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Multi-User Detection for Group Orthogonal Multi-Carrier Code Division Multiple Access System in Frequency Selective Rayleigh Fading Channel

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Abstract

Code Division Multiple Access (CDMA) suffers from multi-user interference (MUI), and intersymbol interference (ISI) under frequency selective multi-path fading channels. Orthogonal Frequency Division Multiple access (OFDM) is MUI free but achieves lower diversity than CDMA system employing the same error control coding. Merging the advantage of OFDM and CDMA to minimize MUI and enable maximum available diversity for every user, multi carrier code division multiple access (MC-CDMA) is used.

In this paper the performance of group orthogonal multi-carrier code division multiple access (GO-MC-CDMA) system using multi-user detection is evaluated by simulation over two-paths frequency selective Rayleigh fading channel. Simulation results show that successive interference cancellation is better than parallel interference cancellation for higher signal-to noise ratio (SNR).

Finally, the effect of near far problem using minimum mean-square error (MMSE) detection and interference cancellation detections is considered. To overcome near-far problem, it has been shown that MMSE detector performs better than interference cancellation detector.

الخلاصـــــــة

يعاني نظام تقسيم الشفرات المتعدد الوصول (CDMA) من التداخل بسبب تعدد المستخدمين (MUI) والتداخل بين الرموز (ISI) في قنوات الخفوت الترددية الاختيارية متعددة المسارات. ان نظام تقسيم الترددات المتعامد المتعدد الوصول (OFDM) خالي من التداخل بسبب تعدد المستخدمين (MUI) ولكنه يوفر تفريق الى المسارات المتعددة اقل من نظام تقسيم الشفرات المتعدد الوصول باستخدام تقنية ترميز تصحيح الخطأ. دمج نظام تقسيم الترددات المتعامد المتعدد الوصول (OFDM) مع نظام تقسيم الشفرات المتعدد الوصول (CDMA) للحصول على فوائد النظامين معا لتقليل تأثير التداخل بسبب تعدد المستخدمين وضمان التفريق الاعلى الى المسارات المتعددة وتدعى التقنية الجديدة نظام تقسيم الشفرات المتعدد المداخل ذو الحاملات المتعددة MC-CDMA.

في هذا البحث تم تحليل اداء التجميع المتعامد لنظام تقسيم الشفرات المتعدد المداخل ذو الحاملات المتعددة GO-MC-CDMA باستخدام تقنية كشف تعدد المستخدمين (MUI) عبر مسارين لقناة الخفوت الترددية الاختيارية. وقد بينت نتائج المحاكاة ان تقنية ازالة تداخل الرموز المتعاقب هي افضل من تقنية تداخل الرموز المتوازي عند زيادة نسبة الاشارة الى الضوضاء (SNR) .

اخيرا تم دراسة مشكلة الاقتراب و الابتعاد للاشارة (near-far problem) وتبين ان حل هذه المشكلة يكون باستخدام كاشف القيمة الصغرى لمربع معدل الخطأ (MMSE) .

1. Introduction

While direct sequence code division multiple access (DS-CDMA) spreads symbols in time domain, MC-CDMA spreades symbols in frequency domain [1].

In order to exploit the maximum possible channel diversity while being able to accommodate dynamic load changes, a GO-MC-CDMA scheme that does not require complex code assignment operations is analyzed [2]. In GO-MC-CDMA the set of subcarriers is partitioned into groups, and the users who are assigned subcarriers of the same group are separated via spreading codes.

The effective orthogonal user codes are no longer orthogonal and causes MUI after passing through a frequency selective fading channel. Multi user detection (MUD) can be used to reduces the effect of MUI [3].

In this paper, a GO-MC-CDMA system is desribed. Three schemes of multiuser detectors are presented. BER performance of a GO-MC-CDMA system using multi-user detection is evaluated by simulation over 2-paths frequency selective Rayleigh fading channel. The effect of near far problem is solved by using minimum mean-square error (MMSE) detection.

This paper is organized as follows: GO-MC-CDMA system is described in section 2, multi-user detections are described in section 3, Simulation results are presented in section 4, and conclusions are drawn in section 5.

2. System Model

The system model of GO-MC-CDMA is illustrated in the block diagram of **Fig.(1)**, [2,3]. The N_c subcarriers are partitioned into Ng groups with each group having Q = N_c/Ng subcarriers. A user chooses a specific group of subcarriers to transmit its information bearing symbols; and Q users share Q subcarriers per group, which ensures no spectral efficiency loss [2].

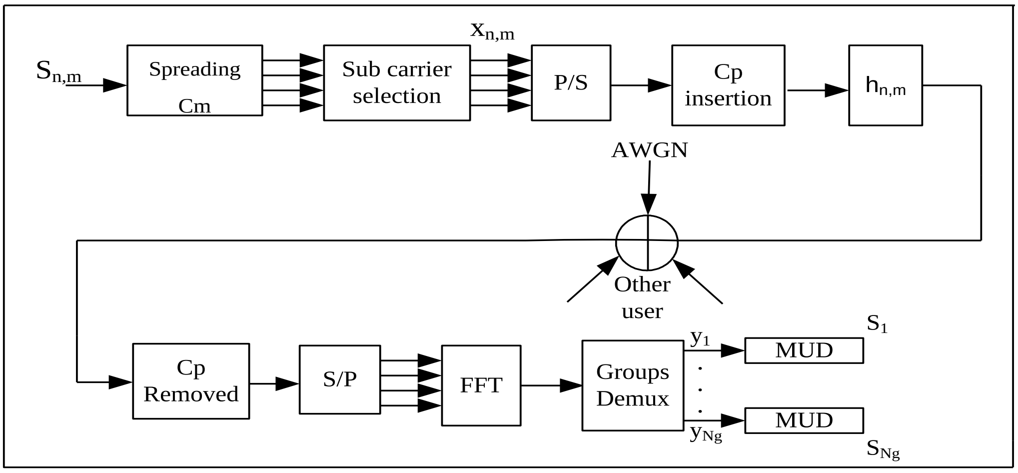

Figure (1) Block diagram of GO-MC-CDMA system

Let $S_{n,m}(i)$ be the information bearing symbol of user m in the nth group transmitted during the time interval [iT, (i + 1)T)], where T is the symbol period. A Q × 1 spreading code $\mathbf{c}_m$ is used to spread $S_{n,m}(i)$ to the Q subcarriers of the nth group.

Let the columns of the $N_c \times Q$ matrix F_n^* comprise the Q digital subcarriers of the nth group [2].

$$F_n^* = \left[f_n^* \;,\quad f_{Ng+n}^* \,,\quad f_{2Ng+n}^* \,,\quad \ldots\quad f_{(Q-1)Ng+n}^* \right] \qquad (1)$$

where:

**: denotes complex conjugate.*

The $N_c \times 1$ signal vector of user m in the nth group during the ith block, modulated on Q subcarriers, can be expressed as [2]:

$$\mathbf{X}_{n,m}(i) = F_n^* \mathbf{c}_m S_{n,m}(i) \qquad (2)$$

After parallel-to-serial (P/S) conversion, a cyclic prefix (CP) chips are added to each block, and the signal is transmitted over a frequency-selective fading channel.

Notice that $\mathbf{X}_{n,m}(i)$ in eq.(2) can be computed using a Q-point FFT, and N_c+1 complex multiplications, which considerably reduces complexity (especially with N_c large) when compared to the case where Q subcarriers in a group are arbitrarily chosen.

At the receiver end, after removing the CP to eliminate interblock interference (IBI), and FFT processing the IBI-free signal, the received samples belonging to different groups of subcarriers are demultiplexed.

Let $\mathbf{h}_{n,m} = [H_{n,m}(e^{-j2\pi n/Nc}), \ldots, H_{n,m}(e^{-j2\pi(n+(Q-1)Ng/Nc})]$ contain the frequency response samples on the FFT grid of the FIR channel of the mth user in the nth group. The Q ×1 data vector for the nth group can be written as [2]:

$$\mathbf{y}_n = \sum_{m=0}^{N_{a,n}-1} D(\mathbf{h}_{n,m})\, \mathbf{c}_m\, S_{n,m} + \mathbf{w}_n \qquad (3)$$

where,

$N_{a,n}$: is the number of active users in the nth group,

D (x): stands for a diagonal matrix with x on its diagonal and

w_n: is zero-mean complex additive white Gaussian noise (AWGN) with variance $N_0/2$ per dimension.

Based on $\mathbf{y}_n$ in eq.(3) , MUD can be applied to detect the information-bearing symbols $\{S_{n,m}\}_{m=0}^{N_{a,n}-1}$ in the nth group.

3. Multiuser Detection

Multi-user detection scheme is used to overcome the multiple access interference (MAI) problem. There has been great interest in improving MC-CDMA detection through the use of multiuser detectors. In multiuser detection, code, timing and amplitude information of multiple users are jointly utilized to detect each individual user [4,5].

Three receivers of interest are presented, the minimum mean square error (MMSE) receiver, multistage parallel interference cancellation (MPIC) receiver and multistage successive interference cancellation (MSIC) receiver [6,7].

3-1 MMSE Detector

The structure of the MMSE detector is illustrated in **Fig.(2)** [3]. It can be regarded as an improved decorrelating detector, because it can solve the problem of noise enhancement in low signal-to-noise ratio (SNR). The MMSE detector is expressed as [3,7]:

$$\mathbf{y}^{\mathbf{MMSE}} = \mathbf{T}\,\mathbf{y}^{\mathbf{MF}} \quad \text{.......... (4)}$$

where:

y^{MMSE}: is the output of MMSE detector,

y^{MF}: is the output of a matched filter, and

T: is transformation matrix expressed as [7]:

$$\mathbf{T} = \left[\mathbf{R} + \frac{\boldsymbol{\sigma}^2}{\mathbf{A}^2}\right]^{-1} \quad \text{.......... (5)}$$

$$\frac{\boldsymbol{\sigma}^2}{\mathbf{A}^2} = \mathbf{diag}\left(\frac{\boldsymbol{\sigma}^2}{\mathbf{A}_1^2}, \frac{\boldsymbol{\sigma}^2}{\mathbf{A}_2^2}, \ldots\ldots, \frac{\boldsymbol{\sigma}^2}{\mathbf{A}_{Na}^2}\right) \quad \text{.......... (6)}$$

$$\mathbf{R} = \mathbf{C}^{\mathbf{T}} \times \mathbf{C} \quad \text{.......... (7)}$$

where:

A: is amplitude of fading signal,

σ^2: is the noise power, and

R: is Na×Na cross correlation matrix of high length spreading codes and therefore fully decouples the multiuser signal.

***C^T**: is Na×K transpose spreading codes matrix, where Na is the number of active users, and K is the spreading code length.*

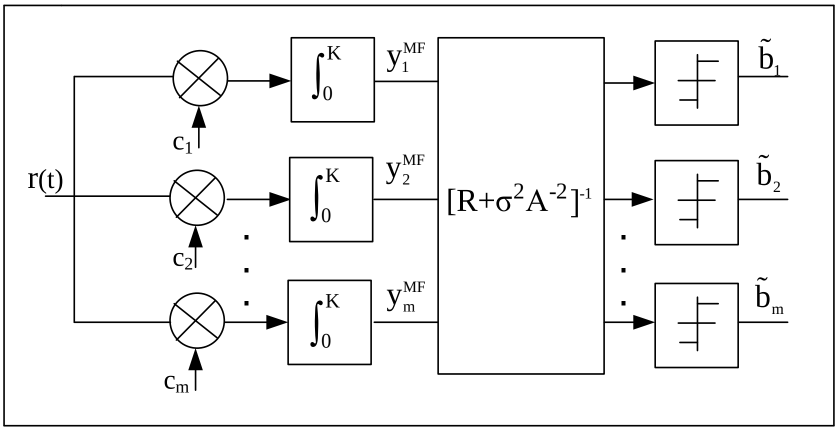

Figure (2) MMSE detector

3-2 Multistage Parallel Interference Cancellation (MPIC)

The multistage interference cancellation receivers have multiple stages of interference cancellation. This technique can be combined with the concept of parallel interference cancellation. At each stage of MPIC, any receiver can be used but the accuracy of the first stage or previous stage affects the performance of the whole receiver [6].

A conventional receiver is considered as a first stage to estimate the channel gain and data symbol. The estimates for each user are used to eliminate the interference of the other user's signal by subtracting the interferer from the desired signal. The interference cancellation depends on the accuracy of estimates at the previous stage. Since the inaccurate estimates lead to imperfect interference cancellation in real system, several stages can be used or a more powerful estimate technique such as a channel coding scheme can be utilized to overcome this imperfection. In addition, an improved MPIC scheme with partial cancellation at each stage is introduced to mitigate bias in the decision statistics of MPIC [7]. The MPIC decision metric for S-stage parallel cancellation scheme is represented as [6]:

$$\hat{b} = \mathrm{sgn}[\, y^{(s)} \,] \qquad (8)$$

where:

$$y_m^{(s)} = \frac{1}{T}\int_0^T r_m^{(s)}(t)\, c_m(t-\tau_m)\, dt \qquad (9)$$

$$r_m^{(s)}(t) = r(t) - \sum_{j \neq m}^{N_a} y_j^{(s-1)}\, c_j(t-\tau_m) \qquad (10)$$

r_m is the S stage signal of the mth user after cancellation and τ_m represents the estimated time delay of the mth user [6]. The first stage parrallel interference cancellation is shown in **Fig.(3)** [6].

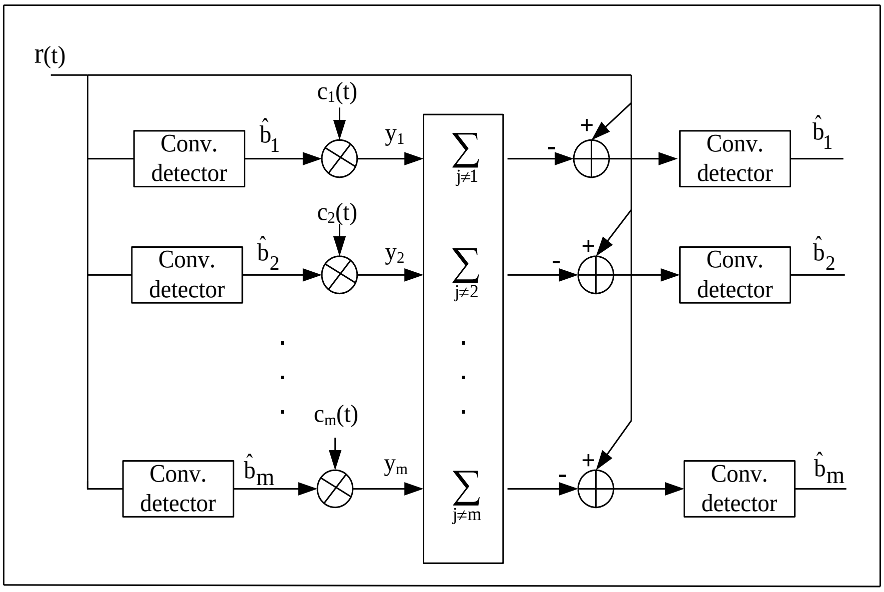

Figure (3) First stage of a MPIC detector

On proceeding subsequent stages, the effect of bias is minimal. The proposed method to reduce the influence of bias is to adopt a partial-cancellation factor $F^{(S)}$ as follows:

$$\mathbf{r_m^{(s)}(t) = r(t) - F^{(s)} \sum_{j \neq m}^{N_a} y_j^{(s-1)}\, c_j(t - \tau_m)} \quad \text{..} \quad \mathbf{(11)}$$

This factor is assigned a value at every stage in the range (0…1) [6].

3-3 Multistage Successive Interference Cancellation (MSIC)

SIC detector takes a serial approach to cancel interference, as shown in **Fig.(4)** [7]. The first operation in the SIC detector consists of sorting the user's signals out in a descending order according to their powers which are estimated from the output of a conventional detector. The first stage in this detector is to regenerate the transmitted signal of the strongest user (in terms of powers and assuming knowledge of the spreading code). This regenerated signal provides an estimate of the MAI caused by the strongest user $b_1(t)$, which is then subtracted from the total received signal r(t), yielding a partially cleaned version of the received signal $r_1(t)$. If the user estimate is accurate, the remaining users see less MAI in the next stages. Thus, this new version of the received signal can be used to detect the next strongest user in the system. This process is repeated until all users are detected [7].

Note that; in each stage the estimate of the users is obtained by making a decision at the output of the conventional detector. The signals are sorted in a descending order because the strongest user can give the most accurate estimate and consequently the removal of this signal will provide the most benefit to the remaining users [7].

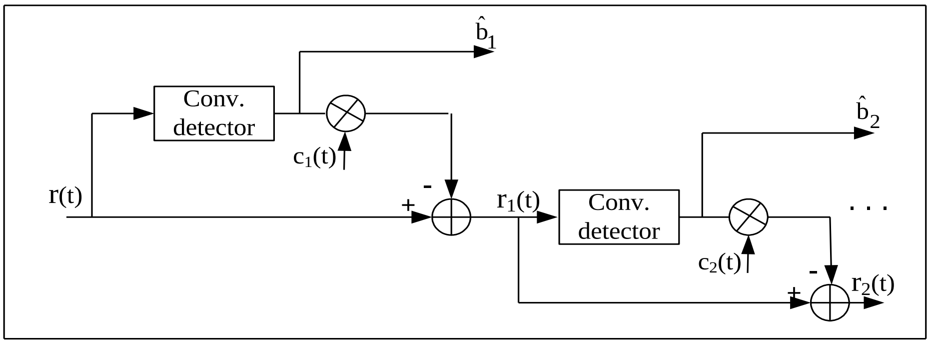

Figure (4) First stage of a MSIC detector

4. Simulation Results

The bit error rate (BER) of GO-MC-CDMA system on 2-paths frequency selective Rayleigh fading channel is estimated by simulation. Assuming:

- data rate of 3 Mbps (BSK Modulation).
- Walsh code with length K=32.
- No. of subcarriers Nc = 256.
- No. of active users Na=4.
- Delay spread Td = 20 ns . Coherence time = 0.167 ms.

Figure (5) shows the bit error rate (BER) versus signal to noise ratio (SNR) of GO-MC-CDMA system with different coherence times. The bit error rate decreases when coherence time is increased.

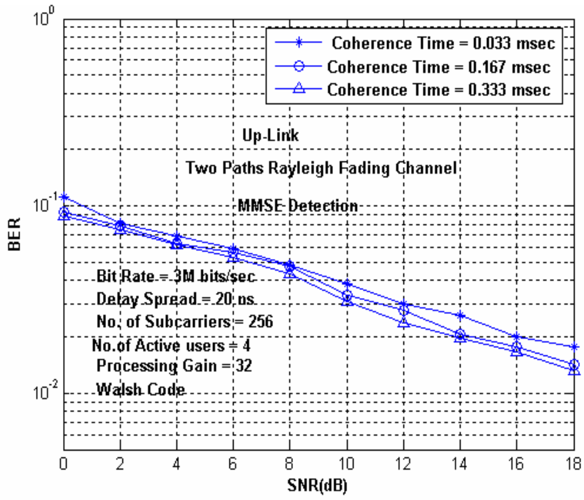

Figure (5) BER performance of GO-MC-CDMA system using different coherence time in two paths Raylrigh fading channel using MMSE detector

Figure (6) shows a comparison between three types of spreading codes in GO-MC-CDMA system. The three types of spreading codes (m-sequence, Gold code, Walsh code) give almost the same bit error rate at low SNR values, because the noise level is very high compared with MAI. This result leads to reduce complexity, if SNR is low, a simple code design (m-sequence) is used,or large number of squences (Gold code) is used.Walsh code gives good BER performance at high SNR values.

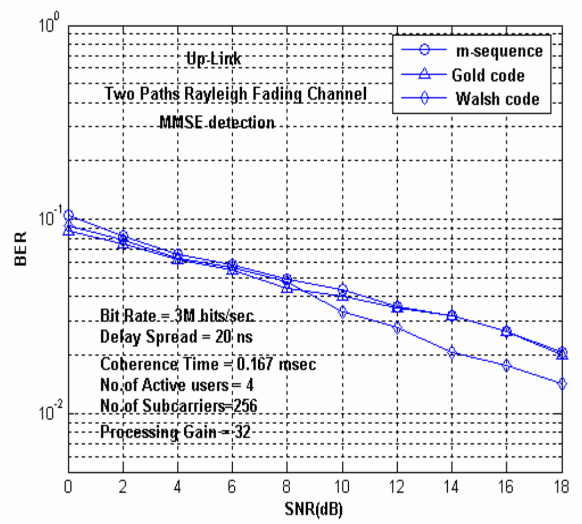

Figure (6) BER performance of GO-MC-CDMA system using different types of spreading codes in two paths Rayleigh fading channel using MMSE detector

Figure (7) shows the bit error rate (BER) versus signal to noise ratio (SNR) of GO-MC-CDMA system using different detectors. The three stages PIC detector gives a better BER performance, while SIC detector is reducing the error rate at SNR values (7-11) dB.

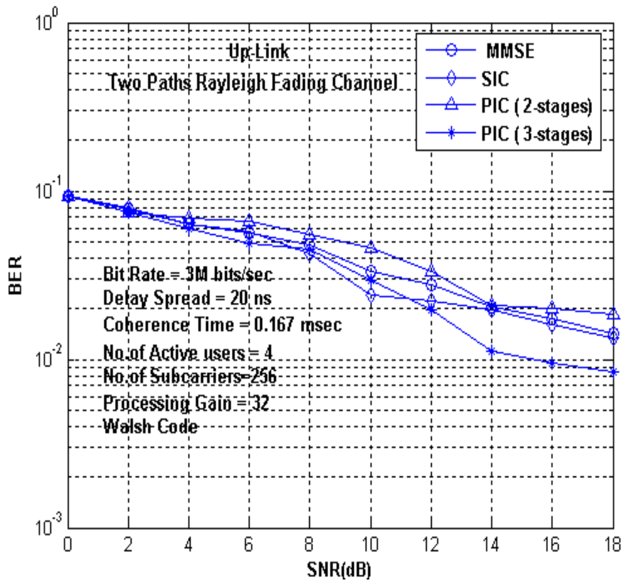

Figure (7) BER performance of GO-MC-CDMA system with different types of data detection techniques in two paths Rayleigh fading channel

For high number of active users, which is shown in **Fig.(8)**, SIC detector is efficient because the number of stages is equal to the number of active users, but the time delay between the users is very high. PIC detector also gives good results when the number of active users is increased, at the expense of system complexity.

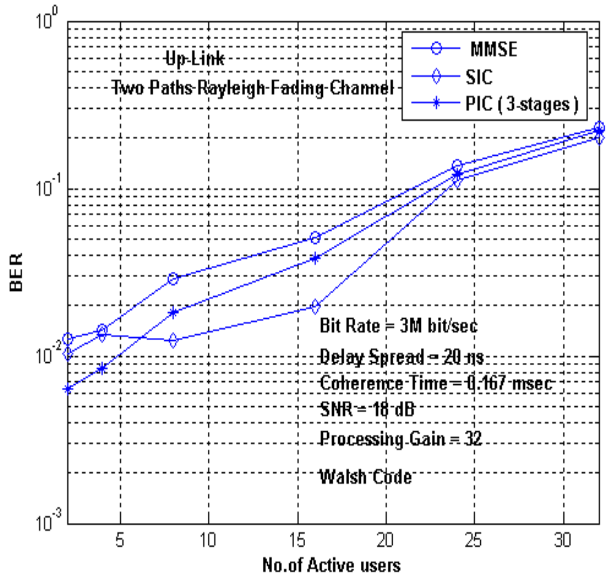

Figure (8) BER performance of GO-MC-CDMA system versus number of active users, using different types of data detection techniques

Figure (9) shows the effect of near-far problem in GO-MC-CDMA system with MMSE detection, where the power of first user is less than all other users power by 3 dB. The bit error rate difference is small compared with non effect problem (0 dB). This means that the MMSE is an efficient detector to overcome this problem.

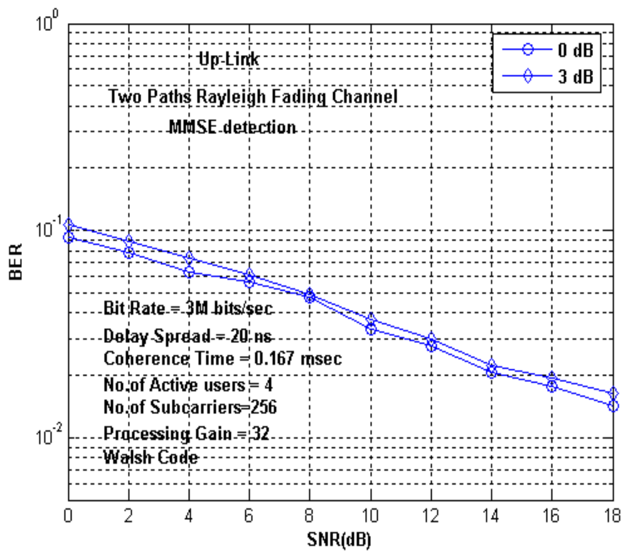

Figure (9) Effect of near-far problem on the performance of GO-MC-CDMA system with MMSE detection

Figures (10) and **(11)** show the effect of near-far problem in GO-MC-CDMA system using SIC and three stages PIC detectors. It is shown that SIC detector is slightly better than PIC detector in solving near-far problem.

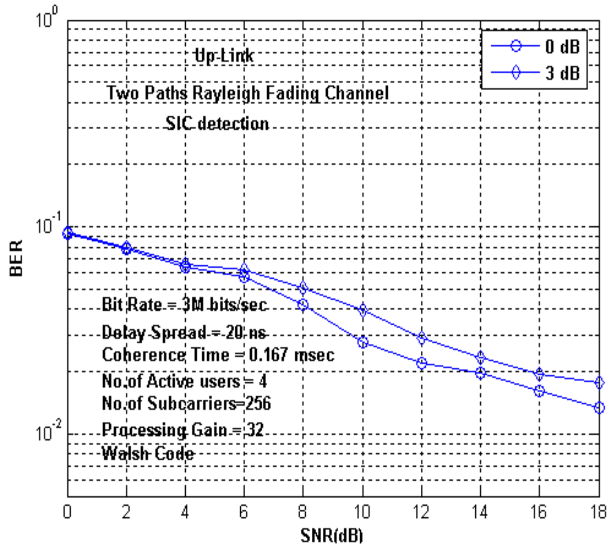

Figure (10) Effect of near-far problem on the performance of GO-MC-CDMA system with SIC detection

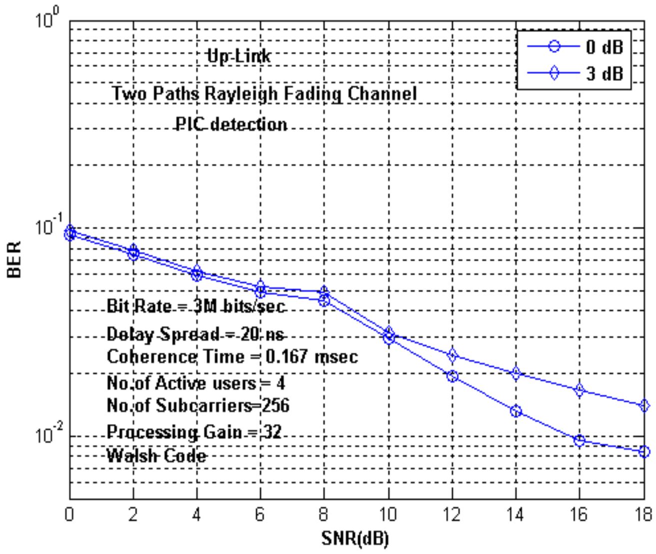

Figure (11) Effect of near-far problem on the performance of GO-MC-CDMA system with PIC detection

5. Conclusions

In this paper, the structure of GO-MC-CDMA system over two paths Rayleigh fading channel is demonstrated. The problem of MAI is overcome by using three types of multi-user detectors.

Since, the number of stages in SIC detector equals the number of active users, it has been shown that for the same number of active users (Na = 4), MPIC (3-stages) detector gives better BER performance than MMSE and MSIC (4-stages) detectors at high SNR values. The time delay between users in MSIC detector is high, and the complexity of MPIC detector becomes high when the number of active users is increased.

Finally, MMSE is considered as an efficient detector in solving near-far problem compared with MPIC and MSIC detectors.

6. References

1. S., Hara, and R., Prasad, ***"Design and Performance of Multicarrier CDMA System in Frequency-Selective Rayleigh Fading Channnels"***, IEEE Trans. Vehicular Technology, Vol. 48, No. 5, Sept. 1999.

2. X., Cai, S., Zhou, and G. B., Giannakis, ***"Group-Orthogonal Multi-Carrier CDMA"***, IEEE Trans. on Comm., 2003, pp. 1-10.

3. Harith A. Nasir, ***"Performance of Group Orthogonal Mulicarrier Code Devision Access over Frequency Selective Rayleigh Fading Channel"***, M.Sc. Thesis, Electrical Engineering Department, College of Engineering, Al-Mustansiriya University, 2006.

4. A., Dual-Hallen, J., Hotzman, and Z., Zvonar, ***"Multiuser Detection for CDMA Systems"***, IEEE Personal Communications Magazine, April 1995.

5. X., Wang, and V., Poor, ***"Blind Equalization and Multiuser Detection in Dispersive CDMA Channels"***, IEEE Trans. on Comm., Jan. 1998.

6. J. G., Andrews, ***"Interference Cancellation for Cellular Systems: A Contemporary Overview"***, IEEE Wireless Communications, April 2005.

7. J. M. L., Rivera, ***"Iterative Multiuser Receivers for Coded DS-CDMA System"***, Ph.D. Thesis, University of Edinburgh, October 2002.