Enhancement of Proposed OFDM-CDMA System by Using DWT over Selective Fading Channel

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Abstract

High transmission bandwidth efficiency in mobile communication can be produced by schemes such as direct sequence code division multiple access (DS/CDMA) and orthogonal frequency division multiplexing (OFDM). The combination of OFDM signaling and CDMA scheme has one major advantage that it can lower the symbol rate in each subcarrier so that longer symbol duration makes it easier to quasi-synchronize the transmission.

In this work, two OFDM-CDMA models were investigated. Also in this work, OFDM-DS-CDMA model was presented. For further enhancement, discrete wavelet transform based OFDM system was proposed to improve the bandwidth efficiency by removing the cyclic prefix (CP). In the proposed (DWT-OFDM-CDMA) system IDWT and DWT replace the IFFT and FFT, respectively. These systems were simulated and evaluated over Rayleigh selective fading channel. The simulation results include a comparison between all systems with different spreading codes. The result shows that the performance of OFDM system enhanced by CDMA system. Furthermore, the performance of OFDM-CDMA systems is further enhanceed using the DWT.

الخلاصة

كفـاءة الإرسال العالية في الاتصالات المحمولة تستعمل تقنيات المزج مثل تقنية تعدد الوصول بتقسيم الرمـز باسـتخدام المتسلسل المباشر (DS-CDMA) وتقنية مزج تقسيمات التردد المتعامدة (OFDM) . أن المـزج بيـن نظام OFDM ونظام CDMA له فائدة مهمة وهي أنها ترسل بنسبة إرسال قليلة في كل حاملة لذلـك فان الفترة الزمنية لكل رمز تكون عالية وهذا يؤدي إلى سهولة التزامن . في هذا العمل تم بحث موديلين رياضـية لـنظام (OFDM-CDMA) . كذلك تم استعراض نظام OFDM-DS-CDMA . من أجل تحسين كفـاءة الـنظام المقـترح فقـد تم اقتراح استخدام مجال المويجة المتقطعة (DWT) في نظام التقسيم الترددي المـتعامد من أجل تحسين كفاءة عرض الحزمة الترددية وذلك بإزالة المعلومات المدارة (CP). في هذا النظام المقـترح تم استخدام معكوس مجال المويجة المتقطعة بدلا من معكوس تحويل الفورير السريع وتحويل الفورير السريع على الترتيب. تمت محاكاة ألانظمه عبر قناة الخبو الانتقائي للتردد نوع رايلي. أن نتائج المحاكاة تتظمن مقارنـة بين جميع الأنظمة. بينت النتائج إلى أن نظامOFDM يتحسن عندما يستعمل مع نظام CDMA أضافه إلى ذلك فأن مواصفات النظام OFDM-CDMAتتحسن باستخدام مجال المويجة المتقطعة (DWT).

1. Introduction

OFDM is a modulation scheme that is capable of overcoming intersymbol interference (ISI) on frequency selective channels in a very efficient way[1]. 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. Adding a cyclic prefix (CP) is the main way for the Fourier based OFDM to eliminate the ISI and Intercarrier Interference (ICI) [1,2]. However, this can decrease the

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bandwidth efficiency greatly, which means that we have 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 efficient spectral containment [3]. In the wavelet based OFDM, the IFFT and FFT blocks are simply replaced by an inverse discrete wavelet transform (IDWT) and discrete wavelet transform (DWT), respectively [2,3]. 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 [3,4]. OFDM scheme has sever disadvantages such as difficulty in subcarrier synchronization, sensitivity to frequency offset and nonlinear amplification [1,5]. However a new multiple access schemes based on a combination of CDMA and muticarrier techniques was proposed [6].

Multicarrier-CDMA (MC-CDMA) system is based on the combination of the advantages of CDMA system (such as interferance rejection, frequency reuse, etc.) with the advantages of OFDM (such as robustness against multipath, impulse noise, etc) [6,7].

2. MC-CDMA System

The MC-CDMA transmitter spreads the original data stream over different subcarriers using a given spreading code in the frequency domain [8,9]. In other words, a fraction of the symbol corresponding to a chip of the spreading code is transmitted through a different subcarrier. In a down link mobile radio communication channel, the Hadamard Walsh codes can be used as an optimum orthogonal set. Hadamard Walsh codes have the perfect orthogonality and can be obtained using matrix operations. The basic unit is the 2*2 matrix H_0 [6,9].

$$H_o = \begin{bmatrix} +1 +1 \\ +1 -1 \end{bmatrix} \qquad \text{.........(1)}$$

The Walsh Hadamard codes of the length 2^n can be generated as [4,9]

$$H_n = \begin{bmatrix} H_{n-1} H_{n-1} \\ H_{n-1} - H_{n-1} \end{bmatrix} \qquad \text{.........(2)}$$

Fig. (1) shows the MC-CDMA system, where G_{MC} denotes the processing gain, N_C the number of subcarriers, $C_j(t)=[C_1^j\ C_1^j\ .....C_{GMC}^j\ ]$ the spreading code of the j-th user and T_S denotes the original symbol duration [7,9].

3. MC-DS-CDMA System

The MC-DS-CDMA transmitter spread serial to parallel converted data streams using a given spreading code in time domain such that the resulting spectrum of each subcarrier can satisfy the orthogonality condition with the minimum frequency separation [6,7]. This scheme is originally proposed for an up link communication channel, because the introduction of OFDM signaling into DS-CDMA scheme is effective for the establishment of a quasi-synchronous channel [1,9]. Fig. (2) shows the MC-DS-CDMA system of the j-th user, where N_C denotes the number of subcarriers, $C_j(t)=[C_1^j\ C_1^j\ .....C_{GMD}^j\ ]$ the spreading code of the j-th user, and GMD the processing gain [1,9]. The MC-DS-CDMA receiver is composed of normal coherent (Non-Rake) receivers, because it is crucial to have frequency non-selective fading over each subcarrier [1,9].

4. The OFDM-CDMA Systems Modeling

4.1 System I

The first investigated OFDM-CDMA system is shown in Fig. (3). Each serial to parallel converted bit is spreaded by using Gold code and Walsh Hadamerd code sequences. The output spreaded data was mapped by using BPSK modulator. The mapped data was serial to parallel converted in to vector equal to the length of spreading code. Therefore, the number of subcarrier (the number of IFFT point) equal to the length of the first serial to parallel converted data (P) multiplied by the length of the spreading code (K).

At the receiver side, the cyclic prefix will be removed. The serial data is converted back to (Nc=P*K) parallel data, which is converted to frequency domain by FFT block. Each K data output vector from the FFT block converted in to serial vector (where K represents length of spreading code sequence). This data equalized by using single tap frequency domain equalizer. The equalized data are demodulated, and then despreaded using the same code used at the transmitter. Finally, the detected bits are parallel to serial converted, and the received bits are estimated.

4.2 System II

Fig. (4) shows the second investigated OFDM-CDMA system. The spreading code with length equal to K is used, to spread the original data stream. The spreaded data nare mapped using BPSK modulator. The parallel frequency domain data are converted in to time domain using IFFT. Cyclic prefix (CP) is used to reduce the effect of ISI and ICI. In this system the length of the output data vector from serial to parallel converter equal to K*P.

At the receiver side, the cyclic prefix is removed, and the FFT is used to find the frequency domain signal. To remove some of the channel effect, single tap frequency domain equalizer is used. The BPSK demodulator is used in the demapping process. After despreading data, the correlation and bit detection is used to find the received bits.

5. The OFDM-DS-CDMA System Modeling

Fig. (5) shows the investigated OFDM-DS-CDMA system. The input data bits is first serial to parallel converted by a vector equal to (or less than) the length of spreading code. Each of P bits is spreaded using a code with processing gain equal to K (where $K \geq P$). The Gold code sequence is used as a spreading code in this system. The spreaded data is mapped using BPSK modulator. In this system the number of subcarrier (the number of IFFT point) equal to the length of spreading code. To reduce intersymbol interference (ISI) and intercarrier interference (ICI), cyclic prefix (CP) was used before data is transmitted over the channel. The receiver basically does the inverse operation. The cyclic prefix was removed. The FFT of each symbol is then taken to find the original transmitted spectrum. A simple single tap equalizer is used to remove the channel effect. Each received carrier is then evaluated and converted back to the data word by demodulating the received symbol. The received data is despreaded using the same spreading code used at the transmitter. Finally the received bit are estimated.

6. The Proposed DWT-OFDM-CDMA Systems

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 [3,4].

In this paper, Haar wavelet is employed due to simplicity. The description of

Haar wavelet in time and frequency domain, respectively are [3]:

$$\Psi(t) = \begin{cases} +1 & 0 \le t \le 1/2 \\ -1 & 1/2 \le t \le 1 \end{cases} \quad \ldots (3)$$

and

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

The first proposed DWT-OFDM-CDMA system (**SystemI** with discrete wavelet) is shown in Fig. (6). As in the FFT-OFDM-CDMA system (System I). Each serial to parallel converted bit is spreaded using spreading code sequences. The output spreaded data was mapped using BPSK modulator. The mapped data was serial to parallel converted in to the vector equal to the length of spreading code. 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 is called approximation and the second group is called details (the length of approximation equal to the length of details). In the proposed system the input parallel (P*K) BPSK data represents approximation part, while zeros are inserted as a details part. The length of the output signal from the IDWT stage equal to 2*P*K. This output data are converted to serial vector, then this vector convolved with the selective Rayligh fading channel.

At the receiver side, the DWT is used to find the corresponding frequency domain of the parallel data. The first half of output data from the DWT stage represents the received signal, and the second half represents the details when is not used in the 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. The received data is despread using the same spreading code used at the transmitter. Finally, the received bit are estimated.

Fig. (7) shows the second proposed DWT-OFDM-CDMA system (**systemII** with DWT). The procedure of system operation is the same as systemI.

7. The Proposed DWT-OFDM-DS/CDMA System

Fig. (8) shows the proposed DWT-OFDM-DS/CDMA system. As in the FFT-OFDM-DS/CDMA system, The input data bits is first serial to parallel converted by a vector equal to (or less than) the length of spreading code. Each of P bits is spreaded using a code with processing gain equal to K (where K ≥ P). In this model the number of subcarrier (the number of IDWT point) equal to 2*length of spreading code.

8. Computer Simulation Tests and Results

An OFDM-CDMA 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-CDMA system tested under the same conditions. Furthermore, the performance of the presented OFDM-DS/CDMA and proposed DWT-OFDM-DS/CDMA systems was tested under the same conditions.

The parameters and system configuration used in the simulation can be summarized by: -

Source data rate	2 Mbps
Modulation scheme	BPSK
Number of subcarrier	128
Number of FFT points	128
Number of DWT point	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 simulated channel	Jacks Model
Number of path	8 paths
Number of finger	2 fingers
Multipath delay spread	$3*10^{-6}$ sec
Doppler frequency	150 Hz
Types of spreading code used	Gold and Walsh Hadmard codes
Processing gain (Gold code)	31
Processing gain (Walsh code)	32
Bit error rate	10^{-5}

A comparison between the performance of investigated OFDM-CDMA systems with Walsh Hadamerd code and Gold code are shown in Fig. (9). System II gives better performance compared with systemic. The performance of investigated systems, shows that the performance of Walsh Hadamard code is better than the performance of Gold code by about 8dB in system I and 5dB in system II at bit error rate 10^{-5}. Therefore, the Walsh Hadamard code more suitable with the simulated systems. This performance was tested with Gold code (K=31),Walsh Hadamard code (K=32), The value of serial to parallel converter (P)=128, and the number of channel finger =2.

To investigate the effect of processing gain (K) on the performance of FFT-OFDM-CDMA system extra test was carried out as shown in Fig. (10). From the figure, the performance of the system is enhanced as the processing gain increased from 8 to 32. However, when K become 64 or 128 the performance is degraded. In OFDM system when the number of subcarrier increased the performance enhanced, but with very large number of subcarrier the sensitivity of the system to any frequency offset increased. Therefore, the system performance is degraded. This degradation in the performance of sytem II is due to the very large number of subcarrier (Nc), because the number of subcarrier in this model =P*K (where P=128).

The effect of increasing P on the performance of FFT-OFDM-CDMA system is presented in Fig. (11). The Walsh Hadamard code with processing gain (K)=32 are used. The figure is shows that the best performance is achived at P=64.

The effect of increasing number of finger on the performance of the investigated OFDM-CDMA system is shown in Fig. (12). Increasing in the number of fingers causes performance degradation. From the figure it is clear that the performance of 2-finger is better than the performance of 4-finger by about 1 dB at bit error rate 10^{-5}. Furthermore, the performance of 4-finger better than the performance of 6-finger by about 1 dB at bit error rate 10^{-5}. This test has been considered for systemII. Fig. (13) shows the performance of the FFT-OFDM-DS-CDMA system with different number of subcarrier. The Gold code with processing gain (K) equal to 31 are used with this system. In this system, the number of subcarrier must be less than or equal the processing gain ($Nc \leq K$). From the figure, it is clear that the performance is degraded if the number of subcarrier is greater than the processing gain and the best performance is achieved when Nc=32.The first Proposed DWT-OFDM-CDMA system gives advantages by about 4dB at bit error rate 10^{-5} compared with first investigated d FFT-OFDM-CDMA system as shown in Fig. (14).

Fig. (15) shows a comparison between performance of second investigated FFT-OFDM-CDMA system and second proposed DWT-OFDM-CDMA model.

The system with DWT gives an advantage of 4.5dB at bit error rate 10^{-5} compared with the FFT system.

Finally, a comparison between performance of proposed DWT and FFT in the OFDM-DS/CDMA system is shown in Fig. (16). The performance of DWT better than the performance of FFT by about 4dB at bit error rate 10^{-5}.

9.Conclusions

Two OFDM-CDMA models were proposed to enhance the performance of OFDM system. The second model is the best. Walsh code gives better performance as compared with Gold code in proposed OFDM-CDMA systems. The performance of proposed OFDM-CDMA systems enhanced with increasing processing gain, but with large processing gain the performance of systems degraded. The last proposed model, OFDM-DS-CDMA, gives less performance compared with other proposed models, but it is effective for the establishment of a quasi-synchronized channel. Therefore, it used in up-link system. OFDM-DS-CDMA system gives a better performance when the number of subcarrier equal to the length of spreading code. The performance of proposed DWT instead FFT in OFDM system is better by about 4dB at BER=10^{-5}. Since, the cyclic prefix (CP) is not used in the proposed systems with DWT, therefore, the bandwidth efficiency of the proposed system is also improved. This enhancement in performance of the proposed system due to the properties of wavelet transform as compared with FFT.

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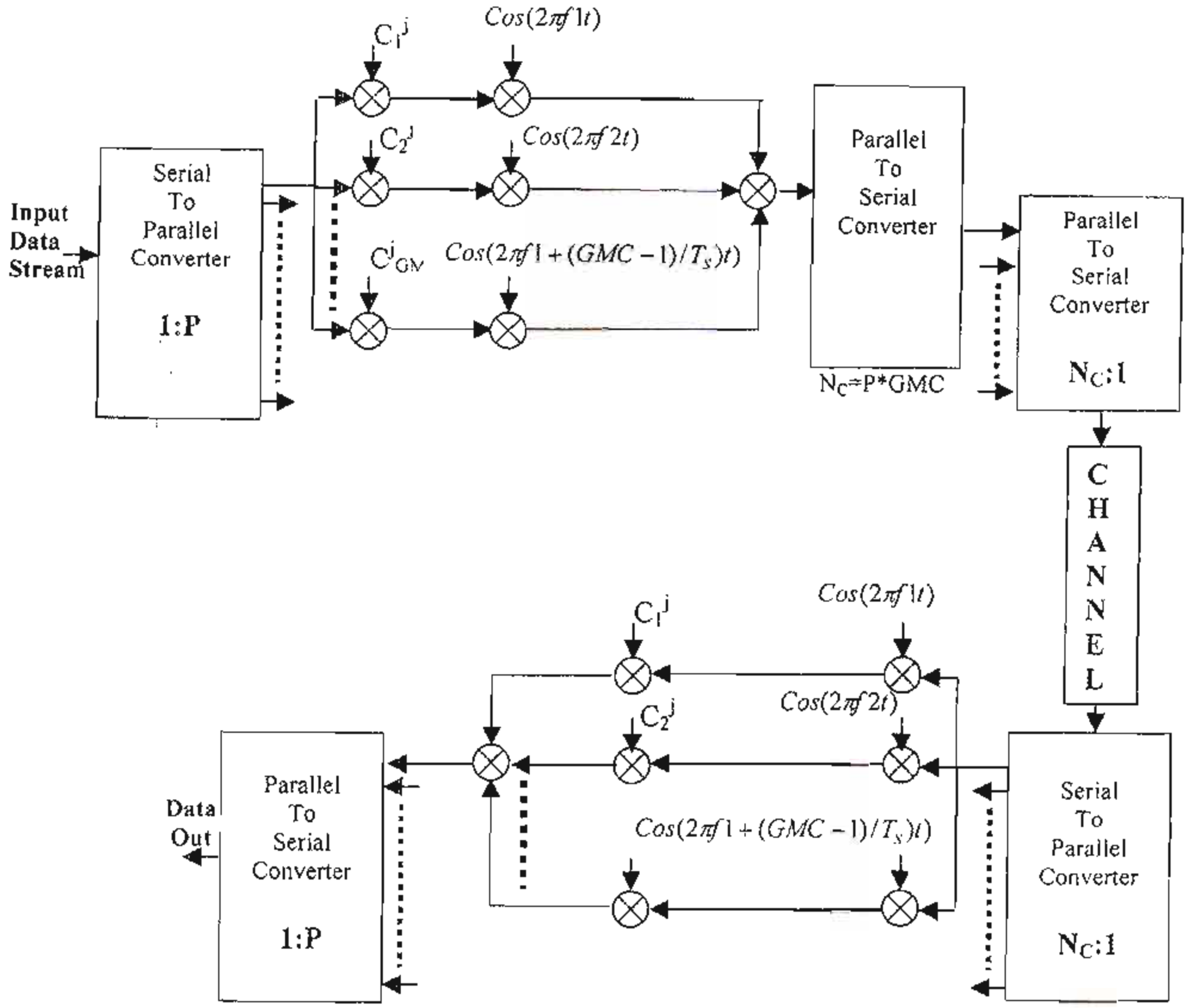

Figure (1) Basic MC-CDMA System when N_C=P*GMC

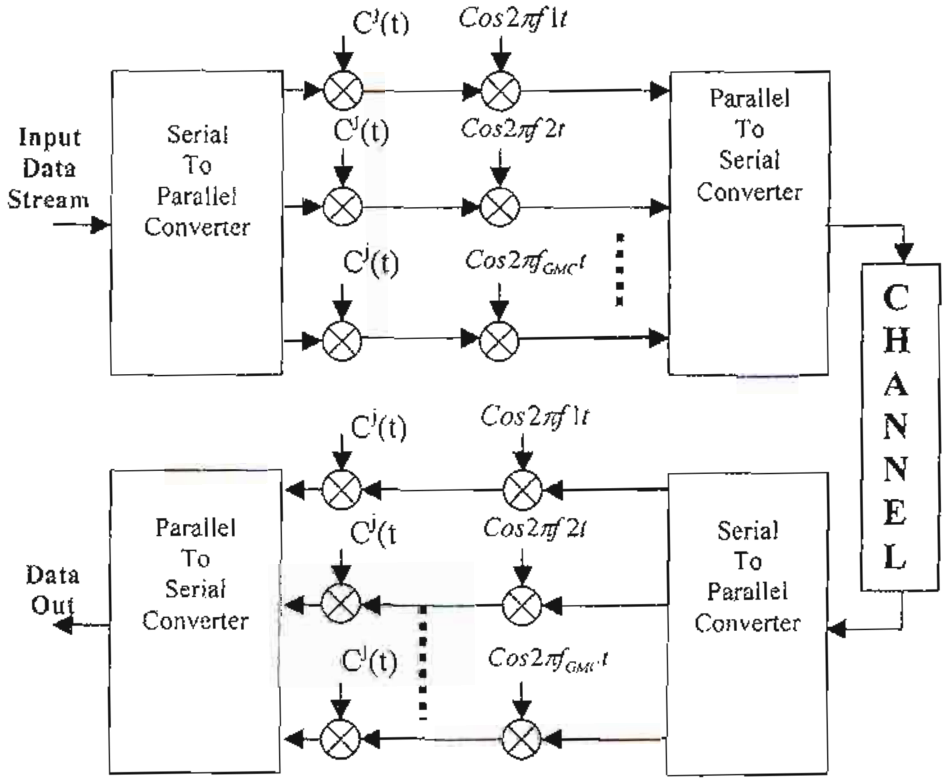

Figure (2) Basic MC-DS-CDMA System

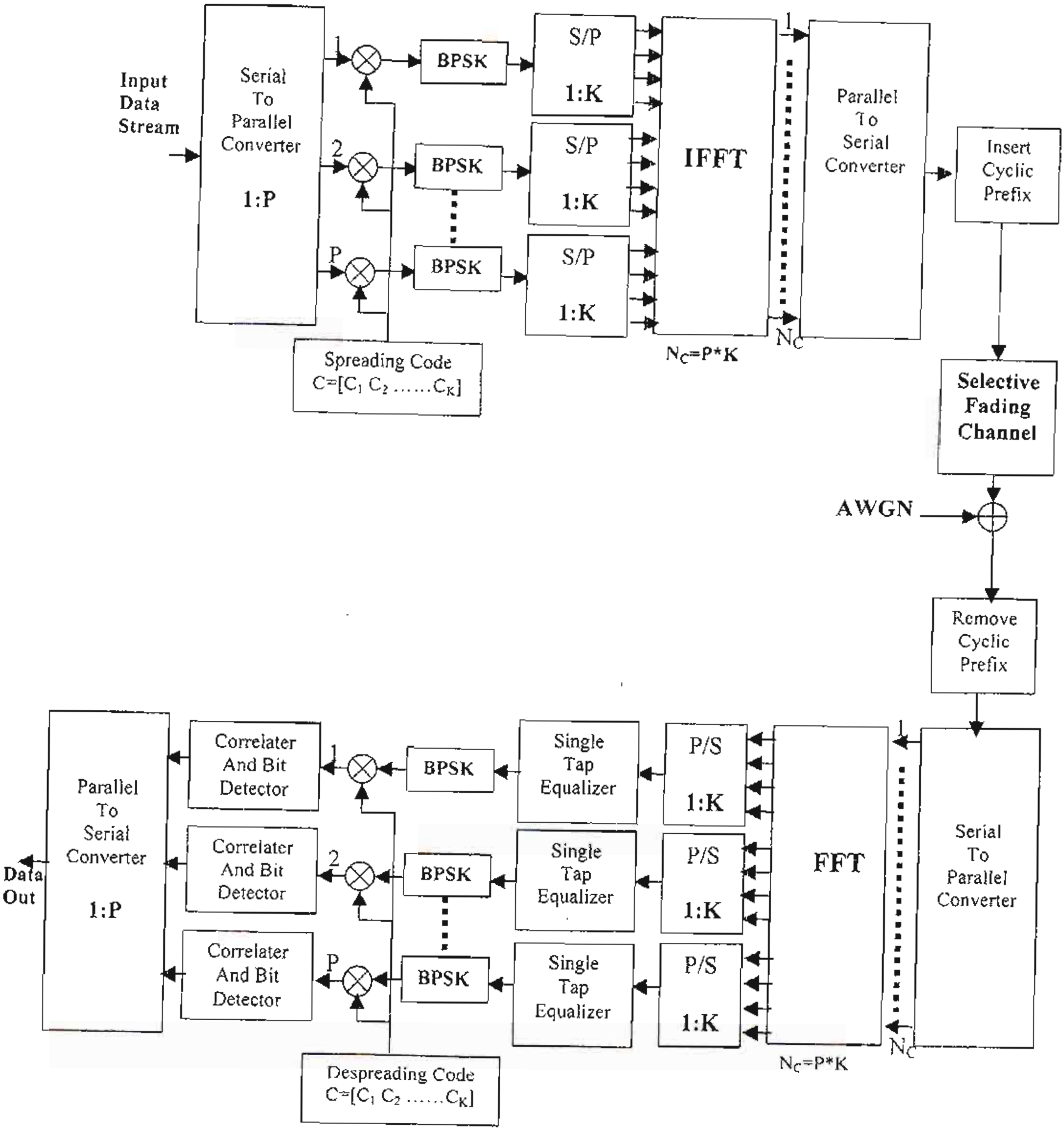

Figure (3) investigated FFT-OFDM-CDMA model (System I)

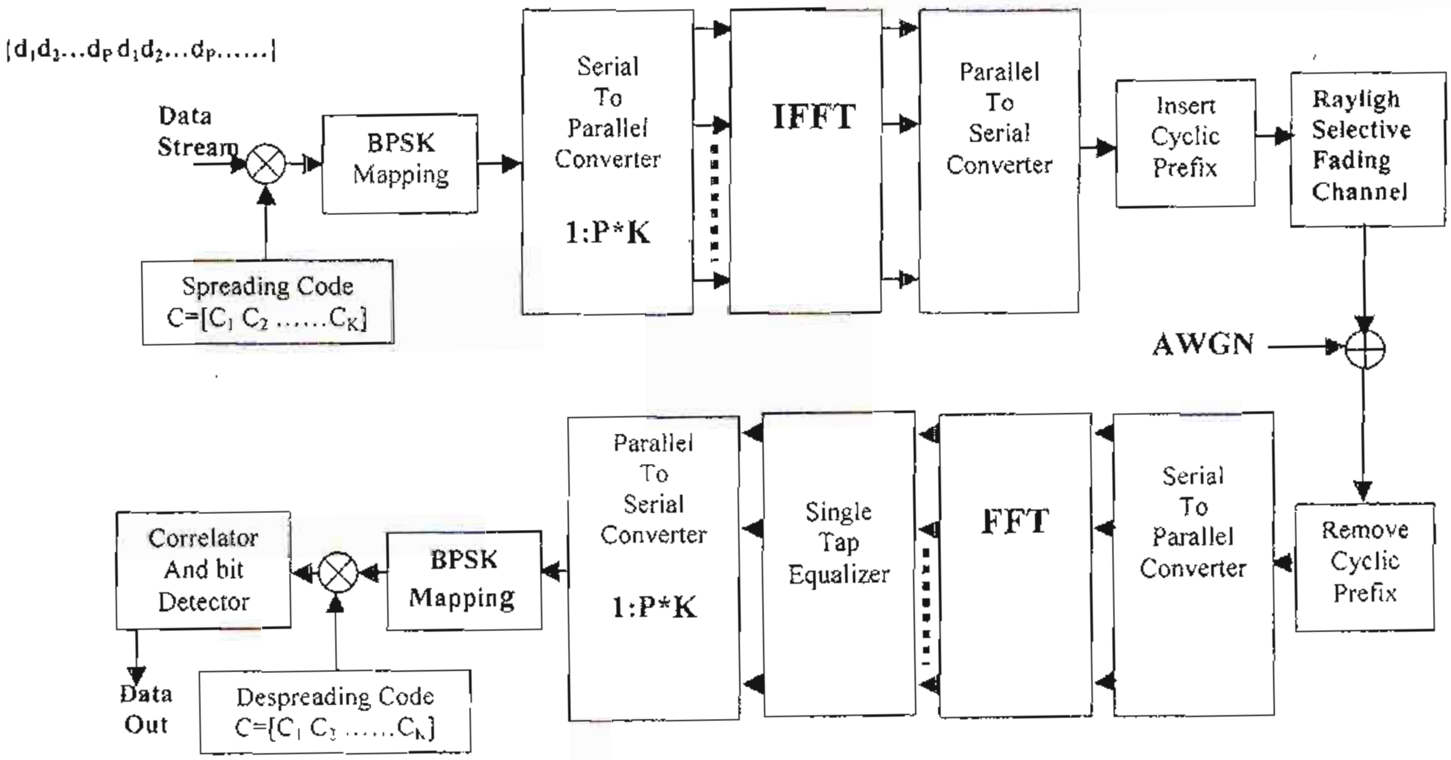

Figure (4) investigated FFT-OFDM-CDMA model (SystemII)

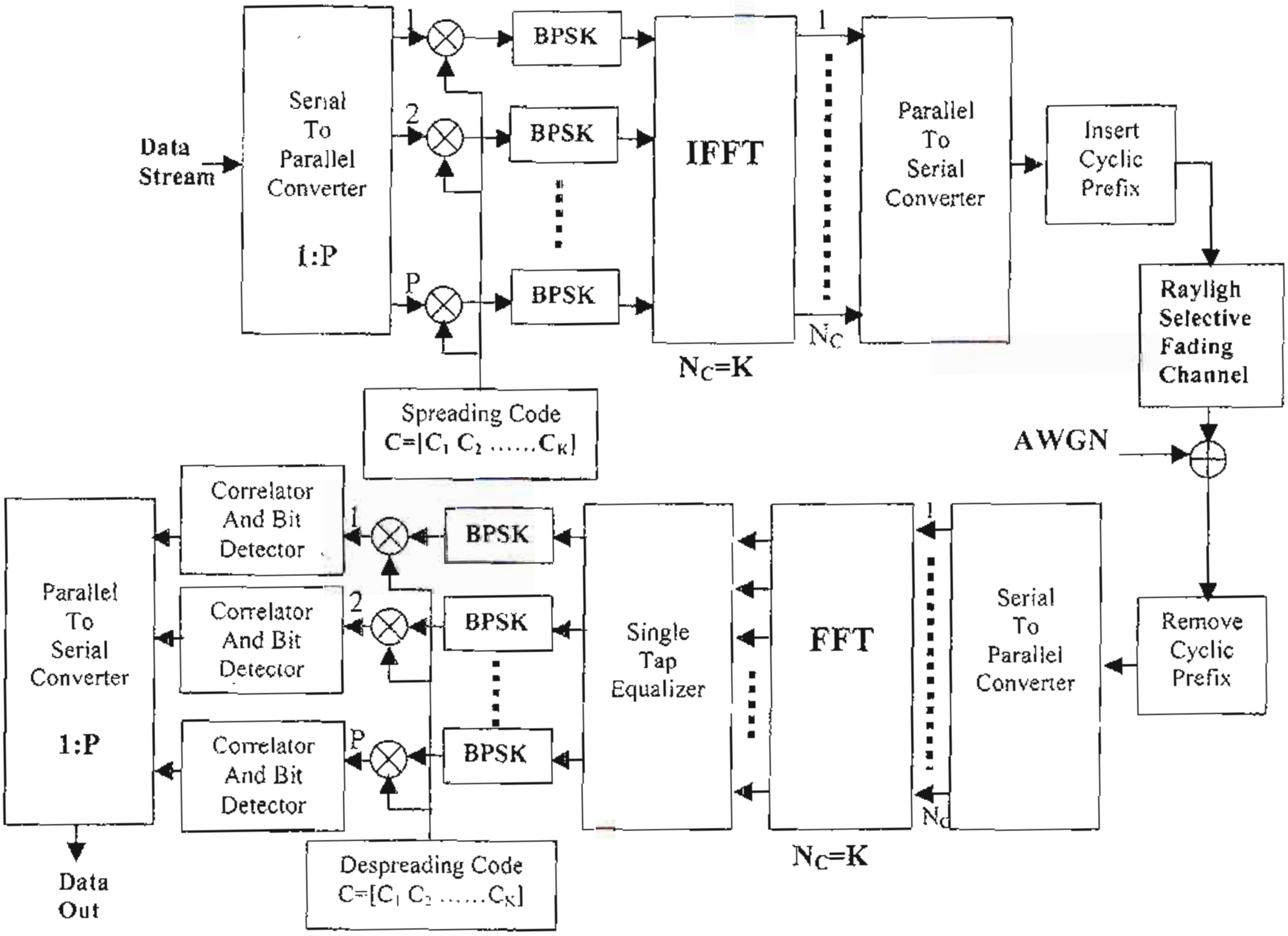

Figure (5) investigated FFT-OFDM-DS-CDMA model when number of subcarrier (N_C) equal the length of spreading code (K)

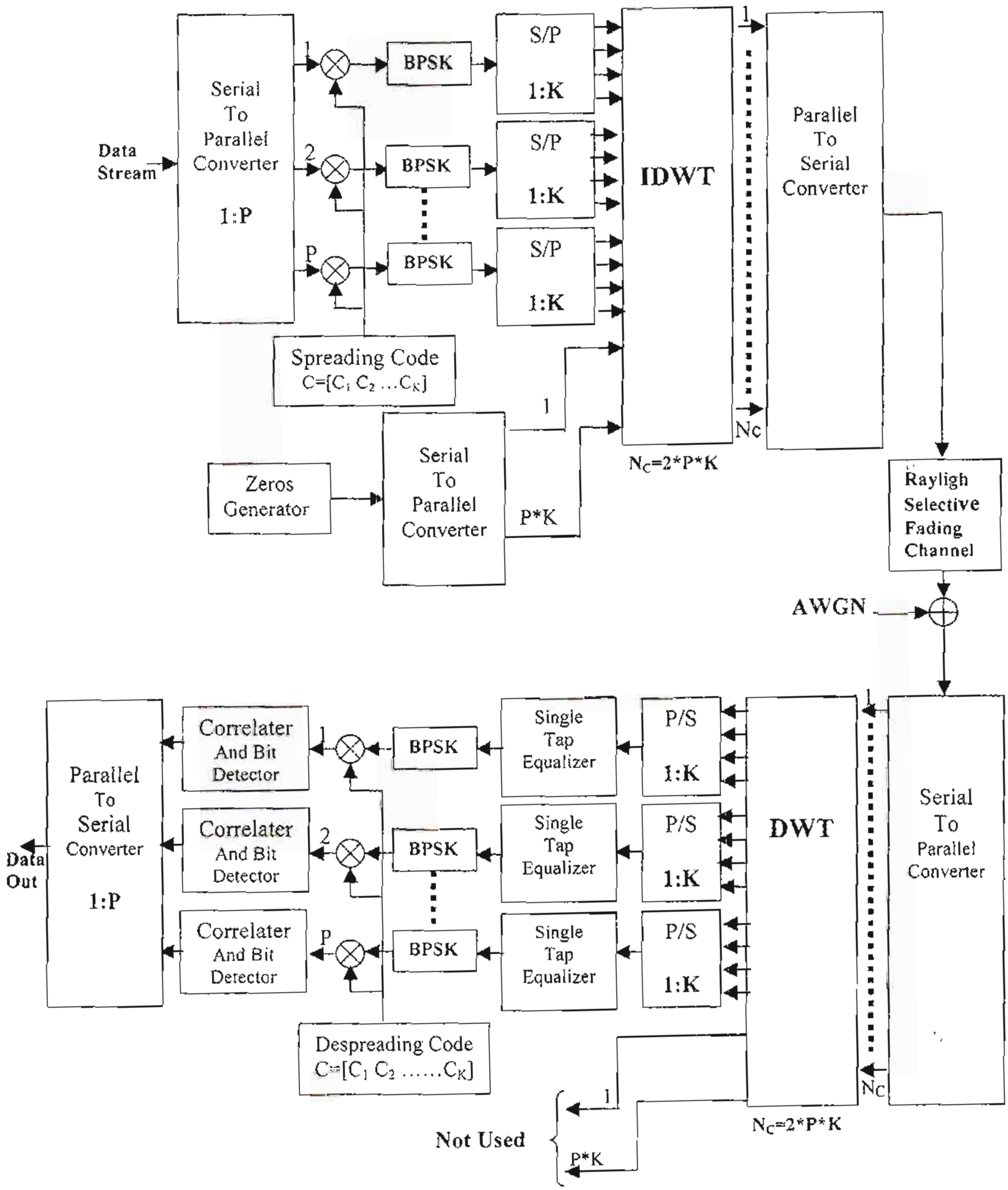

Figure (6) Proposed DWT-OFDM-CDMA model (System I with DWT)

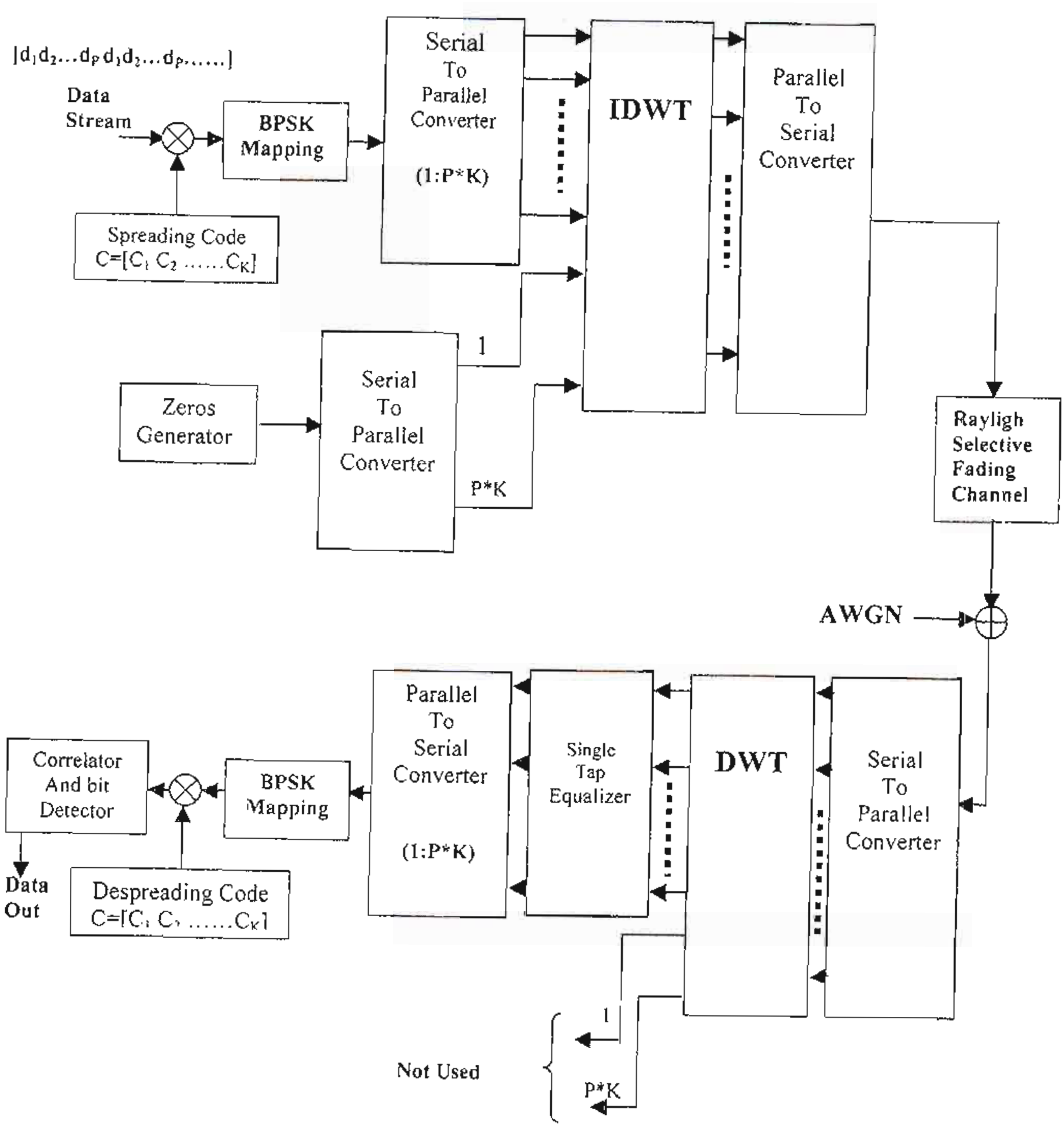

Figure (7) Proposed DWT-OFDM-CDMA Model (System II with DWT)

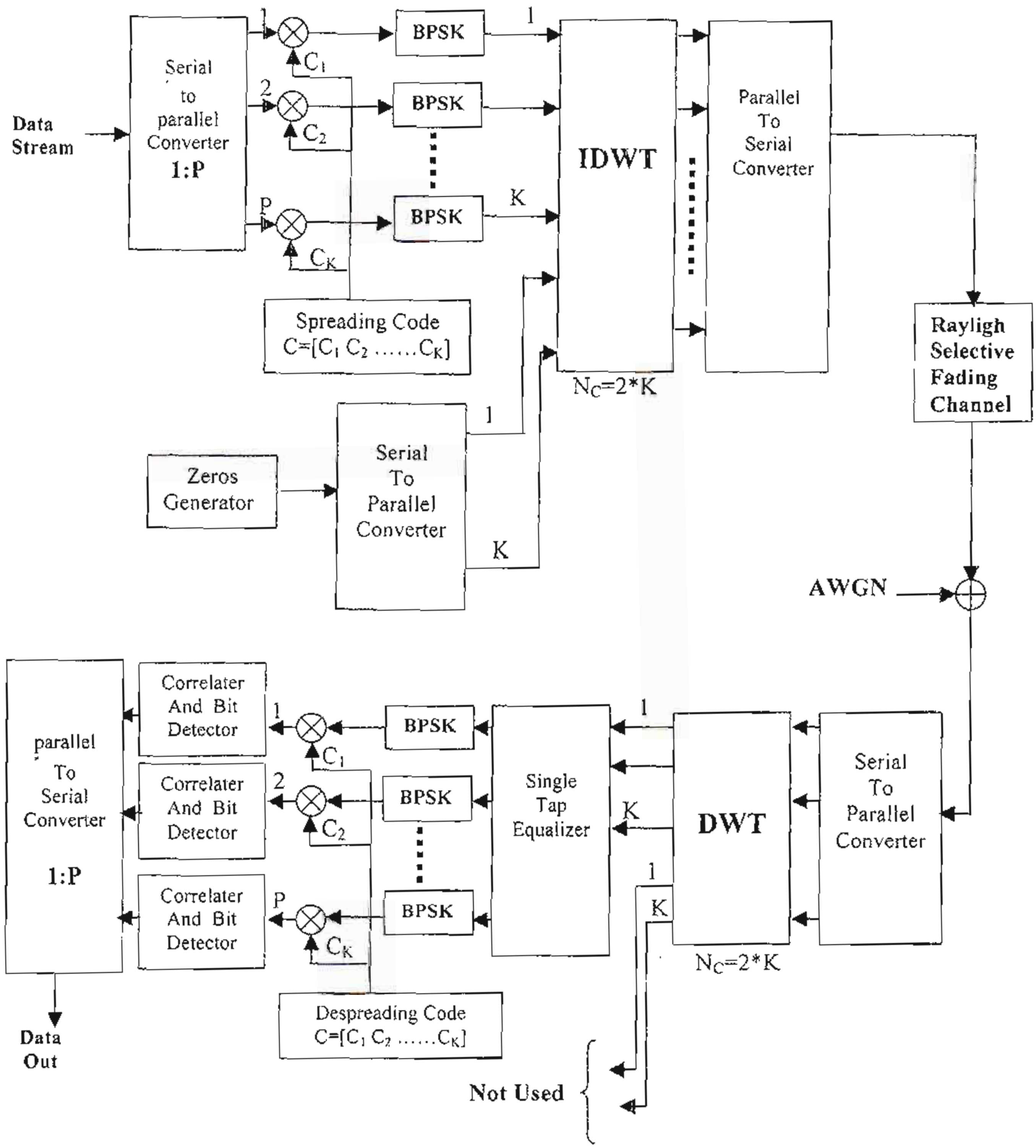

Figure (8) Proposed DWT-OFDM-DS/CDMA model when number of subcarrier (N_C) Equal to 2*Length of Spreading Code (K)

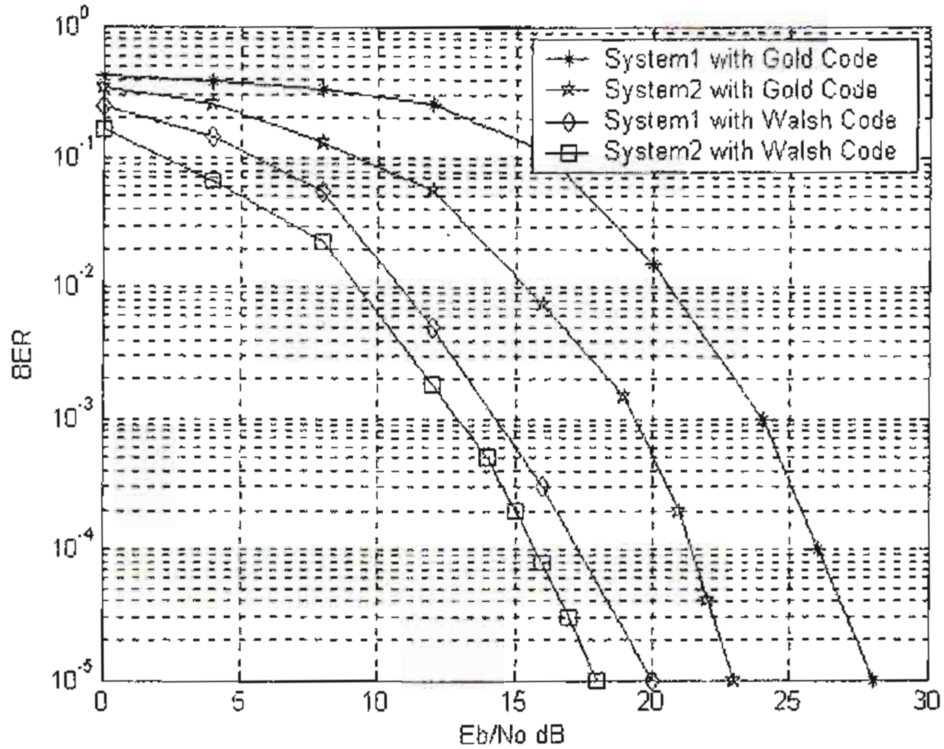

Figure (9) Comparison between performance of FFT-OFDM-CDMA models (systemI and system II) with Gold code and Walsh Hadamard code

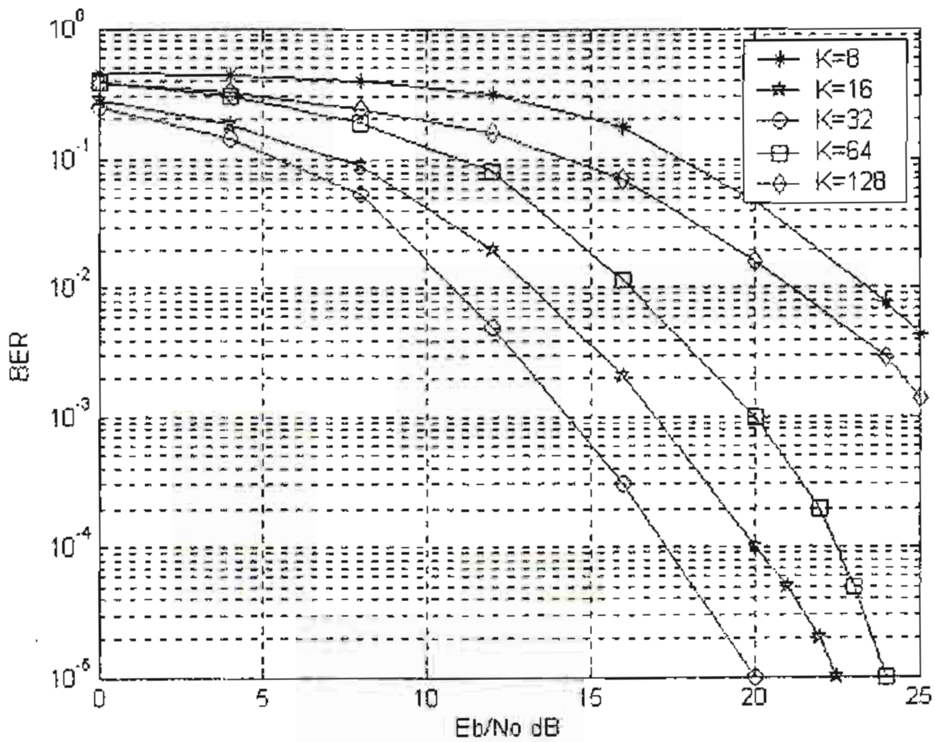

Fig. (10) Performance of FFT-OFDM-CDMA model (System1) over multipath selective fading channel with different processing gain (K), at P=128

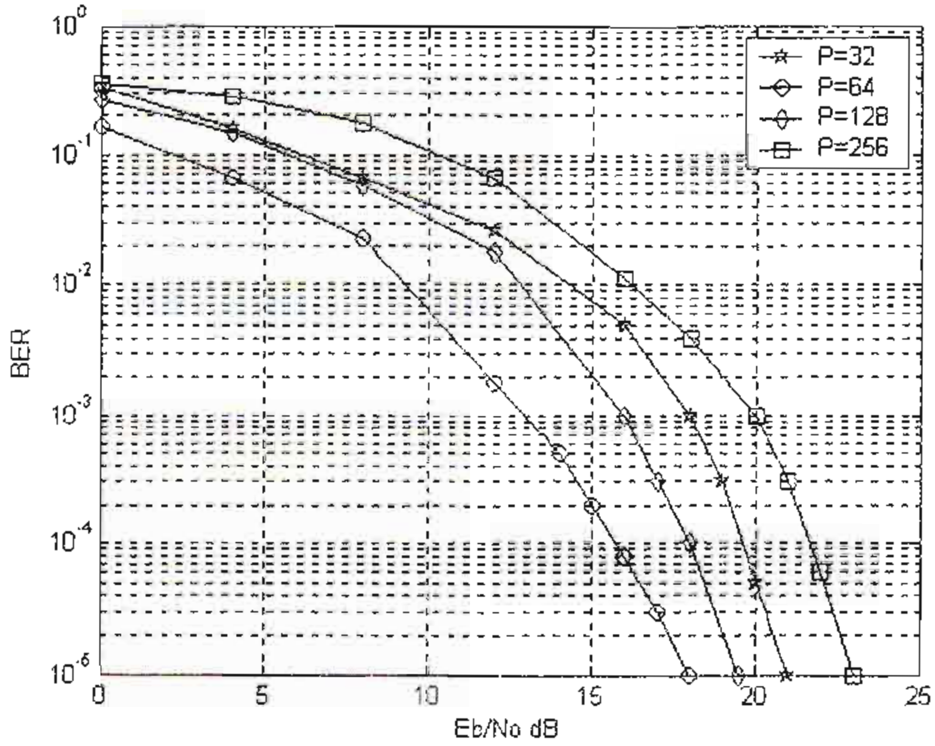

Fig. (11) Performance of FFT-OFDM-CDMA model (System2) over multipath selective fading channel with different number of subcarrier (Nc), at Walsh Hadamard code (K=32)

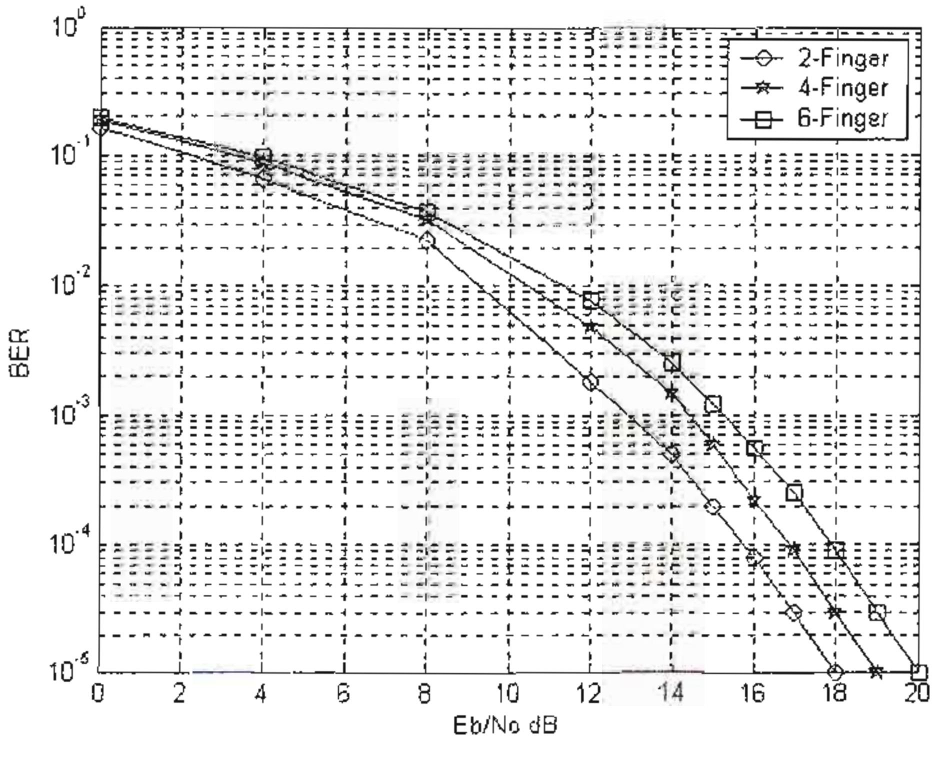

Fig. (12) Performance of FFT-OFDM-CDMA model (System2) over multipath selective fading channel with different number of channel fingers

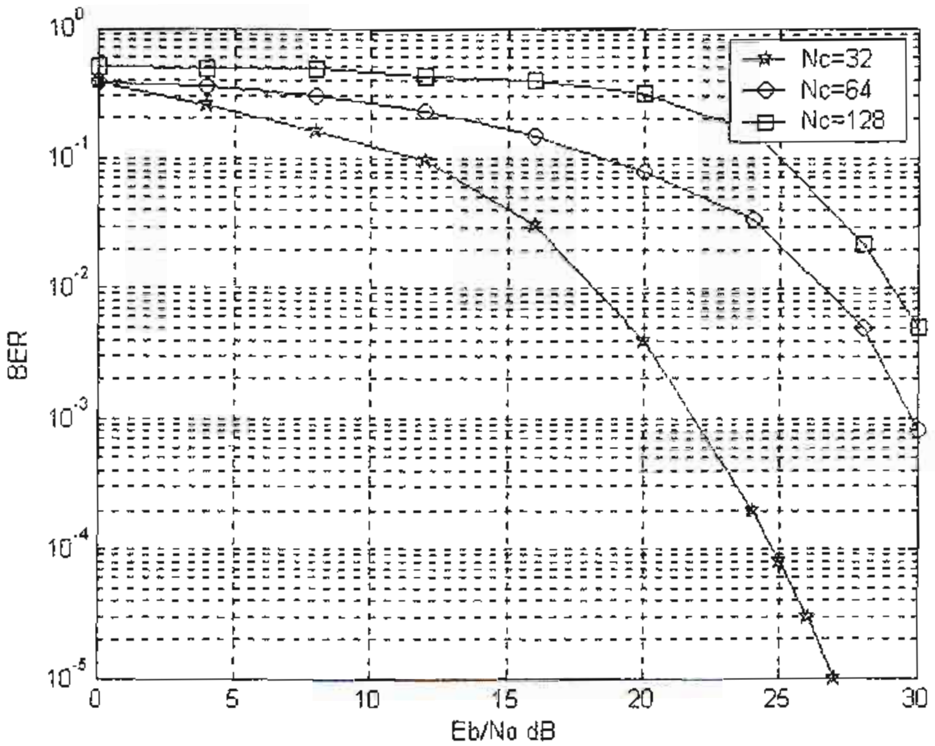

Fig. (13) Performance of presented OFDM-DS-CDMA model over multipath selective fading channel with different number of subcarrier (Nc), at Gold code with K=31

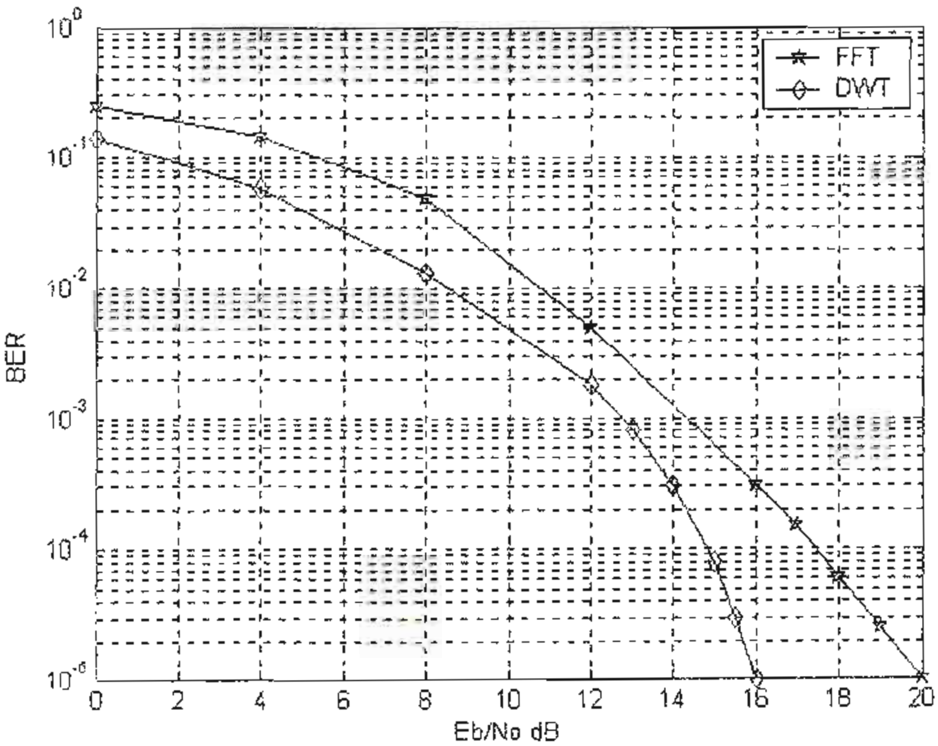

Fig. (14) Comparison between performance of FFT-OFDM-CDMA and DWT-OFDM-CDMA at systemI

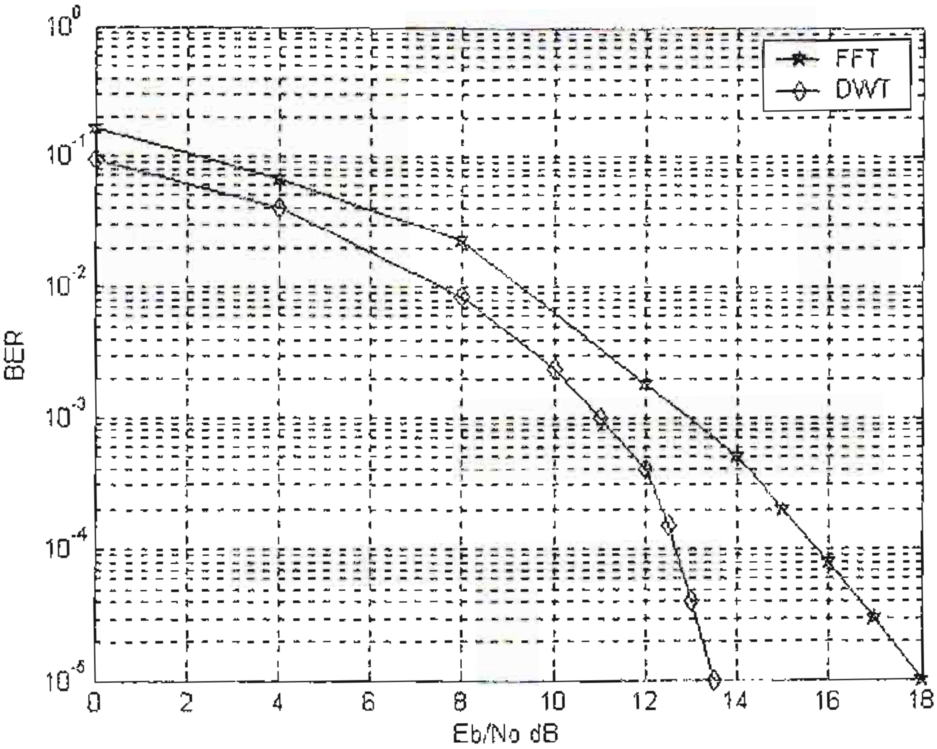

Fig. (15) Comparison between performance of FFT-OFDM-CDMA and DWT-OFDM-CDMA at systemII

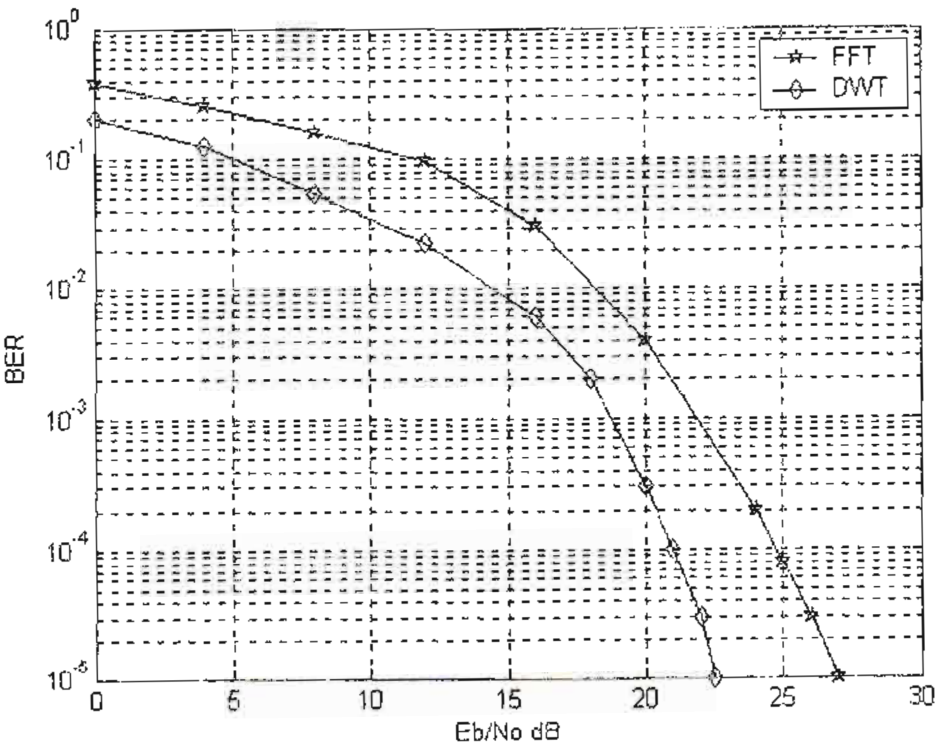

Fig. (16) Comparison between performance of FFT-OFDM-DS/CDMA and DWT-OFDM-DS/CDMA