Investigation of OFDM System Enhancement by Using DS/SS System over Wireless Mobile Radio Channel

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Abstract

Wireless digital communication is rapidly expanding resulting in a demand for systems that are reliable and have a high spectral efficiency. In this work, an OFDM based system has been studied, since it is a good candidate for future wireless services. The combination of direct sequence spread spectrum (DS/SS) with OFDM system was proposed to enhance the performance of system. The designed OFDM system operates at high-speed data rate over fading channel, with cyclic prefix and zero padded, to preserve the carriers orthogonality.

The simulation results are presented for a simulated Rayleigh fading channel. The simulation process includes a comparison between single carrier system, OFDM system, DS/SS system, and the proposed DS/SS/OFDM. The results show the signal performance enhancement of OFDM system by using the proposed system.

بحث تحسين نظام مزج تقسيمات التردد المتعامدة باستخدام نظام نشر الطيف عبر القناة الراديو يه المحمولة

الخلاصة

أن التوسع الهائل في الاتصالات الرقمية اللاسلكية جعل هنالك حاجة إلى نظام موثوق وذو كفاءة طيف عالية. في هذا العمل تم دراسة نظام OFDM لكونه أفضل مرشح لخدمة اللاسلكية. أن تعشيق نظام الطيف المنتشر مع نظام OFDM تم اقتراحه لتحسين النظام. أن النظام المقترح تم تصميمه ليعمل بسرع بيانات عالية عبر القنوات المتحركة مع استخدام الإضافة الد ورانية وحشو الأصفار لإدامة التعامل في الناقلات الترددية.

أن نتائج المحاكاة تم أدراجها في البحث والتي قارنت بين نظام الناقل المنفرد والمتعدد والتي من خلالها تمت مقارنة تأثير عدد النواقل كما تمت دراسة تأثير إضافة الطيف المنتشر إلى النظام. أن النتائج تظهر أداء النظام يكون أفضل باستخدام الطيف المنتشر.

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has been considered as a promising candidate to a high rate data transmission in a mobile environment [1]. 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 modulated with subcarriers spacing, which is selected such that modulated subcarriers are orthogonal over symbol duration. Increasing symbol duration will result in a lower rate parallel subcarriers[1,2]. The transmitter and the receiver for OFDM system can be implemented efficiently by using Fast Fourier Transform (FFT) techniques [2,3].

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

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the signal can be up to N times the average power (where N is the number of carriers). Linear amplifiers that can handle this large amplitude variation are less efficient. Hard limiting of the transmitted signal generates inter-modulation predicts that can interfere with adjacent channels resulting in an increase in the error rate [1,4].

2. OFDM System

2-1 Orthogonality in OFDM Signal

Signals are orthogonal if they are mutually independent of each other. Orthogonality is a property that allows multiple information signals to be transmitted perfectly over a common channel and detected without interference. Loss of orthogonality results in blurring between these information signals and degradation in communications [2,5,6].

The baseband frequency of each subcarrier is chosen to be an integer multiple of the reciprocal of symbol time (T_s), resulting in all subcarriers having an integer number of cycles in the interval (T_s). The number of cycles between adjacent subcarriers differs by exactly one cycle. This property accounts for the orthogonality between the subcarriers in time domain [5].

Another way to view the orthogonality property of OFDM signals is to look at its spectrum. In the frequency domain, each OFDM subcarrier has a sinc ($\sin(x)/x$) frequency response. The sinc shape has a narrow main lobe, with many side-lobes that decay slowly with the magnitude of the frequency difference away from center frequency and nulls evenly spaced with frequency gap equal to the subcarrier spacing [2,5].

2-2 Implementation of OFDM Using Fast Fourier Transform (FFT)

The main objections to the use of parallel systems are the complexity of the equipment required to implement the parallel system and the possibility of severe mutual interference among subchannels when the transmission medium distorts the signal. The equipment can be greatly reduced by eliminating any pulse shaping and by using the Discrete Fourier Transform (DFT) to implement the modulation processes [5,7]. It can be shown that an OFDM signal is effectively the inverse Fourier transform of original data stream, and the bank of coherent demodulators is effectively the Fourier transform. All operations that occur in the transmitter are reversed in the receiver. Further reductions in complexity are possible by using the Fast Fourier Transform (FFT) algorithm to implement the DFT [2,8].The practical OFDM system is as shown in Fig.(1).

2-3 Guard Period in OFDM Signals

OFDM signal experience ISI when their transmitted symbols propagate through fading channels, since the channel impulse response combines contribution from more than one transmitted symbol at the receiver [2,9].

The spread of the duration of each baseband data to a value much larger than the average fade duration, making it robust to fading. However, this spreading not only causing large time delays, but also requiring accurate carrier synchronization technique due to closely separated sub-carrier [2,10].

Bridge the transient effects of the transmitted signal in the receiver for total avoidance of ISI, can only be accomplished by introducing a guard time period T_g between consecutive symbols. The duration of the guard period should be longer than the worst case delay spread of multipath channel and must be limited to realize bandwidth efficiency [2,5]. On the other hand, the duration of the guard interval implies a reduction in the time available for the actual data transfer, which reduces the channel capacity. Therefore, the guard period is always kept relatively small as compared to symbol duration T_s [10].

There are two options for the guard interval, cyclic prefix (CP) and zero padding (ZP).In the cyclic prefix (CP) the last part of the time domain OFDM symbol is copied and put as a preamble, which serves as a guard period to combat ISI. The OFDM symbol duration T_s then originates from the sum of the duration of extension and useful symbol interval, T_g and T_u, respectively, as shown in figure (2)[2,10].

Another approach for guaranteeing symbol delectability over ISI channels is to modify the OFDM setup. Instead of inducing the CP, each IFFT processed block is zero padded ZP, by at least many zeros as the channel order. If the number of zero-padded equals cyclic prefix length, the ZP-OFDM and CP-OFDM transmission have the same spectral efficiency [2,10].

3. OFDM System Model

The OFDM system model is shown in figure (3). 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 in to a PSK format. The data on each symbol is mapped and a PSK signal is generated. Here we used BPSK modulation. After the required spectrum is worked out, an inverse Fourier transform is used to find the corresponding time waveform. The guard period is then added to the start of each symbol. The guard periods used here are cyclic prefix (CP) and zero padding (ZP).

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 guard period is removed. The FFT of each symbol is then taken to find the original transmitted spectrum. 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 data.

4. The Proposed Direct-Sequence OFDM System

There are two common ways of spreading a signal, spreading in time which is usually referred to as direct sequence spread spectrum (DS/SS), and spreading in frequency, also known as frequency hopping spread spectrum (FH/SS)[8,11]. In this work the DS/SS was used. In DS/SS the spectrum spreading is effected by multiplying the data s(t) by the spreading code c(t). In this case, both are assumed to be 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 $T_c \ll T_b$. The spreading code is chosen to have the properties of a random binary sequence, an often used choice for c(t) is a *PN-sequence*. However, a sequence is generated using nonlinear generation techniques is used for security reason[8,11].

The proposed direct sequence OFDM system is shown in figure(4). The spreading generator put after binary data source to spread the original data according to processing gain. The Hadamard Walsh code used to spread the data. The Hadamard Walsh code is used because it is an optimum orthogonal set, and do not have to pay attention to the auto-correlation characteristic of the spreading codes. At receiver the synchronized spreading generator is used to despread the recovered data.

5. Computer Simulation Results: -

An OFDM system was simulated using Matlab to allow various parameters of the system to be varied and tested. The aim of doing the simulation was to measure the performance of OFDM with Rayleigh fading mobile radio channel conditions, and to allow for different OFDM configurations to be tested. Furthermore, the performance of proposed DS/SS-OFDM system tested under the same conditions with different spreading sequence generator type. The parameters and system configuration used in the simulation can be summarized by: -

Source data rate	2 Mbps
Modulation scheme	BPSK
Number of subcarrier	64,128,512, and 1024
Number of FFT points	64,128,512, and 1024
OFDM symbol duration	$16*10^{-6}$ sec
Guard interval	$1.6*10^{-6}$ sec
Guard interval type	CP and ZP
Required bandwidth	2 MHz
Multipath delay Spread	$3*10^{-6}$ sec
Doppler frequency	250 Hz
Processing gain	31 Gold code 32 Hadamrd Walsh code
Bit error rate	10^{-5}

The comparison between performance of single carrier system and OFDM system (when number of subcarrier N =128) over Rayliegh fading mobile radio channel is as shown in Fig (5). It is clear that the performance of OFDM is better than the performance of single carrier by about 19 dB at bit error rate 10^{-5}. This advantage in gain is due to the cancellation of fading effects by the OFDM system.

To investigate the effect of number of subcarrier on the OFDM system extra test was carried out as shown in Figure (6) .From the figure, the performance of system is enhanced as the number of subcarrier increases.

The effect of adding a cyclic prefix (CP) in OFDM gives advantages about 6 dB when N=64 subcarrier, and about 3 dB when N=128, 256, and 512 compared with OFDM at bit error rate 10^{-5} as shown in figure (7).This advantage gained because the itercarrier interference (ICI) is removed or reduced in CP-OFDM and also complete cancellation of intersymbol interferance occurred. The effect of adding cyclic prefix increased with increased number of paths in channel.

When zero padding (ZP) is used instead of cyclic prefix (CP), it gives advantages about 5 dB when N=64 subcarrier, and about 2 dB when N=128, 256, and 512 compared with OFDM system at bit error rate 10^{-5} as shown in figure (8). Therefore, the CP-OFDM gives better advantages than the ZP-OFDM.

A comparison between the performance of OFDM, CP-OFDM, and ZP-OFDM at number of subcarrier N=128 was made as shown in figure (9). From the figure, it can see that the best performance occurs in CP-OFDM.

The relation between the number of subcarriers (N) and the values of Eb/No in dB at bit error rate (BER) =10^{-5} is shown in figure (10). The Eb/No decreased with the increased value of N. The relation between the number of subcarriers (N) and the values of BER at Eb/No =11dB is shown in figure (11). The BER is decreased with the increased value of N.

The performance of single carrier direct sequence spread spectrum (DS/SS) can be simulated by using gold code, with length sequence equal to 31, as spreading generator (processing gain=31) as shown in figure (12). The advantage by using DS/SS system about 23 dB at bit error rate 10^{-5}compared with unspreading case.

The performance of the proposed DS/SS/OFDM system compared with DS/SS single carrier system is shown in figure (13). In this test, the proposed system used the Walsh Hadamrd code as spreading generator, with length=32 and the number of subcarrier N=128. Furthermore, a comparison between performance of OFDM system and proposed DS/SS/OFDM system is shown in figure (14). From figure (13) it is clear that about 5dB at BER=10^{-5} is gained by using the proposed DS/SS/OFDM system compared with DS/SS single carrier system. While from figure (14) it is clear that about 9dB at BER=10^{-5} is gained by using the proposed DS/SS/OFDM system compared with OFDM system. Therefore, the proposed system better than OFDM system and DS/SS system.

6.Conclusions

From the above results, it can be concluded that the CP-OFDM and ZP-OFDM gives advantages when inserted in OFDM symbol because it remove intersymbol interference ISI and reduce intercarrier interferance ICI. The CP-OFDM gives better performance than ZP-OFDM. The performance of OFDM system is enhanced with the increased number of subcarrier. However, this increase is limited by the frequency offset. The performance of the OFDM system can be enhanced further by the use of proposed DS/SS/OFDM system by about 9dB at BER=10^{-5}. This enhancement in performance according to the advantages of spread spectrum system. Also the performance of the DS/SS single carrier system can be enhanced by the use of proposed DS/SS/OFDM system by about 5dB at BER=10^{-5}. This enhancement in performance according to the advantages of OFDM system. There fore the proposed system gives a better performance than the OFDM system and DS/SS single carrier system.

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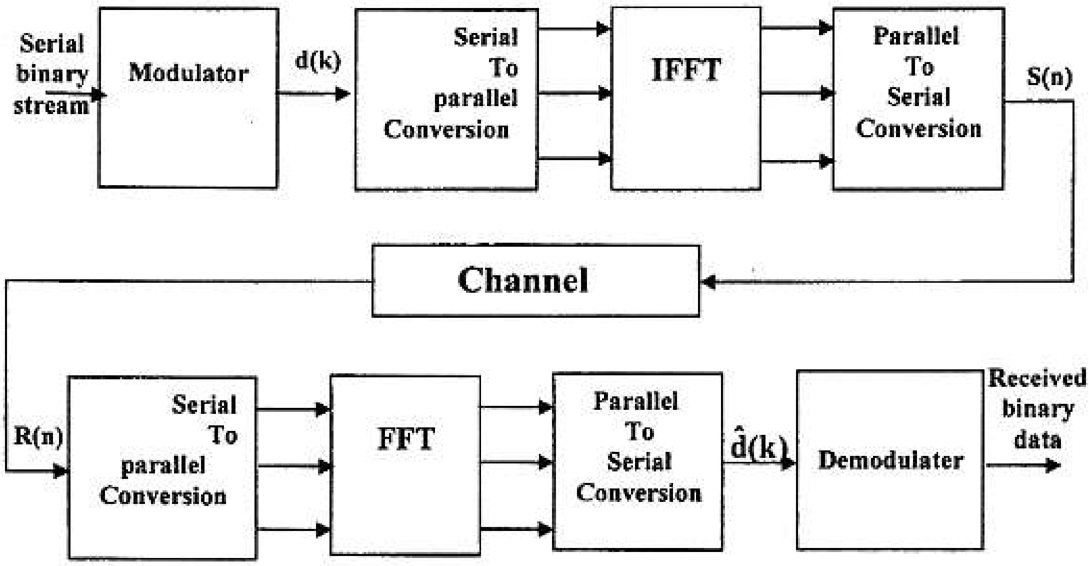


Fig.(1) OFDM system implemented with FFT

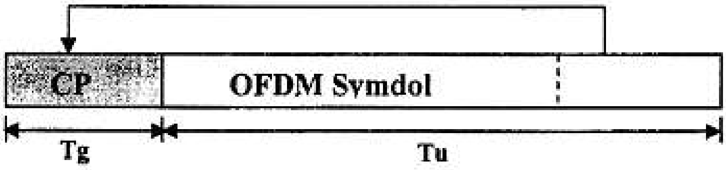
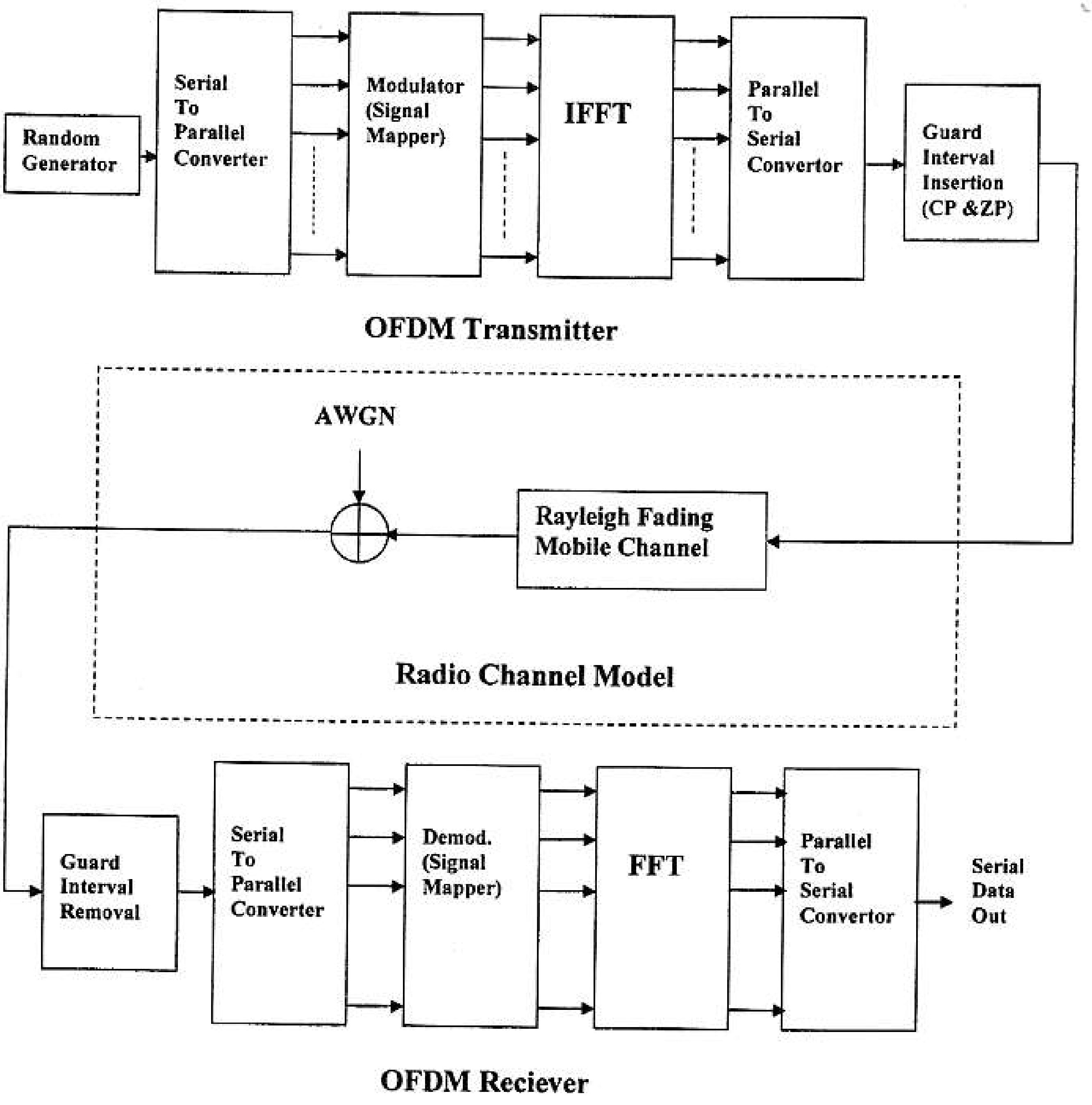


Fig.(2) Addition of guard period to the OFDM signal



Fig(3) OFDM Model Used in Simulation

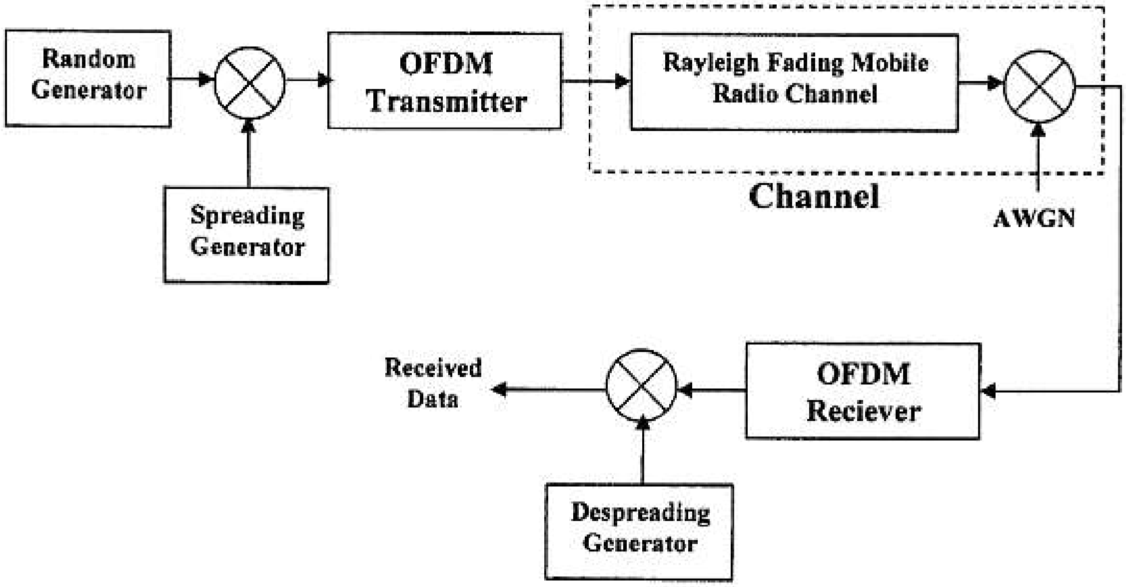
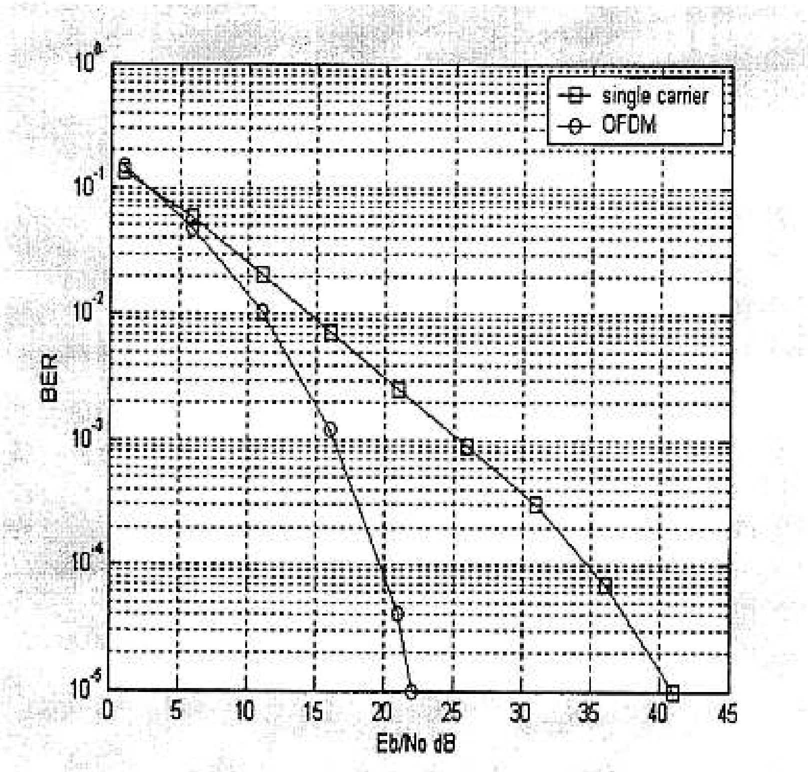


Fig (4) Proposed DS/SS- OFDM system



Figure(5) Comparison between performance of single carrier system and OFDM system over Rayleigh fading mobile radio channel and using BPSK modulation

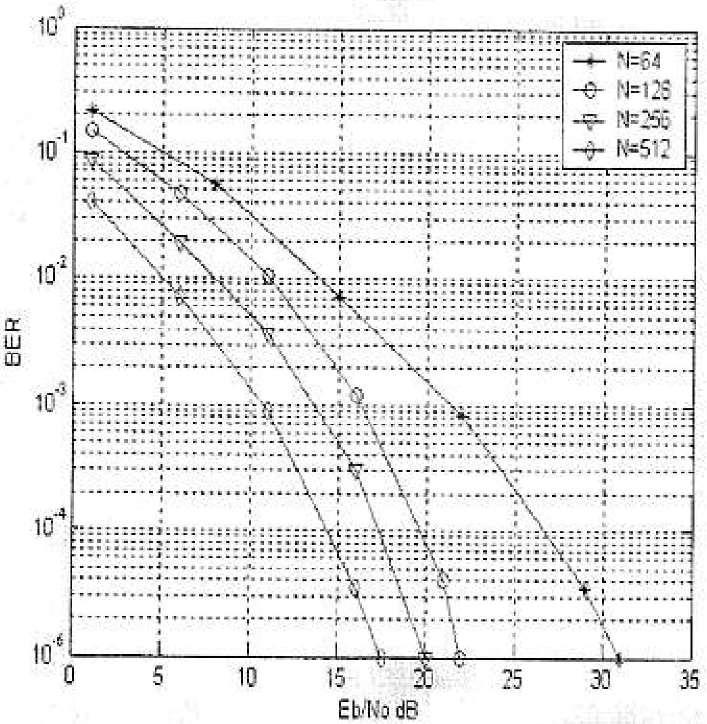


Fig. (6) OFDM performance over Rayleigh fading mobile radio channel with different values of subcarriers (N)

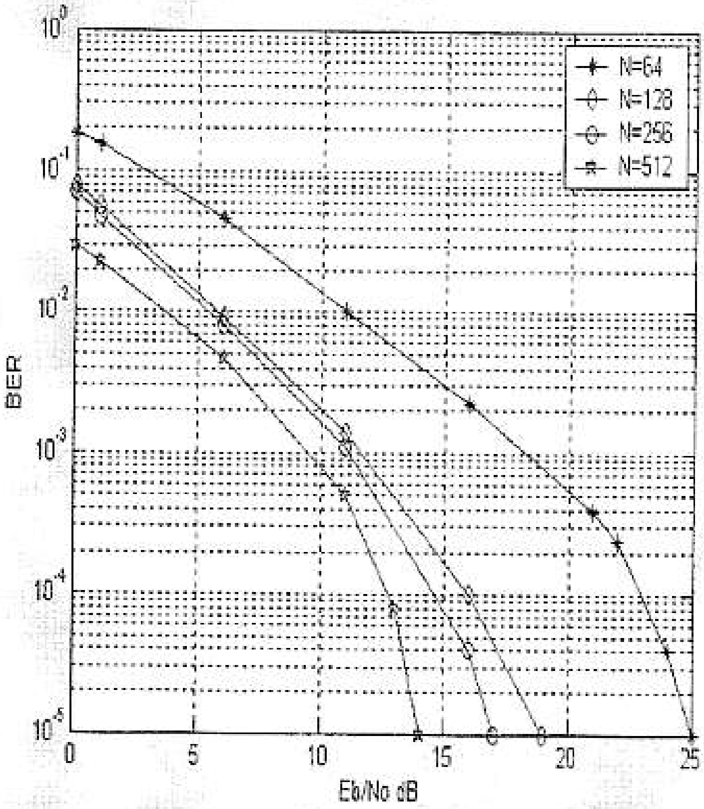


Fig. (7) CP-OFDM performance over Rayleigh fading mobile radio channel with different values of subcarriers (N)

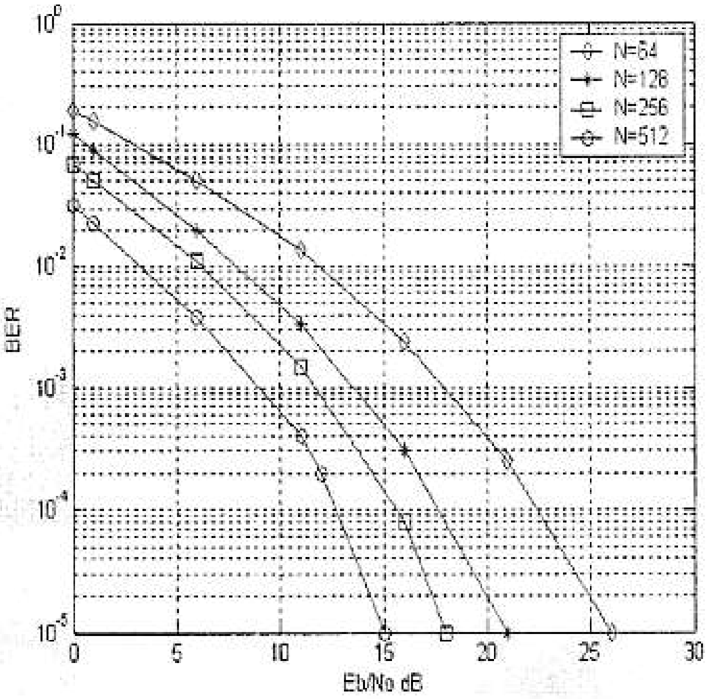


Fig. (8) ZP-OFDM performance over Rayleigh fading mobile radio channel with different values of subcarriers (N)

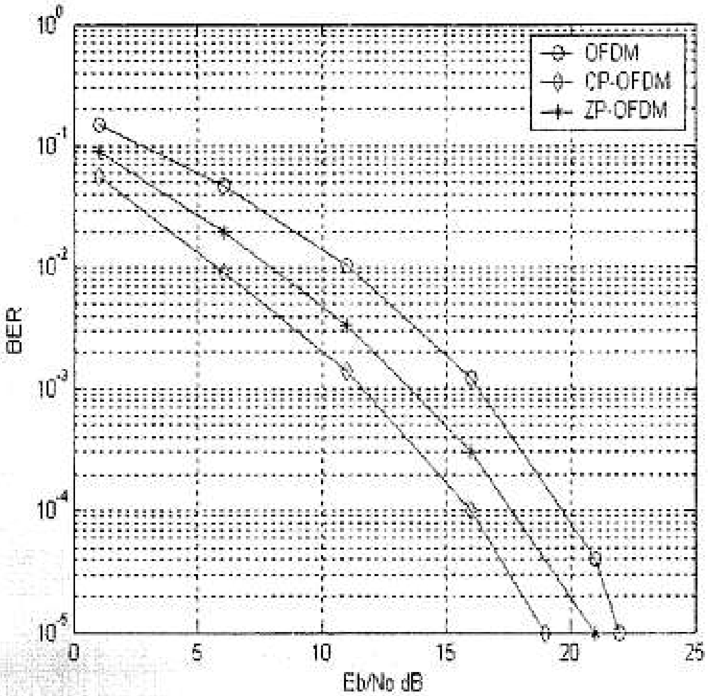


Fig. (9) Comparison between OFDM, CP-OFDM, and ZP-OFDM performance over Rayleigh fading mobile radio channel

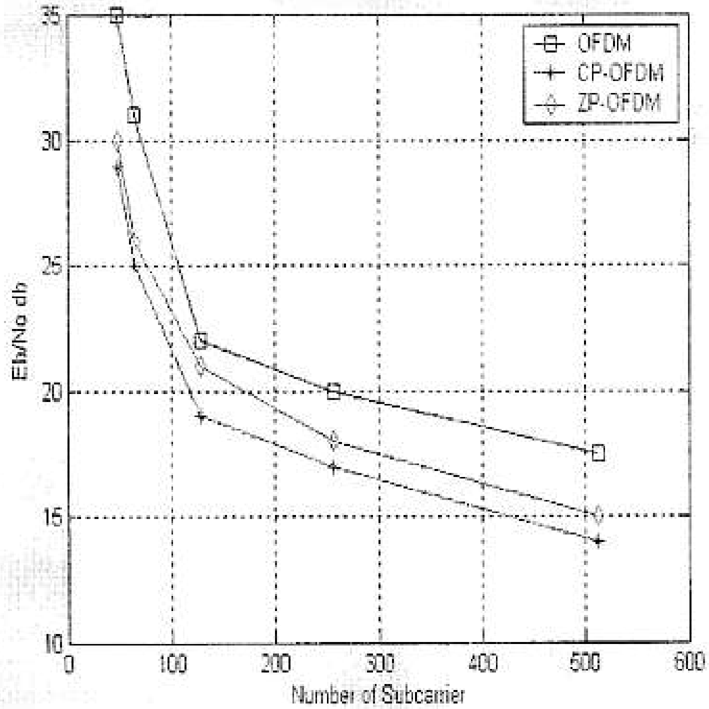


Fig. (10) Relation between number of subcarrier (N) and Eb/No at BER $=10^{-5}$ for OFDM, CP-OFDM, and ZP-OFDM over Rayleigh fading mobile radio channel

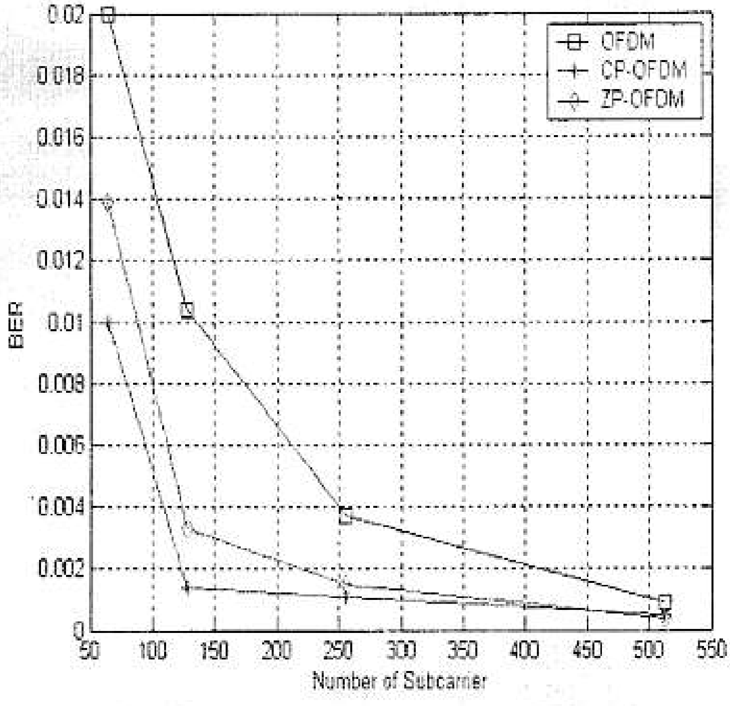


Fig. (11) Relation between number of subcarrier (N) and BER at Eb/No=11 dB for OFDM, CP-OFDM, and ZP-OFDM over Rayleigh fading mobile radio channel

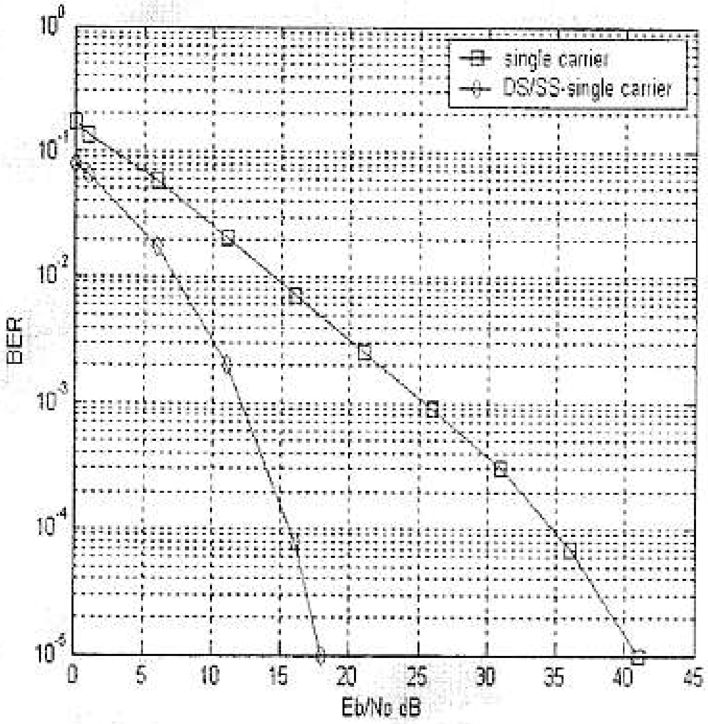


Fig.(12) A comparison between performance of single carrier unspread system and direct sequence spread spectrum system (at processing gain =31)

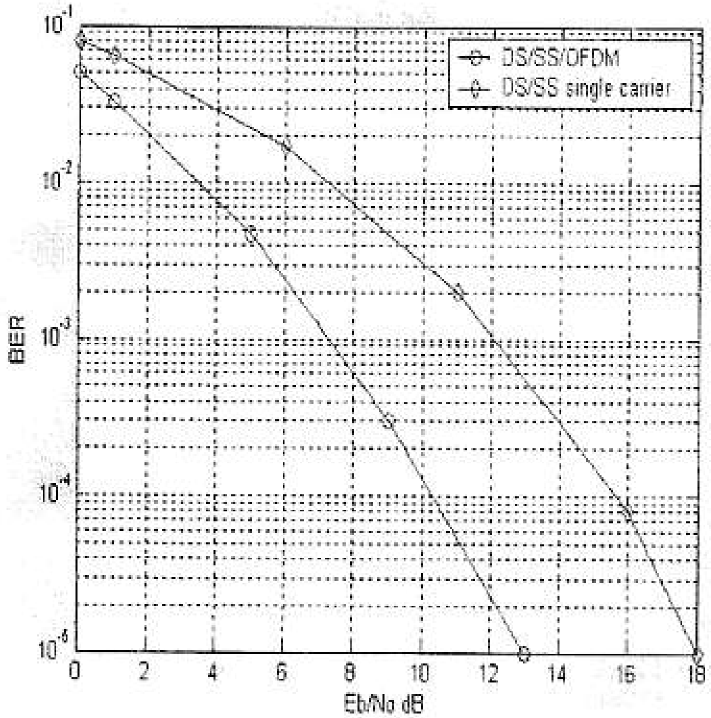


Fig.(13) A comparison between performance of direct sequence spread spectrum system (at processing gain =31)and DS/SS/OFDM system at (processing gain=32, N=128)

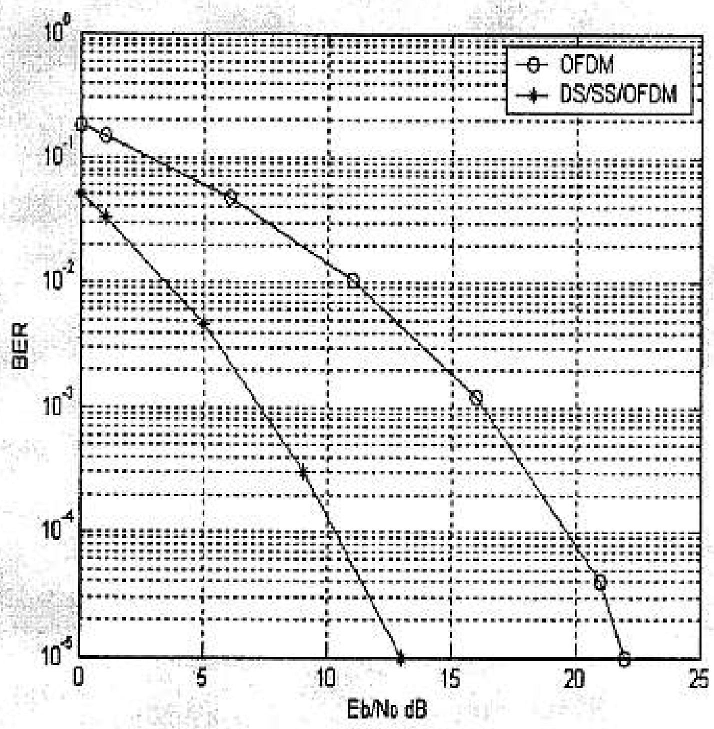


Fig.(14) A comparison between performance of OFDM system and DS/SS/OFDM system at (processing gain =32, N=128)