Another View Point on the Performance Evaluation of an MC-DS-CDMA System

Joy Iong-Zong Chen and Tai Wen Hsieh

Abstract: **The results of performance analysis by adopting the channel scenarios characterized as Weibull fading for an multicarrier-direct sequence-coded division multiple access (MC-DS-CDMA) system are proposed in this investigation. On the other hand, an approximate simple expression with the criterion of bit error rate (BER) versus signal-to-noise ratio (SNR) method is derived for an MC-DS-CDMA system combining with maximal ratio combining (MRC) diversity based on the moment generating function (MGF) formula of Weibull statistics, and it associates with an alternative expression of Gaussian Q-function. Besides, the other point of view on the BER performance evaluation of an MC-DS-CDMA system is not only the assumption of both single-user and multi-user cases applied, but the phenomena of partial band interference (PBI) is also included. Moreover, in order to validate the accuracy in the derived formulas, some of the system parameters, such as Weibull fading parameter (β), user number (K), spreading chip number (N), branch number (L), and the PBI (JSR) values, etc., are compared with each other in the numerical results. To the best of author's knowledge, it is a brand new idea which proposes the evaluation of the system performance for an MC-DS-CDMA system over the point of view with Weibull fading channel.**

Index Terms: **Bit error rate (BER), maximal ratio combining (MRC), moment generating function (MGF), multicarrier-direct sequence-coded division multiple access (MC-DS-CDMA) system, partial band interference (PBI), Weibull fading channel.**

I. INTRODUCTION

In the future, the most important issue for investigating broadband wireless communication system will be addressed in supporting a wide range of services and high data bit rates by employing a variety of techniques. Both in second generation (2G) and third generation (3G) wireless mobile systems, coded division multiple access (CDMA) system has been considered as a significantly attractive multiple access technique. The main reason is because that the CDMA system is an effective approach to combat channel fading and various kinds of narrowband interference in multiple-access environments. However, the capabilities of 3G systems will sooner or later be insufficient to cope with the increasing demands for broadband fixed network services. Based on the motivation, the fourth generation (4G) system, multicarrier-CDMA (MC-CDMA), which is based on the OFDM (orthogonal frequency division multiplexing) signaling, is now being explored [1]. One of the most important types of multicarrier CDMA system is called multicarrier-direct sequence-CDMA (MC-DS-CDMA) system, which has the data sequence multiplied by a spreading sequence of modulating disjoint multiple carriers. The receiver provides correlator for each carrier and is combined with maximal ratio combining (MRC) diversity at the output of the correlator. Generally speaking, MC-DS systems can be categorized into two types: (1) A combination of OFDM and CDMA system and (2) a parallel transmission-scheme of narrowband DS waveform in the frequency domain [2]–[4]. Both aforementioned modulation methods have been dedicated to analysis by combining them with many varieties of considerable scenarios. It is known that the effects of inter-symbol interference (ISI) and fading which occurs in the transmission channel are two major interference sources of interference for wireless communication systems.

During the past about 15 years, there are a lot of signaling schemes with multicarrier technique that have been proposed and analyzed over different assumptions of fading channels. In [4], the researchers evaluated the system performance of an MC-DS-CDMA system with MRC diversity over Rayleigh fading channel. In [5], the researchers, in order to obtain the average bit error rate (BER) performance for an MC-DS-CDMA system, employed three methods to calculate the approximate probability density function (pdf) of the sum of independent identically distribution (i.i.d.) Rayleigh random variables. The results presented by Ziemer and Nadgauda in [6] are to analyze the affect of correlation among the subcarriers for an MC-DS-CDMA system, in which only the AWGN channel is assumed with single user. The performance of an MC-CDMA system with correlated envelopes was not only analyzed by Shi and Latva-aho, but by researchers who also presented the effect of correlated phases in [7]. Performance analysis of MC-CDMA and the MC-DS-CDMA system operating in correlated-Rayleigh fading channels were calculated by Kim *et al.* [8], and Xu and Milstein [9], respectively. Recently, Yang and Hanzo in [10], evaluated the performance for generalized MC-DS-CDMA system over Nakagami-m channel. The authors Kang and Yao in [11] analyzed the performance of MC-CDMA system with independent and correlated subcarriers over Nakagami-m fading channels. The authors, Shi and Latva-aho adopted the MGF methods to calculate the BER of MC-CDMA system over Nakagami-m fading [12]. In publication [13], Chen evaluated the performance of an MC-CDMA system with MRC diversity works in a correlated Nakagami-m fading environment. Most of the mentioned publications are to provide with the system performance of multicarrier scheme in Nakagami-m fading.

Now, it is worth noting that the Weibull fading is an alternatively versatile consideration for evaluation the performance of wireless radio systems. In [14], Weibull has proposed the

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The authors are with the Department of Communication Engineering, Dayeh University 168 University, Rd., Datsuen, Changhua 51505 Taiwan (R.O.C.), email: jchen@mail.dyu.edu.tw, kidd0324@pchome.com.tw.

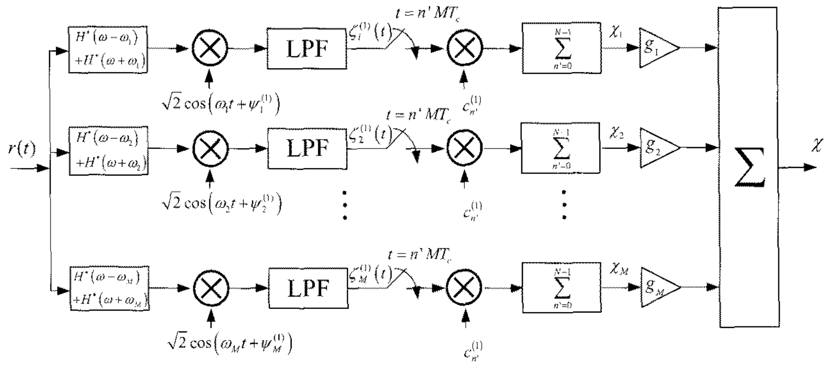

Fig. 1. The receiver block diagram of a MC-DS-CDMA system for the referenced user (1st user).

Weibull distribution first for estimating machinery lifetime and become popularly used in several fields of science, such as weather forecasting and radar systems to model the dispersion of the received signals level caused by some kinds of obstacles. The reasons for assuming that the fading channel characterized by the Weibull distributed in this paper are not only regarded as an approximation to the generalized Nakagami-m distributed with the same order as the Nakagami-m distribution, but it can be considered to exhibit good fit to experimental fading channel of both in indoor and outdoor environments. Furthermore, according to the results of experimental measurements, it has demonstrated that the characteristic of Nakagami-m distribution is versatile than Rayleigh and Rice distribution in the urban area and including the of one-sided Gaussian and Rayleigh distribution [15]. Anyway, the issues of wireless communications over Weibull fading environments have begun to attract much interest from the researchers. For example, the results presented in [16] evaluated the performance of linear diversity of generalized-selection combining (GSC) over independent Weibull fading channels. The authors Sagias *et al.* dealt with the performance of switched and selection combining (SC) diversity by the use of the evaluation of the average signal-to-noise ratio (SNR) with the parameters of amount of fading (AoF) and switching rate in [17] and [18], respectively. In [19] the present author, Chen, derived a closed form with the level crossing rate (LCR) and average fade duration (AFD) for dual-branch SC diversity in correlated-Weibull fading. The authors Karagiannidis *et al.* have completed the performance analysis of linear combining, equal gain combining (EGC) and MRC, over Weibull fading [20]. The results of performance evaluation of MC-CDMA system over a multipath fading channel using the characteristic function (CHF) method has been arrived at in [21] by the researches Smida *et al.*. Besides, in [22] the authors claimed that the results should not be accurate if there is an assumption of interdependence among the input diversity channel without sufficient separation between antennas. It means that multivariate Weibull distribution can be used for analysis of reception with multiple access techniques. Accordingly, in this paper, the method of applying the multivariate MGF of Weibull distribution is adopted to evaluate the performance of an MC-DS-CDMA system.

Reviewing the previous researches, the very important contribution of this paper is clearly aiming to extend the idea of adopting the Weibull distribution as the fading channel model for deriving some results of BER performance of an MC-DS-CDMA system. Both the single and multi-user cases are analyzed for comparison purposes, moreover, the partial band interference (PBI) condition is also taken into account. To the best of author's knowledge, the adopted scenarios of fading environment with Weibull distribution for the performance evaluation of MC-DS-CDMA system were not ever proposed and analyzed, that is, it is the new idea presented in this paper. The paper is organized as follows: After the introduction section, the system and the channel models of an MC-DS-CDMA system are described in Section II. Analytical expressions of average BER performance of an MC-DS-CDMA system in correlated-Weibull channels are derived in Section III. The analytical results from adopting the examples with multiple-user combining with multicarrier are illustrated in Section IV. There is a brief conclusion drawn in Section V.

II. SYSTEM MODELS

A. *Transmitter Model*

The transmitter system proposed in [4] is adopted in this study, and the transmitted signal of a MC-DS-CDMA system of the kth user can be written as

$$s^{(k)}(t)=\sqrt{2E_c}\sum_{n=-\infty}^{\infty} c_n^{(k)} d_h^{(k)} h(t-nMT_c-\tau^{(k)}) \cdot \sum_{i=1}^{M} Re\left[\exp^{j(2\pi f_i t+\theta_i^{(k)})}\right] \tag{1}$$

where E_c is the chip energy, $c_n^{(k)}$ is the pseudo-random spreading sequence, $d_{|n/N|}^{(k)} \in \{+1,-1\}$ denotes the data bit of the kth user, where N indicates the length of PN-sequence, $h(t)$ is the impulse response of the chip wave shaping filter, is an arbitrary time delay uniformly distributed over $[0, NMT_c]$, $Re[\cdot]$ denotes the real part, $\theta_i^{(k)}$ and f_i's, $i=1,2,\cdots,M$ are a random carrier phase uniformly distributed over $(0,2\pi]$ and the carrier frequency, respectively.

B. Receiver and Weibull Fading Channel Model

The receiver block diagram of an MC-DS-CDMA system with band-pass filter (BPF) and low pass filter (LPF) for the referenced user (1st user) is shown in Fig. 1. The output, $\zeta_i^{(1)}(t)$, of the chip-matched filter in the branch for the referenced user is given by [4]

$$\begin{aligned}\zeta_i^{(1)}(t)=&L_p\left\{\left[r(t)\otimes\Im^{-1}\left\{H^*(\omega-\omega_i)+H^*(\omega+\omega_i)\right\}\right]\right.\\&\left.\cdot\sqrt{2}\cos\left\{\omega_i(t)+\theta_i^{'(1)}\right\}\right\}\\=&D_{\zeta_i}^{(1)}(t)+MAI_{\zeta_i}^{(1)}(t)+JSR_{\zeta_i}^{(1)}(t)+N_{\zeta_i}^{(1)}(t)\end{aligned}\quad(2)$$

where $r(t)$ denotes the received signal, $L_p\{\cdot\}$ is applied to express the function of LPF, $\Im^{-1}\{\cdot\}$ represents the inverse Fourier transform, $\{H^*(\omega-\omega_i)+H^*(\omega+\omega_i)\}$ is the frequency response of the BPF in the receiver of an MC-DS-CDMA system. The first term in (2) indicates the desired signal of the referenced user, and can be written as

$$D_{\zeta_i^{(1)}}(t)=\sqrt{E_c}\alpha_i^{(1)}\sum_{n=-\infty}^{\infty}d_h^{(1)}c_n^{(1)}x\{t-nMT_c\}\quad(3)$$

where $\alpha_i^{(1)}$, $i=1,\cdots,M$ is considered as fading envelopes characterized as i.i.d. Weibull random variables (RVs). The second term in (2) is called the multiple access interference (MAI) which is the interference caused from the other users, the third term is the JSR in dB, and the last term indicates the result that the AWGN passes through a LPF.

Now, it needs to evaluate the SNR at the output of the receiver for the referenced user such that the system performance can be achieved. The statistical characteristics of the signal at the output of the ith correlator are to be determined as

$$\chi_i=D_{\chi_i}+MAI_{\chi_i}+JSR_{\chi_i}+N_{\chi_i}\quad(4)$$

where the meaning of each term shown in previous equation is able to refer to the results shown in [4].

A slowly varying Weibull fading channel is assumed for each user. All subcarriers are considered to experience flat fading which may happen at the chance when the assumption of no frequency domain interleaver is employed. Based on the consideration mentioned above, the fading envelope defined in (3) has the pdf expressed as

$$f_{\alpha_i}(\alpha)=\frac{\beta_i}{\Omega_i}\alpha^{\beta_i-1}\exp(-\frac{\alpha^{\beta_i}}{\Omega_i})\quad(5)$$

where Ω_i denotes the average fading power, and the scenario of multichannel reception for a multicarrier system with propagation channel is considered in this paper. The RV set $\alpha_i^{(1)}=[\alpha_1^{(1)}\alpha_2^{(1)}\cdots\alpha_M^{(1)}]$ with the elements defined in (3) consists of M Weibull RVs, which have the MGF for the referenced user proposed in [23], and it is known that the MGF of a Weibull RV for arbitrary fading parameter, β, has been first presented in [24]. The MGF is restated as

$$\begin{aligned}M_{\alpha_i^{(1)}}(s,\beta)=&\frac{(2\pi)^{\frac{1-\beta}{2}}\beta^{(\beta+1/2)}}{Us^{\beta}}G_{1,\beta}^{\beta,1}\\&\cdot\left(U\left(\frac{s}{\beta}\right)^{\beta}\Bigg|_{1,1+\frac{1}{\beta},\cdots,1+\frac{(\beta-1)}{\beta}}^{1}\right)\end{aligned}\quad(6)$$

where U is a scaling constant, β denotes the fading parameter of Weibull distribution, and $G_{c,d}^{a,b}[\cdot]$ is the Meijer's G-function [25].

III. BER ANALYSIS

The conditional mean of $E\left\{\chi_i\left|\alpha_i,d_h^{(1)}\right.\right\}$ shown in (4), which conditions upon the channel attenuation factor $\alpha_i^{(1)}$, are given by

$$\begin{aligned}E\left[\chi_i\left|\alpha_i,d_h^{(1)}\right.\right]=&E\left\{\chi_i\left|\alpha_i^{(1)},\left\{d_h^{(1)}\right\}\right.\right\}\\=&\sqrt{E_c}\alpha_i^{(1)}\sum_{n'=0}^{N-1}\sum_{n=-\infty}^{\infty}d_h^{(1)}c_n^{(1)}c_{n'}^{(1)}\\&\cdot x\left[(n'-n)MT_c\right]\\=&\pm N\sqrt{E_c}\alpha_i^{(1)}.\end{aligned}\quad(7)$$

It is known that the $x\left[(n'-n)NT_c\right]=0$ for $n'\neq n$. The conditional variance of χ_i can be represented as

$$\begin{aligned}\mathrm{Var}\left\{\chi_i|\alpha_i^{(1)}\right\}\equiv&\sigma_i^2\\=&\mathrm{Var}\left\{MAI_{\chi_i}+JSR_{\chi_i}+N_{\chi_i}|\alpha_i^{(1)}\right\}\\=&\mathrm{Var}\left\{MAI_{\chi_i}|\alpha_i^{(1)}\right\}+\mathrm{Var}\left\{JSR_{\chi_i}|\alpha_i^{(1)}\right\}\\&+\mathrm{Var}\left\{N_{\chi_i}|\alpha_i^{(1)}\right\}\end{aligned}\quad(8)$$

where the results of each terms shown in (8) have been calculated and given in [4]. All signals at the output of the correlators are combined with the MRC scheme, and the result can be expressed as $\chi=\sum_{i=1}^{M}G_i\chi_i$, where G_i is defined as the channel estimation of the ith branch. In order to maximize the SNR, the channel estimation G_i is defined as the ratio of the desired signal amplitude to the variance of the noise and interference components in the output, i.e., $G_i=E\left\{\chi_i|\alpha_i^{(1)}\right\}/\mathrm{Var}\left\{\chi_i|\alpha_i^{(1)}\right\}$. Therefore, the SNR, (S/N), at the output of MRC diversity, can be obtained as

$$\left(\frac{S}{N}=\frac{E\left\{\chi_i|\alpha_i^{(1)}\right\}^2}{\mathrm{Var}\left\{\chi_i|\alpha_i^{(1)}\right\}}\right)\equiv N^2E_c\gamma\quad(9)$$

where the referenced user is considered and the instantaneous SNR at the MRC diversity output is given as

$$\gamma=\sum_{i=1}^{M}\frac{(\alpha_i^{(1)})^2}{\sigma_i^2}\equiv\sum_{i=1}^{M}q_i.\quad(10)$$

Generally speaking, it is difficult to obtain the pdf of a random variable γ in (10) directly by using of the method of multivariable transformation. It is known that if α_i in the RV set of $\alpha_i^{(1)}$ is a sample of a Weibull distribution with fading parameter β, then $(\alpha_i^{(1)})^c$ is also a sample of Weibull distribution with parameter β/c [16]. However, the MGF of γ can be obtained by employing the RV set shown in the previous equation, i.e., the MGF of γ is able to be determined as $M_\gamma(s,\beta)=$

$\prod_{i=1}^{M} M_{\alpha_i^{(1)}}(s,\beta)$. Then by changing the variables, the most common solution of approaching the system BER is able to adopt the utilization of conditional pdf. For BPSK signaling, the evaluation of average BER for different scenarios can be approximately achieved by [26]

$$P_{\mathrm{BER}}^{\mathrm{case}} = \int_0^\infty Q\left\{\frac{E(\xi_U)}{\sqrt{\mathrm{Var}(\xi_U)}}\right\} f(\underline{\alpha}^{(1)}) \overbrace{d\alpha_i^{(1)} \cdots d\alpha_M^{(1)}}^{M\ folds}$$
$$= \int_0^\infty Q(\sqrt{N^2 E_c \gamma_{\mathrm{case}}}) f_\gamma(\gamma_{\mathrm{case}}) d(\gamma_{\mathrm{case}}) \quad (11)$$

where $\alpha_i^{(1)} = [\alpha_1^{(1)} \alpha_2^{(1)} \cdots \alpha_M^{(1)}]$ has been defined in (3), $f(\alpha_1^{(1)})$ is the joint pdf (jpdf) of $\alpha_1^{(1)}$, γ_{case} depends on which is the scenario adopted. For the purpose of comprehensive system performance discussion, two cases, single user and multiple user cases are included. Hence, γ_{case} has to be replaced with the corresponding case names by means of the exact subscript, namely, γ_{mu-sc} represents the SNR of multi-user case with single carrier, while $\gamma_{\mathrm{su-mc}}$ indicates the SNR of single-user case with multicarrier. Similarly, the presentation method will be employed for the symbols of variance, σ_0^{case}, and average BER, $P_{\mathrm{BER}}^{\mathrm{case}}$, respectively. The average BER of the assumed cases will be illustrated in the next subsection. The $Q(x)$ in (11) is the Gaussian Q-function and defined as $Q(x) = 1/\sqrt{2\pi}\int_x^\infty e^{-\frac{t^2}{2}} dt$. By changing the variables, the Q-function can be alternatively expressed as

$$Q(x) = \frac{1}{\pi}\int_0^{\pi/2} \exp\left(-\sqrt{0.5}\left(\frac{x}{\sin\theta}\right)^2\right) d\theta. \quad (12)$$

Since the MRC diversity is applied, let $\gamma = \sum_{l=1}^{M}(\alpha_l)^2$, where L represents the received branch number, which is assumed equal to the subcarrier number M.

Note that the MGF of a random variable, γ, can be denoted generally as $M_\gamma(s) = E[e^{-s\gamma}]$. Hereafter, the average BER of an MC-DS-CDMA system over Weibull fading can be derived by substituting the two equations, (6) and (12), into (11), and obtained as

$$P_{\mathrm{BER}}^{\mathrm{case}} = \int_0^\infty Q\left(\sqrt{\sigma_0 \gamma_{\mathrm{case}}}\right) f\left(\gamma_{\mathrm{case}}\right) d\gamma_{\mathrm{case}}$$
$$= \frac{1}{\pi}\int_0^\infty \int_0^{\pi/2} \exp\left(\frac{\sigma_0 \gamma_{\mathrm{case}}}{\sin^2\theta}\right)$$
$$= \frac{1}{\pi}\int_0^{\pi/2} M_{\gamma_{\mathrm{case}}}(s,\beta) d\theta \quad (13)$$

where $s = \frac{\sigma_0}{\sin^2\theta}$ is deduced by the definition of MGF, shown in (6). The system BER of MC-DS-CDMA systems with different kind of conditions over Weibull fading channel with MRC diversity is inspected in the next subsection.

A. *Multi-User Scenario*

A.1 Multicarrier

First, we consider a multi-user case with multicarrier, and assume that the correlation between the spreading codes is adjustable [4]. Thus, the conditional SNR, $\{\gamma_{\mathrm{mu-mc}}|\alpha_i^{(1)}, i = 1, \cdots, M\}$, in the multiple user case with multicarrier at the output of the receiver can be determined from (9), and written as

$$\gamma_{\mathrm{mu-mc}} = N^2 E_c \sum_{i=1}^{L} \frac{(\alpha_i^{(1)})^2}{\frac{(K-1)NE_c}{2}\left(1-\frac{\mu}{4}\right) + \frac{N\eta_0}{2}}$$
$$= \left\{\frac{K-1}{2MN}\left(1-\frac{\mu}{4}\right) + \frac{\eta_0}{2LNE_c}\right\}^{-1} \frac{1}{L}\sum_{i=1}^{L}(\alpha_i^{(1)})^2$$
$$= \sigma_0^{\mathrm{mu-mc}} \frac{1}{L}\sum_{i=1}^{L}(\alpha_i^{(1)})^2 \quad (14)$$

where N represents the chip number per symbol for the multicarrier case, and $\eta_0/2$ is a double-sided PSD of the AWGN. In order to calculate the system BER formula, $P_{\mathrm{BER}}^{\mathrm{mu-mc}}$, for the case of multi-user with multicarrier, by substituting (14) into (13), and can be obtained as

$$P_{\mathrm{BER}}^{\mathrm{mu-mc}} = \int_0^\infty Q\left(\sqrt{\sigma_0 \gamma}\right) f\left(\underline{\alpha}^{(1)} d\alpha_0^{(1)} \cdots d\alpha_L^{(1)}\right)$$
$$= \frac{1}{\pi}\int_0^\infty \int_0^{\pi/2} \exp\left(\frac{\sigma_0^{\mathrm{mu-mc}} \gamma_{\mathrm{mu-mc}}}{\sin^2\theta}\right) \cdot f\left(\gamma_{\mathrm{mu-mc}}\right) d\theta d\gamma_{\mathrm{mu-mc}}$$
$$= \frac{1}{\pi}\int_0^{\pi/2} \prod_{i=1}^{L} \frac{(2\pi)^{\frac{1-\beta}{2}} \beta^{\beta+1/2}}{\mu s_i^\beta} \cdot G_{1,\beta}^{\beta,1}\left(\mu\left(\frac{s}{\beta}\right)^\beta \middle|_{1,1+\frac{1}{\beta},\cdots,1+\frac{(\beta-1)}{\beta}}^{1}\right) d\theta \quad (15)$$

where $s = -\sigma_0^{\mathrm{mu-mc}}/\sin^2\theta$. According to the similar one that the average bit SNR is defined as SNR $= MNE_c/\eta_0$, the $\sigma_0^{\mathrm{mu-mc}}$ in (14) can be replaced with $\sigma_0^{\mathrm{mu-mc}} = \left\{\frac{K-1}{MN}\left(1-\frac{\mu}{4}\right) + \frac{1}{snr}\right\}^{-1}\frac{1}{M}$, where $MNE_c = N_1 E_{c1} = E_b$, and where E_b denotes the bit energy, and N_1 and E_{c1} are the length and the energy of the spreading code, respectively.

The same procedures of performance analysis for the other scenarios are going to be determined in the following section. First of all the calculation of conditional SNR for each case is necessary for determining the average BER.

A.2 Multicarrier and PBI

The conditional SNR, $\{\gamma_{\mathrm{mu-mc-PBI}}|\alpha_i, i = 1, \cdots, L\}$, of a multicarrier with PBI can be determined from (14) and expressed as

$$\{\gamma_{\mathrm{mu-mc-PBI}}|\alpha_i, i = 1, \cdots, L\}$$
$$= \left\{\frac{K-1}{2MN}\left(1-\frac{\mu}{4}\right) + \frac{\eta_0}{2MNE_c} + \frac{\eta_J}{2MNE_c}\right\}^{-1} \frac{1}{M}\sum_{i=1}^{L}(\alpha_i^{(1)})^2 \quad (16)$$

where η_J represents the PSD of JSR defined in (5). By using of the same steps as that of the derived results shown in (16), and the system BER, $P_e^{\mathrm{mu-mc-PBI}}$, can be achieved under this assumption.

B. Single-User Scenario

B.1 Multicarrier

Next, the conditional SNR of single-user and multiple-carrier case, $\{\gamma_{\text{su-mc}}|\alpha\}$, at the output of the receiver can be calculated with the same way that is adopted in the case of multiple users, and the values of the user number $K = 1$ will be put into (14). The conditional SNR, $\{\gamma_{\text{su-mc}}|\alpha\}$, becomes

$$\{\gamma_{\text{su-mc}}|\alpha\}=N^2E_c\sum_{i=1}^{L}\frac{(\alpha_i^{(1)})^2}{\sigma_i^2} =\frac{2NE_c}{\eta_0}\sum_{i=1}^{L}(\alpha_i^{(1)})^2. \quad (17)$$

Thereafter, the conditional SNR, $\{\gamma_{\text{su-mc}}|\alpha\}$, at the rake receiver of a single carrier can be obtained by substituting $K = 1$, and $M = 1$ into (14). Since it is trivial and due to the editorial size, the analysis for this case will be ignored.

B.2 Multicarrier with PBI

When the effect of PBI is considered, the conditional SNR, $\{\gamma_{\text{su-mc}}|\alpha\}$, of multicarrier and single-user case can be written as

$$\{\gamma_{\text{su-mc}}|\alpha\}=\left(\frac{2MNE_c}{\eta_0}+\frac{2MNE_c}{\eta_J}\right)^{-1}\frac{1}{M}\sum_{i=1}^{L}(\alpha_i^{(1)})^2. \quad (18)$$

The system BER, $P_e^{\text{su-mc-PBI}}$, can also be computed by the same procedures described in the previous case.

IV. RESULTS AND DISCUSSIONS

Setting up the performance evaluation with the assumption of Weibull statistics is a distinctive idea, for which it is suitable for characterizing fading channels, and applied in the analysis of the system BER for an MC-DS-CDMA system. In order to validate the accuracy of the calculated system BER formulates for each scenarios considered in previous section, the numerical evaluation is discussed in this section. However, the discussion of the case for single-user accompanied with single-carrier will be excluded in this section, since it can be recognized as a special cases of the multi-user combined with multicarrier, i.e., $K = 1$ and $N = 1$ are for the single-user and single carrier, respectively. The results in Fig. 2 to Fig. 5 illustrate the plots of the BER versus SNR performance for multi-user multicarrier case without the impact of PBI. First the effect of number of subcarrier is shown in Fig. 2 in which the different values of subcarrier number, $M = 4, 6, 8$, are exemplified. The results in Fig. 3 show the BER versus average bit SNR (E_b/N_0) with the parameters of user number, $K = 30$, fading parameter, $\beta = 3$, branch number (equal to the subcarrier number), $L = 4$ ($M = 4$), different values of spreading chip number $M = 8, 16, 32$, and 64. The performance is normally degraded by the factors of much less spreading chip number. It is worth pointing out that the conditions of with JSR and without JSR are shown in this figure. With the fixed spreading chip number $N = 64$ and the same parameters as those adopted in Fig. 2, the results of bit SNR versus

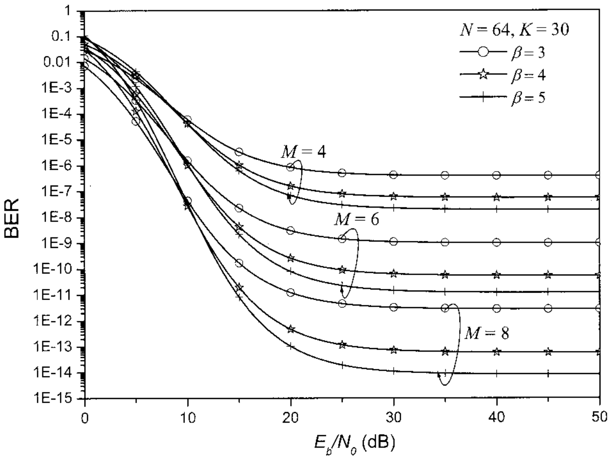

Fig. 2. BER versus SNR with different subcarrier numbers and fading parameters without PBI.

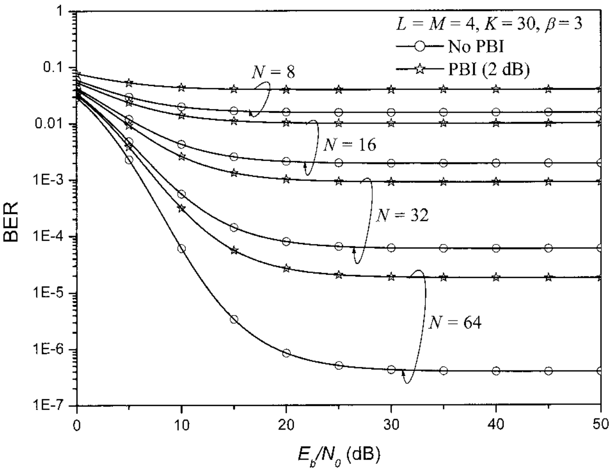

Fig. 3. BER versus SNR with different spreading chip numbers, with and without PBI.

BER curves are shown in Fig. 4. It is reasonable to observe that a significantly higher MAI due to the gradually increasing user number will cause the system performance to decline. In Fig. 5, the SNR value is set as 10 dB, then the user capacity versus BER with different subcarrier number is considered. The results obviously show that the smaller multicarrier number, the lower the user capacity. The influence of PBI with $JSR = 2$ dB and the performance variating with subcarrier number and user number are illustrated in Figs. 6 and 7, respectively. Furthermore, in these two figures, the curves of average BER versus SNR vary with different values of the fading parameter, $\beta = 3, 4, 5$, and the impact of subcarrier number and user number are shown, respectively. It is clearly known that the system performance depends deeply on these three system parameters after the PBI factor is involved. Moreover, the results shown in Fig. 8 are the curves of average BER versus user capacity with the same parameters as those applied in Fig. 5 except the PBI value. It is obviously to note that the user capacity will decrease after the fading parameter increases. Comparing the system performance with different JSR values, $JSR = 0, 2, 4$, and 6 dB, the plots

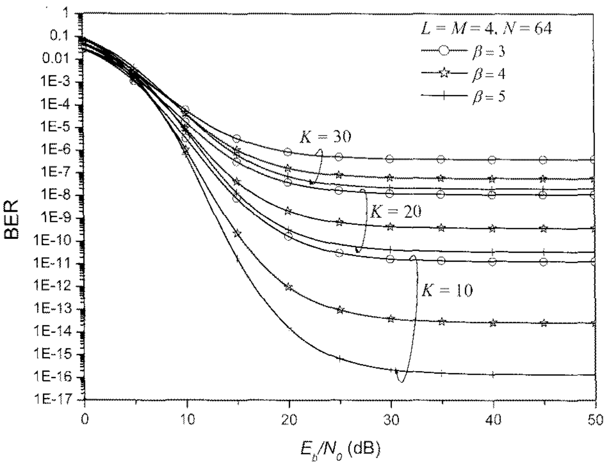

Fig. 4. BER versus SNR with different fading parameters and users number without PBI.

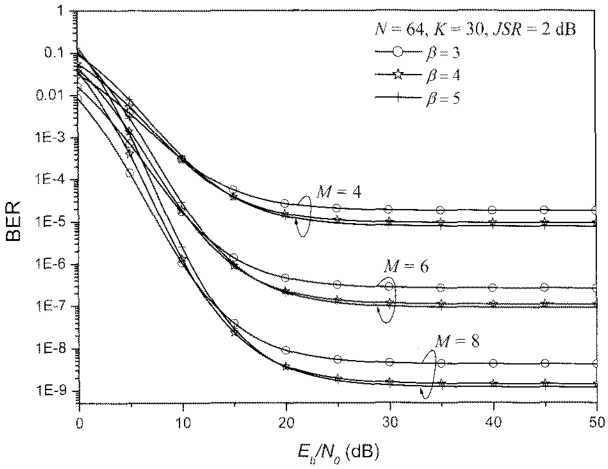

Fig. 6. BER versus SNR with different subcarrier numbers and fading parameters with $JSR = 2$ dB.

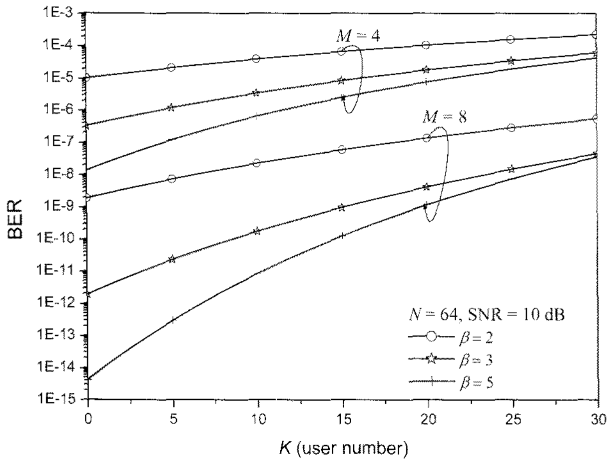

Fig. 5. BER versus user number with different subcarrier number and fading parameters without PBI.

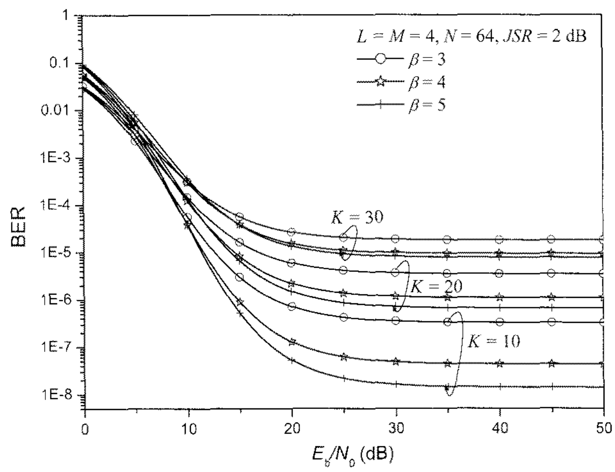

Fig. 7. BER versus SNR with different user numbers and fading parameters with $JSR = 2$ dB.

of BER performance versus SNR is shown in Fig. 9.

Overview all of the results from our previous analysis that reminds us to note the achievements published in [4] and [27], in which MC-DS-CDMA systems are evaluated with the assumption of Rayleigh and Nakagami-m fading model, respectively. The Weibull distribution has been certified that it can be specialized to Rayleigh distribution with the method by setting the fading parameter equal to two, i.e., $\beta = 2$, and it can be regarded as to approximate the Nakagami-m distribution. However, it is difficult to guarantee the facts that described the above since the derived results with the scenario adopted in this paper are very complicated [18]. Nevertheless, the main factors that affect the system performance results of our scenario with Weibull fading channel is in accordance with all of the known parameters in the previous works, for example, the spreading chip number, branch number, user's number, fading parameter, JSR, etc.

V. CONCLUSIONS

In this paper the approximate expression of system performance for an MC-DS-CDMA system with independent fading branches are evaluated. The statistical characteristics, such as pdf of SNR, at the output of a rake (MRC) receiver for considering different cases, i.e., the multi-user and single-user cases, are determined. Meanwhile, in calculating the performance of the average BER for an MC-DS-CDMA system, the new idea of applying the adoption of Weibull statistics for fading channels is an ignored area. It is proved that the fading parameter of the Weibull fading dominates mainly the system performance of MC-DS-CDMA systems. Besides, the influence of JSR parameter is also assumed as one of the system parameters. By comparison, the system BER performance with different branch numbers, user numbers, and spreading chip numbers have provided a targeted and validated analysis. Moreover, the derived results make sure that the PBI coefficients will definitely degrade the performance of an MC-DS-CDMA system no mater which fading model is adopted.

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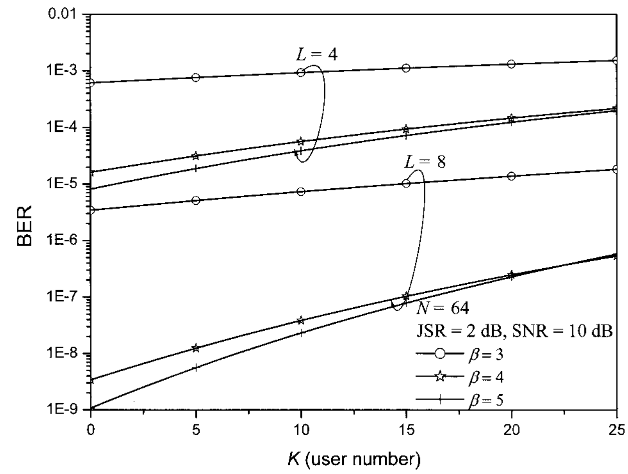

Fig. 8. BER versus user number with different branch number and fading parameters with $JSR = 2$ dB.

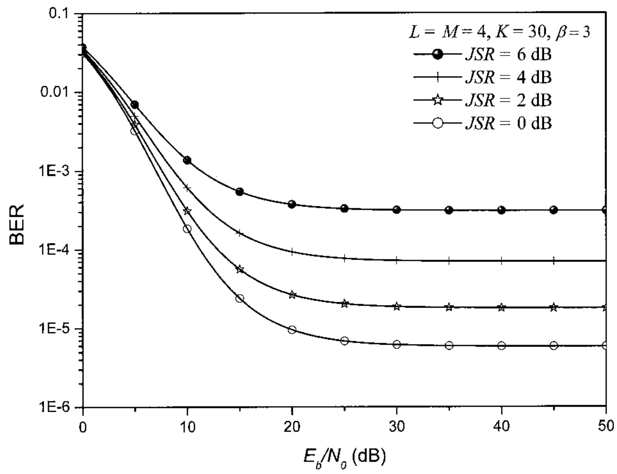

Fig. 9. BER versus SNR with different values of JSR.

the quality of this paper.

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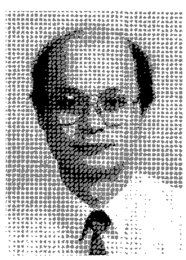
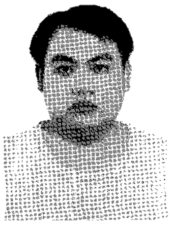


Joy I. Z. Chen was born in Taiwan. He received his B.S. degree in electronic engineering from National Taiwan Technical University, Taipei, Taiwan, in 1985; M.S. degree in Electrical Engineering from Da Yeh University, Chang Hua, Taiwan, in 1995; and the Ph.D. degree in Electrical Engineering from National Defense University, Tao-Yuan, Taiwan, in 2001. He is currently an Associate Professor in the Department of Communication Engineering at Dayeh University, Chang-Hua Taiwan R.O.C. Prior to joining the Da Yeh University faculty, he worked at the Control Data Company (Taiwan) as a Technical Manger from September 1985 to September 1996. His research interests include wireless communications, communication theory, communication statistics, and technical spread spectrum.



Tai Wen Hsieh was born in Miao-Li Taiwan (R.O.C.). He received his B.Sc degrees in Department of Electrical Engineering from the Large China Technical Institute, Hsin-Chu, and M.Sc. degrees in Telecommunications Engineering from the Da Yeh University, Chung Hua, Taiwan, in 1999 and 2005, respectively. He is working to the degree of Ph.D. of Communication Engineering of Dayeh University at Chang-Hua Taiwan (R.O.C.). His research interests include wireless communications, spread spectrum, OFDM, and multicarrier systems.