BER of Overloaded Cellular DS-CDMA System with Imperfect Power Control

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Abstract—**Overloading is a technique to accommodate more number of users than the spreading factor N. This is a bandwidth efficient scheme to increase the number users or data rate in a fixed bandwidth. These schemes can be used to avoid the orthogonal code shortage problem to provide broadband wireless access in cellular communication. One of the efficient schemes to overload a CDMA system is to use two sets of orthogonal signal waveforms (O/O). The first set is assigned to the N users and the second set is assigned to the additional users. An iterative multistage detection (IMSD) technique is used to cancel interference between the two sets of users. In this paper, the BER performance of a new overloading scheme using orthogonal Gold code (OG/OG) sets is evaluated with soft decision interference cancellation scheme (SDIC). It is observed that this scheme provides 25% channel overloading for synchronous DS-CDMA system in an AWGN channel for spreading factor length N = 64, assuming perfect power control. The SNR degradation is about 0.35 dB as compared to single user bound at a BER of 1e-5. With imperfect power control, the BER performance degrades considerably and we can only overload up to 11% with an SNR degradation of about 1.25 dB as compared to perfect power control single user bound at a BER of 1e-5.**

Keywords-DS-CDMA; power controlg; cell overloading

I. Introduction

The number of users supported in a DS-CDMA cellular system is typically less than spreading factor (N), and the system is said to be underloaded. Overloading is a technique to accommodate more number of users than the spreading factor N. This is an efficient way to increase the number users in a fixed bandwidth, which is of practical interest to mobile system operators. Infact this type of channel overloading is provisioned in the **3G** standard [1].

Among the approaches described in the literature, the most efficient ones use multiple sets of orthogonal codes [2]. The concept of overloading in a DS-CDMA system using two sets of orthogonal codes is explained with the help of Fig.1. For the first N users, the system allocates orthogonal codes drawn from the first set of N codes. When the number of intending users exceeds ‘N’, the excess users are accommodated in the system by providing suitable codes drawn from a second set of M codes. In this way, we are able to accommodate more number of users than the spreading length N (K>N), and the cell becomes overloaded.

The number of active users (K) in a conventional synchronous orthogonal CDMA environment is limited by the spreading factor N, which is WT where W is the transmission bandwidth and T is the duration of a symbol. In synchronous CDMA system, synchronism between signatures can be maintained in the downlink of cellular systems with relative ease and hence, orthogonal signatures (Walsh functions) are used in the downlink of **IS-95** and **UMTS** mobile radio standards. Even in the uplink of UMTS, usage of orthogonal signatures has been advocated to realize multi-code channelization. Also, with multicarrier-CDMA, the signal alignment can be maintained for much weaker synchronization requirements, by application of an appropriate cyclic prefix and single-tap equalization. This makes the study of CDMA systems with time aligned signatures and hence overloading justified for both uplink and downlink transmission.

When K exceeds N, the system becomes overloaded and the signatures are no longer orthogonal. This leads to multiple access interference (MAI). In an overloaded system, a conventional matched filter receiver is not optimal, due to the high level of MAI. Multiuser detection (MUD) is required in order to obtain a satisfactory performance of the users. Linear MUD’s, such as the decorrelator, the minimum mean squared error detector or linear decision directed interference cancellation are devised to detect users in an underloaded system. The Maximum Likelihood (ML) detection is not an option because of its complexity that is exponential in the number of users. The nonlinear MUD’s such as multistage parallel interference cancellation (PIC) and successive interference cancellation (SIC) [3], have good complexity-performance trade-off as compared to other MUD’s. Hence these MUDs are suitable for overloaded systems. Thus, the problem of overloading DS-CDMA systems may be stated as: how to increase the number of spreading codes, or the number of users K, without increasing the dimension N, while keeping MAI in minimum, to ensure low complexity of the receiver.

It is interesting to note that several studies have been made in the recent past to understand, analyze and counter the detrimental effects of overloading. Almost all studies consider the uplink or reverse link and several studies suggest usage of appropriate multiuser detection (MUD) schemes at the base station receiver. For example, a method of accommodating K = N + M users in an N-dimensional signal space that does not compromise the minimum Euclidean distance of the orthogonal signaling has been presented in [4] for AWGN channel. A tree-like correlation coefficient structure of user signatures suitable for optimal multiuser detection has been proposed in [5]. In another approach, two sets of orthogonal codes which are orthogonal within the sets is introduced in [6]. In this paper, the orthogonal sets are generated using Walsh Hadamard (WH) codes, where the same WH code set is

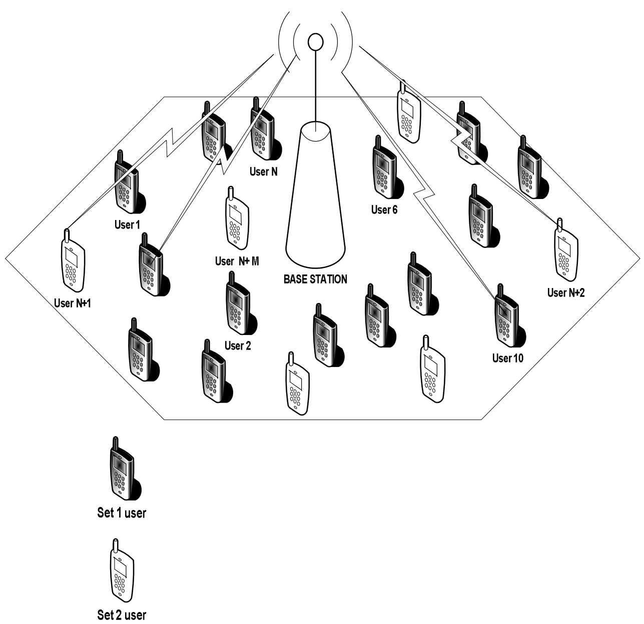

Figure 1. Overloading scheme in a DS-CDMA cellular system

scrambled with set specific scrambling sequence (s-O/O). An iterative multistage detection technique has been proposed to cancel the interference between the two sets of user. In [7], it is shown that for uncoded BPSK modulated CDMA signal with N=64, an overloading of 11% can be achieved in an AWGN channel for s-O/O scheme. Recently, the performance of an overloading scheme where only one orthogonal set is scrambled is evaluated in [8]. Another kind of receiver simplification is presented in [9], where signals are divided into groups that are orthogonal to each other. A new overloading scheme using hybrid techniques has been proposed in [10], where the spreading codes and transmission modes are different for the two sets to increase the overloading performance. The attractive property of overloading scheme was the incentive to integrate a particular type of O/O, called quasi-synchronous sequences (QOS) [11], into cdma2000 standard [12].

To the best of our knowledge, the usage of orthogonal Gold codes has not been considered in any of the overloading schemes. In [13], a new method for generating different orthogonal sets of same length has been proposed. The new algorithm generates (N-1) distinct, orthogonal sets of N sequences of length N. It has been shown that the peak value of crosscorrelation between different sets of same length is less than half the sequence length for $N \geq 32$. Such sequence sets would offer low intracell interference, when used in overloaded environment. In this paper, we have evaluated the BER performance using orthogonal Gold code (OG/OG) sets [13] with SDIC receiver.

This paper is organized as follows. In the next section, we describe the system model for the O/O overloading scheme. In section-3 we explain the IMSD operation and describe the process of iterative interference cancellation. Simulation results are presented and discussed in Section-4. Finally, we present the conclusion of this paper.

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II. System Model

In the sequel we will consider the DS-CDMA system with processing gain N and the number of users K *(=M+N)*. We assume that the channel is a nondispersive additive white Gaussian noise (AWGN) channel and that the different user signals are in perfect time synchronism. The signal $s_{u,k_u}(t)$ is the signature waveform of the k-th user in set-u, where $u \in \{1,2\}$, $k_1 \in \{1,2,3.......N\}$ for set-1 and $k_2 \in \{1,2,3.......M\}$ for set-2 users ($M \leq N$). Here N is number of users in set-1 and M number of users in set-2. The signature waveform may be expressed as:

$$s_{u,k_u}(t) = \sum_{j=1}^{N} s^j_{u,k_u} p_c(t - jT_c) \qquad (2.1)$$

where $s^j_{u,k_u} \in \{-1,1\}$, T_c is the chip duration and $p_c(t)$ is the real valued unit-energy rectangular chip pulse . All users signatures are normalized such that $\left\| s_{u,k_u}(t) \right\|^2 = 1$. We assume that all set-1 users are operational and hence N=Maximum number of users in set-1. Let us denote $\mathbf{S}_1$ and $\mathbf{S}_2$ as the signature matrices of the set-1 and set-2 users respectively. In this paper, we have considered two different orthogonal Gold code sets [13] for set-1 and set-2 users.

Let us denote $\mathbf{b}_1$ and $\mathbf{b}_2$ as the data matrices of the set-1 and set-2 users respectively. The data signal $b_{u,k_u}(t)$ of the k-th users in set-u, can be expressed as

$$b_{u,k_u}(t) = \sum_{l=-\infty}^{\infty} b^l_{u,k_u} p_{T_b}(t - lT_b) \qquad (2.2)$$

where, data sequences $b^l_{u,k_u} \in \{-1,1\}$ are independent and identically distributed (i.i.d.) random variables taking values of +1 and -1 with equal probability. In (2.2), T_b is bit duration, N is the spreading factor and $p_{T_b}(t)$ is the rectangular pulse of the information data bits. Matrices $\mathbf{A}_1$

and $\mathbf{A}_2$ are diagonal matrices of received signal amplitudes for two sets of users and can be expressed as:

$$\begin{aligned}\mathbf{A_1} &= diag[A_{1,1}\cos(\phi_{1,1}),..., A_{1,N}\cos(\phi_{1,\mathrm{N}})]\\ \mathbf{A}_2 &= diag[A_{2,1}\cos(\phi_{2,1}),.., A_{2,M}\cos(\phi_{2,\mathrm{M}})]\end{aligned} \quad (2.3)$$

In (2.3), the received signal amplitude, $A_{u,k_u} = \sqrt{P_{u,k_u}}$, where P_{u,k_u} is the received power of the k-th user of the set-u. A perfect power control is generally assumed in the analysis of CDMA system [14]. Field trials of the CDMA system have indicated that a power control with lognormal average received power distribution and 1 to 2 dB variance is more realistic. Thus the power level of each user received at base station from both sets, denoted as p_i has a log-normal distribution,

$$f(P_{u.k_u}) = \frac{1}{\sqrt{2\pi}\sigma_l P_{u.k_u}} e^{-(\ln P_{u.k_u} - m_l)^2 / 2\sigma_l^2}$$

Where $m_l = m_n \ln(10)/10,\ \sigma_l = \sigma_n \ln(10)/10$, m_n and σ_n are the mean and standard deviation of the corresponding distribution in dB, respectively. Log-normal distribution random variable $P_{u.k_u}$ can be obtained from a normal random variable $X_{u.k_u}$ with transformation $P_{u,k_u} = 10^{X_{u,k_u}/10}$. The mean and standard deviation of X_{u,k_u} are 0 and σ_n , respectively. The amplitude A_{u,k_u} can be derived as $A_{u,k_u} = \sqrt{P_{u,k_u}}$.

The discrete-time matrix model of the received BPSK modulated CDMA signal after demodulating and chip-matched filtering is given as:

$$\begin{aligned}\mathbf{r} &= \mathbf{r_1} + \mathbf{r_2}\\ &= \mathbf{b_1 A_1 S}_1 + \mathbf{b}_2 \mathbf{A}_2 \mathbf{S}_2 + \mathbf{n}\end{aligned} \quad (2.4)$$

Where,

$$\mathbf{r_1} = \mathbf{b_1 A_1 S}_1 \quad (2.5)$$

$$\mathbf{r}_2 = \mathbf{b}_2 \mathbf{A}_2 \mathbf{S}_2 . \quad (2.6)$$

The vector $\mathbf{n}$ is AWGN noise with zero mean, and variance equal to σ^2 . In the next section, we explain iterative multistage interference cancellation receiver, which reduces the high level of interference due to overloading.

III. IRTERATIVE INTERFERNCE CANCELLATION RECEIVER

The received demodulated and chip sampled signal (2.4) is despreaded and we obtain soft outputs of the transmitted bits corrupted by multiple access interference (MAI) from other users and AWGN noise. In conventional matched filter detection, these outputs are fed to the decision device to make the hard decision of the transmitted information bits. In this work, iterative multistage detection (IMSD) technique is used to remove the MAI between two sets users. The basic principle of this receiver is to iteratively remove the estimated interference from each set due to the users of other set in multiple stages such that near single user performance is achieved. The interference power from set2-user (assuming that the useful signal power is normalized) is 1/N, and therefore the total interference power that affects set1-users is M/N. As long as M remains small compared to N, preliminary decisions can be made on the symbols transmitted by set1-users with some good reliability. But each of the set2-users gets an interference power of N (1/N) =1 from set1-users. Clearly the bit error (BER) performance will be poor for this set of users if detection is made prior to interference cancellation. As set1-users are detected with some good reliability, we can estimate the interference created from this set on set2-users. This estimated interference is removed from set2-uers before making the decision. Now in second iteration, interference from set2-users on set-1 are estimated form the first iteration outputs of set-1 and a more reliable set1 bits are obtained. This process continues till we get a near single user performance.

To explain the operation the following notations are used: $\hat{\mathbf{b}}_1^i$ and $\hat{\mathbf{b}}_2^i$ are decisions about set-1 & set-2 user data bits at $\mathrm{i^{th}}$ iteration respectively, $\mathbf{y}_1^i$ and $\mathbf{y}_2^i$ are set-1 and set-2 matched filter outputs at $\mathrm{i^{th}}$ iteration. At each iterative stage of the IMSD detector, the decision on the information bits are made according to the following expressions,

$$\hat{\mathbf{b}}_1^i = \phi\left(\mathbf{S_1^T}(\mathbf{r} - \delta_{2,i}.\mathbf{I}_2^{(i\text{-}1)})\right) \quad (3.1)$$

$$\hat{\mathbf{b}}_2^i = \phi\left(\mathbf{S}_2^T(\mathbf{r} - \delta_{1,i}.\mathbf{I}_1^i)\right) \quad (3.2)$$

where, $\mathbf{I}_1^i = \hat{\mathbf{b}}_1^i \mathbf{A_1 S_1}$; (3.3)

$$\mathbf{I}_2^i = \hat{\mathbf{b}}_2^i \mathbf{A}_2 \mathbf{S_2} \quad (3.4)$$

are estimated Multiple Access Interference (MAI) on set-2 and set-1 users respectively. $\delta_{1,i}$ and $\delta_{2,i}$ $(0 \le \delta \le 1)$ are the partial cancellation factors (PCF) which decides the amount of estimated interference cancellation for set-2 and set-1 respectively in the $\mathrm{i^{th}}$ iteration. The value of PCF is selected to minimize the BER. In this paper, $\delta_{1,i}$ and $\delta_{2,i}$ are set to 1.

In equations (3.1) and (3.2), $\phi(x)$ is the nonlinear decision function. According to the decision function $\phi(x)$, IMSD can be classified as Hard Decision Interference Cancellation (HDIC) or Soft Decision Interference Cancellation (SDIC). For SDIC except for the last iteration, where we take hard

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decision, in other iterations several nonlinear decision functions can be used. We have used piecewise linear approximation of hyperbolic tangent and is defined as:

$$\phi(x) = \begin{cases} x/\theta & |x| < \theta \\ \operatorname{sgn}(x) & |x| \geq \theta \end{cases} \tag{3.6}$$

Where θ is selected to minimize the average BER.

IV. SIMULATION RESULTS

This section presents the Monte-Carlo simulation results of the proposed scheme with SDIC receiver. The simulation has been carried out in MAT-Lab to evaluate the BER performance of the proposed scheme in an AWGN channel. The simulation parameters are given in Table 1. The BER performance of soft decision interference cancellation (SDIC) has been evaluated. The value of the parameter θ is 0.5 for SDIC and it is fixed for all iterations. For all simulations, the system performance is evaluated by means of critical overload. We define the ***critical overload*** as the maximum achievable channel overload $\beta_{max} = (K_{max}\text{-}N)/N$ with interference cancellation, so that the required SNR ($=1/\sigma^2$) for an average BER= 10^{-5} is less than 1 dB as compared to perfect power control single user bound. It is a measure for the maximum acceptable channel overload, so that the system performance is degraded slightly as compared to the single user performance.

In Fig. 2, the BER performance of OG/OG scheme is shown for N=32 and 19% overloading. The BER performance of conventional matched filter receiver with imperfect power control and single user bound with perfect power control are also shown. The standard deviation for imperfect power control is 0.5 dB. It is observed that we can overload the system with less than 1 dB SNR degradation at 1e-5 for N=32 at 19% overloading. With perfect power control, the SNR degradation is about 0.35 dB. So, the critical overload is 19% for N = 32, with imperfect power control of 0.5 dB.

In Fig. 3, the BER performance of OG/OG overloading scheme with SDIC is shown for N=64. The amount of channel overloading is 25% (16 extra users) for perfect power control and 22% (14 extra users) for imperfect power control. The standard deviation of imperfect power control is 0.5 dB. It is observed that the SNR degradation of SDIC receiver is about 0.35 dB as compared to the perfect power control for 25% overloading and perfect power control. With imperfect power control, we have observed that the SNR degradation is more than 1 dB for 25% overloading. For a reduced overloading of 22%, SNR degradation is about 0.45 dB. So the critical overload with imperfect power control is 22% for N=64 with imperfect power control of 0.5 dB.

In Fig.4, the BER performance comparison of OG/OG scheme is shown for 22% overloading, at different values of imperfect power control. The standard deviations are 0 dB, 0.5 dB and 1 dB. It is observed that the SNR degradation is more than 2 dB when standard deviation is 1 dB. So to get an overloading of 22%, the standard deviation of imperfect power control should be less than or equal to 0.5 dB. It can be observed from Fig. 5, that even if we reduce the overloading to 11%, the SNR degradation is about 1.25 dB at a BER of 1e-5 when the standard deviation is 1 dB.

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CONCLUSION

Efficient use of the available radio spectrum is an important requirement for future broadband wireless communication. Overloading is an efficient scheme to increase the data rate or capacity of a DS-CDMA system. A new overloading scheme for DS-CDMA cellular system has been proposed in this work. This scheme is based on orthogonal Gold code sets. The BER performance of soft decision interference cancellation receiver is evaluated through simulation. It is shown that this scheme with soft decision interference cancellation (SDIC) can overload the DS-CDMA systems by 25% at BER of 10^{-5} for N=64, with an SNR degradation of about 0.35 dB as compared to single user bound, assuming perfect power control. With imperfect power control, overloading performance is only 11% with 1.25 dB SNR degradation.

TABLE I

Simulation Parameters

Parameters	***Specifications***
Transmission mode	Synchronous
Modulation/ Spreading	BPSK/BPSK
Spreading factor, N	32, 64
Spreading codes	Orthogonal Gold codes
Power and phase of users	Same and phase is assumed to be zero for all users
Type of Receiver	SDIC
Assumptions	Perfect chip, symbol and carrier synchronization

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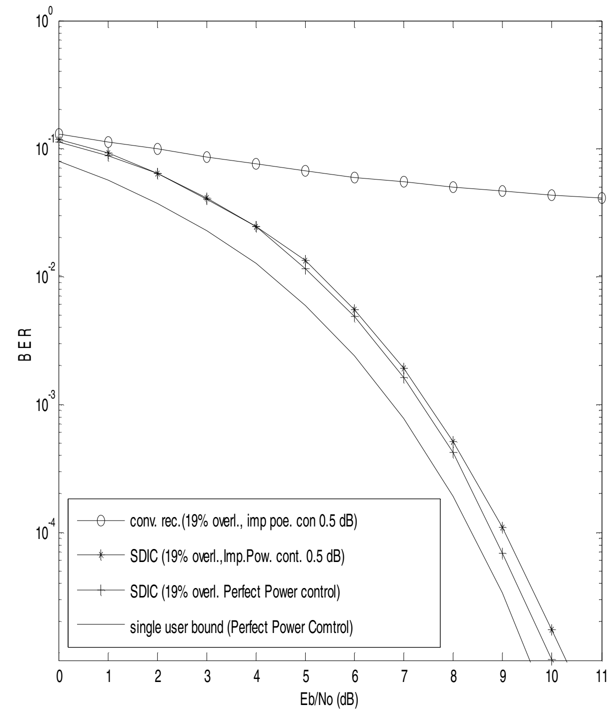

Fig.1 Impact of imperfect power control (standard deviation=0.5 dB) on the BER performance of OG/OG scheme with N=32 and 19% overloading

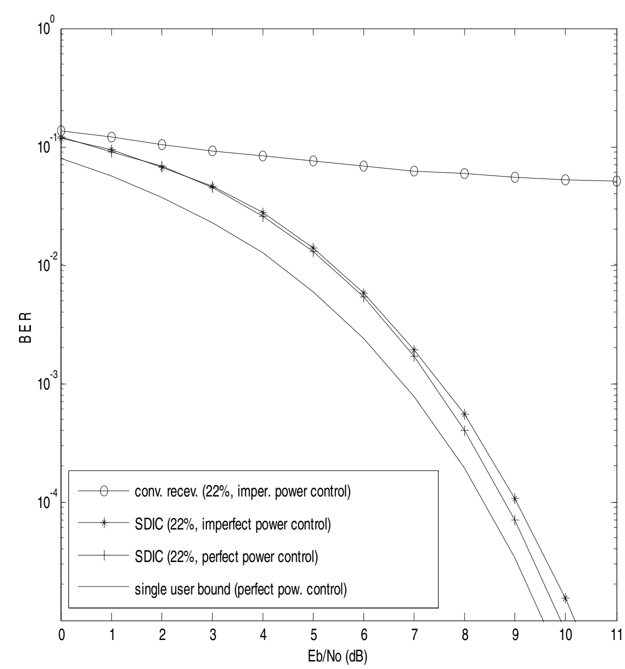

Fig.2 Impact of imperfect power control (standard deviation=0.5 dB) on the BER performance of OG/OG scheme with N=64 and 22% overloading

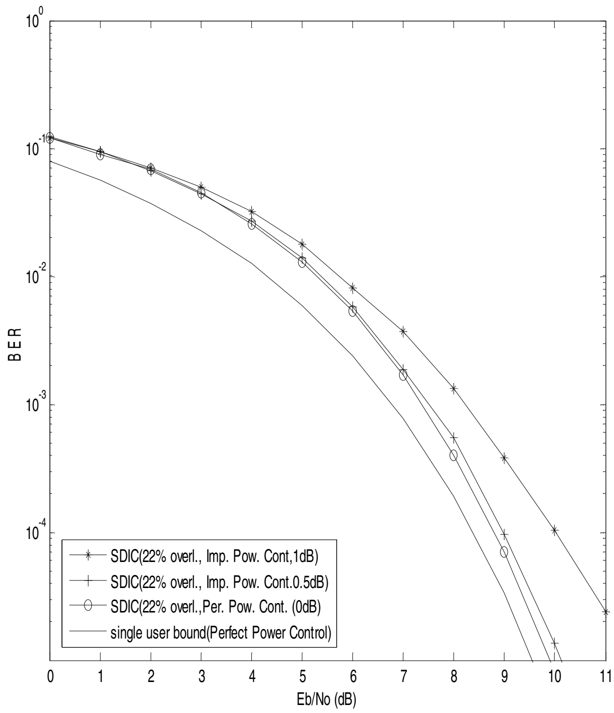

Fig.3 BER performance comparison with imperfect power control of 0dB, 0.5 dB and 1dB, for N=64 at 22% overloading

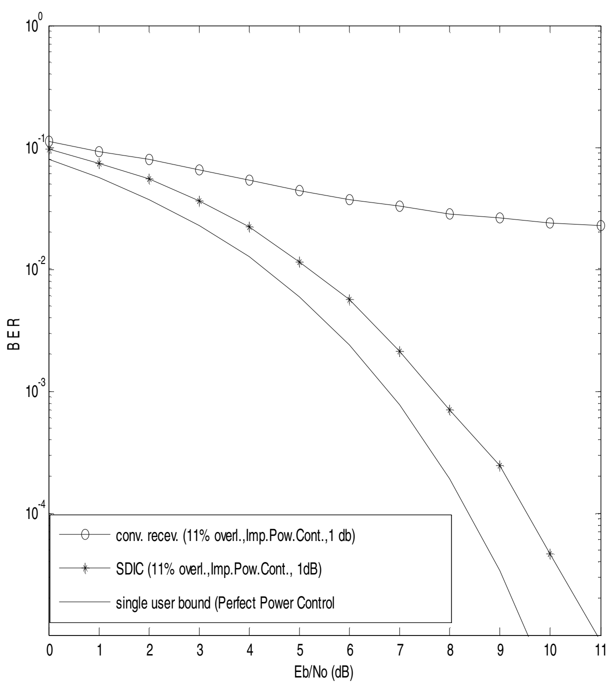

Fig.4 Impact of imperfect power control (standard deviation = 1 dB) on the BER performance of OG/OG scheme with N=64 at 11% overloading