Wireless Pers Commun (2012) 63:785–805
DOI 10.1007/s11277-010-0165-7

On the Impact of CFO for an MC-DS-CDMA System in Weibull Fading Environments

Joy Iong-Zong Chen · Wen Ching Kuo

Published online: 4 November 2010
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Abstract On the basis of CFO (carrier frequency offset) point of view, the system performance results from the analysis by adopting the channel scenarios characterized as Weibull fading for an MC-DS-CDMA (multi-carrier direct-sequence coded-division multiple-access) system is proposed in this article. Moreover, an approximate simple expression with the criterion of BER (bit error rate) versus SNR (signal-to-noise ratio) method is derived for an MC-DS-CDMA system combining with RAKE receiver, which is a special case of MRC (maximal ratio combining) diversity, based on the MGF (moment generating function) formula of Weibull statistics, and it associates with an alternative expression of Gaussian Q-function. In addition, 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 PBI (partial band interference) is also included. Furthermore, with several of the system parameters, such as CFO values, ε, Weibull fading parameter, β, user number, K, spreading chip number, N, branch number, L, and the PBI values, *JSR,* etc., are compared with each other in the numerical results in order to validate the accuracy in the derived formulas. To the best of author's knowledge, it is a brain fresh idea proposed in this paper to evaluate the system performance for an MC-DS-CDMA system on the point of the CFO view over Weibull fading.

Keywords CFO (carrier frequency offset) · MC-DS-CDMA system · MGF (moment generating function) · MRC (maximal ratio combining) · PBI (partial band interference) · Weibull fading

J. I.-Z. Chen (✉)
Department of Communication Engineering, Dayeh University, 168 University Rd., Datsuen, Changhua 51505, Taiwan, ROC
e-mail: jchen@mail.dyu.edu.tw

W. C. Kuo
Division of Extension Education, Transworld Institute of Technology,
1221, Jen-Nang Rd., Chia-Tong Li, Douliou, Yunlin, Taiwan, ROC

1 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 2G (second generation) and 3G (third generation) wireless mobile systems, CDMA (coded-division multiple-access) system have been considered as significantly attractive multiple access techniques. This is for the main reason 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 4G (fourth generation) system, MC-CDMA (multi-carrier CDMA), which based on the OFDM (orthogonal frequency division multiplexing) signaling, are now engaged in exploring [1]. One of the most important types of multi-carrier CDMA system is called MC-DS-CDMA (multi-carrier direct-sequence CDMA) system, which has the data sequence multiplied by a spreading sequence modulates disjoint multiple carriers. The receiver provides correlator for each carrier and at the output of the correlator is combined with RAKE receiver, which is a special case of MRC (maximal ratio combining) diversity. Generally speaking, multi-carrier 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 ISI (inter-symbol interference) and fading 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 multi-carrier technique 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 BER (bit error rate) performance for an MC-DS-CDMA system, employed three methods to calculate the approximate pdf (probability density function) of the sum of i.i.d. (independent identically distribution) 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 the researchers who also presented the effect of correlated phases in [7]. Performance analysis of MC-CDMA system and the MC-DS-CDMA systems operate in correlated-Rayleigh fading channels were calculated by Kim et al. [8], and Xu and Milstein [9], respectively. Recently, the reference [10] in which Yang and Hanzo 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 the publication [13], Chen evaluated the performance of an MC-CDMA system with MRC diversity works in a correlated Nakagami-*m* fading environments. Most of the mentioned publications are to provide with the system performance of multicarrier scheme in Nakagami-*m* fading.

Now, it is worthy noting that the Weibull fading is an alternatively versatile consideration for evaluation the performance of wireless radio systems. In [14] W. Weibull proposed the 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 it can be regarded as an approximation to the generalized Nakagami-*m* distributed with the same order as the Nakagami-*m* distribution, but it can be concerned 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 interesting for the researchers. For example, the results presented in [16] evaluated the performance of linear diversity of GSC (generalized-selection combining) over independent Weibull fading channels. The authors Sagias et al. dealt with the performance of switched and SC (selection combining) diversity by using of evaluation the average SNR (signal-to-noise ratio) with the parameters of AoF (amount of fading) and switching rate in [17] and [18], respectively. In [19] the present author, Chen, derived a closed form with the LCR (level crossing rate) and AFD (average fade duration) for dual-branch SC diversity in correlated-Weibull fading. The authors Karagiannidis et al. have completed the performance analysis of linear combining, EGC (equal gain combining) and MRC, over Weibull fading [20]. The results of performance evaluation of MC-CDMA system over a multipath fading channel using the CHF (characteristic function) method has been arrived at in [21] by the researches Smida et al. Besides, in [22] the authors claimed that the results should not accuracy if the assumption of interdependence among the input diversity channel without sufficient separation between antennas. It means that multivariate Weibull distribution could be involved in the analysis for reception with multiple access techniques. Accordingly, in this paper the means apply multivariate MGF of Weibull distribution is adopted to evaluate the performance of an MC-DS-CDMA system.

Moreover, the CFO (carrier frequency offset) phenomenon, which is caused by the mismatch in frequency generated from the oscillator between the transmitter and the receiver, i.e. the estimation of the receiver goes wrong, induces the ICI (inter-carrier interference) which will abolish the orthogonality of the transmitted data over an MC-CDMA systems [23]. Recently, Liu and Hanzo proposed the exact closed-form for the average BER calculation of OFDM system in the presence of both CFO and phase estimation error in frequency-selective fading channels [24]. In additions, the authors Zhou et al. illustrated the impact results of CFO for uplink OFDM/SDMA systems in [25]. In short, the CFO effect has become gradually one serious issue which will explicitly degrade the system performance of an MC-DS-CDMA system.

Reviewing the previous researches, the very important contribution and novelty of this paper are clearly aiming to extend the ideal of adopting the Weibull distributed as the fading 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 purpose, moreover, the PBI (partial band interference) condition is also taken into account. To the best of author's knowledge, the adopted scenarios of fading environment with Weibull distributed for the performance evaluation of MC-DS-CDMA system were not ever proposed and analyzed, that is, it is the new ideal presented in this paper.

The analysis of system BER (bit error rate) for an MC-DS-CDMA system in independent or correlated fading channels have ever been addressed and investigated by a number of papers [1,2]. However, the more versatile Weibull fading channels were relatively sparse considered and often assumed to be independent [3,4]. In [3–5], some closed-form calculations of BER and outage probability on Weibull fading channels were given for many of the general digital linear modulation schemes with traditional combining schemes, however, most of the analysis mentioned above weren't include an MC-DS-CDMA systems with multiple-access technique.

A closed-form expression of system BER for an MC-DS-CDMA system with MRC diversity operating under the assumptions of correlated-Weibull fading channels is presented in this letter. Not only the joint MGF (moment generating function) of the Weibull RVs (random variable) adopted, but an alternative expression of the Gaussian Q-function was applied in this investigation. Finally, the numerical evaluation held for validating the correctness of the derived equations. In addition, in order to involve the effect of the rate of average power decay in the scenario with MC-CDMA system, the exponential MIP (multipath intensity profile) was assumed.

In this letter, we present a simple closed-form average BER expression for the MC-DS-CDMA systems with MRC in correlated-Weibull fading channels. The much simpler approximation formulas of average BER directly extensions of the MGF method were derived. The paper is organized as follows, in Sect. 2 the system models are described, and the system BER Performance is analyzed in Sect. 3; the numerical results and a brief discussion are shown in Sect. 4; finally, a simple conclusion is drawn in Sect. 5.

2 System Models

2.1 Transmitter Model

The transmitter block diagram proposed in [4] was shown in Fig. 1 again for adopting as the transmitter model in this research. In the block diagram of the transmitter, an MC-DS-CDMA system in which a unique spreading sequence is assumed to serve for each user, and the active users employs M subcarrier, which is supposed equal to the number of the branch number of propagation channel, and BPSK (binary phase shift keying) modulation scheme is used. The overall bandwidth of an MC-DS-CDMA system with all the subcarrier is given by $BW_M = (1+\mu)/MT_c$, where $0 < \mu \leq 1$ is roll-off factor, M is number of sub-carrier, and T_c is the chip duration. From the points described above, the total bandwidth of the MC-DS-CDMA system of the k-th user can be computed as $BW_T = (1+\mu)/T_c$. The transmitted signal of an MC-DS-CDMA system of the k-th user shown in Fig. 1, can be written as [7]

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

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

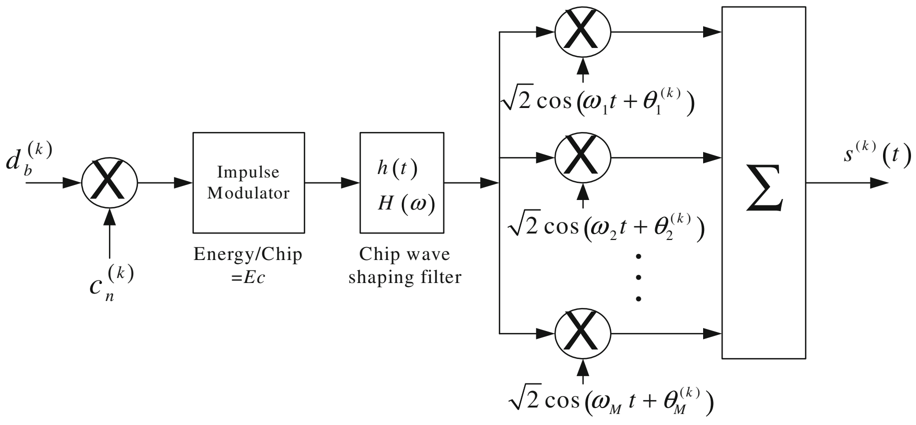

Fig. 1 The transmitter block diagram of an MC-DS-CDMA system of the k-th referenced user

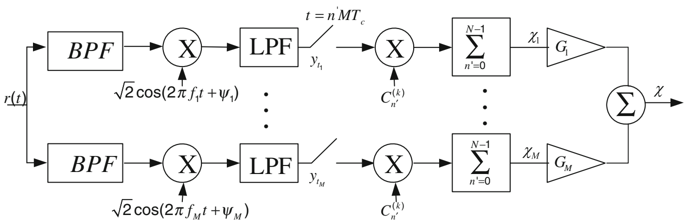

Fig. 2 The receiver block diagram of an MC-DS-CDMA system of a referenced user

2.2 Receiver Model

The receiver block diagram of an MC-DS-CDMA system with BPF (band-pass filter) and LPF (low pass filter) filter is illustrated In Fig. 2. The complex lowpass equivalent impulse response of the i-th channel is $\{c_i = \xi_i \cdot \delta(t), i = 1 \ldots M\}$, and $\xi_i^{(k)} = \alpha_i^{(k)} \exp\left(j\beta_i^k\right)$, where $\alpha_i^{(k)}$ and β_i^k correspond to represent attuation factor and phase-shift for i-th channel of the k-th user. The complex equivalent impulse response of the channel is expressed as $c(t) = \sum_{l=0}^{L-1} \alpha_l \delta(t - lT_c)$. The received signal at the receiver is given as [4]

$$r(t) = \sum_{k=1}^{K} \left\{ \sqrt{2E_c} \sum_{n=-\infty}^{\infty} d_h^{(k)} c_n^{(k)} h\left(t - nMT_c - \tau^{(k)}\right) \right. \\ \left. \times \sum_{\mathrm{i}=1}^{M} \alpha_i^{(k)} \cos\left(2\pi f_i t + \psi_i^{(k)}\right) \right\} + N_w(t) + N_J(t) \tag{2}$$

where K denotes the user number, $\psi_i^{(k)} = \theta_i^{(k)} + \beta_i^{(k)}$, $N_w(t)$ is AWGN with a double-sided PSD (power spectral density)of $\eta_0/2$, $N_J(t)$ is partial band of Gaussian interference with a PSD of $S_{n_J}(f)$, which is written as

$$S_{n_J}(f) = \begin{cases} \frac{\eta_J}{2}, & f_J - \frac{W_J}{2} \le |f| \le f_J + \frac{W_J}{2} \\ 0\ \ , & \text{otherwise} \end{cases} \tag{3}$$

where f_J and W_J represent the bandwidth of the interference and the center frequency, respectively. Then the interference (Jamming)-to-signal ratio, JSR, is defined as the ratio of the interference power value to signal power, and can be written as

$$\mathrm{JSR} = \frac{\eta_J W_J}{E_b/T} = (1+\mu)\,\frac{\eta_J}{E_b}\frac{N}{M} \tag{4}$$

where E_b is defined as the bit energy. The output from the chip-matched filter in the branch ζ_i is give by [4]

$$\zeta_i = D_{\zeta_i} + MAI_{\zeta_i} + JSR_{\zeta_i} + N_{\zeta_i} \tag{5}$$

where the first term of the previous equation denotes the desired signal of the reference case can be written as

$$D_{\zeta_i}(t) = \sqrt{E_c}\alpha_i^{(1)} \sum_{n=-\infty}^{\infty} d_h^{(1)} c_n^{(1)} x\,(t - nMT_c) \tag{6}$$

then the second term in (5) is the interference comes from the other users, callas the MAI (multiple access interference), when the user number K approximates as Gaussian random variable, and can be determined as

$$MAI_{\zeta_i}(t) = \sum_{k=2}^{K}\left\{\sqrt{E_c}\xi_i^{(k)} \sum_{n=-\infty}^{\infty} d_h^{(k)} c_n^{(k)} \cdot x\left(t - nMT_c - \tau^{(k)}\right)\right\} \tag{7}$$

where $\xi_i^{(k)} \equiv \alpha_i^{(k)} \cos\phi_i^{(k)}$ and is i.i.d. (identical independent distribution) Gaussian, $\phi_i^{(k)} = \psi_i^{(k)} - \psi_1^{(k)}$. The third term in (5) is the JSR defined in (3), can be represented as

$$JSR_{\zeta_i}(t) = LPF\left[\sqrt{2}n'_{i,j}(t)\cos\left(2\pi f_i t + \psi_{1,i}\right)\right] \tag{8}$$

where $LPF[\cdot]$ is applied to express the function of LPF, and the last term of (5) indicates the output signal caused by the fact that the AWGN passes to LPF, and which can be expressed as

$$N_{\zeta_i}(t) = LPF\left[\sqrt{2}n'_{w,i}(t)\cos\left(2\pi f_i t + \psi_i^{(1)}\right)\right] \tag{9}$$

where the terms $n'_{i,j}(t)$ in (8) and $n'_{w,i}(t)$ in (9) results from passing $n_J(t)$ and $n_w(t)$ in (2), respectively, through the i-th bandpass filter. It is necessary to evaluate the SNR (signal-to-noise ratio) at the output of the receiver for the reference user such that the system performance can be determined. Thus all of the statistics results of the signal at the output of the i-th correlator are to be determined and expressed as

$$\chi_i = D_{\chi_i} + MAI_{\chi_i} + JSR_{\chi_i} + N_{\chi_i} \tag{10}$$

where each terms shown in last equation is adopted as that of the same results studied and published in [4].

2.3 The Fading Channel with CFO Consideration

A slowly varying Weibull fading channel is assumed for each transmitting path. All subcarriers are considered to experience flat but correlated fading which may happen at the chance when if no frequency domain interleaver is employed. For adopting a complex envelope say $a_i, i = 0, 1, \ldots, N-1$, which can given as a function of elements with Gaussian in-phase X_i and quadrature Y_i of a path with components $a_i = (X_i + jY_i)^{2/\beta_i}$, where β_i is the well known fading parameter of the Weibull fading model. The parameter β_i can take values $0 < \beta_i < \infty$. In the special case when $\beta_i = 1$, the Weibull distribution becomes an exponential distribution; when $\beta_i = 2$, the Weibull distribution specializes to a Rayleigh distribution. It is well known that the channel state of radio system will be characterized by the value of fading parameter of the Weibull statics. On the other hand, as β increases, the fading severity decreases. The three values of fading parameter, $\beta = 3, 4, 5$ will be adopted as for discussion in the numerical analysis. Let α_i be the magnitude of a_i, that is, $\alpha_i = |a_i|$. Hence for the Weibull fading model, α_i can be expressed as a power transformation of *a* Rayleigh distributed RV (random variable) $R_i = |X_i + jY_i|$ as $\alpha_i = \sqrt[\beta_i]{R_i^2}$, which has the pdf expressed as

$$f_{\alpha_i}(\nu) = \frac{\beta_i}{\Omega_i}\nu^{\beta_i - 1}\exp\left(-\frac{\nu^{\beta_i}}{\Omega_i}\right) \tag{11}$$

where Ω_i denotes the average energy, which is assumed with exponential MIP (multipath intensity profile), i.e., $\Omega_i = \Omega_o e^{-l\delta}$, where Ω_o is the average power of the first channel path, $\delta \geq 0$ is the rate of average power decay [14].

The MRC combining receiver block diagram of an MC-DS-CDMA system with BPF (band-pass filter) and LPF (low pass filter) for the referenced user (the first subscriber) is illustrated in Fig. 2, and the received equivalent low pass signal [26]. There are A_t total antenna number assumed in the combining receiver and the combining subchannel follows after the LPF. The attenuation factor of the useful data is designed when $n = 1$. In order to include the CFO effect in the system performance evaluation of an MC-DS-CDMA system, the ICI (inter-carrier interference) coefficient caused by the nth subcarrier for $n = 2, \ldots, N$ subchannel is given as [23]

$$m_n = [M]_{1,n} = \Lambda(\varepsilon) \cdot e^{j\pi\frac{N-1}{N}(n-1)} \tag{12}$$

where $\Lambda(\varepsilon) = \sin[\pi\,(n-1+\varepsilon)]/N\sin[\pi\,(n-1+\varepsilon)/N]$, and ε indicates the CFO magnitude. Hence, the SNIR (signal-to-noise-interference ratio) includes the CFO at the combining receiver output of an MC-DS-CDMA system can be determined by put (12) together the SNR and becomes as

$$\Sigma_0 = \left\{\Lambda(\varepsilon)|_{n=1} \cdot \left[\frac{2\cdot(k-1)}{N} + \frac{1}{SNR}\right] + \sum_{n=2}^{N}\left|\Lambda(\varepsilon)e^{j\pi\frac{N-1}{N}(n-1)}\right|^2\right\}^{-1} \tag{13}$$

where *SNR* is the ratio of bit energy and the noise result in each antenna.

3 BER Performance Analysis

The conditional mean of χ_i shown in (10), condition upon the channel attenuation factor $\alpha_i^{(1)}$ are given by

$$
\begin{aligned}
E\left[\chi_i|\alpha_i, d_h^{(1)}\right] &= E\left\{\chi_i|\alpha_i^{(1)}, \left\{d_h^{(1)}\right\}\right\} \\
&= \sqrt{E_c}\alpha_i^{(1)} \sum_{n'=0}^{N-1} \sum_{n=-\infty}^{\infty} d_h^{(1)} c_n^{(1)} c_{n'}^{(1)} \cdot x\left[(n'-n)MT_c\right] \\
&= \pm N\sqrt{E_c}\alpha_i^{(1)}
\end{aligned} \tag{14}
$$

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

$$
\begin{aligned}
Var\left\{\chi_i|\alpha_i^{(1)}\right\} &\equiv \sigma_i^2 \\
&= Var\left\{MAI_{\chi_i} + JSR_{\chi_i} + N_{\chi_i}|\alpha_i^{(1)}\right\} \\
&= Var\left\{MAI_{\chi_i}\right\} + Var\left\{JSR_{\chi_i}\right\} + Var\left\{N_{\chi_i}\right\}
\end{aligned} \tag{15}
$$

where the results of each terms shown in the previous equation can be calculated as the procedure given in [4]. All signals at the output of correlators are combined with the RAKE receiver (MRC reception), and the result can be expressed as

$$
\chi = \sum_{\mathrm{i}=1}^{M} G_i \chi_i \tag{16}
$$

where G_i is defined as the channel estimate of the i-th branch. In order to maximize the SNR, the channel estimate G_i is defined as the ratio of the desired signal amplitude to the variance of the noise and interference components in the output, and is written as

$$
G_i = \frac{E\left\{\chi_i|\alpha_i^{(1)}\right\}}{Var\left\{\chi_i|\alpha_i^{(1)}\right\}} \tag{17}
$$

By combining (14) with (15), then the SNR, (S/N) , at the output of RAKE receiver, which is a special case of MRC diversity, can be obtained as

$$
\left(\frac{S}{N}\right) = \frac{E^2\left\{\chi_i|\alpha^{(1)}\right\}}{Var\left\{\chi_i|\alpha^{(1)}\right\}} \equiv N^2 E_c \gamma \tag{18}
$$

where the reference user (1st user) is considered, and

$$
\gamma = \sum_{\mathrm{i}=1}^{M} \frac{\left(\alpha_i^{(1)}\right)^2}{\sigma_i^2} \equiv \sum_{\mathrm{i}=1}^{M} q_i \tag{19}
$$

where the fading branch $\{\alpha_i^{(1)},\ i = 1, \ldots, M\}$ of the reference user are characterized as correlated-Weibull statistic. Generally speaking, it is difficulty to obtain the pdf for the random variable γ in (19) by using of the method of multi-variable transformation. However, the most common solution of approaching the system BER is the utilization of joint MGF. For BPSK signals, the BER can be approximately achieved by [27]

$$
P_e^{case} = \int_0^{\infty} Q\left(\sqrt{N^2 E_c \gamma_{case}}\right) f_\gamma\left(\gamma_{case}\right) d\gamma_{case} \tag{20}
$$

where the γ_{case} in (20) is going to be depended on what the scenario adopted is. For purpose of widely discussing system performance, 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 is necessary, namely, γ_{mu-sc} represents the SNR of multi-user case with single carrier, while γ_{su-mc} indicates the SNR of single-user case with multi-carrier. Similarly, the method will be employed for the symbols σ_0^{cases} and P_e^{cases} of variance and average BER, respectively. The average BER of those cases will be illustrated in the next subsection, respectively. The $Q(x)$ in (20) is the Gaussian Q-function and defined as

$$Q(\mathrm{x}) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\frac{x^2}{2}} dt \tag{21}$$

By changing the variables and using an alternative representation of the Q-function, except the standard expression, as

$$Q(x) = \frac{1}{\pi} \int_0^{\pi/2} \exp\left(-\sqrt{0.5}\left(\frac{x}{\sin\theta}\right)^2\right) d\theta \tag{22}$$

with the use of RAKE receiver, let $\gamma = \sum_{l=0}^{N-1} (\alpha_l)^2$, then the MGF of γ should be determined such that it's pdf can be calculated..

Note that the MGF of a random variable, γ, can be denoted generally as $M_r(s) = E\left[e^{-sr}\right] = \int_0^{\infty} e^{-sr} f_r(r)\, dr$. Thus, the average BER for a MC-DS-CDMA system over correlated-Weibull fading can be derived by substituting the MGF of correlated-Weibull fading distribution in (11) and the Q-function shown in (22), respectively, into (20), the system BER can be obtained as

$$\begin{aligned} P_{BER} &= \int_0^{\infty} Q\left(\sqrt{\sigma_0 \gamma}\right) f(\gamma)\, \gamma \\ &= \frac{1}{\pi} \int_0^{\infty} \int_0^{\pi/2} \exp\left(-\frac{\sigma_0 \gamma}{\sin^2\theta}\right) f(\gamma)\, d\theta d\gamma \\ &= \frac{1}{\pi} \int_0^{\pi/2} M_\gamma(s, \beta) d\theta \end{aligned} \tag{23}$$

where $s = \sigma_0 / \sin^2\theta$ is generated by the definition of MGF.

3.1 System BER with Dual-Branch

The system BER of an MC-DS-CDMA systems over correlated-Weibull fading channel are going to be inspected by the next subsection with a dual-branch RAKE receiver. The MGF of correlated-Weibull fading with dual-branch can be obtained by putting $L = 2$ into the general form of MGF shown in [22], and it is given as

$$M_{\alpha_1,\alpha_2}(\alpha_1,\alpha_2) = \beta_1\beta_2 \sum_{k=0}^{\infty} \frac{\rho^k}{(k!)^2(1-\rho)^{2k+1}} \prod_{\mathrm{i}=1}^{2} \frac{1}{\left(\alpha_i^{\beta_i}\Omega_i\right)^{k+1}} \times \Upsilon\left[\frac{1}{(1-\rho)\,\alpha_i^{\beta_i}\Omega_i}, (k+1)\,\beta_i\right] \tag{24}$$

where$\Upsilon(\xi, u)$ was defined in [28]. Once the value of β_i was assumed that belongs to rational number, h and λ have to satisfy $\lambda = h \cdot \beta_i$. By using of the formula shown in (23), the system BER with different conditions for all the cases can be analyzed as follows.

3.2 Multi-user Scenario

3.2.1 Multi-carrier

First, we consider a multi-user case with multi-carrier, and assume that the correlation between the spread codes is adjustable as $R_{I_i}(\ell M T_c) = \sum_{n'=\ell}^{N-1} C_{1,n'}C_{1,n-l} = 0$, such that the autocorrelation function, $R_{I_i}(0)$, which can be obtained from [4] and represented as

$$R_{I_i}(0) = \int_{-\infty}^{\infty} S_{I_i}(f)df = \frac{(K-1)E_c}{2}\left(1-\frac{\mu}{4}\right) \tag{25}$$

Thus, the conditional SNR, γ_{mu-mc}, of the multiple user case with multi-carrier at the output of the receiver can be determined from Eq. (14) and (15), which is written as

$$\gamma_{mu-mc} = \sigma_0^{mu-mc} \frac{1}{M} \sum_{\mathrm{i}=1}^{M} (\alpha_{1,i})^2 \tag{26}$$

where σ_0^{mu-mc} is able to be gained by easily put the CFO parameter illustrated in (12) into (19) and denoted as

$$\sigma_0^{mu-mc} = \left\{ \frac{\sin[\pi(\varepsilon)]}{N\sin\left[\frac{\pi(\varepsilon)}{N}\right]} \cdot \left[\left\{\frac{K-1}{MN}\left(1-\frac{\mu}{4}\right)+\frac{1}{snr}\right\}^{-1}\frac{1}{M}+\frac{1}{snr}\right] + \sum_{n=2}^{\mathrm{N}} \left| \frac{\sin[\pi(n-1+\varepsilon)]}{N\sin\left[\frac{\pi(n-1+\varepsilon)}{N}\right]} e^{j\pi\frac{N-1}{N}(n-1)} \right|^2 \right\}^{-1} \tag{27}$$

where N represents the chip number per symbol for the multi-carrier case, and $\eta_0/2$ is a double-sided PSD of the AWGN, $MNE_c = N_1E_{c1} = E_b$, where E_b denotes the bit energy, and N_1 and E_{c1} are the length and the energy of the spreading code, respectively. In order to calculate the system BER formula for the case of multi-user with multicarrier, P_{BER}^{mu-mc}, by substituting (26) into (23), and it can be obtained as

$$
\begin{aligned}
P_{BER}^{mu-mc} &= \int_0^\infty Q\left(\sqrt{\sigma_0 \gamma}\right) f\left(\alpha^{(1)}\right) d\alpha_0^{(1)} d\alpha_1^{(1)} \\
&= \frac{1}{\pi} \int_0^\infty \int_0^{\pi/2} \exp\left(-\frac{\sigma_0^{mu-mc} \gamma_{mu-mc}}{\sin^2\theta}\right) f\left(\gamma_{mu-mc}\right) d\theta d\gamma_{mu-mc} \\
&= \frac{1}{\pi} \int_0^{\pi/2} M_\gamma\left(s, \beta\right) d\theta
\end{aligned} \tag{28}
$$

where γ_{mu-mc} and σ_0^{mu-mc} are shown in (26) and (27), respectively, and next by substituting the MGF shown in (24) into (23), the system BER formula becomes as

$$
\begin{aligned}
P_{BER}^{mu-mc} = \frac{1}{\pi} \int_0^{\frac{\pi}{2}} \beta_1 \beta_2 \sum_{k=0}^\infty \frac{\rho^k}{(k!)^2 (1-\rho)^{2k+1}} \prod_{\mathrm{i}=1}^{2} \frac{1}{\left(s_i^{\beta_i} \Omega_i\right)^{k+1}} \Upsilon \\
\times \left[\frac{1}{(1-\rho) s_i^{\beta_i} \Omega_i}, (k+1)\beta_i\right] d\theta
\end{aligned} \tag{29}
$$

where $s_i = -\sigma_0^{mu-mc}/\sin^2\theta$. We define the average bit SNR as $snr = MNE_c/\eta_0$.

3.2.2 Single-carrier

Similarly, the conditional SNR, γ_{mu-sc}, of a single-carrier RAKE receiver, can be determined as

$$
\gamma_{mu-sc} = \sigma_0^{mu-sc} \sum_{\mathrm{i}=1}^{M} \left(\alpha_i^{(1)}\right)^2 \tag{30}
$$

where σ_0^{mu-sc} is denoted as

$$
\begin{aligned}
\sigma_0^{mu-sc} = \Bigg\{ \frac{\sin[\pi(\varepsilon)]}{N \sin\left[\frac{\pi(\varepsilon)}{N}\right]} \cdot \left[\left\{ \left\{ \frac{K-1}{2N_1}\left(1-\frac{\mu}{4}\right) + \frac{\eta_0}{2N_1 E_{c1}} \right\}^{-1} + \frac{1}{snr} \right\}^{-1} \frac{1}{M} + \frac{1}{\mathrm{snr}} \right] \\
+ \sum_{n=2}^{\mathrm{N}} \left| \frac{\sin[\pi(n-1+\varepsilon)]}{N \sin\left[\frac{\pi(n-1+\varepsilon)}{N}\right]} e^{j\pi\frac{N-1}{N}(n-1)} \right|^2 \Bigg\}^{-1}
\end{aligned}
$$

where the symbol of the length and the chip energy of the spreading sequence are replaced with the symbols N_1, and E_{c1}, respectively. The system BER, P_{BER}^{mu-sc}, of this case can be obtained by putting (11) and (22) into (20) and exactly calculated as

$$
\begin{aligned}
P_{BER}^{mu-sc} &= \int_0^\infty Q\left(\sqrt{\sigma_0 \gamma}\right) f\left(\alpha^{(1)}\right) d\alpha_0^{(1)} d\alpha_1^{(1} \\
&= \frac{1}{\pi} \int_0^\infty \int_0^{\pi/2} \exp\left(-\frac{\sigma_0^{mu-sc} \gamma_{mu-mc}}{\sin^2\theta}\right) f\left(\gamma_{mu-sc}\right) d\theta d\gamma_{mu-sc}
\end{aligned}
$$

$$= \frac{1}{\pi} \int_0^{\pi/2} M_\gamma (s, \beta) d\theta \tag{31}$$

where γ_{mu-sc} and σ_0^{mu-sc} are shown in (29), and next with the same way as in the previous case by substituting the MGF shown in (24) into (23), the system BER formula for this case becomes as

$$P_{BER}^{mu-sc} = \frac{1}{\pi} \int_0^{\frac{\pi}{2}} \beta_1 \beta_2 \sum_{k=0}^{\infty} \frac{\rho^k}{(k!)^2 (1-\rho)^{2k+1}} \prod_{\mathrm{i}=1}^{2} \frac{1}{\left(s_i^{\beta_i} \Omega_i\right)^{k+1}} \Upsilon \times \left[\frac{1}{(1-\rho) s_i^{\beta_i} \Omega_i}, (k+1) \beta_i \right] d\theta \tag{32}$$

where $s_i = -\sigma_0^{mu-sc} / \sin^2 \theta$. The average bit SNR is defined as $snr = MNE_c/\eta_0$, thus the σ_0^{mu-sc} in (31) can be replaced with $\sigma_0^{mu-sc} = \left\{ \frac{K-1}{2N_1} \left(1 - \frac{\mu}{4}\right) + \frac{\eta_0}{2N_1 E_{c1}} \right\}^{-1}$, where $MNE_c = N_1 E_{c1} = E_b$, E_b denotes the bit energy, N_1 and E_{c1} are length and energy of the spreading code, respectively.

3.2.3 Multi-carrier and PBI

The conditional SNR, $\gamma_{mu-mc-PBI}$, of a multi-carrier with PBI can be determined from (13) and expressed as

$$\gamma_{mu-mc-PBI} = \sigma_0^{mu-mc-PBI} \frac{1}{M} \sum_{\mathrm{i}=1}^{M} \left(\alpha_{1,i}\right)^2 \tag{33}$$

where

$$\sigma_0^{mu-mc-PBI} = \left\{ \frac{\sin[\pi(\varepsilon)]}{N \sin\left[\frac{\pi(\varepsilon)}{N}\right]} \cdot \left[\left\{ \frac{K-1}{2MN} \left(1 - \frac{\mu}{4}\right) + \frac{\eta_0}{2MNE_c} + \frac{\eta_J}{2MNE_c} \right\}^{-1} \frac{1}{M} + \frac{1}{\mathrm{snr}} \right] + \sum_{n=2}^{\mathrm{N}} \left| \frac{\sin[\pi(n-1+\varepsilon)]}{N \sin\left[\frac{\pi(n-1+\varepsilon)}{N}\right]} e^{j\pi \frac{N-1}{N}(n-1)} \right|^2 \right\}^{-1},$$

where η_J represents the JSR defined in (4). By using of the same steps as that of the derived results expressed in (27), and the system BER under this assumption, $P_e^{mu-mc-PBI}$, can be determined as

$$\begin{aligned} P_e^{mu-mc-PBI} &= \int_0^{\infty} Q\left(\sqrt{\sigma_0 \gamma}\right) f\left(\alpha^{(1)}\right) d\alpha_0^{(1)} d\alpha_1^{(1)} \\ &= \frac{1}{\pi} \int_0^{\infty} \int_0^{\pi/2} \exp\left(- \frac{\sigma_0^{mu-mc-PBI} \gamma_{mu-mc-PBI}}{\sin^2 \theta} \right) \\ &\quad \times f\left(\gamma_{mu-mc-PBI}\right) d\theta d\gamma_{mu-mc-PBI} \end{aligned}$$

$$= \frac{1}{\pi} \int_{0}^{\pi/2} M_{\gamma}\,(s,\beta) d\theta \tag{34}$$

where $\gamma_{mu-mc-PBI}$ and $\sigma_0^{mu-mc-PBI}$ are shown in (33), and next by substituting the MGF shown in (27) into (34), the system BER formula becomes as

$$P_{BER}^{mu-mc-PBI} = \frac{1}{\pi} \int_{0}^{\frac{\pi}{2}} \beta_1 \beta_2 \sum_{k=0}^{\infty} \frac{\rho^k}{(k!)^2\,(1-\rho)^{2k+1}} \times \prod_{\mathrm{i}=1}^{2} \frac{1}{\left(s_i^{\beta_i}\Omega_i\right)^{k+1}} \Upsilon\left[\frac{1}{(1-\rho)\,s_i^{\beta_i}\Omega_i}, (k+1)\,\beta_i\right] d\theta \tag{35}$$

where $s_i = -\sigma_0^{mu-mc-PBI}/\sin^2\theta$. We define the average bit SNR as $snr = MNE_c/\eta_0$, thus the $\sigma_0^{mu-mc-PBI}$ in (32) can be replaced with $\sigma_0^{mu-sc} = \left\{\frac{K-1}{2MN}\left(1-\frac{\mu}{4}\right) + \frac{\eta_0}{2MNE_c} + \frac{\eta_J}{2MNE_c}\right\}^{-1}\frac{1}{M}$, where $MNE_c = N_1 E_{c1} = E_b$, and E_b denotes the bit energy, N_1 and E_{c1} are length and energy of the spreading code, respectively.

3.3 Single-user Scenario

3.3.1 Multi-carrier

Next, the conditional SNR of single-user and multiple-carrier case, γ_{su-mc}, at the output of the receiver can be calculated with the same way as that adopted in the case of multiple user's, and the values of the user number will be substituted by $K = 1$into (23). The conditional SNR, γ_{su-mc}, becomes as

$$\gamma_{su-mc} = \sigma_0^{su-mc} \sum_{\mathrm{i}=1}^{M} (\alpha_{1,i})^2 \tag{36}$$

where σ_0^{su-mc} is denoted as

$$\sigma_0^{su-mc} = \left\{ \frac{\sin[\pi(\varepsilon)]}{N\sin\left[\frac{\pi(\varepsilon)}{N}\right]} \cdot \left[\frac{\eta_0 \cdot M}{2MNE_c} + \frac{1}{\mathrm{snr}}\right] + \sum_{n=2}^{\mathrm{N}} \left| \frac{\sin[\pi(n-1+\varepsilon)]}{N\sin\left[\frac{\pi(n-1+\varepsilon)}{N}\right]} e^{j\pi\frac{N-1}{N}(n-1)} \right|^2 \right\}^{-1}$$

By following the same steps as shown in (19), we can obtain the system BER, P_e^{su-mc}, for single-user and multi-carrier case as

$$
\begin{aligned}
P_e^{su-mc} &= \int_0^{\infty} Q\left(\sqrt{\sigma_0 \gamma}\right) f\left(\alpha^{(1)}\right) d\alpha_0^{(1)} d\alpha_1^{(1)} \\
&= \frac{1}{\pi} \int_0^{\infty} \int_0^{\pi/2} \exp\left(-\frac{\sigma_0^{su-mc} \gamma_{su-mc}}{\sin^2 \theta}\right) f\left(\gamma_{su-mc}\right) d\theta d\gamma_{su-mc} \\
&= \frac{1}{\pi} \int_0^{\pi/2} M_{\gamma}\left(s, \beta\right) d\theta \qquad (37)
\end{aligned}
$$

where γ_{su-mc} and σ_0^{su-mc} are shown in (36), and next by substituting the MGF shown in (25) into (37), the system BER formula becomes as

$$
\begin{aligned}
P_{BER}^{su-mc} &= \frac{1}{\pi} \int_0^{\frac{\pi}{2}} \beta_1 \beta_2 \sum_{k=0}^{\infty} \frac{\rho^k}{(k!)^2 (1-\rho)^{2k+1}} \prod_{\mathrm{i}=1}^{2} \frac{1}{\left(s_i^{\beta_i} \Omega_i\right)^{k+1}} \Upsilon \\
&\quad \times \left[\frac{1}{(1-\rho) s_i^{\beta_i} \Omega_i}, (k+1) \beta_i\right] d\theta \qquad (38)
\end{aligned}
$$

where $s_i = -\sigma_0^{su-mc}/\sin^2 \theta$. We define the average bit SNR as $snr = MNE_c/\eta_0$, thus the σ_0^{su-mc} in (36) can be replaced with$\sigma_0^{mu-sc} = 2NE_c/\eta_0$, where $MNE_c = N_1 E_{c1} = E_b$, E_b denotes the bit energy, N_1 and E_{c1} are length and energy of the spreading code, respectively.

3.3.2 Single- carrier

Similarly, the conditional SNR of a single-carrier RAKE receiver, γ_{su-sc}, is given as

$$
\gamma_{su-sc} = \sigma_0^{su-sc} \sum_{i=i}^{L} \left(\hat{\alpha}_{1,i}\right)^2 \qquad (39)
$$

where σ_0^{su-sc} is denoted as

$$
\sigma_0^{su-sc} = \left\{ \frac{\sin[\pi(\varepsilon)]}{N \sin\left[\frac{\pi(\varepsilon)}{N}\right]} \cdot \left[\frac{\eta_0 \cdot M}{2MNE_c} + \frac{1}{\mathrm{snr}}\right] + \sum_{n=2}^{\mathrm{N}} \left| \frac{\sin[\pi(n-1+\varepsilon)]}{N \sin\left[\frac{\pi(n-1+\varepsilon)}{N}\right]} e^{j\pi \frac{N-1}{N}(n-1)} \right|^2 \right\}^{-1}
$$

where L is the number of resolvable paths of the channels. Note that the parameter has been set as $MNE_c = N_1 E_{c1} = E_b$ in the last equation. Thus the average BER, P_e^{su-sc}, of single-user and single-carrier can be determined as

$$
\begin{aligned}
P_e^{su-sc} &= \int_0^{\infty} Q\left(\sqrt{\sigma_0 \gamma}\right) f\left(\alpha^{(1)}\right) d\alpha_0^{(1)} d\alpha_1^{(1)} \\
&= \frac{1}{\pi} \int_0^{\infty} \int_0^{\pi/2} \exp\left(-\frac{\sigma_0^{su-sc} \gamma_{su-sc}}{\sin^2 \theta}\right) f\left(\gamma_{su-sc}\right) d\theta d\gamma_{su-sc}
\end{aligned}
$$

$$= \frac{1}{\pi} \int_{0}^{\pi/2} M_{\gamma}\,(s, \beta) d\theta \tag{40}$$

where γ_{su-sc} and σ_0^{su-sc} are shown in (39), and next by substituting the MGF shown in (25) into (40), the system BER formula becomes as

$$P_{BER}^{su-sc} = \frac{1}{\pi} \int_{0}^{\frac{\pi}{2}} \beta_1 \beta_2 \sum_{k=0}^{\infty} \frac{\rho^k}{(k!)^2\,(1-\rho)^{2k+1}} \prod_{i=1}^{2} \frac{1}{\left(s_i^{\beta_i} \Omega_i\right)^{k+1}} \Upsilon \\ \times \left[\frac{1}{(1-\rho)\, s_i^{\beta_i} \Omega_i}, (k+1)\, \beta_i \right] d\theta \tag{41}$$

where $s_i = -\sigma_0^{su-sc}/\sin^2\theta$. We define the average bit SNR as $snr = MNE_c/\eta_0$, thus the σ_0^{su-sc} in (39) can be replaced with $\sigma_0^{su-sc} = 2NE_c/\eta_0$, where $MNE_c = N_1 E_{c1} = E_b$, E_b denotes the bit energy, N_1 and E_{c1} are length and energy of the spreading code, respectively.

3.3.3 Multi-carrier with PBI

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

$$\gamma_{su-mc-PBI} = \sigma_0^{su-mc-PBI} \frac{1}{M} \sum_{i=1}^{M} \left(\alpha_{1,i}\right)^2 \tag{42}$$

where $\sigma_0^{su-mc-PBI}$ denoted as

$$\sigma_0^{su-mc-PBI} = \left\{ \frac{\sin[\pi(\varepsilon)]}{N \sin\left[\frac{\pi(\varepsilon)}{N}\right]} \cdot \left[\left(\frac{2MNE_c}{\eta_0} + \frac{2MNE_c}{\eta_J} \right)^{-1} \frac{1}{M} + \frac{1}{\text{snr}} \right] \right. \\ \left. + \sum_{n=2}^{\text{N}} \left| \frac{\sin[\pi(n-1+\varepsilon)]}{N \sin\left[\frac{\pi(n-1+\varepsilon)}{N}\right]} e^{j\pi \frac{N-1}{N}(n-1)} \right|^2 \right\}^{-1}$$

The system BER, $P_e^{su-mc-PBI}$, is also can be determined by the same procedures of the last case, and obtained as

$$\begin{aligned} P_e^{su-mc-PBI} &= \int_{0}^{\infty} Q\left(\sqrt{\sigma_0 \gamma}\right) f\left(\alpha^{(1)}\right) d\alpha_0^{(1)} d\alpha_1^{(1)} \\ &= \frac{1}{\pi} \int_{0}^{\infty} \int_{0}^{\pi/2} \exp\left(-\frac{\sigma_0^{su-mc-PBI} \gamma_{su-mc-PBI}}{\sin^2\theta} \right) \\ &\quad \times f\,(\gamma_{su-mc-PBI})\, d\theta d\gamma_{su-mc-PBI} \\ &= \frac{1}{\pi} \int_{0}^{\pi/2} M_{\gamma}\,(s, \beta) d\theta \end{aligned} \tag{43}$$

where $\gamma_{su-mc-PBI}$ and $\sigma_0^{su-mc-PBI}$ are shown in (42), and next by substituting the MGF shown in (25) into (43), the system BER formula becomes as

$$P_{BER}^{su-mc-PBI} = \frac{1}{\pi}\int_0^{\frac{\pi}{2}} \beta_1\beta_2 \sum_{k=0}^{\infty} \frac{\rho^k}{(k!)^2(1-\rho)^{2k+1}} \times \prod_{\mathrm{i}=1}^{2} \frac{1}{\left(s_i^{\beta_i}\Omega_i\right)^{k+1}} \Upsilon\left[\frac{1}{(1-\rho)s_i^{\beta_i}\Omega_i}, (k+1)\beta_i\right] d\theta \tag{44}$$

where $s_i = -\sigma_0^{su-mc-PBI}/\sin^2\theta$. The average bit SNR as $snr = MNE_c/\eta_0$, thus the $\sigma_0^{su-mc-PBI}$ in (42) can be replaced with $\sigma_0^{su-mc-PBI} = 2NE_c/\eta_0$, where $MNE_c = N_1E_{c1} = E_b$, E_b denotes the bit energy, N_1 and E_{c1} are length and energy of the spreading code, respectively.

4 Results and Discussion

On the basis of each scenario considered in last section, several of the numerical evaluating results are discussed in this section. The result shown in this subsection adopts varied parameters, such as those mentioned in the introduction section. In Fig. 3 shows plots of BER versus average bit SNR (E_b/N_0) with user number, $K = 30$, receive path number, $M = 4$, subcarrier number, $N = 64$, and without the PBI, different values of fading parameters of Weibull distribution, $\beta = 3, 4, 5$, and different CFO values, $\varepsilon = 0.5, 0.25, 0$. The performance is normally degraded by the factor of much less fading parameters, and the less CFO values the better system performance is. With the fixed subcarrier number $N = 64$, and the same parameters were adopted in Fig. 3 except the fading parameter, $\beta = 3$ and with the PBI, $JSR = 2dB$. Results of bit SNR versus BER curves are shown in Fig. 4 with different user

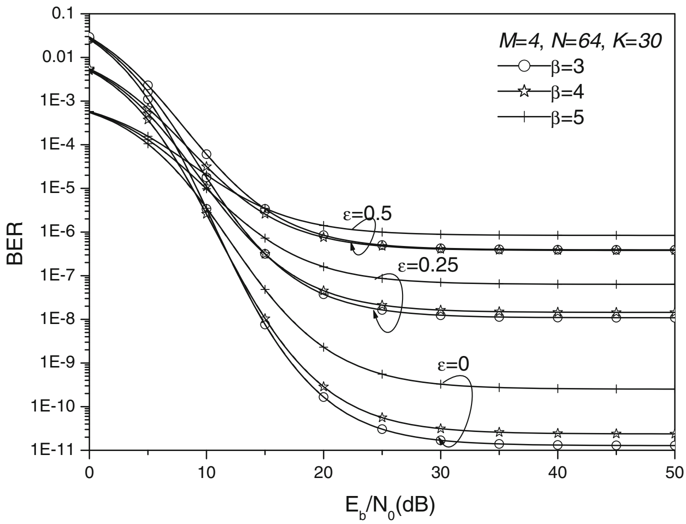

Fig. 3 Plots of BER versus SNR with different CFO values without PBI

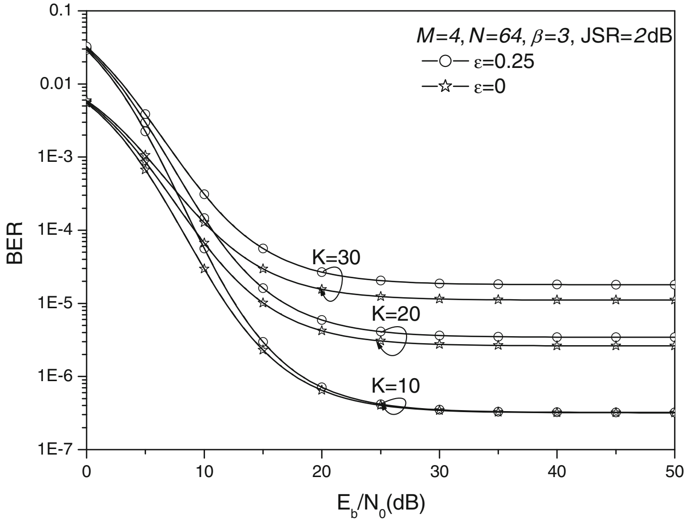

Fig. 4 Plots of BER versus SNR with different user numbers and $JSR = 2dB$

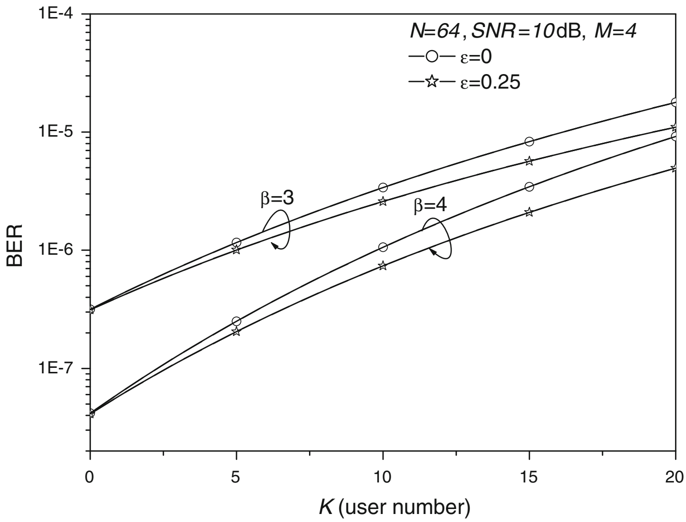

Fig. 5 Plots of BER versus user number with different CFO values and fading parameters without PBI

numbers and different CFO values. It is reasonable to observe that the much more MAI due to the much more user number will cause the system performance become decline. The same things described in Fig. 4 are shown in Fig. 5 in which curves of BER versus user number are presented. However, some parameters are different adopted in Fig. 5, such as the SNR fixed with, $SNR = 10dB$, and without PBI. In other words, the results from the influence of PBI are illustrated in Figs. 6 and 7. In the former one where curves of BER versus average bit SNR are variating with different CFO values, $\varepsilon = 0.5, 0.25, 0$, and the situation with PBI and without PBI. It is worthy understanding that the system performance always superior when the situation is in PBI nonexistence, *i.e.*, it is significant that when the value of PBI is

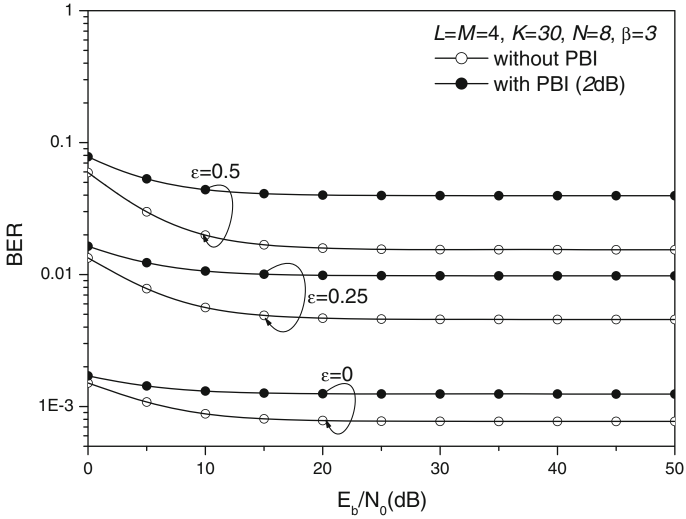

Fig. 6 Plots of BER versus SNR with different CFO values

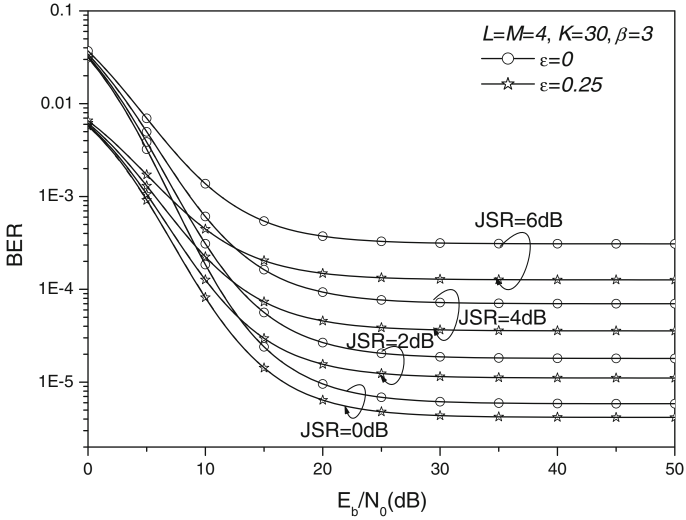

Fig. 7 Plots of BER versus SNR with different CFO values and JSR values

smaller, the better performance of the system is. Hence, in order to insist on this phanomena the different PBI values, $JSR = 0, 2, 4, 6\,dB$, are employed to obtain results of BER versus average bit SNR and depicted in the latter one. On the other hands, it can easily understand from both figures that the system performance become inferior, once the PBI factor is taken into account and increase. Finally, in Fig. 8 the plots of BER versus SNR are presented for discussing to the subcarrier number. It is valuable to observe that much more increases in subcarrier number will cause the system performance becomes superior.

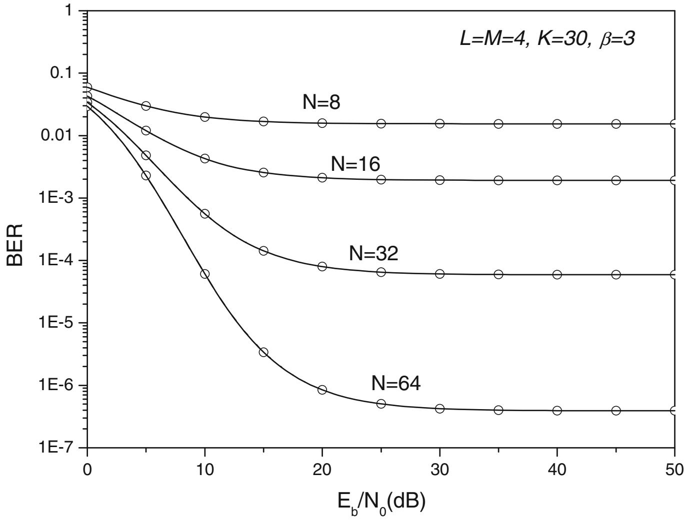

Fig. 8 Plots of BER versus SNR with different subcarrier numbers

5 Conclusions

In this paper the approximate expression of system performance for MC-DS-CDMA system with correlation coefficient between fading branch is evaluated. The pdf of SNR at the output of Rake receiver (MRC diversity scheme) for MC-DS-CDMA system under different cases, which are combined with multi-user and single-user cases, is determined. Besides, the influence of JSR is also assumed for one of the system parameter. By comparison the system BER with the different correlation coefficients, branch number, and number of subcarrier are considered to analyze for the purpose of validation. The derived results prove that the correlation coefficients will degrade the performance of MC-DS-CDMA system definitely. 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 Rayleigh distribution. However, what are the main factors that affect the system performance results from our scenario with Weibull fading channel is in accordance with that all of the known main parameters in the previous works, for example, the number of spreading chip number, branch number, user's number, fading parameter, and JSR etc.

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Author Biographies

Joy Iong-Zong Chen was born in Taiwan, ROC. He received his B.Sc. degrees in Electronics Engineering from the National Taiwan Technical University, Taipei, Taiwan, and M.Sc. degrees in electrical engineering from the Dayeh University, Chung Hua, Taiwan, in 1985 and 1995, respectively, and Ph.D. degrees in Electrical Engineering from National Defense University, Tao-Yuan, Taiwan, in 2001. He is currently an associate professor of Dep. of Electrical Engineering Dayeh University at Chang-Hua Taiwan. Prior to joining the Dayeh University, he worked at the Control Data Company (Taiwan) as a technical manager since Sep. 1985 to Sep. 1996. His research interests include wireless communications, spread spectrum technical, OFDM signaling and multicarrier-CDMA systems.

Wen Ching Kuo was born in Taiwan. He received his B.Sc. degree in Public Administration from the Tamkang University, Taipei, Taiwan, and M.Sc. degree in Business Administration from the Dayeh University, Chung Hwa, Taiwan, in 2002 and 2003. He is currently a director of Extension Education Center of Transworld Institute of Technology. His research interests include Education of Technology, Administration of Technology.