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The Effects of Unequal Branch Gains on Performance of MC-CDMA over Generalized Fading Channels

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ABSTRACT

In this paper, the average bit error probabilities of Multi-Carrier Code Division Multiple Access (MC-CDMA) system over the generalized fading channels are derived and evaluated. The effects of gain unbalance between branches on the bit error rates of the system are also examined. The numerical results indicate that the performance of MC-CDMA becomes better as the fading factor m increases. Besides, if the number of the carriers gets more, the error probability of the system will decrease. Remarkably, the effects of gain unbalances between branches on the MC-CDMA system will suffer more performance degradation.

Keywords: MC-CDMA, gain unbalance, generalized fading

一般化衰落波道環境下不平衡分支權重對多載波分碼多重進接系統效能之影響

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摘 要

本論文探討在一般化衰落環境下多載波分碼多重進接系統(MC-CDMA)之性能及具有不平衡分支權重時對效能的影響。本研究結果已經證實多載波分碼多重進接系統在一般化衰落波道下，隨衰落因素m值增加性能將有所改善；而系統載波數目愈多，性能改善也愈多。此外在具有分支間不平衡權重會時降低系統性能。

關鍵詞:多載波分碼多重進接系統,不平衡權重,一般化衰落

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I. INTRODUCTION

This paper presents a very promising technique for development of high capacity wireless communications. MC-CDMA includes a combination of multi-carrier modulation and code division multiple access, and has been paid attention to mobile communications because its high data-rate transmission [1-3].

Many MC-CDMA systems have been proposed over the past years. Li and Latva-aho [4] evaluated performances of MC-CDMA system for uplink and downlink in frequency selective Rayleigh fading channels. The authors presented a new technique based on alternative Gaussian approximation (AGA) for determining the bit error rate (BER) of MRC. Such a technique provided a powerful tool to evaluate the BER of MC-CDMA systems. Zhu and Gunawan [5] proposed a controlled maximal ratio combining (MRC) technique that incorporates power control for the uplink MC-CDMA system in Rayleigh fading channels. It has been shown that the controlled MRC algorithm can improve the MC-CDMA performance, especially in low SNR environments. Yue and Do [6] analyzed the performance of a downlink multi-carrier CDMA over Rayleigh fading channels without using RAKE technique.

Bit error probability (BEP) of MC-CDMA system with MRC in the uplink correlated Rayleigh fading channels was analyzed by Part et al. [7]. The authors assumed both perfect channel estimation and sub-carrier synchronization. Shi and Latva-aho [8] calculated the BER of a synchronous MC-CDMA system in Rayleigh fading channels based on a moment generating function method without any assumption about the multiple-access interference (MAI) distribution. Smida et al. [9] presented an efficient and accurate performance evaluation method for binary MC-CDMA system over Rayleigh fading channels. This method is based on the formulation of the characteristic function and no any statistical or spectral behavior of the interference is assumed. Although there are many papers dealing with performance analysis of MC-CDMA system [4-9], the fading channels are all assumed to be Rayleigh distributed.

The Nakagami-m multipath fading channels has been demonstrated to closely model various multipath channels [10]. The probability density functions (PDF) of Nakagami-m spans the range from the fading channel that is worse than the Rayleigh fading channel to non-fading Gaussian channels by varying the parameter m from 1/2 to infinity.

Annamalai and Tellambura [11] derived BER of multilevel quadrature amplitude modulation (MQAM) in conjunction with L-fold antenna diversity on arbitrary Nakagami fading channel; both MRC and EGC predetection diversity techniques have been taken into consideration. Elnoubi and Hashem [12] compared the performance of two CDMA systems in Nakagami fading channels. They are CDMA with RAKE receiver and MC-CDMA system. MRC and EGC are used in RAKE receiver and MC-CDMA system, respectively. Nevertheless, they didn't take into account the effect of unequal branch gains in MC-CDMA system yet.

Simon and Alouini [13] presented performance analysis of multi-carrier DS-CDMA systems over generalized fading channels. The average BER of such systems with/without partial band interference was derived and compared with a single carrier RAKE system.

Halpern [14] examined the effects of gain unbalance on performance of different diversity combiners and derived the SNR distribution for two-branch diversity system with the gain unbalance between branches under a Rayleigh channel. Beaulieu [15] investigated the effects of gain unbalance between branches on the probability distribution of SNR and bit errors rates at the output of the L-branch EGC over Nakagami channel. Both the coherent phase shift keying and differential coherent phase shift keying modulation schemes were discussed.

Rician fading model is a frequent statistical model and may be used to describe both the microcellular environment and the mobile satellite-fading channel. In [16], Abu-Dayya and Beaulieu examined the performance of L-branch EGC over Rician fading channels. In addition, the effects of gain unbalance on the bit error rate were also investigated. Nevertheless, the authors did not consider an MC-CDMA system.

The purpose of this paper is to investigate the performance of uplink MC-CDMA systems over generalized fading channels and to examine the performance due to unequal branch gains. The resultant system performance is further compared with the conventional single-carrier DS-CDMA system.

The remaining of this paper is organized as follows. In Section II, we discuss the MC-CDMA system, which includes the description of the transmitted signal, the channel model and the receiver model. In Section III, we derive the uplink average BER expressions of the MC-CDMA with MRC and EGC in Nakagami fading channels. In addition, we analyze the effect of unequal branch gains on system performance over generalized fading channels. We give numerical results and brief discussion in Section IV. Finally, the conclusion is given in Section V.

II. DESCRIPTION OF SYSTEM AND FADING CHANNEL PROPERTIES

The block diagram of an MC-CDMA system at the front end of receiver is shown in Fig. 1. At the transmitter, a single data bit is replicated into N parallel copies through a serial-to-parallel converter. $d_q[k] \in \{+1,-1\}$ denotes the kth information bit of the qth user. Each branch of the parallel stream is multiplied by a chip of the user's specific spreading code. $c_q[i]$. Then each of parallel branches is binary phase-shift keying modulated to a corresponding subcarrier. In this scenario, we assume that all users' signals experience different fading channel characteristics and the Walsh Hadamard orthogonal codes are employed for spreading purpose due to its excellent orthogonality between any two code words. Therefore, the signals in different users can be assumed independent and identically distributed (i.i.d.).

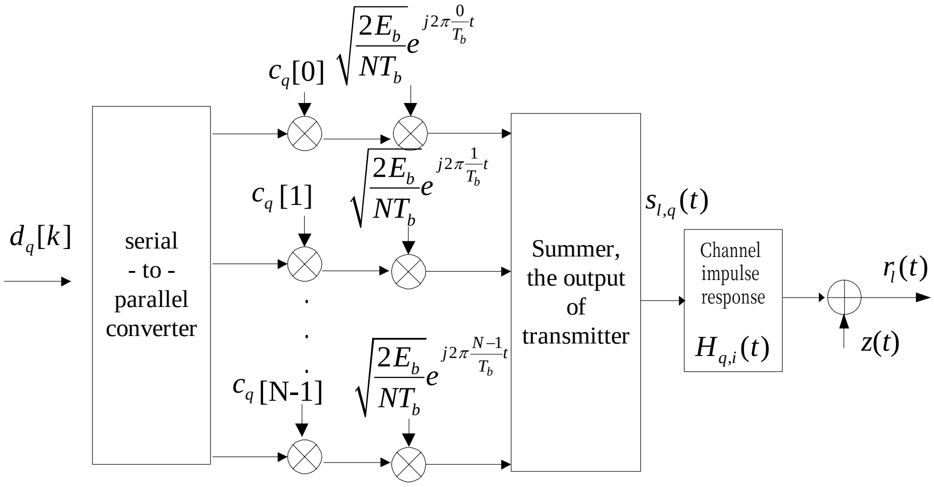

Fig.1. Block diagram of transmitter and channel in an MC-CDMA system.

The transmitted signal $s_l(t)$ of such an MC-CDMA system can be expressed as

$$s_l(t) = \sqrt{\frac{2E_b}{NT_b}} \sum_{k=-\infty}^{\infty} \sum_{q=0}^{M-1} d_q[k] \sum_{i=0}^{N-1} c_q[i] e^{j2\pi\frac{i}{T_b}t}, \quad kT_b < t \le (k+1)T_b \tag{1}$$

where the energy per bit is denoted as E_b, the number of subcarriers is represented by N, and the number of users M. The qth user's spreading code with the ith chip is denoted as $c_q[i] \in \{+1,-1\}$. Besides, to achieve high spectral efficiency, the subcarriers are intentionally spaced $1/T_b$, T_b being the bit duration of the considered system. Consequently, the bandwidth of the transmitted signal can be defined as $W = N/T_b$.

In this paper, we assume the channel experiences frequency selective and slow Nakagami fading. The transmitted signal through each subcarrier, however, is a narrow band signal and experiences frequency non-selective Nakagami fading because its bandwidth is assumed less than the channel coherence bandwidth. As a result, the frequency response of the channel for such a narrowband signal can be treated as constant in individual subcarrier in a symbol interval. The channel impulse response for MC-CDMA system can be expressed as follows:

$$H_{q,i}(t) = \alpha_{q,i} e^{j\theta_{q,i}} \delta(t) \tag{2}$$

With the non-selectivity assumption, $H_{q,i}(t)$ is regarded as a complex random variable for any time instant. $\{\alpha_{q,i}\}$ and $\{\theta_{q,i}\}$ stand for the amplitude and the phase distortion introduced by the channel, respectively. In the latter discussion, $\{\alpha_{q,i}\}$ and $\{\theta_{q,i}\}$ are assumed to be i.i.d. Nakagami random variables and uniform random variables over the interval $[0, 2\pi)$, respectively.

The random channel gains $\{\alpha_{q,i}\}'s$ are treated to be independent Nakagami random variables and the corresponding probability density functions (PDF) can be written by

$$p_\alpha(\alpha_{q,i}) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m \left(\alpha_{q,i}\right)^{2m-1} e^{\frac{-m\alpha_{q,i}^2}{\Omega}}, \quad \alpha_{q,i} \ge 0 \tag{3}$$

In the above equation $\Gamma(\cdot)$ is the well-known

Gamma function and m is named as the Nakagami fading parameter $(m \geq 0.5)$.

The configuration of receiver of the 0*th* user in MC-CDMA system is demonstrated in Fig.2.

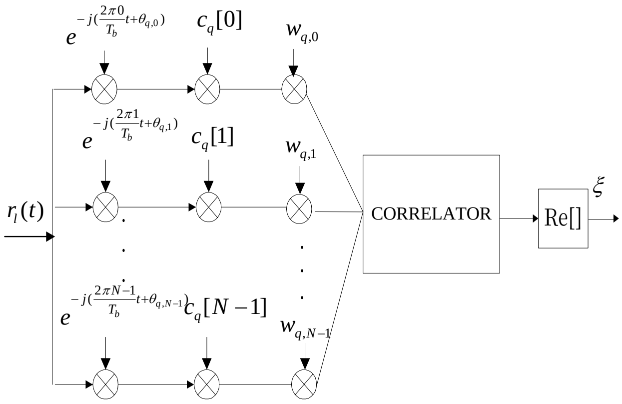

Fig.2. The structure of receiver of the 0*th* user in MC-CDMA system.

The received signal $r_l(t)$ can be written as

$$r_l(t) = s_l(t) * H_{q,i}(t) + z(t) \tag{4}$$

where $z(t)$ denotes additive white Gaussian noise (AWGN) of zero mean with single sided power spectrum density of N_0 and $*$ stands for convolution.

III. PERFORMANCE ANALYSIS OF BER OVER NAKAGAMI FADING CHANNELS

3.1 Interference Analysis

In this section, we shall analyze the characteristics of interference. The received signal over each sub-carrier is picked up and then multiplied by a chip of the user's assigned code. Depending on the chosen combining schemes, the combining weight $w_{0,i}$, for the 0*th* user's (the reference user) and the *ith* sub-carrier, can be made or estimated. Taking the perfect MRC as an example, the combining weight is set to $\alpha_{0,i}$ and the decision variable at the detector's output ξ_0 is composed of three trrms:

$$\xi_0 = S_0 + I_0 + \eta_I \tag{5}$$

where S_0 denotes the desired signal term and η_I denotes the noise term. I_0 is the interference term and represents the multiple access interference from all the other users with *ith* sub-carrier. The desired signal term S_0 for the reference user (i.e., $q = 0$) is expressed as

$$S_0 = \sqrt{\frac{2E_bT_b}{N}} d_0[k] \sum_{i=0}^{N-1} \alpha_{0,i} w_{0,i} \tag{6}$$

The interference term I_0 is expressed by

$$I_0 = \sqrt{\frac{2E_bT_b}{N}} \sum_{q=1}^{M-1} d_q[k] \sum_{i=0}^{N-1} c_q[i] c_0[i] \cdot \alpha_{q,i} w_{0,i} \cos(\phi_{q,i}) \tag{7}$$

where $\phi_{q,i} = \theta_{q,i} - \theta_{0,i}$. I_0, and with the aid of central limit theorem (CLT), it can, given $\alpha_{0,i}$, be treated as a Gaussian random variable with the assumption that the total number of users and carriers, $N(M-1)$ is reasonably large [17], for example, larger than 6. I_0 can be shown to be of zero mean and variance can be obtained as

$$Var\left[I_0 \middle| \alpha_{0,i}\right] = \frac{E_bT_b}{N}(M-1)\Omega \sum_{i=0}^{N-1} w_{0,i}^2 \tag{8}$$

Finally, the last term η_I, represents the interference due to the thermal noise and follows the Gaussian distribution with zero mean. η_I is expressed by

$$\eta_I = \sum_{i=0}^{N-1} c_0[i] w_{0,i} \int_{kT_b}^{kT_b+T_b} \left[x(t)\cos(\frac{2\pi it}{T_b}+\theta_{0,i}) + y(t)\sin(\frac{2\pi it}{T_b}+\theta_{0,i}) \right] dt \quad (9)$$

and its variance as

$$Var[\eta_I] = N_0 T_b \sum_{i=0}^{N-1} w_{0,i}^2 \quad (10)$$

3.2 Performance of BER for MRC over Nakagami Fading

In this section, we evaluate the BER of the system. Since the terms, S_0, I_0, η_I, can be viewed to be mutually uncorrelated [18], henceforth, the total variance of interferences given $\alpha_{0,i}$ can be expressed as

$$Var\left[\xi_0 \left|\alpha_{0,i}\right.\right] = Var\left[I_0 \left|\alpha_{0,i}\right.\right] + Var[\eta_I] \quad (11)$$

Accordingly, the conditional signal-to-noise ratio, γ can be expressed as

$$\gamma = \frac{\frac{2E_b}{N} S_{mrc}}{\frac{E_b}{N}(M-1)\Omega + N_0} \quad (12)$$

where $S_{mrc} = \sum_{i=0}^{N-1} \alpha_{0,i}^2$.

The PDF of S_{mrc} is found as [20]

$$p_S(S_{mrc}) = \frac{1}{\Gamma(m_s)} (\frac{m_s}{\Omega_s})^{m_s} (S_{mrc})^{m_s-1} e^{\frac{-m_s S_{mrc}}{\Omega_s}}, \quad S_{mrc} \ge 0 \quad (13)$$

The average bit error can be expressed as

$$\bar{P}_{e(mrc)} = \int_0^\infty p_S(S_{mrc}) P\left(e\left|S_{mrc}\right.\right) dS_{mrc} \quad (14)$$

where

$$P\left(e\left|S_{mrc}\right.\right) = Q\left(\sqrt{\gamma}\right) \quad (15)$$

Therefore

$$\bar{P}_{e(mrc)} = \frac{1}{2}\left[1 - \sqrt{\frac{\gamma_s}{1+\gamma_s}} \sum_{k=0}^{mN-1} \binom{2k}{k} \left(\frac{1}{4(1+\gamma_s)}\right)^k \right] \quad (16)$$

with

$$\gamma_s = \frac{E_b \Omega}{mE_b(M-1)\Omega + mNN_0} \quad (17)$$

3.3 Performance of BER for EGC over Nakagami Fading

For EGC, the combining weight w_{0s} is set to unity. It is readily shown that the terms of S_0, I_0, and η_I are mutually uncorrelated [18]. Similarly, the conditional signal-to-noise ratio, γ can be expressed as

$$\gamma = \frac{\frac{2E_b}{N} S_{egc}}{\frac{E_b}{N}(M-1)\Omega + N_0} \quad (18)$$

where $S_{egc} = \left(\sum_{i=0}^{N-1} \alpha_{0,i}\right)^2 / N$, the average bit error can be written as

$$\bar{P}_{e(egc)} = \frac{1}{2}\left[1 - \sqrt{\frac{\gamma_s}{1+\gamma_s}} \sum_{k=0}^{mN-1} \binom{2k}{k} (\frac{1}{4(1+\gamma_s)})^k \right] \quad (19)$$

where

$$\gamma_S = \frac{E_b \Omega \left(\frac{5m-1}{5m}\right)}{mE_b(M-1)\Omega + mNN_0} \quad (20)$$

3.4 Performance of BER for Gain Unbalance EGC over Nakagami Fading

Consider an L-branch EGC where the power gain of the ith branch ($i=1,\cdots,L$) is some factor β_i ($0<\beta_i \le 1$) less than the gain in the Lth branch **[**15,19**]**. Then the amplitude of the resultant signal at the output of the EGC is

$$\alpha = \alpha_1 + \alpha_2 + \cdots + \alpha_L \quad (21)$$

where α_i is the amplitude of the signal received by the ith channel. Assume that the $\alpha_i{}'s$ are independent Nakagami random variables with the same fading parameter.

$$\Omega_i = E[\alpha_i^2] = \beta_i \Omega, \quad i = 1,2,\cdots,L-1 \quad (22)$$

$$E[\alpha_L^2] = \Omega \quad (23)$$

Let Z be the resultant noise as

$$Z = Z_1 + Z_2 + \cdots + Z_L \quad (24)$$

where

$$E[Z_i^2] = \beta_i \Psi, \quad i = 1,2,\cdots,L-1 \quad (25)$$

and

$$E[Z_L^2] = \Psi \quad (26)$$

Note that, in spite of the gain unbalance, all the branches have equal average SNR. The conditional signal-to-noise ratio is represented as

$$\Gamma = \frac{\frac{2E_b}{N}(1+\sum_{i=1}^{L-1}\beta_i)\alpha_i^2}{\frac{E_b}{N}(M-1)(1+\sum_{i=1}^{L-1}\beta_i)\Omega + (1+\sum_{i=1}^{L-1}\beta_i)N_0} \quad (27)$$

The conditional error rate can be written as

$$P_e(\alpha) = Q(\sqrt{\Gamma}\alpha) \quad (28)$$

where the conditioning is on the signal amplitude. Equation (28) is averaged over all values of α to obtain the average bit error rate in fading conditions. That is,

$$\overline{P}_{e(unbal\_egc)} = \int_0^\infty P_e(\alpha) P(\alpha) d\alpha \quad (29)$$

where $P(\alpha)$ is the pdf of sum of independent Nakagami distributed RV's. $P(\alpha)$ can be expressed in terms of a convergent infinite series [23]

$$P(\alpha) = \frac{2}{TT} \sum_{\substack{n=1 \\ n\ odd}}^{\infty} [e^{-jnw\alpha}\Phi(n\omega) + e^{jnw\alpha}\Phi(-n\omega)] \quad (30)$$

where $\omega = \frac{2\pi}{TT}$, TT is the period of the squarewave.

$$\Phi(n\omega) = \prod_{i=1}^{L} \Phi_i(n\omega) \quad (31)$$

$$\begin{aligned}\Phi_i(n\omega) &= E[e^{jn\omega\alpha_i}] \\ &= E[\cos(n\omega\alpha_i)] + jE[\sin(n\omega\alpha_i)] \\ &= A_{in} e^{j\tau_i}\end{aligned} \quad (32)$$

and

$$A_{in} = \sqrt{E^2[\cos(n\omega\alpha_i)] + E^2[\sin(n\omega\alpha_i)]} \quad (33)$$

$$\tau_i = \tan^{-1}\{\frac{E[\sin(n\omega\alpha_i)]}{E[\cos(n\omega\alpha_i)]}\} \quad (34)$$

Substituting (32) into (31) to obtain

$$\Phi(n\omega) = A_n e^{j\tau_n} \quad (35)$$

where $A_n = \prod_{i=1}^{L} A_{in}$, and

$$\tau_n = \sum_{i=1}^{L} \tau_i \tag{36}$$

It can also be shown

$$\Phi(-n\omega) = A_n e^{-j\tau_n} \tag{37}$$

Using [24: 6.311, P.680 and 6.315.2, P680], then (29) can be written as

$$\bar{P}_{e(unbal\_egc)} = \frac{2}{TT} \sum_{\substack{n=1 \\ n\ odd}}^{\infty} A_n B_n \cos(\tau_n - \alpha_n) \tag{38}$$

where

$$B_n = \sqrt{\frac{[1-e^{\frac{-n^2\omega^2}{4b^2}}]^2}{(n\omega)^2} + \frac{{}_1F_1(1;\frac{3}{2};\frac{-n^2\omega^2}{4b^2})^2}{\pi b^2}} \tag{39}$$

$$\alpha_n = \tan^{-1}\left\{ \frac{\sqrt{\pi} b[1-\exp(\frac{-n^2\omega^2}{4b^2})]}{n\omega[{}_1F_1(1;\frac{3}{2};\frac{-n^2\omega^2}{4b^2})]} \right\} \tag{40}$$

$$b = \sqrt{\frac{\frac{E_b}{N}(1+\sum_{i=1}^{L-1}\beta_i)}{\frac{E_b(M-1)\Omega(1+\sum_{i=1}^{L-1}\beta_i)}{N} + (1+\sum_{i=1}^{L-1}\beta_i)N_0}} \tag{41}$$

Equation (38) is used to compute the BER. There is a tradeoff in choice of the value of TT [15]. In this paper, the value of TT has been chosen as 500.

3.5 Performance of BER for Gain Unbalance EGC over Rician Fading

Rician Fading channel is another useful model for wireless communications. In this section, we investigate the effects of gain unbalances at the output of the EGC combiner over Rician Fading channels. In a Rician fading environment, α_i is the amplitude of the signal received by the ith channel, assume that α_i is a Rician random Variable with PDF [25].

$$f_{\alpha_i}(x) = \frac{2x(1+\kappa_i)}{\Omega_i} \exp(-\kappa_i - \frac{(1+\kappa_i)x^2}{\Omega_i}) \cdot \mathrm{I}_0(2x\sqrt{\frac{\kappa_i(1+\kappa_i)}{\Omega_i}}), \quad x \ge 0 \tag{42}$$

where

$$\kappa_i = \frac{\text{power in specular component}}{\text{power in random component}} \tag{43}$$

$$\Omega_i = E[\alpha_i^2] \tag{44}$$

$\mathrm{I}_0(\cdot)$ is the modified Bessel function of the first kind and order zero. For $\kappa_i = 0$ ($-\infty$ dB), there is no specular component and (42) reduces to a Rayleigh PDF.

The conditional signal-to-noise Γ is represented as (27). The average bit error rate can be written as

$$\bar{P}_e = \int_0^{\infty} P_e(\alpha) P(\alpha) d\alpha \tag{45}$$

where $P(\alpha)$ is the PDF of sum of independent Rician RV's. By using the convergent infinite series expressions [16], we obtain the PDF of independent RV's. It is not surprising that the average bit error rate in (45) has the same form as (38), but A_n and τ_n are different due to the Rician distribution. The computation of A_n and τ_n is as follows.

$$A_n = \prod_{i=1}^{L} \sqrt{\Phi_{\mathrm{I}_i}^2 + \Phi_{R_i}^2} \tag{46}$$

$$\tau_n = \sum_{i=1}^{L} \tan^{-1}(\frac{\Phi_{\mathrm{I}_i}}{\Phi_{R_i}}) \tag{47}$$

where

$$\Phi_{1_i} = \frac{nwe^{-\kappa_i}}{\sqrt{1+\frac{\kappa_i}{\Omega_i}}} \sum_{j=0}^{\infty} \frac{\Gamma(j+\frac{3}{2})}{(j!)^2} \kappa_i^j \, {}_1F_1(j+\frac{3}{2}, \frac{3}{2}, \frac{-n^2 w^2 \Omega_i}{4(1+\kappa_i)}) \quad (48)$$

$$\Phi_{R_i} = e^{-\kappa_i} \sum_{j=0}^{\infty} \frac{\kappa_i^j}{j!} \, {}_1F_1(j+1, \frac{1}{2}, \frac{-n^2 w^2 \Omega_i}{4(1+\kappa_i)}) \quad (49)$$

IV. NUMERICAL RESULTS

In this section, several numerical results based on the derivations in the previous sections will be discussed and illustrated. Fig. 3 shows the BER curves of an MC-CDMA system with 10 users with various numbers of subcarriers for the Nakagami fading parameter m =1. EGC and MRC techniques are used at the receiver.

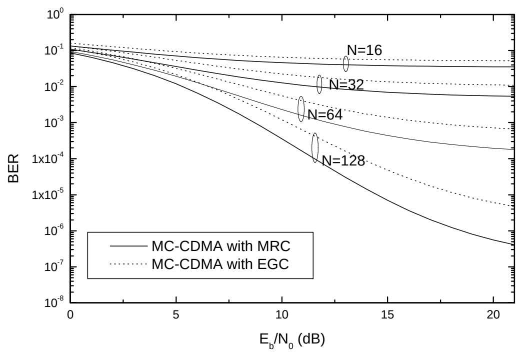

Fig.3. BER of MC-CDMA with 10 users and different numbers of subcarriers, N , for the Nakagami fading parameter m =1.

Fig. 4 shows the BER comparison of an MC-CDMA system using EGC and MRC of 8 subcarriers and 1 user with different Nakagami fading parameters m .

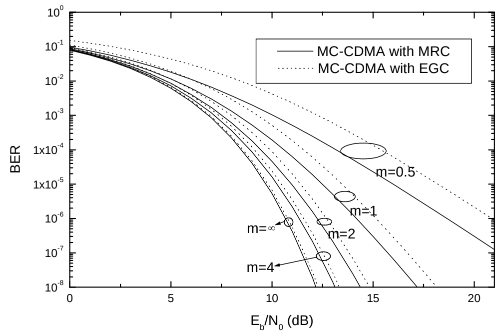

Fig.4. BER of MC-CDMA with 8 subcarriers and 1 user with different fading parameters, m .

Fig. 5 shows the BER comparison of MC-CDMA system using EGC and MRC with varying numbers of subcarriers. It demonstrates that as number of subcarriers increases, the performance of MC-CDMA system increases for both MRC and EGC, and MC-CDMA with MRC is better than that with EGC. In addition, when the fading parameter m increases, the performance of MC-CDMA system with MRC is better than that with EGC. On the other hand, when the numbers of subcarriers increases, the capacity of an MC-CDMA system with MRC is better than that with EGC.

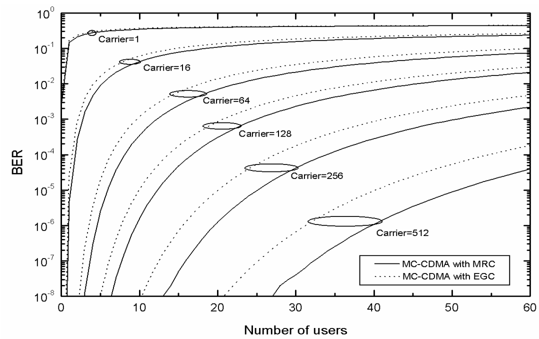

Fig.5. BER comparison of MC-CDMA with different numbers of subcarriers for varying number of users at the Nakagami fading parameter m =1, $S/N = 20dB$.

Fig. 6 illustrates the BER comparison of an MC-CDMA system using EGC and that using MRC with 64 subcarriers and 10 users versus DS-CDMA with 4 branches [22].

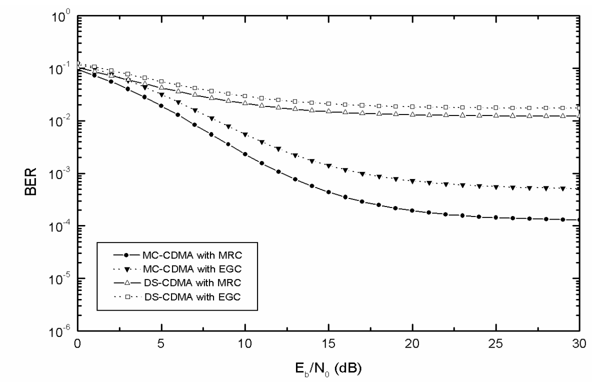

Fig.6. BER comparison of MC-CDMA with 64 subcarriers and 10 uses versus DS-CDMA with 4 branches with the Nakagami fading parameter m =1.

Fig. 7 shows the BER comparison of MC-CDMA system with four branches using EGC, that using MRC with 64 subcarriers, and DS-CDMA [22]. It can be observed that the performance of MC-CDMA system is superior to that of DS-CDMA. Besides, it can be observed that the capacity of an MC-CDMA system is superior to that of DS-CsDMA as well.

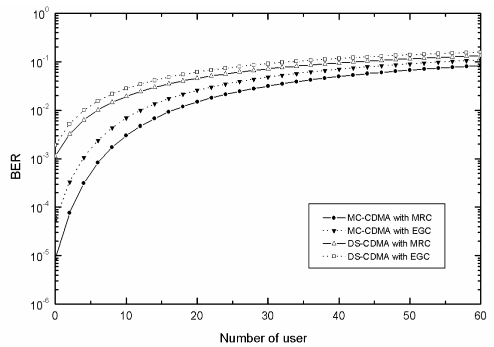

Fig.7. BER comparison of MC-CDMA with 64 subcarriers versus DS-CDMA with 4 branches for varying number of users with the Nakagami fading parameter m =1, $E_b / N_0 = 10dB$.

Shown in Fig. 8 is the effect of unbalance gain on the BER of MC-CDMA with 8 subcarriers and 6 users for the Nakagami (m =1) and Rician (κ_i =0) fading. It can be shown that Nakagami (m =1) and Rician (κ_i =0) reduce to a Rayleigh fading environment. The gains between branches are assumed to be 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, 1. The unbalance gains between branches will suffer more performance degradation.

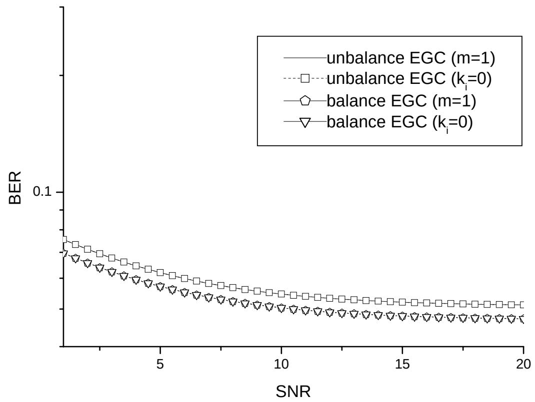

Fig.8. BER of MC-CDMA with 8 subcarriers and 6 users and effect of unbalance EGC for Nakagami (m =1) and Rician (κ_i =0) fading.

V. CONCLUSION

In this paper, we have analyzed the performance of an MC-CDMA system in an uplink generalized fading channel. The effects of gain unbalance between branches on the bit error rates at the output are also investigated. The numerical results indicate that the performance of MC-CDMA becomes better as the fading factor m increases. Besides, if the number of the carrier gets more, the error probability of the system will decrease. In addition, when comparing with the DS-CDMA system, the MC-CDMA system has demonstrated its superiority in system performance to the traditional CDMA system. Remarkably, it is also seen the effects of gain unbalances between branches on MC-CDMA system will suffer more performance degradation. Our results show that unbalanced gains between branches should be taken into account in designing MC-CDMA systems.

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