Effect of Erroneous Power Control on the Performance of Overloaded cellular UCDS-CDMA

Amiya Singh
Department of |Electronics and Communication
National Institute of Technology
Rourkela-769008, India
amiyasingh87@gmail.com

Poonam Singh
Department of |Electronics and Communication
National Institute of Technology
Rourkela-769008, India
psingh@nitrkl.ac.in

***Abstract*— Channel overloading in Code Division Multiple Access (CDMA) paves the way to achieve more no of users (>N) in a space with dimension equal to the spreading factor (N).It puts its own priority over the conventional CDMA to provide broadband access in cellular wireless communication. A new overloading scheme for the uplink of cellular CDMA has been proposed in [7] using unequal chip delay spreading (UCDS). It divides all the active users into G groups with each group containing L number of users. Each user in a group is assigned the same orthogonal code, but with different chip durations (multiple of Tc/L). For spreading, all the L Users in a group use the assigned unique code with the insertion of predefined time delay. During spreading each user in a group has to go through unequal time delay between each successive spreading chip. Addition of suitable delays helps in maintaining the correct time alignment among all the users in a group. The receiver uses a very simple orthogonal successive interference cancellation (OSIC) multi user detector in order to recover the message bits of all the users. In this paper, the performance of this new overloading scheme (UCDS-CDMA) with an overloading factor (OF) of TWO has been evaluated with different levels of error in power control. The system model has been designed mainly for the uplink of the cellular CDMA over an additive white Gaussian noise (AWGN) channel. The effect of erroneous power control in the uplink of UCDS-CDMA costs a SNR of 1.1 dB, 1.3 dB and 1.6 dB as compared to the conventional perfectly power controlled underloaded CDMA (OF=1) with the power control error of 1 dB, 1.5 dB and 2 dB respectively at a BER of 10^{-3}.**

Keywords—UCDS-CDMA; OSIC; MAI; Overloading; power control; Near-Far Problem;

I. INTRODUCTION

For more than a decade, Code Division Multiple Access (CDMA) has been effective in offering seamless service to the consumers in cellular wireless domain. The capacity to achieve high data rate along with multirate traffic control has made its presence reliable for the 3G standard. Still the wide access of the CDMA system gets limited due to the scarcity of unique orthogonal codes. In other words, maximum number of N users can be accommodated within a N dimensional code space of with N denoted as the spreading gain or spreading factor. The system gets underloaded when the number of total users (K) is less than the assigned spreading factor (N) i.e. K<N. This problem can be smartly addressed using an effective overloading scheme. When the total number of users goes beyond the spreading gain (K>N), then the system gets overloaded. With the increase of overloading, the faithfulness of the system gets attenuated due to the increase in intracell multiple access interference (MAI). Various overloading techniques have been proposed in the literature for the cellular system [2-10].

The technique of overloading is applicable to both uplink and downlink of the cellular CDMA. For the downlink, the system architecture must carry a receiver with less complexity in order to avoid the extra computational load and hence lower battery life of the mobile handsets. In the downlink, the base station transmits all signals together, such that they suffer equal path loss before their arrival at any of the intended users. It helps in maintaining a proportional unbiased relationship between the interference and the user's required signal level at the transmitter (base station) and receiver (mobile). Hence no power control mechanism is required for the downlink of CDMA systems which reduces the complexity of the receiver design.

However the scenario for the uplink shows a wide variation as compared to the downlink. Here different user's signal gets access to different path losses due to the randomness in their location inside a particular cell and variation in radio propagation path. Hence, though the entire user's signal gets transmitted with the same power, but they arrive at the base station with different levels of power. It creates a serious problem at the base station in the error free reception of the weak users dominated by the strong interfering signals of other intracell users. Hence power control in the uplink not only fights with the interference from shadowing and the Near-Far problem, but also maintains the transmitter power at the minimum level required for the error free transmission. Thus the battery life of the user handsets gets longer. Though the uplink is usually treated with several power control techniques, still intensive field study claims to have a log-normal variation in the received power level with a standard variance between 1 to 2 dB. Several proposals suggested in the literature [2-10] have made it quite worthy to absorb and analyze the effect of channel overloading in CDMA in different environments. One of the techniques suggests

Random Orthogonal / orthogonal (O/O) CDMA with two sets of different orthogonal codes for two sets of users [2]. In [3], a more improved random O/O CDMA has been proposed where codes of one set is displaced in time with respect to those of the other set. [5] proposes a s-O/O scheme, where the users of the second set are assigned the scrambled version of the same orthogonal code used by the first set of users. The main drawback of the above techniques is the use of non linear multi user detectors whose performance always maintains a trade off with its complexity. In these systems, the complexity is more due to the massive computations involved in the estimation of the interference. In [9], the idea of a group orthogonal CDMA using collaborative spreading achieves oversaturation with a very simple receiver structure. It carries a demerit of low sum data rate due to the addition some overhead bits for coding. Superposition coding is another technique investigated in [6]. Here all the active users in a cell get divided into G groups with each group having L users. It assigns the same orthogonal code to all the users in a group but with different level of transmitted power. It exploits the existing power control schemes to identify the different users with same code at the receiver.

In [7], a new overloading technique has been proposed for the uplink of cellular CDMA over a synchronous AWGN channel. It also divides all the active users in a cell into G groups with each having L users. Each user in a group is allocated the same spreading sequence but with different chip durations. As shown in Fig. 2 the spreading of each user's data involves the conventional direct sequence spreading but with the insertion of predefined delay between successive spread chips. The delay that each chip of spread data undergoes varies from user to user inside a group. But the users in different groups share the same set of delays. It maintains an inverse relationship with the chip duration (1) i.e. the code with largest chip duration (Tc) faces the minimum delay (ZERO) and vice versa. Choosing the amount of delay (T_d) for a user in a particular group with chip duration (t_c) is governed by the following relation.

$$T_d + t_c = Tc \qquad (1)$$

Where $tc = l\,Tc/L \qquad l = 1, 2, 3 \ldots L$

The receiver includes a simple orthogonal successive interference cancellation (OSIC) multi user detector which detects L different user's data in L successive stages of detection. The proposed scheme performs nearly similar to the underloaded case. It also achieves superiority in terms of sum data rate and different levels of error protection to different sets of users. More over it carries its uniqueness in having a high data rate at the receiving end as compared to that of the transmitter.

In this paper, we extend our work on UCDS-CDMA [7] for the uplink in order to study and analyze its performance over the synchronous AWGN channel with imperfect power control. As mentioned earlier, the log-normal variation of the received power at the base station over a range of 1 to 2 dB makes the ideal power control mechanism erroneous. Thus, it's very essential to analyze the reliability of UCDS-CDMA in an erroneous power controlled uplink. Simultaneously, the comparative analysis of the results will unleash the true figures of the system's performance in a non ideal power controlled uplink.

Organizing the rest of the paper, Section-II includes the system model for the UCDS-CDMA. Section-III explains the orthogonal successive interference cancellation (OSIC) followed by the result analysis in Section-IV. Finally we present the conclusion of this paper.

II. SYSTEM MODEL

Implementing the system model for the UCDS-CDMA for the uplink demands to divide all the active users (K) into G groups, where each group carries L users i.e. K= GL. This system will lead to an overloading efficiency or overloading factor of L i.e. OF=K/N=L. Here we consider the design of an overloaded system with OF=2. Thus, there will be two users in each group sharing the same code with different chip durations. We assume that the channel is nondispersive and AWGN in nature. All the users are assumed to be in perfect synchronism.

Out of the two users in a group, the primary user is assigned the sequence with maximum chip duration Tc and the secondary user is assigned the same sequence but with a chip duration of $T_c/2$ as shown in Fig. 1. Hence in each group, the delays of ZERO and $T_c/2$ are assigned to the primary and secondary users respectively (1). The signatures of the primary and secondary users can be defined by (2) and (3) respectively.

$$C_{g1}(t) = \sum_{n=1}^{N} s(n)\, g(t-(n-1)T_c) \qquad (2)$$

$$C_{g2}(t) = \sum_{n=1}^{N} s(n)\, g(t-(n-1)T_c/2) \qquad (3)$$

Where $s(n) \in \{1, -1\}$, g(t) is the chip waveform of unit energy. N is the spreading factor i.e. $N=T_b/T_c$. T_c and $T_c/2$ are the chip durations of primary and secondary users.T_b is the bit duration of the message signal. All the user signatures are normalized i.e. $\|C_{g1}(t)\|^2=\|C_{g2}(t)\|^2=1$.

Assuming the user data to be BPSK pass band modulated the spreading for the primary and secondary users in each group is done using the unique code sequence (r_1) and (r_2). It's followed by the insertion of the predefined delay between each successive spread chips as given in Fig. 2.

As evident from Fig. 2**,** the addition of suitable time delay between successive spread chips has divided each duration of T_c into two separate time slots of durations $T_c/2$. These two time slots carry the data of the users with two different levels of multiple access interference (MAI).

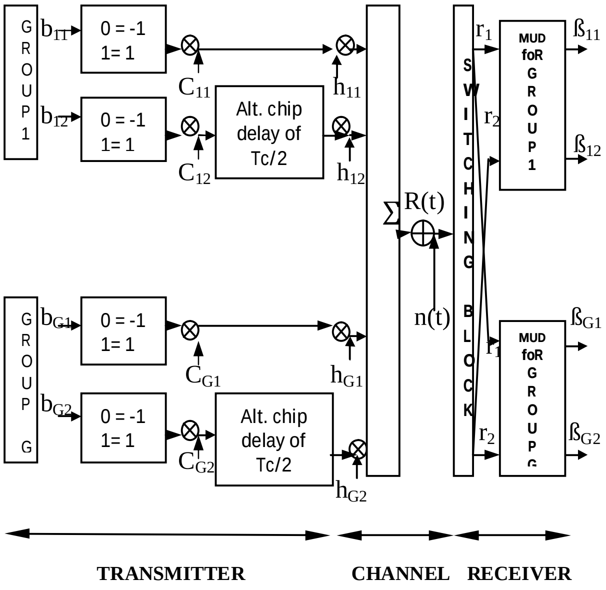

Figure 1. System Model of UCDS-CDMA

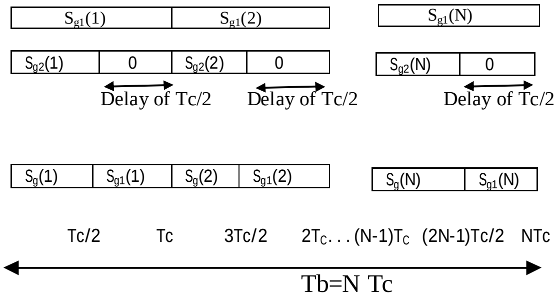

Figure 2. Unequal chip delay spreading for a single bit of data of g^{th} group with group size L=2. 1st, 2nd & 3rd row of blocks showing the transmitted sequence of User-1 (with tc =Tc), User-2 (with tc=Tc/2) and grouped signal of both respectively, where tc as the chip duration.

In other words, as shown in 3rd row in (2), analyzing the time slot of 0 to T_c of the final transmitted sequence of all the users, it can be easily noticed that the time slot $T_c/2$ to T_c contains the signal from primary users only and hence enjoy ZERO interference. Therefore, all the primary users can be easily detected by the use of simple matched filter receiver. In contrast to it, the time slot 0 to $T_c/2$ finds the existence of two different types of users i.e. primary and secondary users of each group. Hence, in this time slot the interference is maximum raising the demand of a multiuser detector.

Assuming the ideal impulse response for each uplink path i.e. $h_{gl}=1$, each user's transmitted signal can be written as

$$S_{gl}(t) = P_{gl}(t) * h_{gl}(t) \tag{4}$$

Where $P_{gl}(t)$ is the pass band modulated spread data of the l^{th} user of the g^{th} group. l=1,2 and g=1,2. . .G. The combined signal of all the users can mathematically formulated as

$$S(t) = \sum_{g=1}^{G} S_g(t) \tag{5}$$

Where $S_g(t)$ represents the combined transmitted signal of g^{th} group. Finally the noisy signal at the receiving antenna at the base station is

$$R(t)= S(t) + n(t) \tag{6}$$

Where S(t) is the sum of the transmitted signal of all the users and n(t) is the white Gaussian noise, additive in nature.

Let E_P and E_s form the diagonal matrices containing the received signal amplitudes for all the Primary and Secondary users. Then they can be expressed as

$$\begin{aligned} E_P &= diag\,[E_{P1}, E_{P2}, E_{P3} \ldots E_{PG}] \\ E_S &= diag\,[E_{S1}, E_{S2}, E_{S3} \ldots E_{SG}] \end{aligned} \tag{7}$$

Where E_{Pg} and E_{Sg} are the received signal amplitude of the g^{th} primary and secondary users respectively with defined as follows.

$$E_{Pg}= \sqrt{P_{Pg}} \text{ and } E_{Sg}= \sqrt{P_{Sg}} \tag{8}$$

P_{Pg} and P_{Sg} are the received power for the g^{th} primary and secondary users at the base station respectively. In [7], a perfect power control has been assumed for the analysis of UCDS-CDMA system. But as already mentioned, a power control with a log-normal variation and 1 to 2 dB variance is more realistic. Hence assuming the received power ($P_{Pg}= P_{Sg}=P_g$) of all the users to obey log-normal distribution.

If μ_l, σ_l, μ_n, σ_n, are the mean and standard deviation of the log-normal and normal distribution respectively then they are guided by the following mathematical relationship

$$\mu_l = \mu_n \ln(10)/10$$

$$\sigma_l = \sigma_n \ln(10)/10,$$

Hence the log-normal distribution random variable P_g can be obtained from the normal distribution using the following relation

$$P_g = 10^{Xg/10} \tag{9}$$

Where Xg is a normal random variable with zero mean and σ_n standard deviation. Hence the modified amplitude of the received signal according to log-normal distribution becomes

$$E_g = \sqrt{Pg} \tag{10}$$

Now the use of the modified amplitude (11) for the simulation will produce a more accurate result for the non ideal uplink.

III. ORTHOGONAL SUCESSIVE INTERFERENCE CANCELLATION (OSIC)

Prior to applying the above multi user detection (MUD) technique, the received signal is allowed to pass through a switching block. It collects the samples of the received signal R(t) (6) at a regular interval of T_c to produce TWO separate sub streams as shown in Fig. 3.

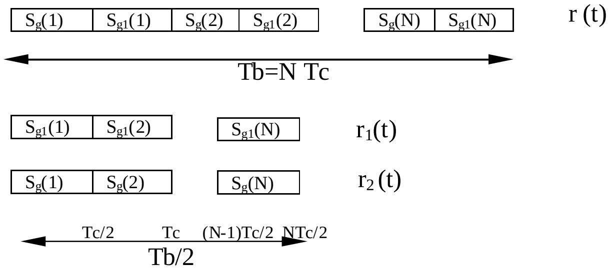

Figure 3. Input and Output signal of 'Switching Block' shown in Fig. 1 with Row-1 blocks showing the input signal r(t), Row-2 and Row-3 blocks showing the two output sub streams as $r_1(t)$ & $r_2(t)$

The ultimate detection of all the users takes place in two different stages. The two separated sub streams can be mathematically defined as follows

$$\begin{aligned} r_1(t) &= \textstyle\sum_{n=1}^{N} r(t)\, g(t - nTc/2) \\ r_2(t) &= \textstyle\sum_{n=1}^{N} r(t)\, g(t - (n-1)Tc/2) \end{aligned} \tag{11}$$

As shown in Fig. 3, r_1 (t) is found to contain the signals of all the primary users only. Hence they can be easily detected with a simple matched filter in the first stage of OSIC. In this case the matched filter will be fully optimal due to the absence interference due to any other user. The error performance of the detected primary users is very close to that of the underloaded case and hence they are highly error protected (HEP). Whereas, r_2 (t) in Fig. 3 contains the signals of both primary and secondary users. Thus each secondary user is now subjected to excess interference from two types of sources i.e. (a) from other (G-1) secondary users and (b) from G primary users. Due to the assignment of perfect orthogonal sequences with approximately zero peak cross correlation to all the secondary users, the interference due to other secondary users is negligible and can be neglected. Use of the same code by the primary users is the main source of excess interference on the secondary users. But this problem can be easily solved by estimating the level of interference from the known data of primary users already detected in the first stage of OSIC. Once the interference is known then using proper cancellation technique and a simple threshold logic, the message bits of the secondary users can also be easily detected. It's very essential to note that, the first stage of detection of the highly error protected (HEP) users plays the major role in the recovery of the secondary users with less error as compared to the primary users.

Fig. 3 finds the length of the two sub streams i.e. $r_1(t)$ and $r_2(t)$ to be of duration $T_c/2$ instead of T_c. It adds an extra edge of increased data rate at the receiving end which is twice to that of the transmitting end.

In order to explain the process of detection, the following notations are used followed by the mathematical analysis. b_P ,b_S and $ß_P$, $ß_S$ indicate the transmitted and received bits of the primary and secondary users respectively. C_P and C_S are the codes assigned to the primary and secondary users respectively. R_1 and R_2 are the demodulated signals separated at the output of the switching block. Ǿ ( ) represents the hard decision logic used to detect the message bits. I_{SP} is the multiple access interference caused by the primary users on the secondary. Finally, n is the AWGN noise with a power spectral density of No/2. The following relations give an mathematical overview of the steps involved at the receiver.

$$R_1 = b_P\, C_S + n \tag{12}$$

$$R_2 = b_P\, C_P + b_S\, C_S + n \tag{13}$$

$$ß_P = \acute{Ø}\,(R_1\, C_S^T) \tag{14}$$

$$\text{Where}\quad \acute{Ø}\,(y) = \begin{cases} 1 & y \geq 0 \\ -1 & y < 0 \end{cases}$$

$$I_{SP} = ß_P\, C_S \tag{15}$$

$$\begin{aligned} ß_S &= \acute{Ø}\,((R_2 - I_{SP})\, C_S^T) \\ &= \acute{Ø}\,((R_2 - ß_P\, C_S)\, C_S^T) \end{aligned} \tag{16}$$

IV. SIMULATION AND COMPARISON

In this section the simulated results of the UCDS-CDMA with error in power control mechanism has been presented. The simulation was carried out in MATLAB-R2011 platform to evaluate the BER performance of the proposed scheme with the use of Walsh Hadamard sequence of code length N=64 as the spreading code. As per the demand of the proposed technique, in total 64 groups (G=64) have been taken with each group having 2 users (L=2). The simulations were performed assuming the channel to be of nondispersive AWGN type showing perfect synchronous behavior at the transmitting end. Comparison of the results has been made based on both perfect power control and erroneous power control with different levels of power control error expressed in dB.

Fig. 4 reflects the BER performance of the highly error protected (HEP) users with different levels of power control error as compared to the conventional underloaded CDMA with OF=1. It's highly overwhelming to find the HEP users performing with equal efficiency as that of the conventional underloaded CDMA in perfect power controlled uplink. But a marginal deviation is observed for the same users with imperfect power control. With the power control errors of 1 dB, 1.5 dB, 2dB, the HEP users seem to sacrifice a SNR of 0.7 dB, 0.9 dB, 1.1 dB as compared to the underloaded CDMA in perfectly power controlled scenario to achieve a BER of 10^{-3}.

In Fig. 5, the BER performance of the low error protected (LEP) users with the insertion of various levels of error in power control has been manifested. In perfect power control case, the LEP users have to bear a cost of 0.4 dB SNR as compared to the conventional underloaded CDMA at a BER of 10^{-3}. Comparing the reliability of these users in imperfect power control case, it is observed that they have to bear a significant price of 1.4 dB, 1.7 dB, 2.6 dB SNR as compared to the perfectly power controlled conventional CDMA (OF=1) with a variance of 1dB, 1.5dB and 2dB in power control respectively to maintain a BER level of 10^{-3}. Hence the LEP users are subjected to more error as compared to the HEP users in an erroneous power controlled uplink.

Fig. 6 focuses on comparison of the average BER of all the users (HEP and LEP) in UCDS-CDMA (OF=2) with increasing level of errors in power control. It's observed that the conventional underloaded CDMA (OF=1) in an ideal power controlled uplink outperforms the UCDS-CDMA with a net gain of 0.2 dB, 1.1 dB, 1.3 dB and 1.6 dB in SNR with the power control error of 0 dB, 1 dB, 1.5 dB and 2dB respectively at a BER of 10^{-3}.

In Fig. 7, the BER response of conventional underloaded CDMA (OF=1) has been analyzed with an exposure to different levels of imperfect power control. The observation shows that the conventional underloaded CDMA (OF=1) with a power control error of 1 dB perform in the same way as the UCDS-CDMA (OF=2) with ideal power control. In other words the conventional CDMA delivers a sacrifice of 0 dB, 0.4 dB, 0.9 dB SNR as compared to the UCDS-CDMA with perfect power control with an error of 1dB, 1.5 dB and 2 dB in order to achieve a BER of 10^{-3}.

V. CONCLUSION

Overwhelming demand of the cellular wireless communication puts a major challenge to serve more number of users within limited spectrum. Overloading is an effective technique to meet this demand in the next generation broadband communication systems. Hence in order to meet the random behavior of the wireless channel correct evaluation of any system is highly essential under every possible adverse condition. In depth analysis of a newly proposed overloaded cellular CDMA system has been reflected in this work. It was observed that, the performance of the UCDS-CDMA with an overloading factor of (OF=2) was tracked to bear a cost of 1.1 dB, 1.3 dB and 1.6 dB SNR as compared to the perfectly power controlled underloaded CDMA (OF=1) with a power control error of 1dB, 1.5 dB and 2dB respectively in order to meet a BER of 10^{-3}.

REFERENCES

[1] Chang Shih-Chun, Weldon Edward J. "Coding for T Users Multiple Access Channels". *IEEE Transaction on Information Theory 1979*, 25-6: 684-691.

[2] Vanhaverbeke F, Moneclacy M, Sari H, "DS-CDMA with two sets of orthogonal sequences and iterative detection". *IEEE Communication Letters* 2000, 4:289-291

[3] Vanhaverbeke F, Monocracy M, "An improved OCDMA/OCDMA schemes based on displaced orthogonal user sets". *IEEE Communication Letters* 2004, 8:265-267

[4] Nguyen Ha.H, Shwedyk Ed, "A New Construction of signature waveforms for synchronous CDMA systems". *IEEE Transactions on Broadcasting* 2005, 51:520-529

[5] P. Kumar, M. Ramesh and S. Chakrabarti. "Performance evaluation of orthogonal/scrambled orthogonal overloaded DS-CDMA system", IEEE International Conference on Wireless Communications and Networks (WOCN), July 2007.

[6] Tahir Yassen H.,Chee Kyun Ng,Noordin Nor K., Ali Borhnuddin Mohd., Khatun Sabira (2011). "Superposition Coding with unequal error protection for the Uplink of overloaded DS-CDMA system". *Springer Wireless Personal Communication.*

[7] A. Singh, P Singh, "Synchronous Overloaded system for the uplink of cellular CDMA with unequal chip delay spreading", Communicated and Accepted for the IEEE International Conference on computers and devices for communication (CODEC-2012),December 2012 ."Unpublished"

[8] Ali, F. H. & Honary, B. (1994). Collaborative coding and decoding techniques for multiple access channels. *IEE proceedings Communications*, 141(2), 56-62

[9] Ali, F. H, Shakya I and Stipidis E. (2010). Collaborative spreading for the downlink of overloaded CDMA. *Willey Wireless Communications & Mobile Computing.* 10: 383-393.

[10] P. Kumar, S. Chakarabarti."BER of overloaded DS-CDMA with imperefect power control". IEEE Region 10 Colloquium and Third ICIIS, Decem 2008.

[11] Vanhaverbeke F, Moneclacy M. "Optimal Signature Sets for oversaturated quasi scalable direct sequence spread spectrum systems". IEEE Transactions on Information Theory 2005, 51-3:1136-1139.

[12] Paul Cotae, Fatou Diop Mbengue . "On the power efficient resource allocation for the overloaded multipath CDMA systems". IEEE Sarnoff Symposium, 2009. (SARNOFF '09)

[13] Mosa Ali Abu Rgheff, *"Introduction to CDMA Wireless Communication".*

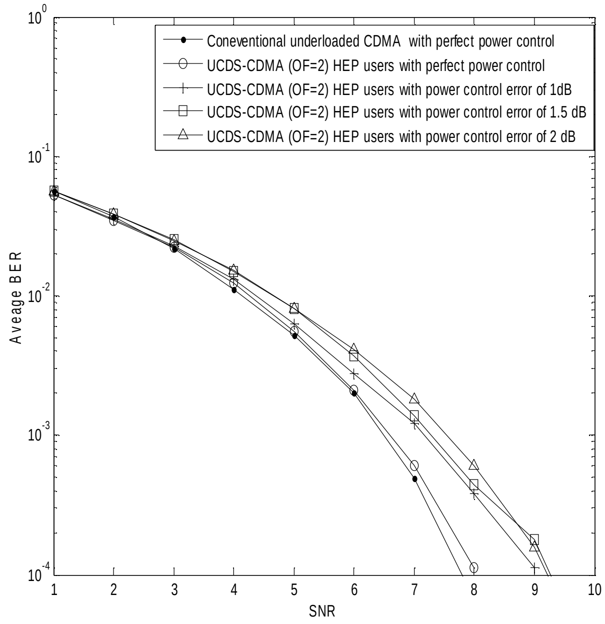

Figure 4. BER performance of the HEP users in UCDS-CDMA (OF=2) with different levels of power control error as compared to the Underloaded DS-CDMA (OF=1) with perfect power control.

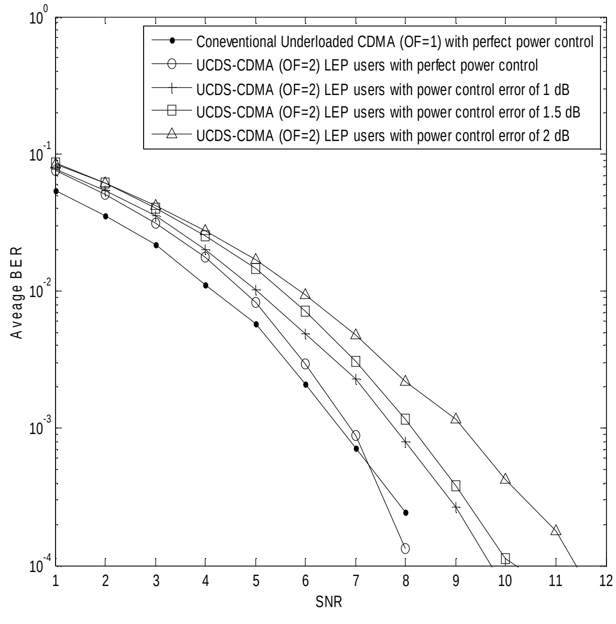

Figure 5. BER performance of the LEP users in UCDS-CDMA (OF=2) with different levels of power control error as compared to the Underloaded DS-CDMA (OF=1) with perfect power control.

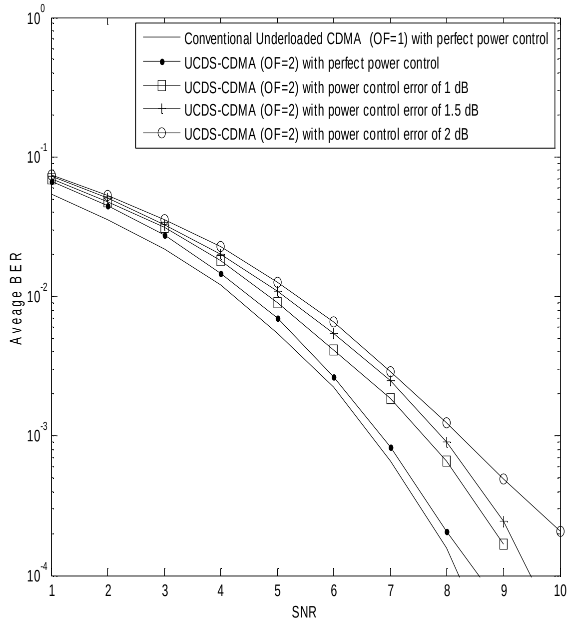

Figure 6. Average BER performance of all the users (HEP and LEP) in UCDS-CDMA (OF=2) with different levels of power control error as compared to the Underloaded DS-CDMA (OF=1) with perfect power control.

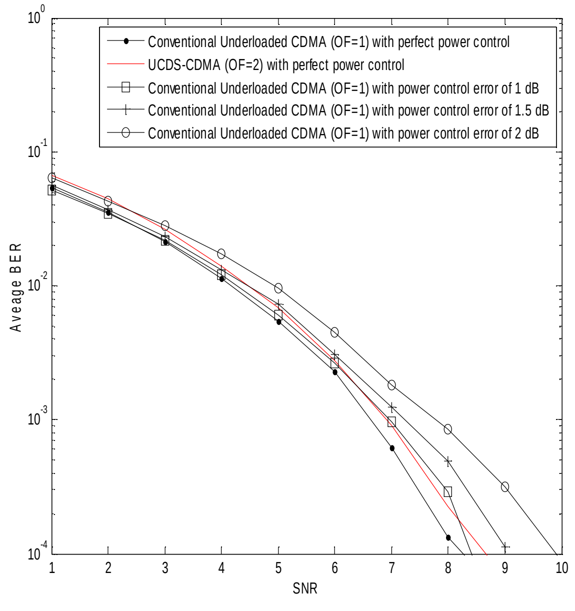

Figure 7. BER performance of Underloaded DS-CDMA (OF=1) with different levels of power control error as compared to the UCDS-CDMA (OF=2) with perfect power control.