# A New WP-MC/MCD-CDMA System Using Two-dimensional Spreading Code

Natiq Abdullah Ali

Technical College of Management, Baghdad, Iraq
E-mail: apdr_natiq@yahoo.com

## Abstract

The Fourth Generation (4G) of wireless communication networks is able to handle much higher data rates in the range of 1Gb, the WLAN environment and 100 Mb in cellular networks. Also, the 4G can support various multimedia services such as voice, data and video, which require multirate transmission and large bandwidth. In this paper, the Wavelet Packets (WP), Multicarrier (MC), Multicode (MCD) and multiuser (MU) are combined together in Code Division Multiple Access (CDMA) communication system to yield a novel communication system that is WP-MC/MCD/MU/CDMA. Besides, the wireless communications networks require multirate transmission. Therefore, to improve the system performance in multirate transmission, the two-dimensional spreading codes with different length are used in the proposed system. The overall transceiver system is simulated and modeling using Matlab R2008a. The proposed system is evaluated under the Additive White Gaussian Noise (AWGN) and Rayliegh channels. The Bit Error Rate (BER) results show that the proposed system gives improvement in the performance as compared with the currently systems and is reliable and good candidate for the 4G cellular mobile systems.

**Keywords:** OFDM, MC, CDMA, spreading codes, WP, MCD, MU.

**نظام *WP–MC/MCD–CDMA* جديد باستخدام الرمز المنتشر ثنائي الأبعاد**

ناطق عبدالله علي

**خلاصة**

إنّ الجيلَ الرابعَ (4G) مِنْ شبكاتِ الاتصال اللاسلكي قادر على مُعَالَجَة نِسَبِ بياناتٍ عالية جداً، وبمدى 1Gb في أنظمة الـ WLAN و 100 Mb في الشبكاتِ الخلويةِ. وأيضاً، الـ 4G يُمْكِنُ أَنْ يَدْعمَ خدماتَ متعددة الأوساطَ مثل الصوتِ والبياناتِ والفيديو ، واللذان يَتطلّبانِ إرسالَ متعدّدَ وسعة نطاق كبيرةَ. في هذاالبحث، الـ (WP)، (MC) ، (MCD) ، (MU) أستخدمت سوية لتصميمنظام اتصال مبتكرِ الذي هو WP–MC/MCD/MU/CDMA. إضافةً إلى ذلك، تَتطلّبُ شبكةَ الاتصالاتِ اللاسلكية إرسالَ متعدّدَ. لذا، ولتَحسين أداءِ النظامَ في الإرسالِ المتعدّدِ، فقد تم استخدام تقنية الـ two–dimensional spreading codes بأطوالِ مختلفةِ في النظامِ المُقترَحِ. إنّ النظامَ المقترح تم تنفيذه باستخدام الـ Matlab R2008a. إنّ النظامَ المُقترَحَ نفذ باستخدام قناة الـ AWGN وقناة الـ Rayliegh. بينت نسبة خطإِ القطعة BER بأنّ النظامَ المُقترَحَ قدم تحسيناً في الأداءِ كما هو مُقارن بالأنظمةِ المُقترَحةِ حالياً ومرشّحُ موثوقُ وجيدُ لأنظمة الـ 4G والأنظمة الخلوية.

**الكلمات المفتاحية:** OFDM، MC، CDMA، الرموز المنتشرة، WP، MCD، MU

## 1. Introduction

The future wireless mobile communication systems will be required to support high speed transmission rate. The high data rate requires broad frequency bands. Unfortunately in broadband wireless channel, the severe frequency-selectivity due to the more number of resolvable multiple paths fading degrades the BER performance [1].

The growth of wireless applications and spectral limitations are serious concerns for both the military and civilian communities. "A special spectrum task force set up by Federal Communications Commission (FCC) revealed that in many bands spectrum access is a more significant problem than physical scarcity of the spectrum" [2].

Wireless connectivity of mobile devices and notebook computers is the hallmark feature of the next generation of network infrastructure. A major challenge to the traffic capacity of such systems is the complex characteristics of the mobile channel encompassing multipath propagation [3].

The demand for high data rate wireless multi-media applications has increased significantly in the past few years [4].

## 2. Multiple Access Techniques

In communication systems, there are three types of multiple access technique namely Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA). TDMA and FDMA are techniques that use time and frequency slots to share system resources, while CDMA uses orthogonal code sequences to share resources in both frequency and time. When CDMA is compared with TDMA and FDMA, we can see that CDMA is an excellent resource sharing technique since it uses the entire spectrum and time slots. Compared to FDMA in which the spectrum is divided into several sub-bandwidths, and compared to TDMA in which the time duration is divided into several time slots [5,6].

There are three types of multiple access schemes based on the combination of CDMA and Orthogonal Frequency Division Multiplexing (OFDM). These are (a) Multicarrier (MC)-CDMA; (b) Multicarrier Direct Sequence (MC-DS)-CDMA, and (c) Multitone (MT)-CDMA. The signals of these systems can be easily transmitted and received using the Fast Fourier Transform (FFT) without increasing the complexities of the transmitter and receiver and have the attractive feature of high spectral efficiency due to minimally densely spaced subcarrier [4].

## 3. OFDM

Orthogonal Frequency Division Multiplexing (OFDM) has recently gained a lot of attention and is a potential candidate for 4G systems [7]. OFDM is very efficient in spectrum usage and is very effective in a frequency selective channel. By taking advantage of recent improvements in Digital Signal Processing (DSP) and Radio Frequency (RF) technologies, OFDM can provide higher data rates and is a very good choice for service providers to compete with wire-line carriers. A variation of OFDM which allows multiple accesses is Multi-Carrier CDMA (MC-CDMA) which is essentially an OFDM technique where the individual data symbols are spread using a spreading code in the frequency domain [7].

Multicarrier (MC) modulation, in particular orthogonal frequency division multiplexing (OFDM), has been successfully applied to various digital communications systems. OFDM can be efficiently implemented by using the discrete Fourier transform (DFT). Furthermore, for the transmission of high data rates its robustness in transmission through dispersive channels is a major advantage. For MC-CDMA, spreading in frequency and/or time direction is introduced in addition to the OFDM modulation. MC-CDMA has been deemed a promising candidate for the downlink of future mobile communications systems [8].

## 4. MC-CDMA

Broadband wireless access for evolving mobile internet and multimedia services are driving a surge of research on future wireless communication systems, which have to be highly spectral efficient in order to support multi-user access and high data rates. Therefore, MC-CDMA formed by combining orthogonal frequency division multiplexing

OFDM with Code Division Multiple Accesses (CDMA) became significant research topics. The former is well suited for high data rate applications in frequency selective fading channels and the later is a multiplexing technique where number of users is simultaneously available to access a channel. With its capability of synchronous transmission, MC-CDMA is suitable for downlink of cellular communication systems. High data rate MC-CDMA systems can additionally employ MIMO techniques like the Alamouti codes [1,9,10].

Using a given spreading code, the MC-CDMA transmitter spreads the original data stream over different subcarriers in frequency domain. MC-CDMA scheme is robust to frequency selective fading. For MC-CDMA system, there are some detection techniques such as Equal Gain Combining (EGC), Orthogonal Restoring Combining (ORC), Maximum Ratio Combining (MRC) and MMSE. The MMSE scheme can achieve better performance [1].

The MC-CDMA proved to be a suitable technique for the downlink transmission. Uplink transmission, due to the more complex propagation conditions, introduces additional problems which result in harder applicability of MC-CDMA in uplink [11].

## 5. The Proposed System Model

In this section, a Wavelet Packets (WP) based Multicarrier (MC)/Multicode (MCD) CDMA communication system denoted as WP-MC/MCD-CDMA is proposed, described and semi-modeled analytically.

The framework for evaluating the performance of the system is presented in terms of the signal power, noise power, and the throughput of the system. The proposed system model is described as, Transmitter, Channel and Receiver.

**Transmitter System Model**

The transmitter model of WP-MC/MCD-CDMA system assuming $K$ users transmitting information simultaneously is shown in Fig. (1). The data $d_k(t)$ for the $k^{th}$ user is a random complex sequence given by [4,6,7]:

$$d_{hj}(t) = \sum_{i=-\infty}^{\infty} d_{hj}^{i} \prod_{T/H}\left(t - \frac{iT}{H}\right) \quad \ldots (1)$$

Where $\prod_x(\cdot)$ represents a rectangular pulse of duration $x$. and $J$ is the number of substreams in the multicode part,

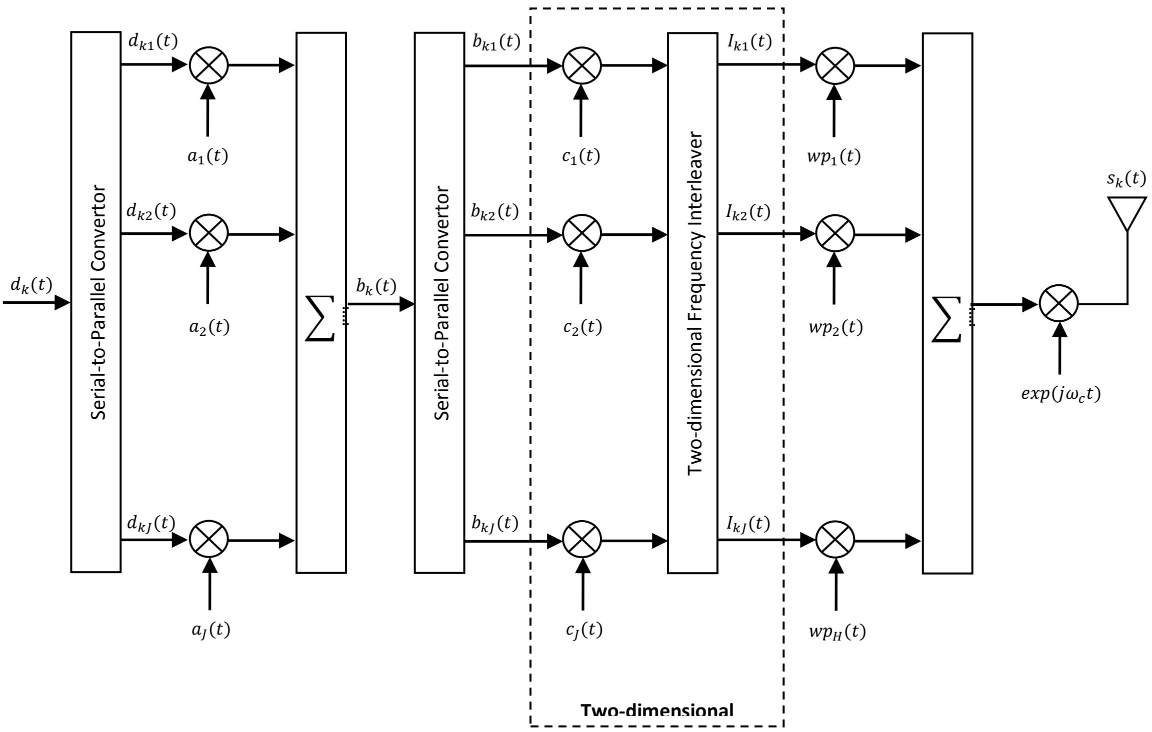


**Fig. 1. The Proposed Transmitter Model [4].**

After the S/P conversion, the data substreams are coded by a set of orthogonal signals $a_j(t)$ to reduce the Inter-Substream Interference (ISSI) resulting from the interference between the $J$ substreams themselves. The orthogonal signal coding the $j^{th}$ substream is given by

$$a_j(t) = \sum_{i=0}^{N_c-1} a_j^i \prod_{T_c}(t - iT_c) \quad \ldots\ldots (2)$$

where $N_c$ is the code length, $T_c$ is the chip duration, and $a_j$ has a chip rate $1/T_c$. Note that $a_j^i$ and $d_{kj}^i \in \{\pm 1\}$ with probabilities $P(1) = P(-1) = 0.5$ (equal probabilities).

In order to maintain orthogonality of the coding signals, the maximum number of substreams $J$ is limited to $N_c$ . The coded substreams are added and the resulting signal $b_k(t)$ is given by [5]

$$b_k(t) = \sum_{j=1}^{J} a_j(t)\, d_{kj}(t) \quad \ldots\ldots (3)$$

This signal is again S/P converted into $H$ superstreams $b_{kh}(t)$ and is given by

$$b_{kh}(t) = \sum_{j=1}^{J} d_{kjh}(t) a_j(t) \quad , \quad h = 1, \ldots\ldots, H \ldots\ldots (4)$$

where $d_{kjh}(t)$ with period $T$, is the data symbol of $k^{th}$ user, $r^{th}$ substream of the $h^{th}$ superstream.

The modulation of the superstreams by the PN sequence corresponding to the $k^{th}$ user, and is given by [5,6]

$$c_k(t) = \sum_{i=0}^{N_n-1} c_k^i \prod_{T_n}(t - iT_n) \quad \ldots\ldots (5)$$

where $N_n$ is the length of the PN code sequence and $c_k^i \in \{\pm 1\}$ with probabilities $P(1) = P(-1) = 0.5$.

Each of the spreading superstreams will be used to modulate a wavelet packets $w_{ph}(t)$, where the $h^{th}$ wavelet packet is given by [3,4]

$$wp_h(t) = \sum_i w_h(t - iT_n) \quad \ldots\ldots (6)$$

Assuming identical power for all user, the transmitted signal $s_k(t)$ is given as [4,6]

$$s(t) = \sqrt{2p}\sum_{h=1}^{H} Re\left[b_{kh}(t)c_k(t)wp_h(t)\exp(j\omega_c t)\right] \quad \ldots\ldots\ldots\ldots\ldots (7)$$

**Channel Model**

The channel is considered a conventional multipath channel with equivalent transfer function $h(t)$ given by [5,6]:

$$h(t) = \sum_{l=1}^{L} A_{kl}\, e^{j\theta_{kl}}\delta(t-\tau_{kl}) \quad \ldots \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where $L$ is the number of the propagation paths, $A_{kl}$is the path gain of the path $l$ for user $k$, $\tau_{kl}$ is the time delay of path $l$ for user $k$, uniformly distributed over the symbol duration $\theta_{kl}$ is the phase of path $l$ for user $k$ uniformly distributed over the interval [0, 2π].

The output of the channel $y(t)$ for the $k^{th}$ user is given by [5,6]

$$y(t) = s(t) * h(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

**Receiver System Model**

At the receiver, the signal is detected using the single user detection method. The received signal is demodulated by the carrier, despread by a user specific code sequence, multiplied by the wavelet packets and correlated over a period $T$ to recover the super bitstream, which is then P/S converted. The output signals of the P/S converter is again despread by each code in multicode part to recover the $J$ parallel data streams before correlated over a period $T$. Finally, the correlated outputs from $J$ paths is P/S converted torecover the original data bit.The receiver is assumed to be a synchronous receiver, designed to detect the first substream of the first user's first wavelet packet for the signal propagating via the first path. The receiver system model is shown in Fig. 2.

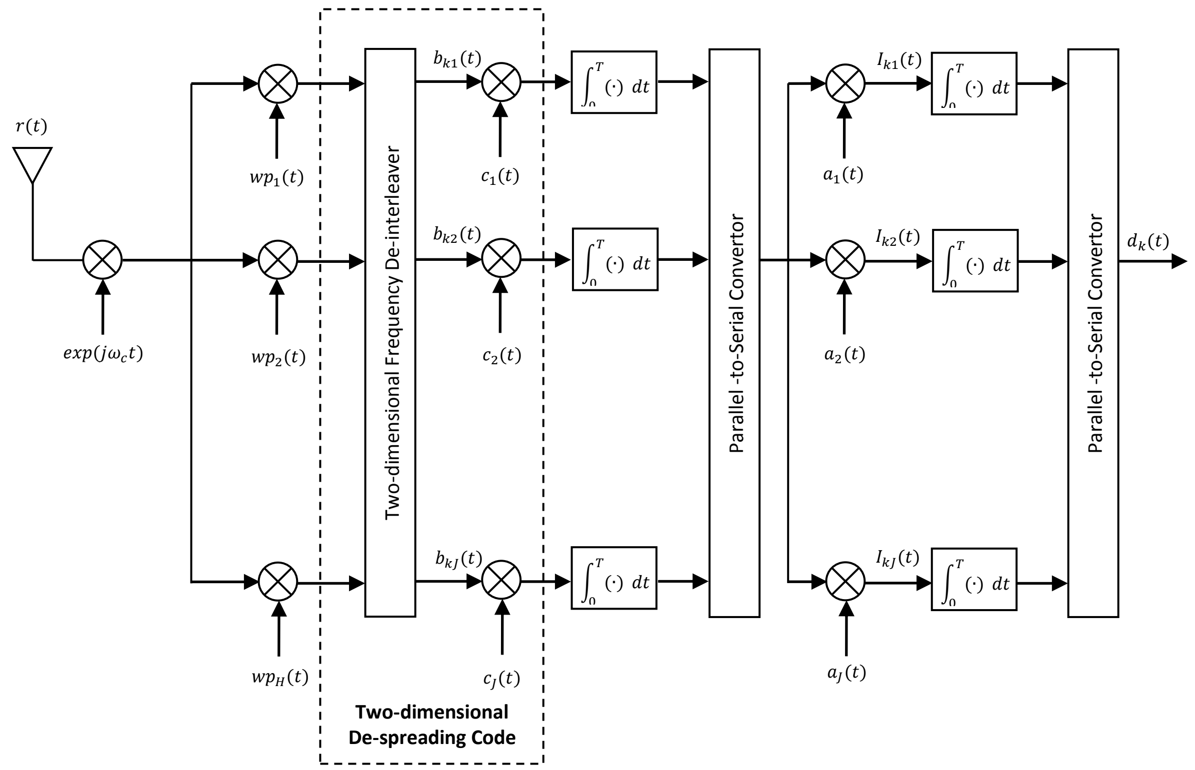


**Fig. 2. The Proposed Receiver Model.**

## 6. Results and Discussions

The Signal-to-Interference-Noise-Ratio (SINR) performance for the proposed system is presented and discussed in this section. Also, the performance of the proposed system is compared with the currently proposed systems.

The effects of some parameters on the system performance such as the number of users $K$, the number of multicodes substreams $J$, family of wavelet packets,the length of the filter of wavelet packet, and their superstreams numbers $H$ were investigated.

Also, SINR performance of the proposed system is compared with WP-MC/MCD-CDMA system proposed in [4]. The BPSK modulation is used in the simulation. The parameters listed below are used in the simulation.

Wavelet packets Daubechies 3 dB, number of wavelet packets superstreams $H = 4$, Period for the encoder $T = 10^{-6} sec$, The delay time

$\rho = T_n/10$, Length of PN code $N_1 = 2$ , Number of user $K = 30$, Local mean power $\Omega = 10\,dB$, Number of multipath $L = 3$, Number of multicode substreams $J = 4$, Path gain for target user $10\,dB$, Sum of amplitude levels of all multipath components $Q$, $MIP\ Q = L\ Q = L = 3$.

In the case of delay range, the same channel is used for all systems compared. This means all systems have the same propagation delay in the same communication environment.

### 6.1 SINR Performance Comparison

In this section, the proposed system WP-MC/MCD-CDMA is compared with the system proposed in [4]. These systems will be compared by the SINR and bit error rate performance. Here assume that the two systems use BPSK modulation. Fig. (3) illustrates the SINR performance of the two systems.

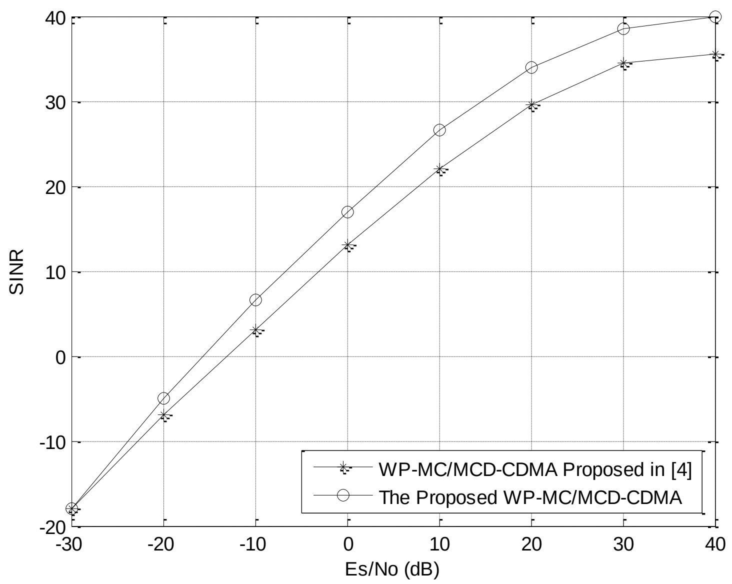


**Fig. 3. SINR performance for the two systems for BER of $10^{-4}$ .**

All the parameters used in this simulation are given in section (6). As it is shown from the figure, the proposed system outperforms the system in [4] and has the highest SINR. This is due to use of various lengths of two dimensional spreading codes. Besides, the using of wavelet packets results in lower side lobe energy leakage and is negligible. As shown in Fig. 3 the $E_s/N_o$ = 20 dB for the system in [4] and is equal to 35 dB for the proposed system, i,e, gives 15 dB gain. In this case, the proposed system provides better performance by minimizing the interference between substreams with several carriers.

Also, using multicarrier in this system increases the bandwidth of the signal and can suppress the effect of narrowband signal.

### 6.2 BER Performance Comparison

In this sub-section, the BER performance of the proposed system is compared with that proposed in [4]. In order to give fair results, the same parameters used for this simulation are the same as that used in the previous simulation. Figure (4) illustrates the BER performance for the two systems. The BPSK modulation scheme is also used in the simulation. It can be noticed from the figure that the proposed system has the lowest BER and it outperforms the other one. This is because of using multicode scheme with multicarrier can decrease inter-carrier interference. As shown in Fig. (4), the proposed system gives 20 dB $E_s/N_o$ gain as compared with the system proposed in [4] at BER $= 10^{-4}$.

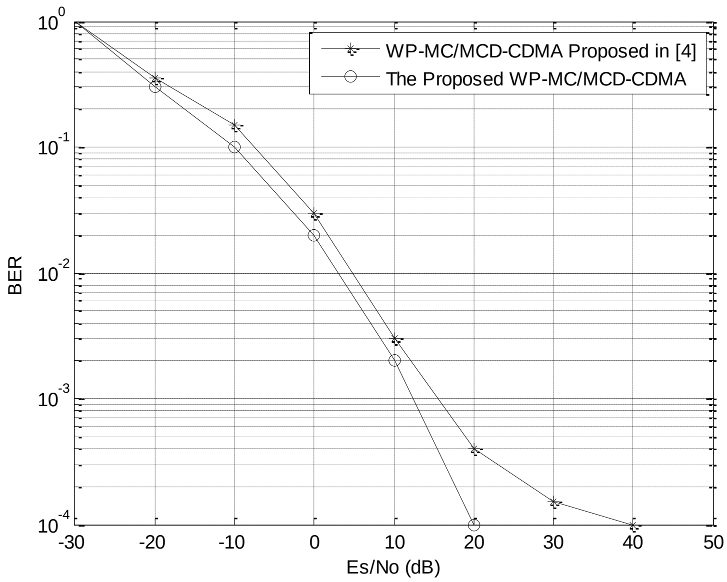


**Fig. 4. The BER performance for the two systems.**

### 6.3 Outage Probability Performance Comparison

The outage performance of WP-MC/MCD-CDMA system is compared with the CDMA based system given in [4]. For this simulation, $E_s/N_o = 10\ dB$ is used and the other parameters are the same as that presented in section (6). Figure (5) illustrates the outage probability performance for the two systems. The BPSK modulation is also used in this part of simulation.

Notice that the new proposed system WP-MC/MCD-CDMA is outperformed the one proposed in [4]. This is also due to the using of two dimensional spreading codes.

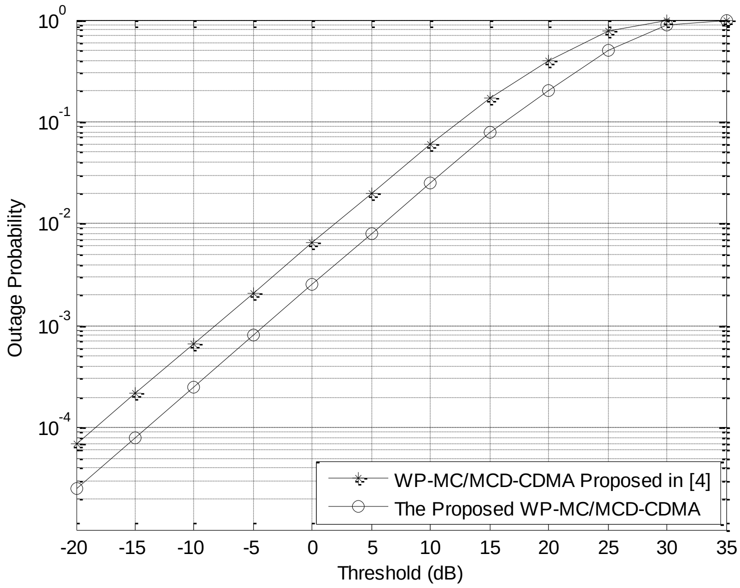


**Fig. 5. The outage probability performance for the two systems.**

## 7. Conclusions

This paper handles a proposed transmission and receiving schemes for 4G systems, namely WP-MC/MCD-CDMA. Simulations compare the error and $E_s/N_o$ performance of the proposed system in a cellular environment. Through the using of spreading codes, the BER of the multi users system is improved according to the values of SINR. In such a way, that the average user throughput is maximized. Simulation results have also shown that spreading codes yields in general a significant improvement of the throughput at higher SINRs, while enabling satisfactory throughput at low SINRs. Moreover, the application of spreading codes results to be particularly advantageous when the mobile Rayliegh channel is considered.

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