of l^{th} cluster be denoted by $\beta_{k,l}$ and its phase $\theta_{k,l}$. Hence impulse response given will become

$$h(t) = \sum_{l=0}^{\infty}\sum_{k=0}^{\infty} \beta_{k,l}\, e^{j\theta_{k,l}}\, \delta(t - T_l - \tau_{k,l})$$

$\theta_{k,l}$ is statistically independent uniform random variable and $\beta_{k,l}$ is statistically independent positive random variable. The IEEE group made some modification on S-V channel using log-normal distribution to express multipath amplitudes and using another log-normal stochastic variable to express general multipath fluctuations.

Mathematically, the impulse response is described as

$$h_i(t) = X_i \sum_{l=0}^{L}\sum_{k=0}^{K} \propto_{k,l}^{i}\ \delta(t - T_l^i - \tau_{k,l}^i)$$

where

- $\{\propto_{k,l}^{i}\}$ are the multipath gain coefficients,
- $\{T_l^i\}$ is the delay of the l^{th} cluster,
- $\{\tau_{k,l}^i\}$ is the delay of the k^{th} multipath component relative to the l^{th} cluster arrival time (T_l^i),
- $\{X_i\}$ represents the log-normal shadowing, and i refers to the i^{th} realization.

The channel coefficients are defined as a product of small-scale and large-scale fading coefficients, i.e.

$$\alpha_{k,l} = p_{k,l}\, \xi_l\, \beta_{k,l},$$

The amplitude statistics of the measurements were found to best fit the log-normal distribution rather than the Rayleigh that was used in the original S-V model. In addition, the large-scale fading is also log-normally distributed.

$$20\log10(\xi_l \beta_{k,l}) \propto \text{Normal}(\mu_{k,l}, \sigma_1^2 + \sigma_2^2).$$

Or $|\xi_l \beta_{k,l}| = 10^{\frac{(\mu_{k,l}+n_1+n_2)}{20}}$

where $n_1 \propto \text{Normal}(0, \sigma_1^2)$. and $n_2 \propto \text{Normal}(0, \sigma_2^2)$. Are independent and correspond to the fading on each cluster and ray, respectively. The behavior of the power delay profile is

$$E[|\xi_l \beta_{k,l}|^2] = \Omega_0\, e^{-T_l/\Gamma}\, e^{-X_{k,l}/\gamma}$$

which reflects the exponential decay of each cluster, as well as the decay of the total cluster power with delay. In the above equations, ξ_l reflects the fading associated with the l^{th} cluster, and $\beta_{k,l}$ corresponds to the fading associated with the k^{th} ray of the l^{th} cluster[18].

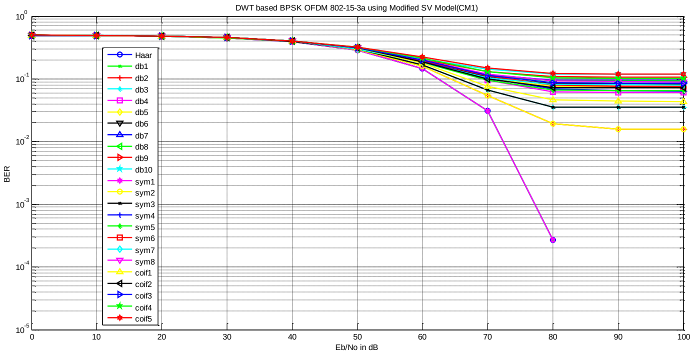
III. Simulation Environment, Result and Discussion

Following UWB channels parameters were consider for performance analysis

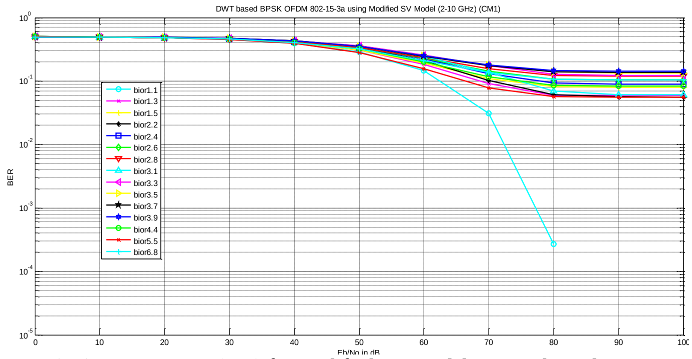
Channel Type	Cluster arrival rate (Lam)	Mean No of Cluster (Lmean)	Cluster decay factor (Gam)
CM1 (Residential LOS)	0.047	3.0	22.61
CM2 (Residential NLOS)	0.12	3.5	26.27
CM3 (Office LOS)	0.016	5.4	14.6
CM4 (Office NLOS)	0.16	3.1	19.8
CM5 (Outdoor LOS)	0.0448	13.6	31.7
CM6 (Outdoor NLOS)	0.0243	10.5	104.7
CM7 (Industrial LOS)	0.0709	4.75	13.47
CM8 (Industrial NLOS)	0.089	1.0	5.83

Channel Type	Ray decay factor (gamma0)	Mean Nakagami m-factor (m0)	SD of entire impulse response (std_shd)	Freq. depende-ncy factor (Kappa)
CM1 (Residential LOS)	12.53	0.67	2.22	1.12
CM2 (Residential NLOS)	17.5	0.69	3.51	1.53
CM3 (Office LOS)	6.4	0.42	0	0.03
CM4 (Office NLOS)	11.2	0.5	3.9	0.71
CM5 (Outdoor LOS)	3.7	0.77	0.83	0.12
CM6 (Outdoor NLOS)	9.3	0.56	2.0	0.13
CM7 (Industrial LOS)	0.615	0.36	6.0	-1.103
CM8 (Industrial NLOS)	0.3	0.3	6.0	-1.427

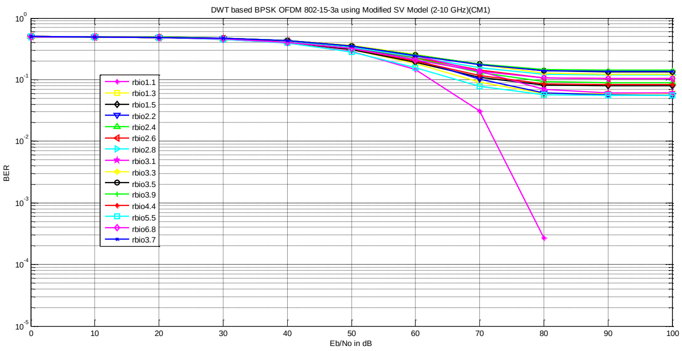
OFDM with 128 subcarriers is considered for simulation. Simulation has been carried out for 54 wavelet namely Haar, db1 to db10, sym1 to sym8, coif 1 to coif5, bio-orthogonal family and reverse bio-orthogonal family.



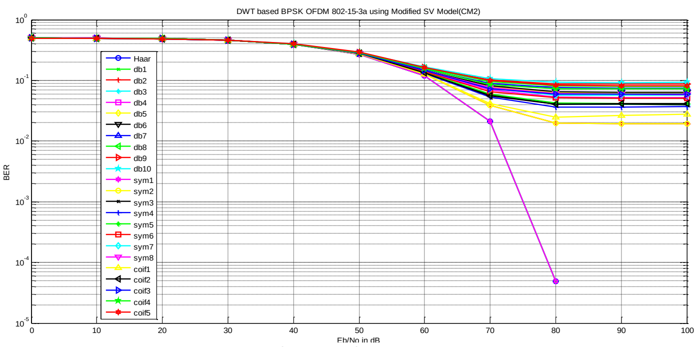
Fig(a.1):DWT-OFDM(128) for modified SV Model UWB Chaanel CM1



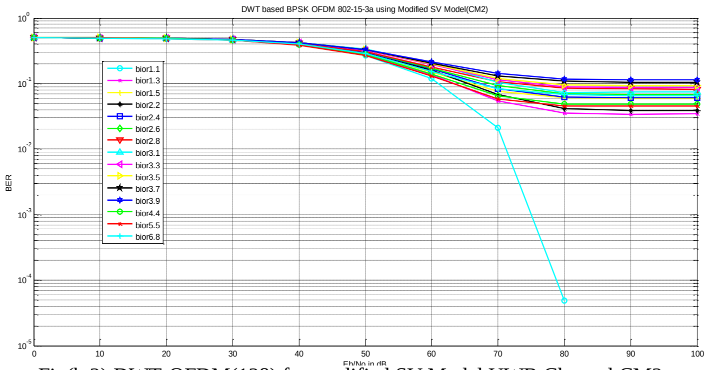
Fig(a.2):DWT-OFDM(128) for modified SV Model UWB Chaanel CM1



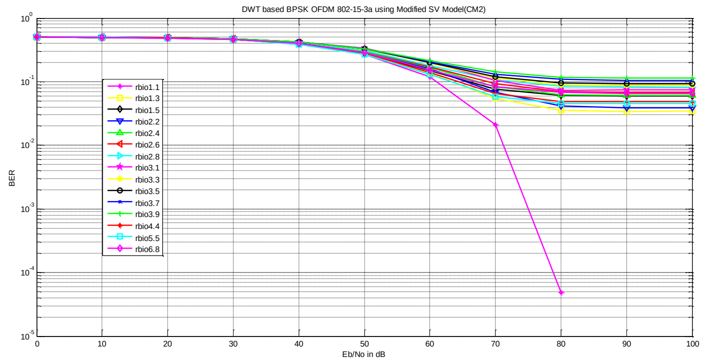
Fig(a.3):DWT-OFDM(128) for modified SV Model UWB Chaanel CM1



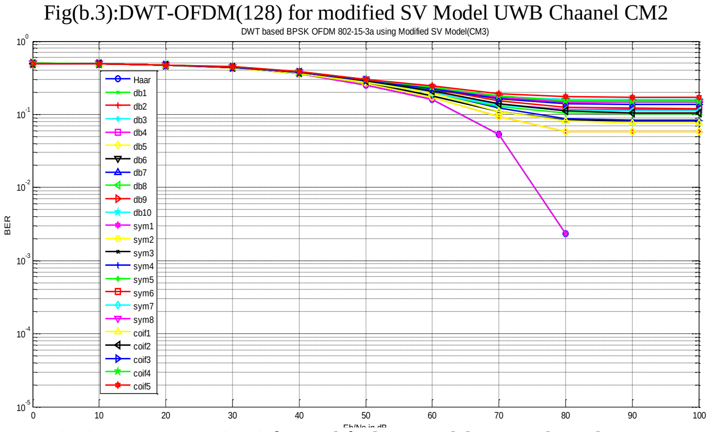
Fig(b.1):DWT-OFDM(128) for modified SV Model UWB Chaanel CM2



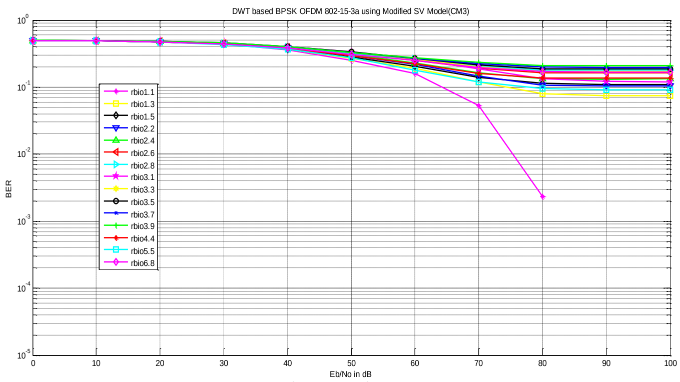
Fig(b.2):DWT-OFDM(128) for modified SV Model UWB Chaanel CM2



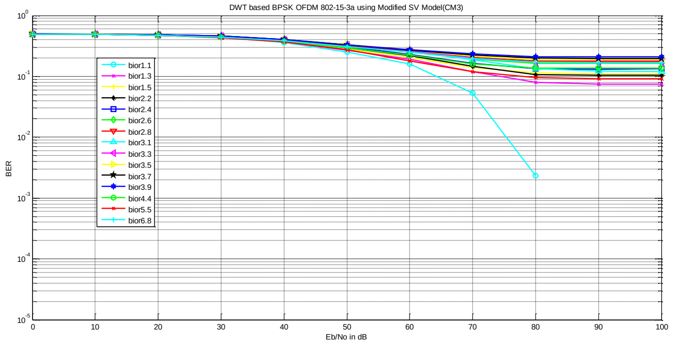
Fig(b.3):DWT-OFDM(128) for modified SV Model UWB Chaanel CM2



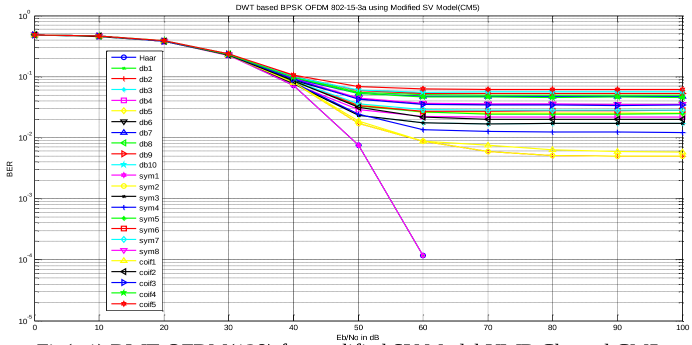
Fig(c.1):DWT-OFDM(128) for modified SV Model UWB Chaanel CM3



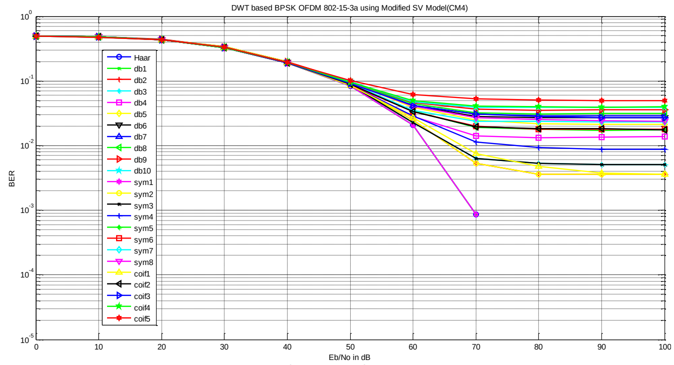
Fig(c.2):DWT-OFDM(128) for modified SV Model UWB Chaanel CM3



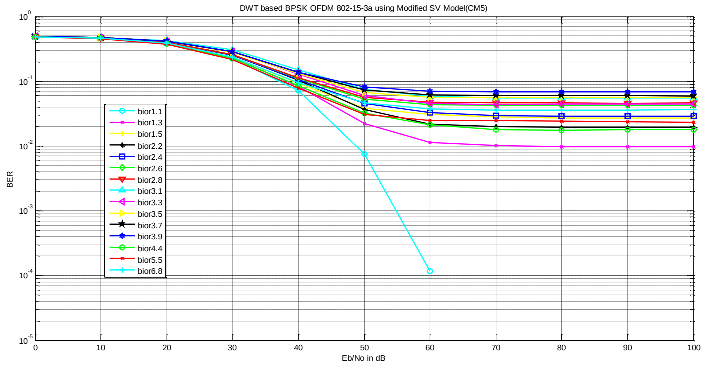
Fig(c.3):DWT-OFDM(128) for modified SV Model UWB Chaanel CM3



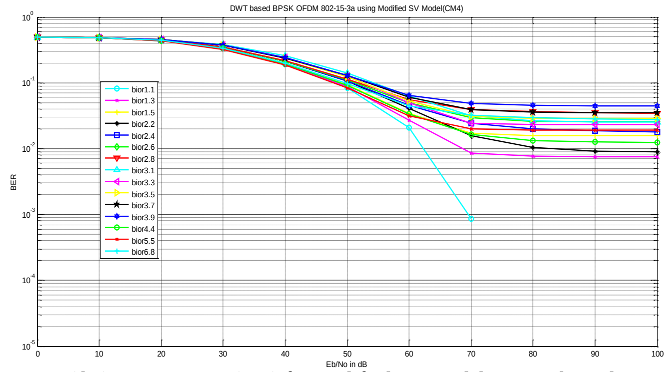
Fig(e.1):DWT-OFDM(128) for modified SV Model UWB Chaanel CM5



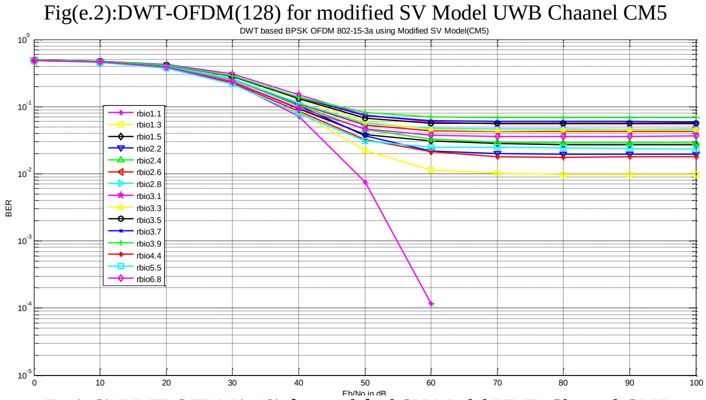
Fig(d.1):DWT-OFDM(128) for modified SV Model UWB Chaanel CM4



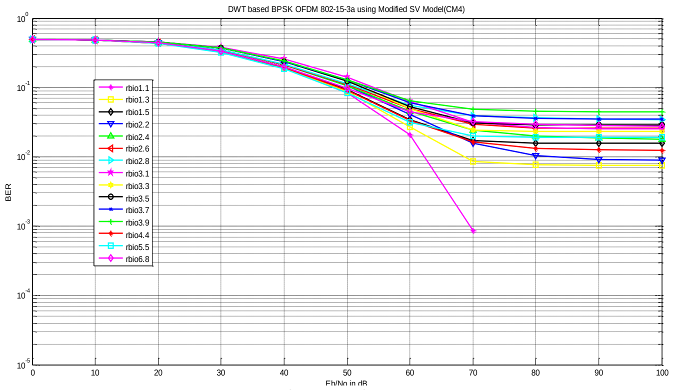
Fig(e.2):DWT-OFDM(128) for modified SV Model UWB Chaanel CM5



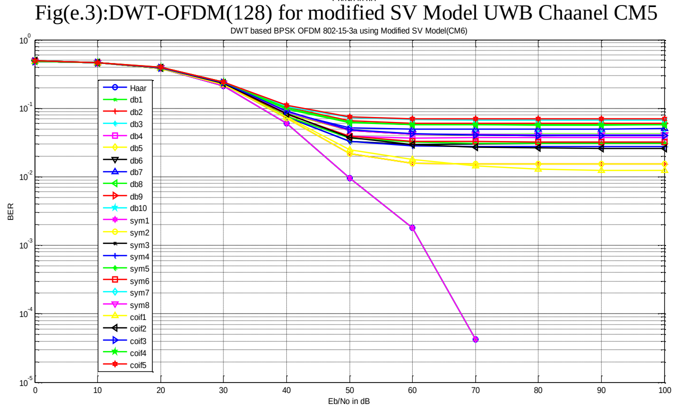
Fig(d.2):DWT-OFDM(128) for modified SV Model UWB Chaanel CM4



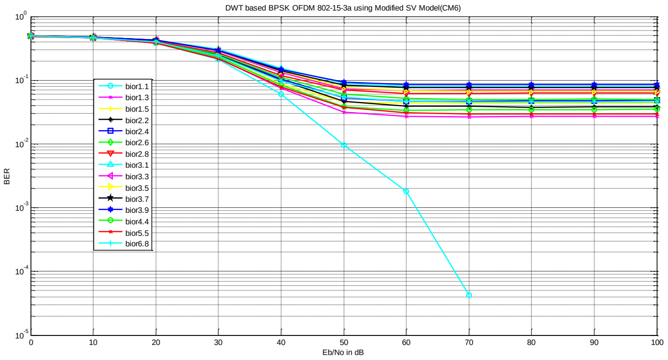
Fig(e.3):DWT-OFDM(128) for modified SV Model UWB Chaanel CM5



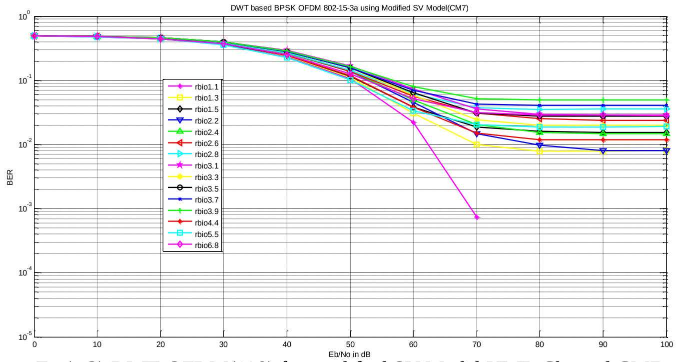
Fig(d.3):DWT-OFDM(128) for modified SV Model UWB Chaanel CM4



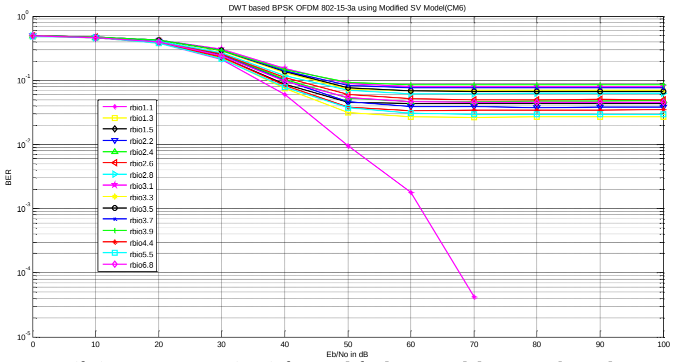
Fig(f.1):DWT-OFDM(128) for modified SV Model UWB Chaanel CM6



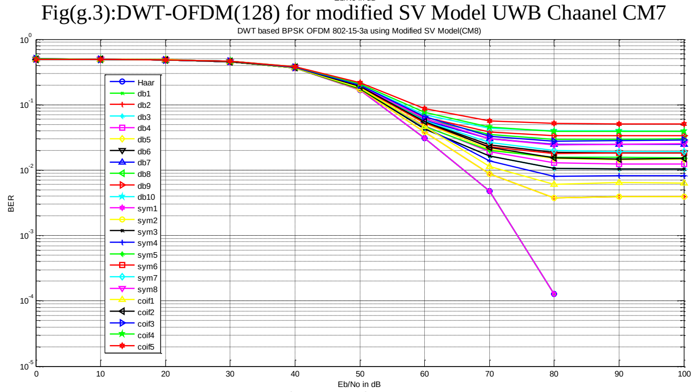
Fig(f.2):DWT-OFDM(128) for modified SV Model UWB Chaanel CM6



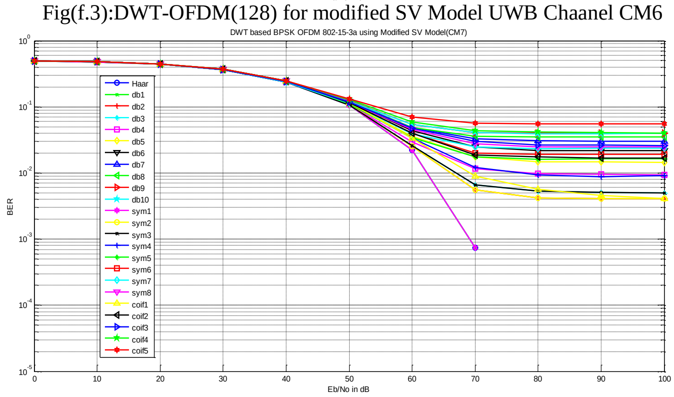
Fig(g.3):DWT-OFDM(128) for modified SV Model UWB Chaanel CM7



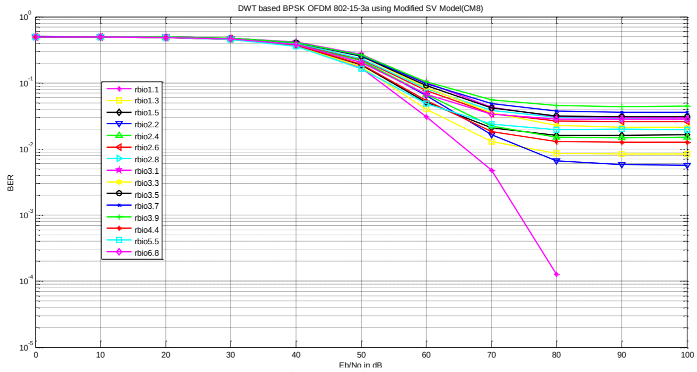
Fig(f.3):DWT-OFDM(128) for modified SV Model UWB Chaanel CM6



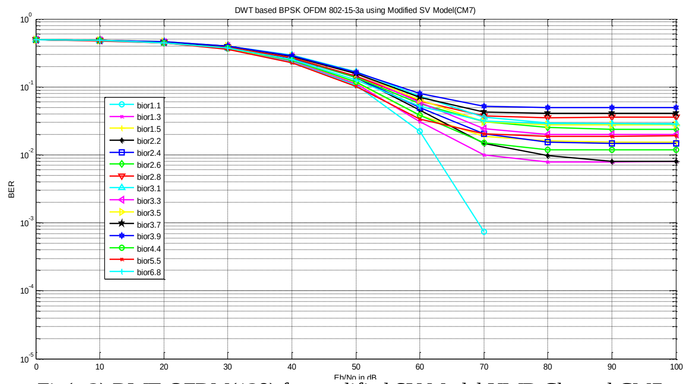
Fig(h.1):DWT-OFDM(128) for modified SV Model UWB Chaanel CM8



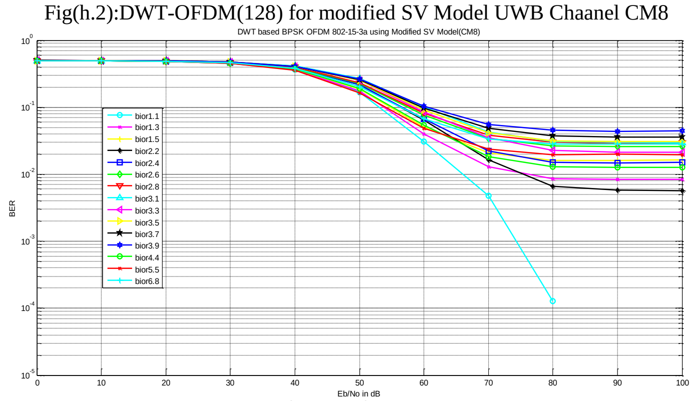
Fig(g.1):DWT-OFDM(128) for modified SV Model UWB Chaanel CM7



Fig(h.2):DWT-OFDM(128) for modified SV Model UWB Chaanel CM8



Fig(g.2):DWT-OFDM(128) for modified SV Model UWB Chaanel CM7



Fig(h.3):DWT-OFDM(128) for modified SV Model UWB Chaanel CM8

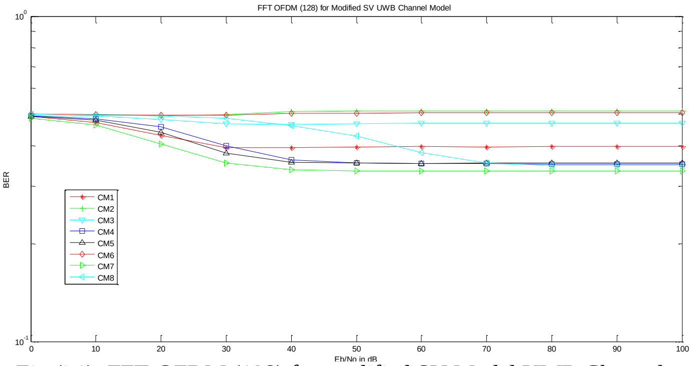


Fig (i.1): FFT-OFDM (128) for modified SV Model UWB Channel

Simulation results indicate that lower order wavelets like Haar, db1, sym1, bior1.1 and rbior1.1 show good performances for all channel models. The channel model CM2 has a better performance as compared to CM1 for same SNR value. Similarly channel CM4 exhibits better performance as compared to CM3. However LOS channel CM7 shows better performance than CM8 for same SNR value. Thus in general the performance is better in case of NLOS model as compared to LOS model. However in case of industry model, LOS model provides better performance than NLOS model. The results for other wavelet types do not indicate appreciable improved performance but exhibit much better performance as compared to FFT OFDM. The results indicate good BER performance for Eb/No (SNR) above 60 dB for most of the models. DWT OFDM shows improved performance over FFT OFDM due to time and frequency diversity advantage offered by wavelets.

V. CONCLUSION

This paper, presents a valuable implementation of DWT OFDM diversity and its comparison with FFT OFDM for modified SV model based UWB channel. It can be concluded that lower order wavelet such as Haar, db1, sym1, etc reveal better performance for UWB channel. Wavelet based analysis is more immune to impulse and narrow band noise as compared to Fourier based OFDM resulting in improved spectral efficiency. Results further reveal that DWT OFDM has robust ability to repel inter carrier interference and noise. Wavelet provides advantage of time and frequency diversities unlike FFT and hence suitable for fast fading UWB channels.

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