Effect of Power Control Step Size on the Performance of the SIC Scheme in Power-Controlled DS/CDMA Systems

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Abstract: In this paper, we investigate the effect of power control step size on the performance of the SIC scheme in DS/CDMA systems. We investigate the average power control iteration and its standard deviation and evaluate the outage performance for several different values of power control step size. Because the SIC scheme requires fine control in the received signal power, the better outage performance is obtained for the smaller power control step size. However, the smaller power control step size requires larger amount of power control iteration in order to make the power control converge to the steady state. Under the simulated environment, the proper power control step size is about 0.3-0.4dB from both convergence speed of power control algorithm and outage performance points of view.

1. Introduction

For last several decades, Direct-Sequence/Code-Division-Multiple-Access (DS/CDMA) systems have been enormously studied in the world as an efficient solution for the next generation wireless communication from both capacity and multiple categories of services points of view [1]. Third generation DS/CDMA system is being prepared and tested in the real field with various kinds of services such as images and moving pictures with music stream as well as voice. One big drawback of DS/CDMA systems comes from the interference caused by the multiple access users. In order to mitigate this multiple access interference, there have been lots of researches about multi-user detection, smart antenna and so on. In this paper, we focus our attention on the Successive Interference Cancellation (SIC) scheme, which is known as the most feasible version of sub-optimum multi-user detectors owing to its simple structure and adequate performance enhancement compared with optimum and other sub-optimums [2-3].

In the SIC scheme, it is essential to enforce the power disparity in the received signal power profile in order to enhance the performance as shown in [4-5]. However, as either the number of concurrent users or the background noise increases, the received signal power disparity becomes quite small. It results in the difficulty in the power control procedure.

There are two possible ways for the power control. In one case, the power control step size is set to relatively big, where the performance such as outage becomes worse than the other case explained later. However, at the same time the power control converges fast to the steady state in the power control algorithm. In the other case, the power control step size is set to relatively small, where the performance becomes better than the former case. However, it slowly converges to the steady state in the power control algorithm.

In this paper, we investigate the effect of power control step size in the SIC scheme with the consideration of received signal power disparity in a DS/CDMA system. We compare the mean and standard deviation of power control iteration, that is counted from the equal received Signal to Noise Ratio (SNR) to the steady-state power-controlled received Signal to Interference plus Noise Ratio (SINR). We examine several different values of power control step size in order to evaluate its convergence speed and variation from the mean value. In addition, we evaluate the outage probability for the performance comparison together with the convergence speed of the power control algorithm.

This paper is organized as follows : In Section 2, we analyze the performance of the SIC scheme and show the power control algorithm with the performance measures. Section 3 is devoted to show the system model and simulation results. Finally, we conclude this paper in Section 4.

2. Performance Analysis / Power Control

2-1. Performance Analysis

We consider a typical 7-cell structure of a DS/CDMA system. At the base station, we make use of the SIC scheme in order to better detect the received signal. The functional structure and cancellation flow are explained in detail in [6]. Center cell is assumed to be home cell and numbered to 1. Other 6 neighboring cells are interfering cells numbered from 2 to 7. We assume that there are K_i users in the i-th cell, where i=1,2,⋯,7. Received SINR of the j-th user in the reference home cell, $\gamma_{1,j}$, can be represented by

$$\gamma_{1,j} = \frac{S_{1,j}}{\eta_{1,j}} \tag{1}$$

where $S_{1,j}$ and $\eta_{1,j}$ are the received signal power and the interference plus noise term of the j-th user in the center cell, respectively. $\eta_{1,j}$ can be further expressed as follows :

$$\eta_{1,j} = \frac{1}{6N}\sum_{k=j+1}^{K_1} S_{1,k} + \frac{1}{6N} I_{other} + \frac{N_0}{2T} + \frac{1}{6N}\sum_{l=1}^{j-1}\eta_{1,l} \tag{2}$$

where N is the processing gain, N_o is the background noise, and T is the bit period. I_{other} is the other cell interference. In Eq.(2), the first term represents the uncancelled home cell interference, the second term represents the interference from the users in 6 neighboring cells, the third term represents the background noise, and the last term represents the remaining home cell interference after the (j-1) cancellations.

Other-cell interference can be further expressed as follows :

$$I_{other} = \sum_{i=2}^{7}\sum_{j=1}^{K_i} S_{i,j}\frac{r_{i,i,j}^{4}}{r_{1,i,j}^{4}} \qquad (3)$$

where $S_{i,j}$ is the received signal power at the i-th base station from the j-th user in the i-th cell, $r_{i,i,j}$ is the distance from the j-th user to the i-th base station in the i-th cell, and $r_{1,i,j}$ is the distance from the j-th user in the i-th interfering cell to the base station 1. It is assumed that the path loss is proportional to the forth power of the distance from mobile user to base station [7].

Then the probability of bit error of the j-th user in the reference home cell can be evaluated as follows assuming BPSK transmission :

$$P_e^{1,j} = Q\left(\sqrt{\gamma_{1,j}}\right). \qquad (4)$$

where Q(•) is the Gaussian Q function defined as follows :

$$Q(x) = \frac{1}{2\pi}\int_0^x \exp\left(-\frac{y^2}{2}\right)dy. \qquad (5)$$

2-2. Power Control Algorithm

Figure 1 shows the flow chart of the power control algorithm. In the power control algorithm, there are two cases of unsatisfactory power control termination and one case of satisfactory power control termination explained as follows :

It is assumed that the power control algorithm is started with same received SNR for each user. At first, we increase the power control iteration by 1, which is used as a performance measure in the next subsection. If the power control iteration exceeds the maximum limit, then we stop the power control procedure and evaluate performance. This is one kind of unsatisfactory power control termination.

Otherwise, the received SINR is evaluated for each user. If all the SINR values for K_1 users satisfy the conditions described in the figure, then it is said that the power control is successfully performed and all users' signals satisfy the service quality. This can be called the satisfactory power control termination. The reason why we test the second condition is that, without this condition, received signal power of certain users can be unnecessarily high so that the service quality of those users satisfies the reference level unnecessarily well. At the same time, those users excessively interfere other users in the home cell and the neighboring cells.

If any of two SINR conditions is not satisfied for any user, then we check whether the received SINR can be adjusted further or not. If the received SINR values of all users are same as the second previous values, then it means the power control makes the same received SINR value for every second iteration. In this case, we stop the power control procedure and evaluate performance. This is the other kind of unsatisfactory power control termination.

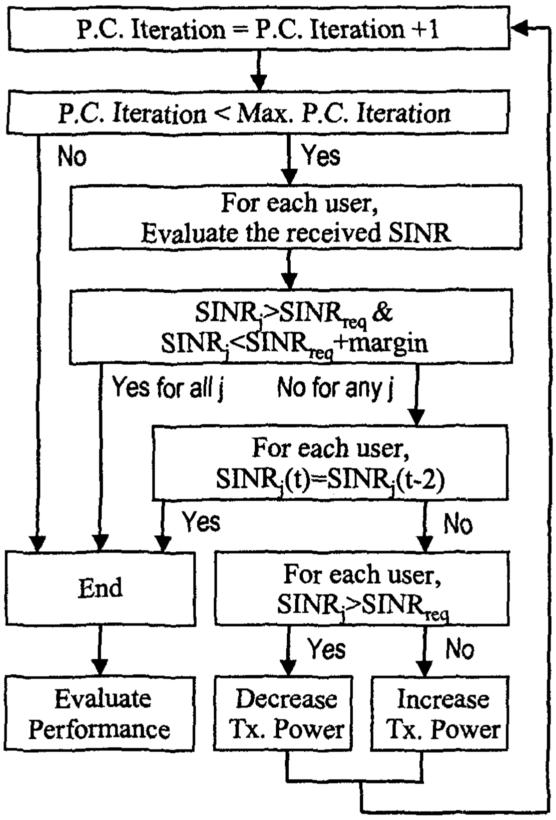

Figure 1. Flow chart for the power control procedure

If any received SINR value of concurrent users is different from the second previous values, the transmission power adjustment is performed. For each user, if the received SINR is greater than the required SINR, then the transmission power of that user in the next transmission period is decreased as follows :

$$Tx.\ Power(t+1) = Tx.\ Power(t) - P_{step} \qquad (6)$$

where *Tx. Power(t+1)* and *Tx. Power(t)* are the transmission power of a certain user at the next and present time period, respectively, and P_{step} is the power control step size. In the other case, where the received SINR is smaller than the required SINR, the transmission power of that user in the next transmission period is increased as follows :

$$Tx.\ Power(t+1) = Tx.\ Power(t) + P_{step}. \qquad (7)$$

2-3. Performance Measure

We evaluate three performance measures in order to show the performance of the SIC scheme with several different values of power control step size in DS/CDMA systems.

First two performance measures, mean and standard deviation of power control iteration, are related to the convergence speed of the power control algorithm to the stead state of the received SINR. In this paper, the steady state means either that the power control is successfully performed so that the every user's service quality is satisfactory or that the power control does not affect any more

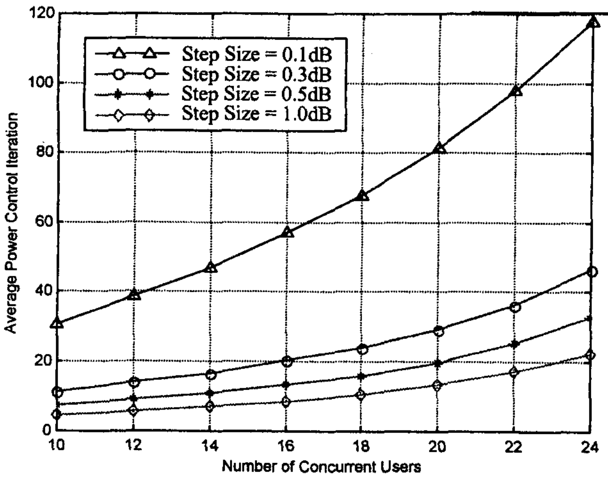

Figure 2. Average Power Control Iteration

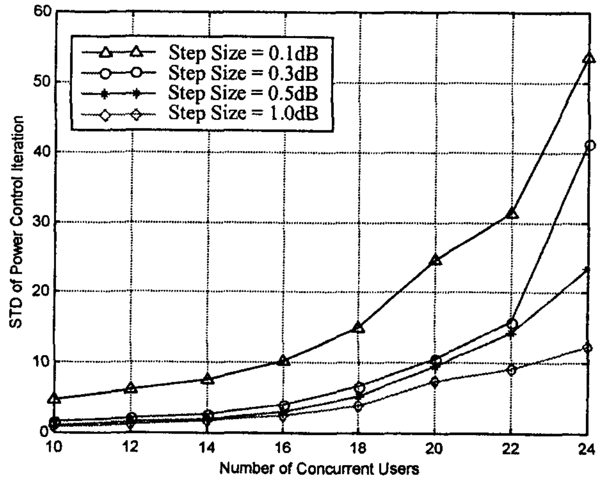

Figure 3. Standard Deviation of Power Control Iteration

on the received SINR because the received SINR remains same as the second previous SINR as explained in previous subsection.

The third performance measure is related with the service quality of the SIC scheme, which is the outage probability defined as the probability that the service quality does not satisfy the pre-specified level. Outage happens when the transmission power of mobile user reaches its maximum or the amount of received interference exceeds a certain level so that the ratio of the received signal power to the interference does not satisfy the required level of SINR.

3. System Model and Simulation Results

3-1. System Model

For the simulation, the system model is assumed as follows : We consider a reverse link of DS/CDMA systems with the SIC scheme. User signals are asynchronously received at the corresponding base station. Power control is performed based on the measured SINR as depicted in Figure 1, and the power control channel is error free. Target

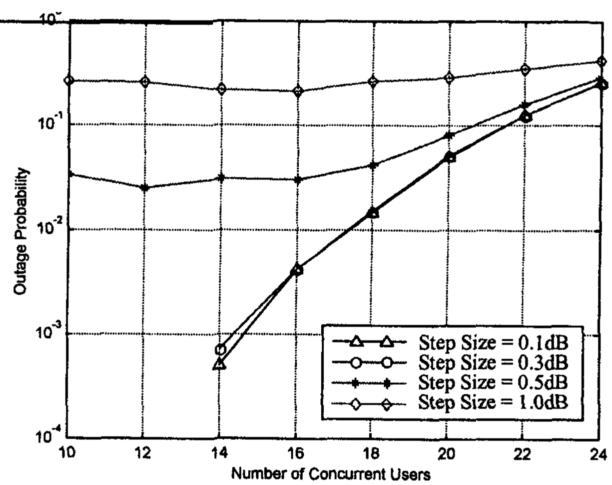

Figure 4. Outage Performance Comparison

service quality is 10^{-3} of Bit Error Rate (BER) considering voice service. Initial received SNR is 10dB, and the power control step size is changed from 0.1dB to 1dB. Power control margin in the power control algorithm is also same as the power control step size. Maximum power control iteration is assumed to 1,000. Processing gain is 63, and the path loss exponent is 4. Noise floor is -170.07dBm [8], maximum transmission power of mobile users is 100mW, and the cell radius is 2km. Simulation is performed 5,000 times for a certain number of concurrent users with random user locations.

3-2. Simulation Results

Figure 2 and Figure 3 show the average power control iteration and its standard deviation for several different values of power control step size, respectively, where STD in Figure 3 stands for the standard deviation. As we can easily expect, for the bigger power control step size, the smaller average power control iteration and standard deviation are obtained. In addition, for the same power control step size, as the number of concurrent users increases, there is required more average power control iteration and it has bigger variation as shown in the figures.

Figure 4 shows the outage performance for the SIC scheme with several different values of power control step size. It is observed that the outage probability becomes worse for the same number of concurrent users as we increase the power control step size. The reason is as follows : In the SIC scheme, fine control in the received signal power is required to optimize the system performance. If the power control step size is too big, then the power control is not fine enough to get the best performance. It results in the worse outage performance for bigger power control step size.

Figure 5 shows the average power control iteration and its standard deviation for a fixed number of concurrent users, where the number of concurrent users is assumed to 15. As we have seen in Figure 2 and Figure 3, the smaller values of average iteration and standard deviation in power control iteration are obtained for the bigger power control step size. However, as shown in the next figure, bigger power

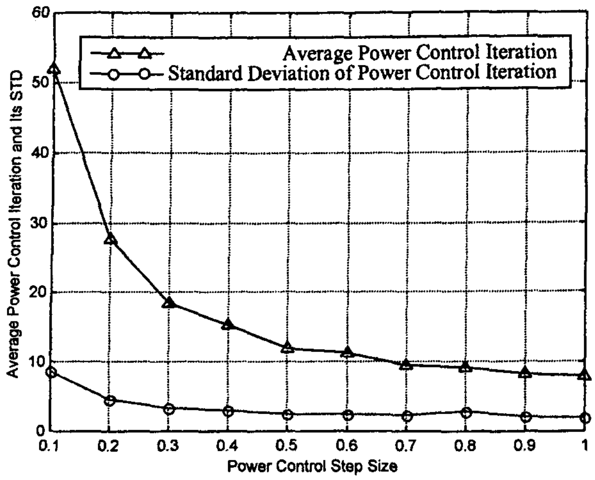

Figure 5. Average Power Control Iteration and Its Standard Deviation for Fixed Number of Concurrent Users (K=15)

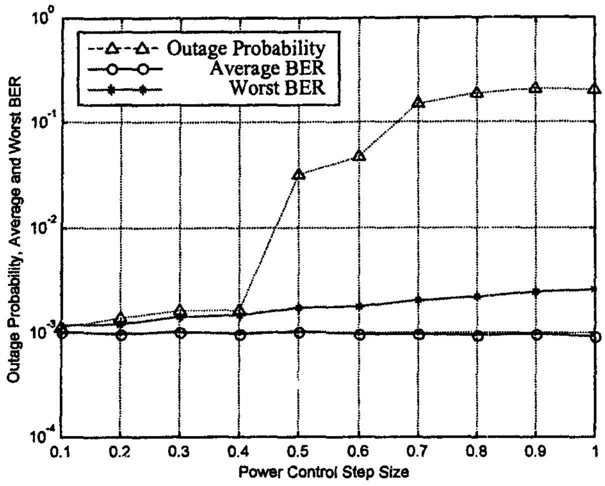

Figure 6. Outage Probability, Average and Worst BER for Fixed Number of Concurrent Users (K=15)

control step size provides worse values of both outage probability and worst BER.

Figure 6 shows the outage probability, average BER and worst BER among the 15 concurrent users. Average BER of 15 users is maintained to be steady and that is about 10^{-3} of BER, which is the assumed target BER performance. As the power control step size increases, however, the worst BER among 15 users increases. In addition, the outage probability also increases. If the power control step size is not small enough, then the fine control in the received signal power is difficult to be accomplished. This results in the higher outage performance for the bigger power control step size.

4. Concluding Remarks

In this paper, we have investigated the effect of power control step size on the performance of the SIC scheme owing to the knowledge that the SIC scheme requires fine control in the received signal power in order to optimize its performance. We have shown the convergence speed of the power control with its standard deviation, and at the same time we have evaluated the outage performance for several different values of power control step size. It is observed that the better performance is obtained for the smaller power control step size. On the other hand, bigger power control step size produces the faster power control convergence. Under the simulated environment, the best choice for the power control step size is about 0.3-0.4dB as both convergence speed in the power control and outage performance points of view.

References

[1] R. Prasad, *CDMA for Wireless Personal Communications*, Artech House Publisher, 1996.

[2] S. Moshavi, "Multi-User Detection for DS-CDMA Communications," IEEE Commun. Mag., Vol.34, No.10, pp.124-134, Oct. 1994.

[3] P. Patel and J. Holtzman, "Analysis of a Simple Successive Interference Cancellation Scheme in a DS-CDMA System," IEEE J. Select. Areas Commun., Vol.12, No.5, pp.796-807, June 1994.

[4] G. Mazzini, "Equal BER with Successive Interference Cancellation DS-CDMA Systems on AWGN and Ricean Channels," Proc. PIMRC'95, Vol.2, pp.727-731, Sep. 1995.

[5] C. Lee, G. Ko and K. Kim, "BER Performance of a Successive Interference Cancellation Scheme with an Optimum Geometric Power Disparity in a DS/CDMA System," Proc. WPMC'2000, Vol.1, pp.408-411, Nov. 2000.

[6] C. Lee, G. Ko and K. Kim, "Performance Analysis of an SIC Scheme with an Activity-Based Disparity Estimation in a DS/CDMA System," IEICE Trans. Commun., Vol.E85-B, No.2, pp.495-501, Feb. 2002.

[7] P. Hatrack and J. Holtzman, "Reduction of Other-Cell Interference with Integrated Interference Cancellation/ Power Control," Proc. VTC'97, Vol.3, pp.1842-1846, May 1997.

[8] V. Garg, *IS-95 CDMA and CDMA2000 : Cellular/ PCS Systems Implementation*, Prentice-Hall, 2000.