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OFDM System Performance Enhancement Using Wavelet Transform and DS-SS System over Multipath Fading Channel

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Abstract

In this paper discrete wavelet transform based orthogonal frequency division multiplexing (DWT-OFDM) system its proposed to improve the bandwidth efficiency by removing the cyclic prefix (CP). For further enhancement of performance of the proposed DWT-OFDM system model a combination of direct sequence spread spectrum (DS/SS) with DWT-OFDM system was proposed.

Computer simulations were presented for showing the performances of systems over selective Rayleigh fading channel. The simulation process included a comparison between single carrier system, FFT-OFDM system, DS/SS-OFDM system, proposed DWT-OFDM system, and proposed DS/SS-DWT-OFDM system for different conditions. The result showed the proposed DWT-OFDM system a better performance than FFT-OFDM system. Furthermore, the performance of DWT-OFDM system enhancement by using DS/SS system.

Keywords: Multicarrier, OFDM, Wavelet-OFDM, DS/SS-OFDM.

تحسين أداء منظومة تقسيم التردد المتعامد باستخدام تحويل مجال المويجه ونظام نشر الطيف عبر قناة الحبو الانتقائي

الخلاصة

في هذا العمل تم اقتراح استخدام مجال المويجة المتقطعة (DWT) في نظـام التقسيم الترددي المتعامد من أجل تحسين كفاءة عرض الحزمة الترددية وذلك بأزالة المعلومات المدارة (CP). من أجل تحسين كفاءة النظام المقترح فقد تم أقتراح أستخدام خليط من فرش الطيف بأستخدام المتسلسل المباشر (DS/SS) مع النظام المقترح. النتائج المقدمة في هذا البحث نفذت بأستخدام الموديل الرياضي لقناة الأضعاف نوع رايلي. تمت المقارنة بين نظام الموجة الحاملة المفردة ونظام FFT-OFDM ونظام DS/SS-OFDM ونظام DWT-OFDM المقترح ونظام DS/SS-DWT-OFDM. من خلال تحليل النتائج تبين أن نظام OFDM المقترح يعطي كفاءة أفضل من نظام OFDM التقليدي. أضافة الى ذلك فأن مواصفات النظام المقترح تتحسن بأستخدام تقنية الطيف المنتشر.

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1-Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been considered as a promising candidate to a high rate data transmission in a mobile environment. The principle of the OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of overlapped subcarriers; these subcarriers are orthogonal over symbol duration [1].

OFDM is a modulation scheme that is capable of overcoming intersymbole interference (ISI) on frequency selective channels in a very efficient way. A single digital information stream is divided into multiple information streams. The data streams are modulated and mapped on orthogonal carriers. Thus many low bit rate signals are transmitted in parallel, instead of one high bit rate signal. The low bit rate signals hardly suffer from ISI in frequency selective channels, and because of orthogonality of the sub-carriers, it is possible to demodulate the received signal without crosstalk between the information on the subcarruers[2].

Although OFDM is relatively immune to ISI, it can still be affected and equalization will help to combat with ISI and Intercarrier interference (ICI). Moreover, equalizers for OFDM system will much less complex due to the reasons described above [3]. An elegant and simple method is to use a so-called guard interval between the transmitted symbols. This is also referred as cyclic prefix (CP) extension. A number of symbols from the end of each block can be appended to the beginning of the block as cyclic prefix (CP)[4]. Thus, after the convolution with the channel memory is cleared at the end of each block this cyclic prefix insertion is, however, is just redundancy and decrease the information rate[5,6]. There are two major obstacles in using OFDM in transmission system. First it is very sensitive to frequency offset caused by misalignment in carrier frequencies or Doppler shift. These imperfections will destroy sub-carrier orthogonality and introduce inter-carrier interference (ICI) among sub-carrier in addition to attenuation and rotation of each of the sub-carriers phase. The second disadvantage is that the peak power of the signal can be up to N times the average power (where N is the number of carriers) [7,8].

Increasing symbol duration will result in lower rate parallel subcarriers. The transmitter and the receiver for OFDM system can be implemented efficiently by using Fast Fourier Transform (FFT) techniques[1]. Adding a cyclic prefix (CP) is the main way for the Fourier based OFDM to eliminate the ISI. However, this can decrease the bandwidth efficiency greatly, which means that there is a long way go to improve the bandwidth efficiency. To decrease the bandwidth waste brought by adding CP, wavelet base is proposed due to its excellent orthogonality between subcarriers and wonderful spectral containment. In wavelet based OFDM the IFFT and FFT blocks are simply replaced by an inverse discrete wavelet transform (IDWT) and discrete wavelet transform (DWT)[9], respectively.

Due to higher spectral containment between subchannels, wavelet based OFDM is better able to ameliorate the effects of narrowband interference and is inherently more robust with respect to ICI than traditional Fourier based OFDM. Wavelet OFDM is implemented via overlapped waveforms to preserve data rate[10].

2- FFT-OFDM Model

The FFT-OFDM system model is as shown in figure (1). The input serial data stream is formatted into the word size required for transmission. The data is then transmitted in parallel by assigning each data word to one carrier in the transmission. The data to be transmitted on each carrier is modulated into a BPSK format. After the required spectrum is worked out, an inverse Fourier transform (IFFT) is used to find the corresponding time waveform. The guard period is then added to the start of each symbol. Acyclic prefix is used here as a guard period.

A channel model is then applied to the transmitted signal. The model allows for the signal to noise ratio and multipath to be controlled. The signal to noise ratio is set by adding a known amount of white noise to the transmitted signal.

The receiver basically does the inverse operation to the transmitter. The cyclic prefix is removed. The FFT of each symbol is then taken to find the original transmitted spectrum. Single tap frequency domain equalizer is used to enhance the detection performance. Each transmitted carrier is then evaluated and converted back to the data word by demodulating the received symbol. The data words are then combined back to the same word size as the original signal.

3- The Proposed DWT-OFDM Model

The discrete wavelet transform (DWT) operates on data vector whose length is an integer power of 2, transforming it in to numerically different vector of the same length[10].

In this paper, Haar wavelet is employed due to simplicity. The description of Haar wavelet in time and frequency domain respectively are[9]:

$$\Psi(t) = \begin{cases} +1 & 0 \le t \le 1/2 \\ -1 & 1/2 \le t \le 1 \end{cases} \quad (1)$$

$$\phi(\omega) = j\frac{4}{\omega}\sin(\frac{4}{\omega})e^{j\frac{\omega}{2}} \quad (2)$$

The DWT-OFDM system model is as shown in figure (2). As in the FFT-OFDM model, the input serial data stream is converted in to parallel word size required for transmission. The data to be transmitted on each carrier is modulated into a BPSK format. an inverse discrete wavelet transform (IDWT) is used to find the corresponding time domain waveform. The IDWT require two groups of data input, the first part called approximation and the second group called details (the length of approximation equal to the length of details). In the proposed system the input parallel BPSK data represents approximation part, while zeros are inserted as a details part.The length of output signal from the IDWT stage equal to double the length of parallel BPSK data. This output data are converted to serial vector, then this vector convolute with selective Rayligh fading channel.

At the receiver side, the DWT is used to find the corresponding frequency domain of the parallel data. The length of data out is 2N. The first half of 2N output data from DWT stage represents the received signal, and the second half represent details and not used for detection. Single tap

Frequency domain equalizer is used to overcome some distortion. Each transmitted subcarrier is then evaluated and converted back to the data word by demodulating the received symbol.

4-The Proposed DS/SS-DWT-OFDM Model

In DS/SS the spectrum spreading is achieved by multiplying the data s(t) by spreading code c(t). It is assumed that the binary sequence taking on the value +1 and -1. The duration of data bit is T_b, and the duration of spreading code chip, called *chip period*, is T_c. There are usually many chips per bit, so that $T_c << T_b$. The spreading code is chosen to have the properties of random binary sequence, an often used choice for c(t) is a PN-sequence. However, a sequence is generated using nonlinear generation technique is used for security reason[8].

The proposed direct sequence OFDM system is as shown in figure (3). The spreading generator put after binary data source to spread the original data according to processing gain. The Gold code and Walsh Hadamard code sequences are used as spreading codes. At the receiver the synchronized spreading generator is used to despread the recovered data.

5-Computer Simulation Tests and Results

An OFDM system was simulated using MATLAB version 7 to allow various parameters of the system to be varied and tested. Furthermore, the performance of proposed DWT-OFDM model tested under the same conditions. When the number of subcarrier equal to 128, the number of IDWT point equal to 256 (128 approximation and 128 details). At the receiver, the length of data out from the DWT equals to 256 (the first 128 subcarrier represent the received data, while the second 128 subcarrier represent the details).

The performance of the above systems was tested with proposed DS/SS-OFDM system with different spreading code types.

The parameters and system configuration used in the simulation were taken from the standards of the third generation mobile and OFDM system. these parameters can be summarized by the followings

data rate	2 Mbps
Modulation	BPSK
Subcarriers	128
FFT points	128
IDWT points	256
DWT points	256
OFDM symbol duration	$16*10^{-6}$ sec
Guard interval	$1.6*10^{-6}$ sec
Guard interval type	Cyclic prefix (CP)
Required bandwidth	2 MHz
Model of channel	Jacks Model
Number of paths	8 path
Number of fingers	2 fingers
Multipath delay Spread	$3*10^{-6}$ sec
Doppler frequency	150 Hz
spreading code used	PN-code and Gold code
Processing gain	31

To investigate the effect of number of subcarrier on the OFDM system extra test was carried out as shown in Figure (4). From the figure, the performance of system is enhanced as the number of subcarrier increased. In these tests the selective fading configuration contains 2-

fingers, 3-fingers, 4-fingers, and so on, the effect of increasing number of finger on the performance of system is shown in figure (5). This increase in the number of fingers causes performance degradation. From the figure it is clear that the performance of 2-fingers is better than the performance of 4-fingers by about 2 dB at bit error rate 10^{-5}. Also the performance of 4-fingers better than the performance of 6-fingers by about 4 dB at bit error rate 10^{-5}.

The relation between the number of subcarrier and energy per bit to noise ratio (E_b/N_o) in dB at different number of fingers was shown in figure (6). The E_b/N_o (in dB) decreased as the number of subcarrier increased. This relation at bit error rate 10^{-5}.

The performance of OFDM system with different mobile velocity (in mile/h) is shown in figure (7). The performance degrades with increased mobile velocity.

Figure (8) shows the effect of increasing the velocity of mobile station on the performance of OFDM system at different number of subcarrier. The figure shows the performance degrade with increasing velocity. When the velocity increased the Doppler frequency increased, and hence the number of fade per second increased. Therefore, the performance degrades.

The relation between the number of finger and Eb/No (in dB) at bit error rate 10^{-5} was shown in figure (9). The best performance occurs with minimum number of finger. When the number increased the value of intersymbol interference (ISI) increased. Therefore, the performance degraded.

A comparison between performance of FFT-OFDM and proposed DWT-OFDM was shown in figure (10). This comparison at the same number of subcarrier, and under the same channel conditions. From the figure, it is clear that about 5 dB at bit error rate $10^{-5}$is gained by using the proposed DWT-OFDM system.

Figure (11) shows that the performance of proposed DWT-OFDM model enhanced with increasing number of subcarrier. The performance when N=512 better than the performance of system when N=64 by about 5 dB at bit error rate 10^{-5}.

Increasing the number of channel finger have the same effect with proposed system, as shown in figure (12).

The performance of proposed DS/SS-OFDM model is shown in figure (13). The performance of proposed DS/SS-OFDM better than the performance of OFDM by about 13 dB at bit error rate 10^{-5}, and number of subcarrier (N) =128. While, the performance of proposed DS/SS-DWT-OFDM was gained by about 14dB compared with the performance of proposed DWT-OFDM (shown in figure (10)), at bit error rate 10^{-5}.

Furthermore, the performance of the proposed DS/SS-DWT-OFDM better than the performance of the proposed DS/SS-OFDM by about 6dB.

Gold code given performance better than PN code by about 1dB as shown in figure (14), therefore Gold code was used in the proposed system.

6-Conclusions

From the above results, it can be concluded that the performance of OFDM system enhanced with increased the number of subcarrier.

On the other hand performance of system degrades with increase of the mobile velocity or increase of the number of channel fingers.
The performance of OFDM system can be enhanced further by the use of proposed DWT-OFDM system by about 5dB at BER=10^{-5} . The cyclic prefix (CP) not used In the proposed DWT-OFDM, therefore, the bandwidth efficiency of proposed system also enhanced. This enhancement in performance of proposed system according to advantages of wavelet transform.
The performance of both FFT-OFDM system and the proposed DWT-OFDM system can be enhanced by using the direct sequence spread spectrum (DS/SS) system, the gain in the proposed DS/SS-OFDM system about 13dB at BER=10^{-5} compared with FFT-OFDM. While DS/SS-DWT-OFDM gives better performance by about 14dB at BER=10^{-5} compared with DWT-OFDM system.

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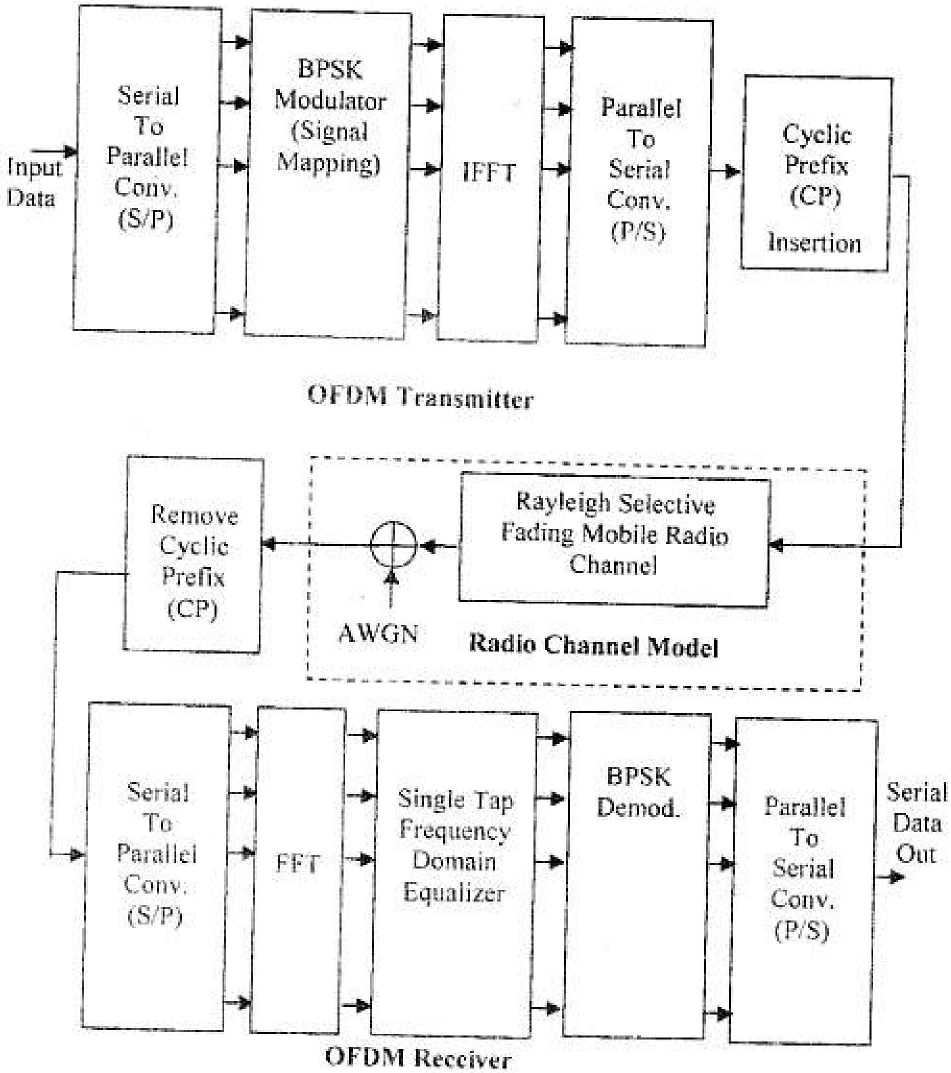

Fig.(1) FFT-OFDM Model Used in Simulation

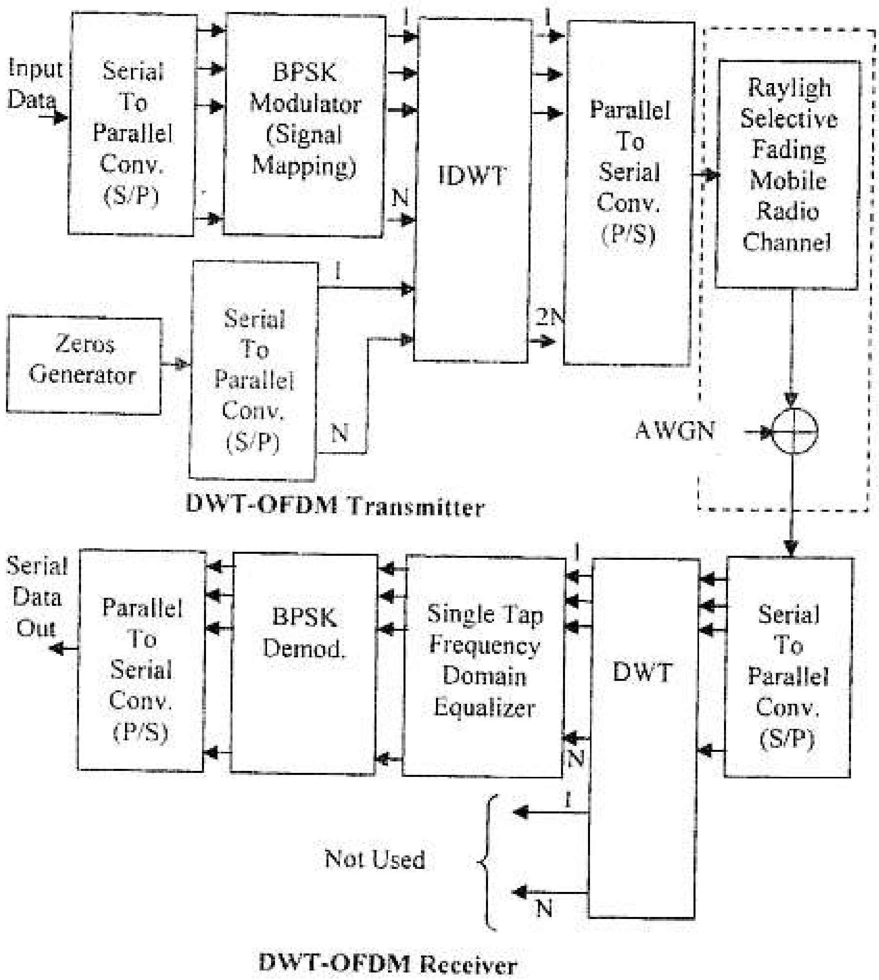

Fig. (2) Proposed DWT-OFDM Model

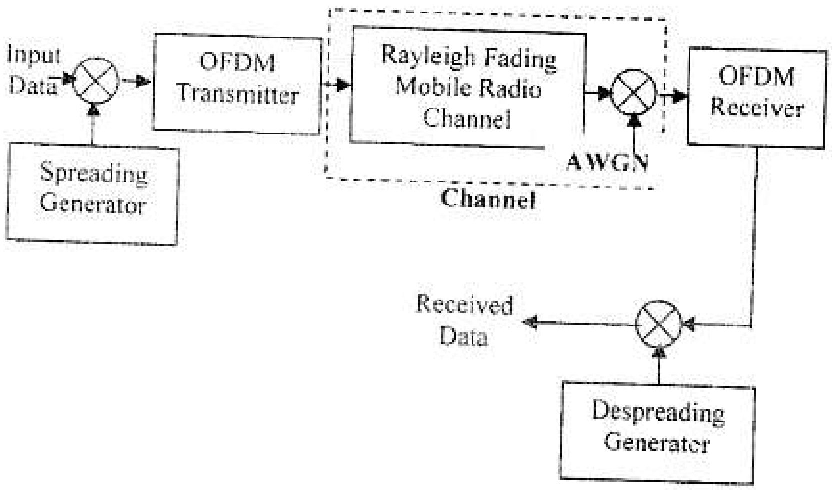

Fig. (3) Proposed DS/SS- OFDM System

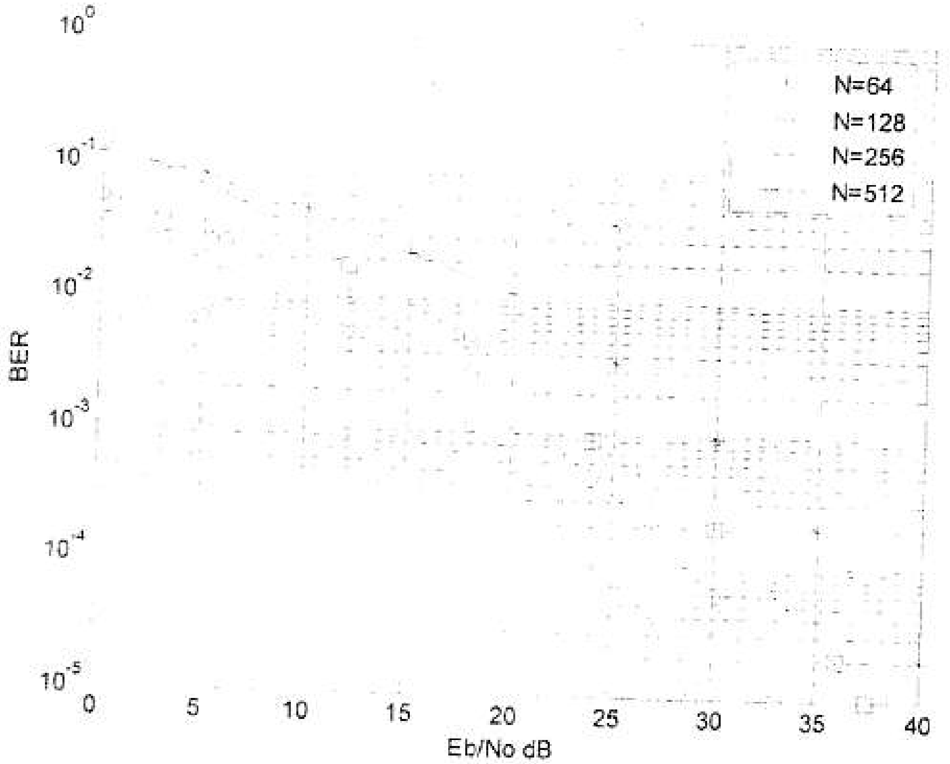

Fig. (4) Performance of FFT-OFDM System at Different Number of Subcarrier

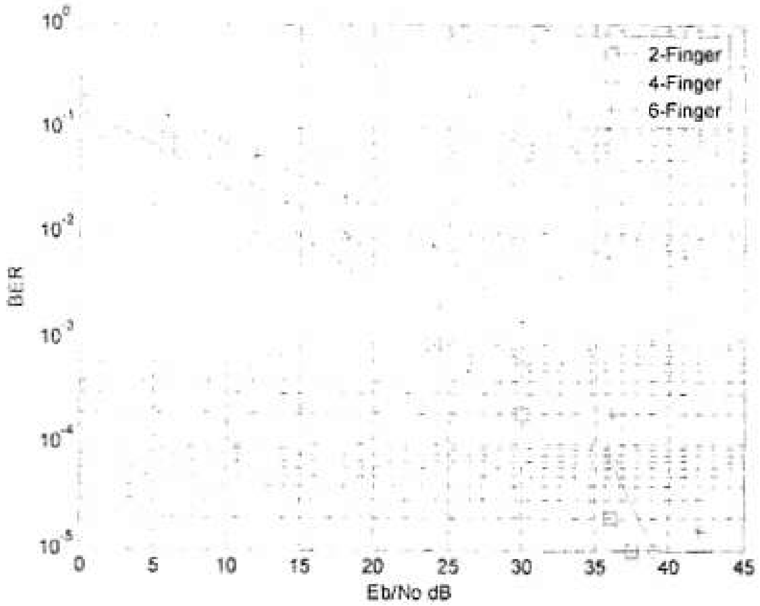

Fig. (5) Performance of FFT-OFDM System at Different Number of Fingers

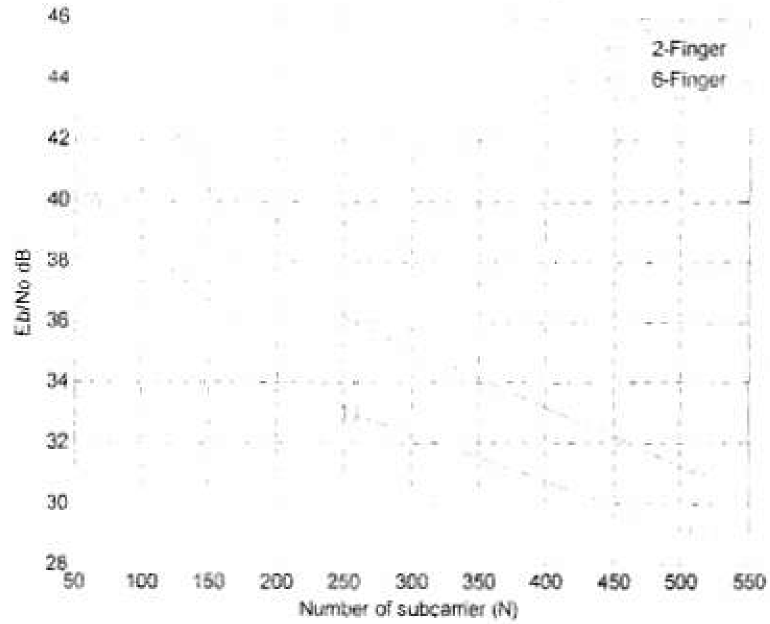

Fig. (6) Relation between Number of Subcarrier and Eb/No (dB)
at Different Number of Selective Channel Fingers

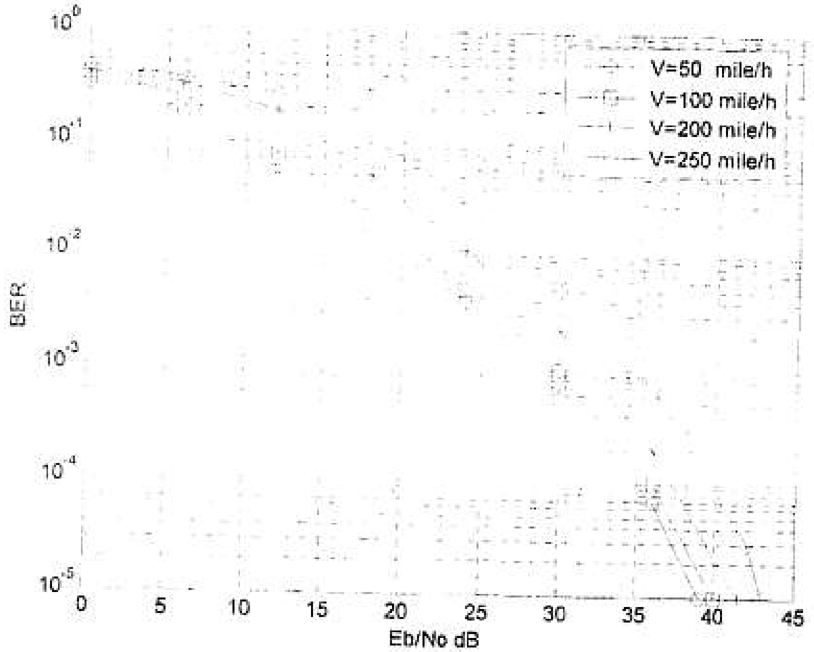

Fig. (7) Performance of FFT-OFDM System at Different Mobile Velocity (in mile/h)

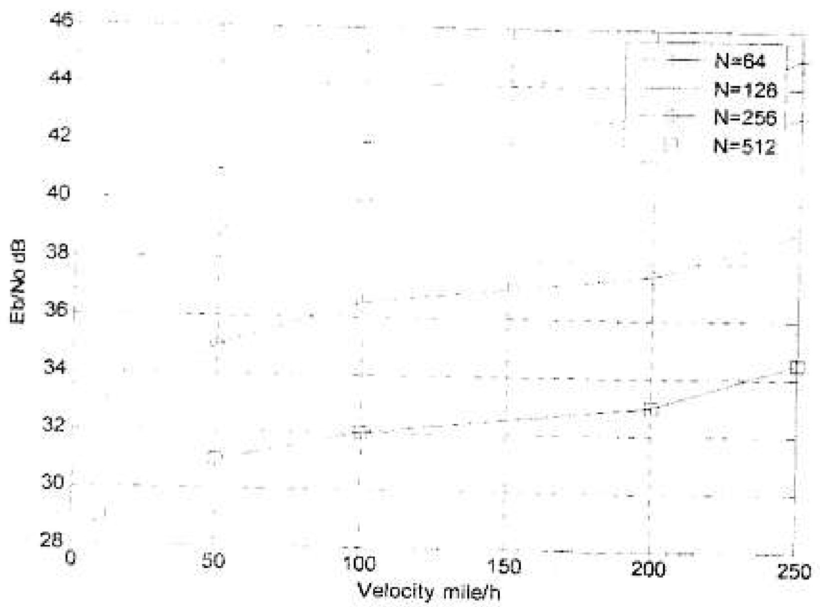

Fig. (8) Relation between Mobile Velocity and Eb/No (dB) in FFT-OFDM System at Different Number of Subcarrier, and Number of Finger=2

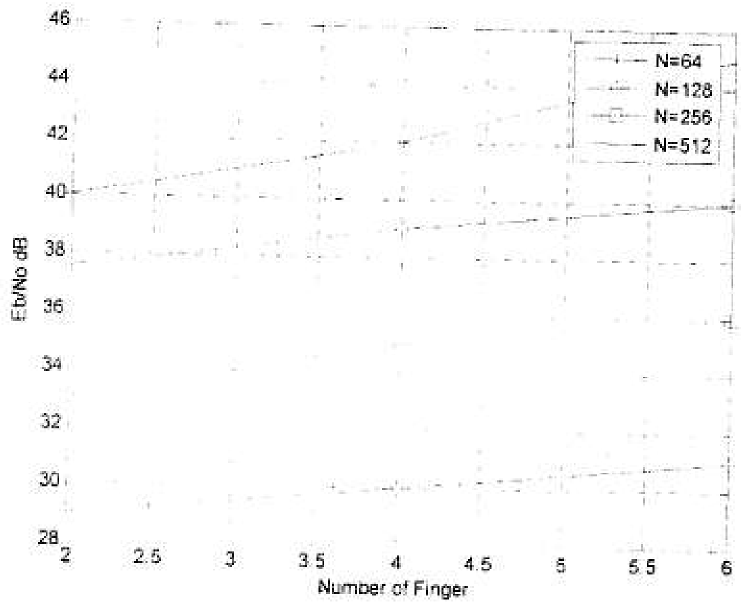

Fig. (9) Relation between Number of Finger and Eb/No (dB) in FFT-OFDM System at Different Number of Subcarrier, and Mobile Velocity=50 mile/h

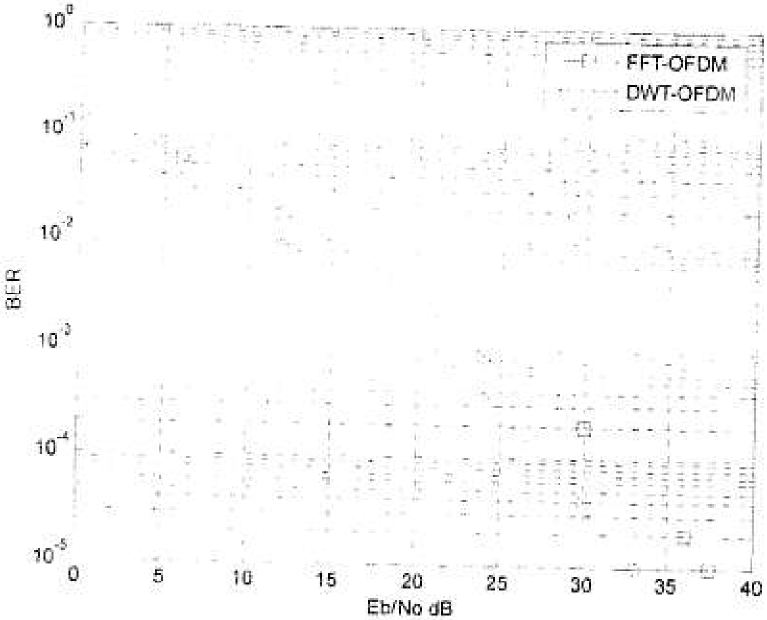

Fig. (10) Comparison between Performance of FFT-OFDM and Proposed DWT-OFDM Model at N=128

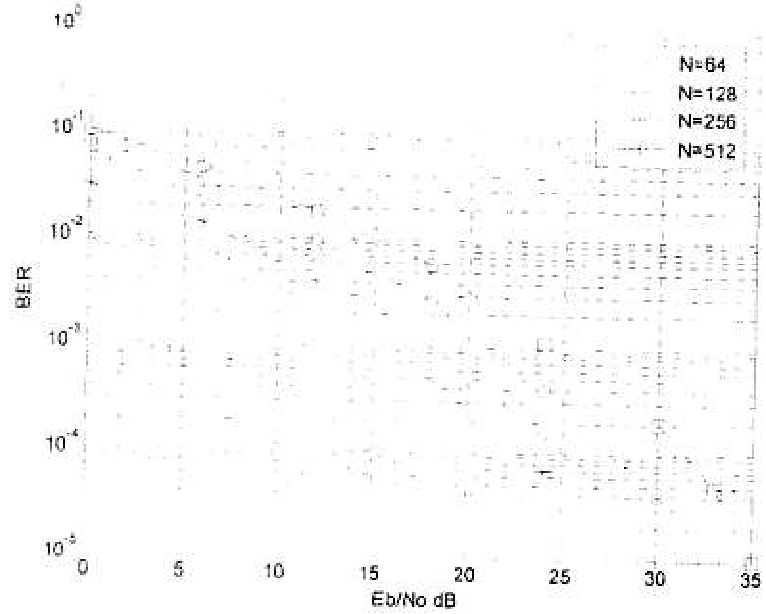

Fig. (11) Performance of Proposed DWT-OFDM System at Different Number of Subcarrier

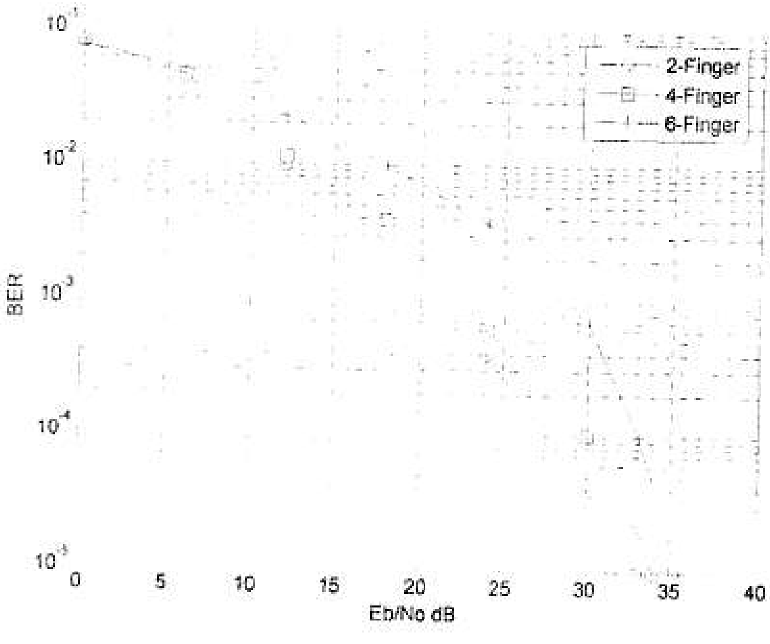

Fig. (12) Performance of Proposed DWT -OFDM System at Different Number of Fingers, and N=128

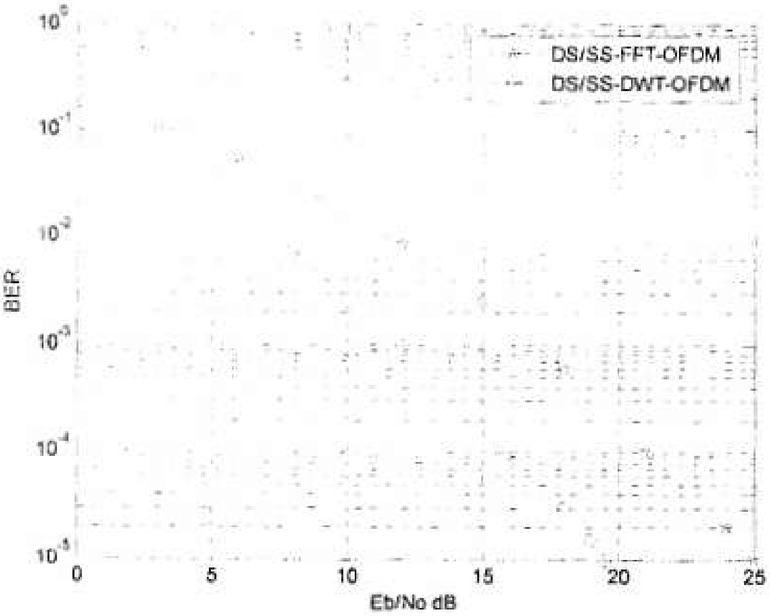

Fig. (13) Comparison between Performance of Proposed DS/SS-FFT-OFDM Model and Proposed DS/SS-DWT-OFDM Model at N=128

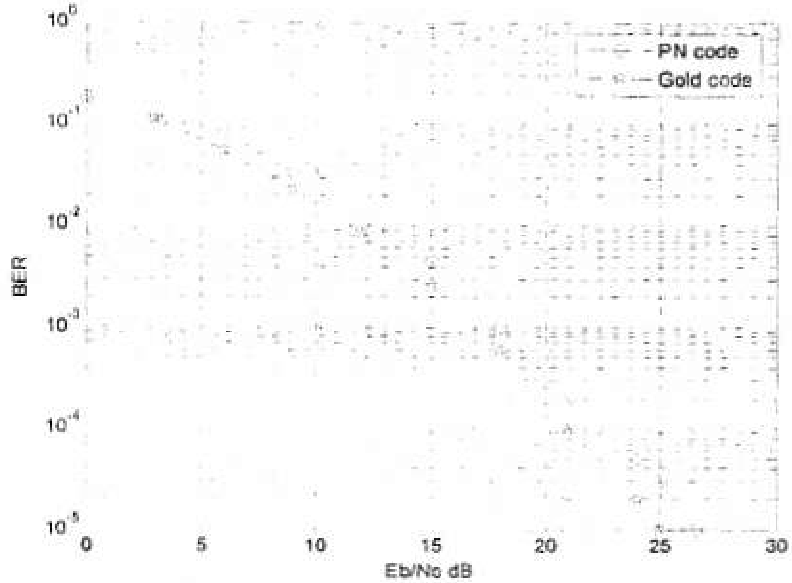

Fig. (14) Comparison between Performance of Gold Code and PN-Code in Proposed DS/SS-OFDM Model