DS-CDMA 셀룰라 시스템의 역방향 링크에서 소프트 핸드오프 영역비율의 효과

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Effects of soft handoff region ratio on the reverse link capacity of a DS-CDMA cellular system

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ABSTRACT

In this paper, effects of soft handoff region on the reverse link capacity of a DS-CDMA cellular system are investigated. The reverse link capacity of a CDMA cellular system is calculated at a given soft handoff region ratio (SHRR) and path loss model. The results show that the reverse link capacity increases by 1 ~ 4 channels according to the soft handoff region ratio and the path loss model. However, in the case of the path loss model having a large attenuation exponent (μ = 5) and a small shadowing standard deviation (σ = 6 dB), the reverse link capacity is no more increased by increasing SHRR.

I. Introduction

There have been studies on soft handoff [1]. These studies show that soft handoff has various advantages such as radio link diversity, interference reduction and cell coverage extension. In previous studies, these results are obtained under the assumption that the entire service area is soft handoff region. In the real environment of DS-CDMA cellular systems [2-4], however, the service area is divided into two areas, one is the normal area and the other is the soft handoff region. The soft handoff region boundary is designed by cell planning of the cellular system in such a way that the system performance can be optimized. Since radio link diversity gain can be obtained within soft handoff region, the soft handoff region ratio will have an effect on the reverse link capacity of a CDMA cellular system. In previous studies, however, no soft handoff region ratio (SHRR) is considered as a parameter affecting the reverse link capacity. In this paper, SHRR will be considered as a parameter affecting the reverse link capacity. Effects of soft handoff region ratio on the reverse link capacity of a DS-CDMA cellular system are investigated.

The remainder of this paper is organized as follow. In section II, soft handoff region boundary is modeled. In Section III, the procedure of obtaining reverse link capacity with soft handoff region is described in detail. In section IV, simulation and capacity calculation results are shown. In section V, conclusions are presented.

II. Soft handoff region boundary modeling

In CDMA cellular systems, the boundary of soft handoff region is determined by handoff parameters (i.e. T_ADD and T_DROP). Soft handoff region is denoted as the shadowed area in Fig. 1. In this paper a hexagonal cell shape is

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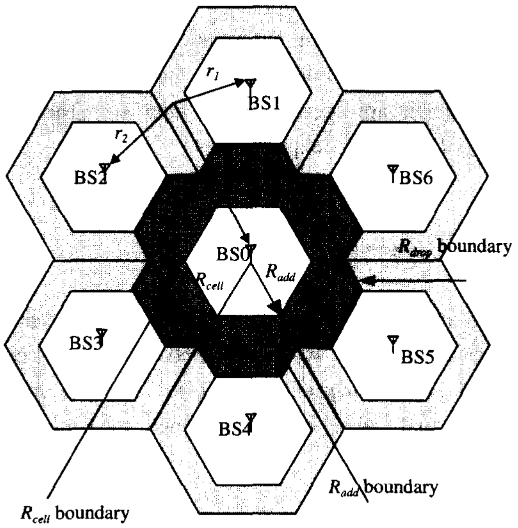
assumed. R_{cell} boundary represents the hard handoff boundary within which the pilot strength of the cell is stronger than any other neighboring cell. R_{cell} denotes the maximum distance from the cell site to R_{cell} boundary. R_{add} boundary represents the inner boundary determined by the handoff parameter T_ADD, at which soft handoff of a mobile user is initiated. For example, if a mobile user moves from BS0 to BS6 in Fig.1 and enters into the R_{add} boundary, the mobile user has two communication links with BS0 and BS6, simultaneously. R_{add} denotes the maximum distance from the cell site to the inner boundary. R_{drop} boundary denoted by the bold line represents the outer boundary determined by the handoff parameter T_DROP, at which soft handoff of the mobile user is terminated and the communication link between the mobile user and BS0 is released.



Shadowed area denotes soft handoff region

Fig. 1 Soft handoff region in a CDMA cellular system

If a cell is a hexagonal cell shape, the soft handoff region inside of R_{drop} boundary can be thought to be composed of twelve trapezoids as in Fig. 1.

In this paper, the width of the soft handoff region belonging to a cell is defined as the height of the trapezoids composing the soft handoff region. For the convenience of analysis, in this paper, it is assumed that the T_ADD and T_DROP values are set to be equal so that all the soft handoff regions belonging to distinct cells respectively have the same width. In Fig. 1, the width of the soft handoff region belonging to a cell is denoted ***d***. In this paper, soft handoff region ratio (SHRR) is defined as the ratio of the soft handoff region to the total cell coverage area. Then the SHRR of BS0 in Fig. 1 can be expressed as

$$SHRR = \frac{2(R_{cell}^2 - R_{add}^2)}{2R_{cell}^2 - R_{add}^2} \tag{1}$$

Ⅲ. Reverse link capacity with soft handoff region

In CDMA cellular systems, a link diversity gain can be obtained when the mobile user holds two communication links. Since mobile users hold two communication links in only soft handoff region, the reverse link capacity of the CDMA cellular system may significantly depend on SHRR. In order to consider SHRR as a parameter affecting the reverse link capacity, the ratio of user signal power to the interference received from other cell users, I_o/S, should be calculated with different SHRR parameter first. From central limit theory, I_o/S can be treated as Gaussian random variable [4]. Therefore, it is important to obtain the mean E(I_o/S) and the variance Var(I_o/S) of I_o/S. From the E(I_o/S) and Var(I_o/S), the reverse link capacity can be calculated by using [4-5]

$$\Pr(BER > 10^{-3}) = \sum_{k=0}^{N-1} \binom{N-1}{k} \alpha^k (1-\alpha)^{N-1-k} Q\left(\frac{\delta - k - E(I_o/S)}{\sqrt{Var(I_o/S)}} \right) \tag{2}$$

where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-y^2/2} dy \quad \text{and} \quad \delta = \frac{W/R}{E_b/N_o} - \frac{\eta}{S} \tag{3}$$

and W is the frequency band assigned, k is the number of users which are in voice active state, R

is the bit rate, E_b/N_o is energy per bit to interference density ratio, η is background noise, α is voice activity factor, respectively. The reverse link capacity N_c is defined as the maximum integer N satisfying $\Pr(BER > 10^{-3}) < 0.01$.

In order to estimate $E(I_o/S)$ and $Var(I_o/S)$, the propagation loss model should be considered first. In general, the propagation loss is modeled as the product of the th power of distance and a log-normal component representing shadowing losses. For a user at a distance r from a cell site, propagation loss is proportional to $P(\mu, \xi) = r^{\mu} 10^{\xi/10}$. If an interfering user is located at distance r_1 from its cell site and distance r_0 from the given cell site, the user, when active, produces the interference to the given cell site equal to [4][5]

$$\begin{aligned}\frac{I(r_0, r_1)}{S} &= \left(\frac{10^{\xi_1/10}}{r_0^{\mu}}\right)\left(\frac{r_1^{\mu}}{10^{\xi_0/10}}\right) \\ &= \left(\frac{r_1}{r_0}\right)^{\mu} 10^{(\xi_1 - \xi_0)/10} \leq 1 \end{aligned} \tag{4}$$

where ξ_i is the dB attenuation in BS i due to shadowing and a Gaussian random variable with zero mean and standard deviation σ dB. Let $I_{o,in}$ denote the interference received at BS0 from mobile users which are located in SR_{in} region, which is the soft handoff region inside of R_{drop} boundary and is heavily shadowed in Fig. 1. $I_{o,in}/S$ can be expressed as

$$\frac{I_{o,in}}{S} = \sum_{j=0}^{6} \sum_{i=1}^{N_{in,j}} \left[\begin{array}{c} \dfrac{\chi_{i,BSj} \cdot I_{i,BSj}(r_0, r_1)}{S} \quad ; \\ r_1^{\mu} 10^{\xi_1/10} < r_0^{\mu} 10^{\xi_0/10} \end{array} \right] \tag{5}$$

where $I_{i,j}(r_0,r_1)$ is the interference produced by user i in cell j, $N_{in,j}$ denotes the number of mobile users within SR_{in} region in cell BSj, and r_1 and r_0 refer to the distance from the mobile user to the nearest cell site and to cell site BS0, respectively. $x_{i,BSj}$ is a random variable representing the voice activity of the user with distribution

$$\chi = \begin{cases} 1 & \text{with prob.}\, \alpha \\ 0 & \text{with prob.}\, 1 - \alpha \end{cases} \tag{6}$$

The interference is summed over the sample space for which the inequality is satisfied.

Let $I_{o,out}$ denote the interference received at BS0 from mobile users which are located in SR_{out} region, which is the other soft handoff region outside of R_{drop} boundary and is lightly shadowed in Fig. 1. $I_{o,out}/S$ can be expressed as

$$\begin{aligned}\frac{I_{o,out}}{S} &= \sum_{j=1}^{M} \sum_{i=1}^{N_{out,j}} \left[\begin{array}{c} \dfrac{\chi_{i,BSj} \cdot I_{i,BSj}(r_0, r_1)}{S} \quad ; \\ r_1^{\mu} 10^{\xi_1/10} < r_2^{\mu} 10^{\xi_2/10} \end{array} \right] \\ &+ \sum_{j=1}^{M} \sum_{i=1}^{N_{out,j}} \left[\begin{array}{c} \dfrac{\chi_{i,BSj} \cdot I_{i,BSj}(r_0, r_2)}{S} \quad ; \\ r_2^{\mu} 10^{\xi_2/10} < r_1^{\mu} 10^{\xi_1/10} \end{array} \right] \end{aligned} \tag{7}$$

where $N_{out,j}$ denotes the number of mobile users within soft handoff region SR_{out} in cell BSj, r_2 refers to the distance from the mobile user to the second nearest cell site, and ξ_2 refers to the corresponding random propagation component in dB. If $I_{o,no}$ is defined as the interference from users which are located within non soft handoff region, $I_{o,no}$ can be expressed as

$$\frac{I_{o,no}}{S} = \sum_{j=1}^{M} \sum_{i=1}^{N_{no,j}} \left[\frac{\chi_{i,BSj} \cdot I_{i,BSj}(r_0, r_1)}{S} \right] \tag{8}$$

where $N_{no,j}$ denotes the number of mobile users which are located within non soft handoff region in cell BSj. Using equations (4) - (8), the ratio of the total other cell interference to signal is obtained as

$$\frac{I_o}{S} = \frac{I_{o,in} + I_{o,out} + I_{o,no}}{S} \tag{9}$$

We can obtain the mean and variance of I_o/S at a given path loss model and SHRR, using equations (4)~(9). Then, the capacity of the DS-CDMA can be calculated by substituting the mean and variance into equation (2).

Ⅳ. Simulation and capacity calculation results

A total of 20,000 I_o/S samples are obtained from computer simulation based on equations (4) ~ (9) at a given SHRR and path loss model. In this simulation, nine path loss models are considered, those are (μ = 3, σ = 6, σ = 8 and σ = 10 dB), (μ = 4, σ = 6, σ = 8 and σ = 10 dB) and (μ = 4, σ = 6, σ = 8 and σ = 10 dB). The SHRR is changed from 0 percent to 100 percent at the given pass loss model. For the simulation, the followings are assumed.

1) Voice activity factor α = 3/8 [4].

2) The cellular system consists of one center cell and 18 cells surrounding the center cell since the interference from other cells beyond the 18 outer cell is negligible [5].

3) Mobile users are uniformly distributed in the cellular system service area, and all the cells have the same number of users [4].

$E(I_o/S)$ and $Var(I_o/S)$ for each path loss model and the given SHRR are obtained from the samples by using equations (10) and (11) [5].

$$E\left(\frac{I_o}{S}\right)=\frac{1}{L}\sum_{l=1}^{L}\left(\frac{I_o}{S}\right)_l \qquad (10)$$

$$Var\left(\frac{I_o}{S}\right)=\frac{1}{L}\sum_{l=1}^{L}\left[\left(\frac{I_o}{S}\right)_l-E\left(\frac{I_o}{S}\right)\right]^2 \qquad (11)$$

where L denotes the number of total sample.

The results are shown in tables 1, 2 and 3. The reverse link capacities are obtained under the condition that W=1.25MHz, R=8kbps and E_b/N_o = 7dB. The results are shown in Figs.2, 3 and 4. Fig. 2 shows that the reverse link capacity is increased by increasing SHRR and is heavily affected by SHRR and shadowing factor when μ = 3 and σ = 10 dB. The reverse link capacity is increased from 24 to 28 channels with SHRR. In the case that attenuation exponent μ = 5 and σ = 6 dB, however, no reverse link capacity is increased by increasing SHRR as shown in Fig. 4. From the results, it can be said that the reverse link capacity is less affected by SHRR in the pass loss model of small σ than large σ. That is, it may be meaningless to have a high SHRR in the area with small σ. These facts can be used for cell planning to increase the efficiency of a CDMA cellular system.

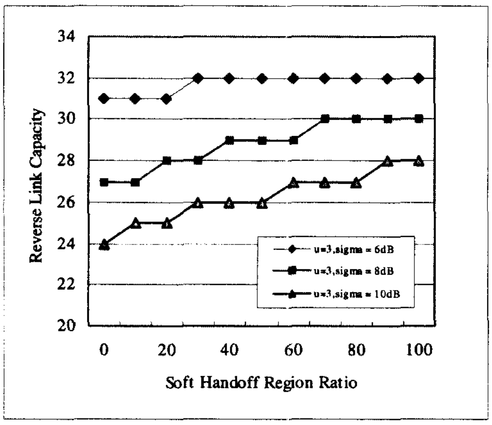


Fig. 2 Reverse link capacity with SHRR (at μ = 3, σ = 6, 8 and 10 dB)

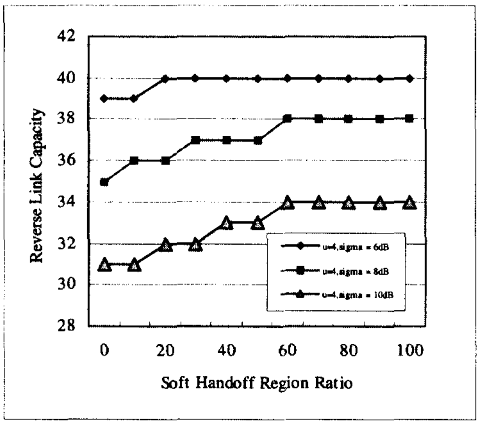


Fig. 3 Reverse link capacity with SHRR (at μ = 4, σ = 6, 8 and 10 dB)

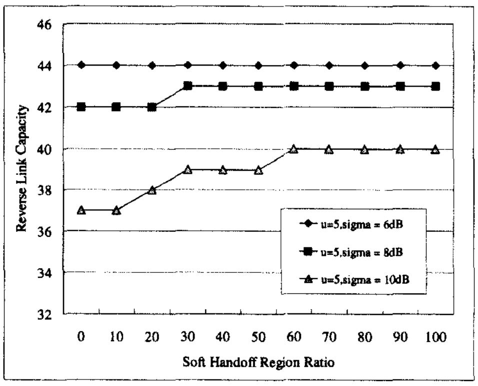


Fig. 4 Reverse link capacity with SHRR (at μ = 5, σ = 6, 8 and 10 dB)

Table 1. Mean and variance of I/S (at μ = 3, σ = 6, σ = 8 and σ = 10 dB)

SHRR(%)	μ =3, σ =6 dB		μ =3, σ =8 dB		μ =3, σ =10 dB	
	E(I/S)	Var(I/S)	E(I/S)	Var(I/S)	E(I/S)	Var(I/S)
0	0.357Ns	0.105Ns	0.457Ns	0.164Ns	0.527Ns	0.216Ns
10	0.347Ns	0.101Ns	0.444Ns	0.161Ns	0.514Ns	0.224Ns
20	0.339Ns	0.102Ns	0.430Ns	0.152Ns	0.501Ns	0.210Ns
30	0.330Ns	0.093Ns	0.417Ns	0.142Ns	0.488Ns	0.198Ns
40	0.323Ns	0.096Ns	0.406Ns	0.137Ns	0.475Ns	0.193Ns
50	0.320Ns	0.095Ns	0.395Ns	0.137Ns	0.462Ns	0.182Ns
60	0.316Ns	0.094Ns	0.385Ns	0.131Ns	0.450Ns	0.173Ns
70	0.316Ns	0.096Ns	0.378Ns	0.129Ns	0.438Ns	0.174Ns
80	0.314Ns	0.096Ns	0.376Ns	0.129Ns	0.428Ns	0.171Ns
90	0.315Ns	0.095Ns	0.374Ns	0.125Ns	0.423Ns	0.171Ns
100	0.315Ns	0.093Ns	0.373Ns	0.129Ns	0.420Ns	0.166Ns

Table 2. Mean and variance of I/S (at μ = 4, σ = 6, σ = 8 and σ = 10 dB)

SHRR(%)	μ =4, σ =6 dB		μ =4, σ =8 dB		μ =4, σ =10 dB	
	E(I/S)	Var(I/S)	E(I/S)	Var(I/S)	E(I/S)	Var(I/S)
0	0.189Ns	0.060Ns	0.250Ns	0.086Ns	0.340Ns	0.141Ns
10	0.184Ns	0.055Ns	0.240Ns	0.082Ns	0.328Ns	0.134Ns
20	0.180Ns	0.055Ns	0.232Ns	0.079Ns	0.318Ns	0.130Ns
30	0.177Ns	0.057Ns	0.224Ns	0.078Ns	0.305Ns	0.121Ns
40	0.175Ns	0.058Ns	0.219Ns	0.075Ns	0.296Ns	0.115Ns
50	0.175Ns	0.056Ns	0.214Ns	0.075Ns	0.287Ns	0.110Ns
60	0.174Ns	0.059Ns	0.210Ns	0.071Ns	0.278Ns	0.112Ns
70	0.175Ns	0.058Ns	0.209Ns	0.074Ns	0.272Ns	0.108Ns
80	0.175Ns	0.060Ns	0.208Ns	0.073Ns	0.267Ns	0.107Ns
90	0.175Ns	0.060Ns	0.209Ns	0.074Ns	0.265Ns	0.102Ns
100	0.175Ns	0.058Ns	0.210Ns	0.074Ns	0.265Ns	0.105Ns

Table 3. Mean and variance of I/S (at μ = 5, σ = 6, σ = 8 and σ = 10 dB)

SHRR(%)	μ =4, σ =6 dB		μ =4, σ =8 dB		μ =4, σ =10 dB	
	E(I/S)	Var(I/S)	E(I/S)	Var(I/S)	E(I/S)	Var(I/S)
0	0.120Ns	0.043Ns	0.149Ns	0.050Ns	0.217Ns	0.083Ns
10	0.117Ns	0.041Ns	0.144Ns	0.050Ns	0.209Ns	0.081Ns
20	0.115Ns	0.042Ns	0.139Ns	0.050Ns	0.201Ns	0.079Ns
30	0.116Ns	0.041Ns	0.136Ns	0.049Ns	0.194Ns	0.071Ns
40	0.115Ns	0.042Ns	0.133Ns	0.049Ns	0.187Ns	0.072Ns
50	0.116Ns	0.044Ns	0.132Ns	0.048Ns	0.182Ns	0.071Ns
60	0.116Ns	0.044Ns	0.131Ns	0.048Ns	0.177Ns	0.070Ns
70	0.115Ns	0.043Ns	0.131Ns	0.049Ns	0.173Ns	0.067Ns
80	0.116Ns	0.043Ns	0.132Ns	0.051Ns	0.172Ns	0.073Ns
90	0.116Ns	0.045Ns	0.132Ns	0.047Ns	0.172Ns	0.065Ns
100	0.116Ns	0.043Ns	0.132Ns	0.049Ns	0.172Ns	0.068Ns

In this path loss model used, the parameter σ represents shadowing standard deviation. The smaller σ in path loss model, the smaller link diversity gain by soft handoff. In addition, when attenuation exponent μ is 5, interference from other cell users I_o is significantly reduced. Therefore, Var(I_o/S) is less effected by soft handoff region ratio. Consequently, as shown in Fig. 4, in path loss model of μ = 5 and μ = 6, reverse link capacity is not increased with SHRR.

Ⅳ. Conclusions

In this paper, the effects of SHRR on the reverse link capacity are investigated. The reverse link capacity of a DS-CDMA cellular system is calculated at a given SHRR and path loss model. The results show that the reverse link capacity increases by 1 ~ 4 channels according to the soft handoff region ratio. In the case that the path loss model has a large attenuation exponent (μ = 5) and a small shadowing standard deviation (σ = 6 dB), the reverse link capacity is no more increased by increasing SHRR. With this path loss model, it may be desirable to have a small SHRR. With the path loss model having a small attenuation exponent μ = 3 and a large shadowing standard deviation σ = 10 dB, a high SHRR is desirable for the reverse link capacity increase. When shadowing standard deviation σ is less than 8 dB and the SHRR is greater than 50%, the reverse link channel increase is just one channel or less. As the SHRR increases, the call blocking rate of the cellular system keeps increasing due to the increase of channel holding time. Therefore, it is highly recommended that the SHRR be less than 50% under the condition. These results are expected to be useful for cell planing and the reverse link budget design.

References

[1] A. J. Viterbi, A. M. Viterbi and K.S. Gilhousen, "Soft handoff extends DS-CDMA

cell coverage and increases reverse link capacity," *IEEE Journal. On Selected Areas in Comm.*, vol. 12, no.8, pp. 1281-1288, Oct. 1994.

[2] TIA/EIA Interim Standard (IS-95), Mobile station - base station compatibility standards for dual-mode wideband spread spectrum cellular system, July 1993.

[3] Qualcomm, *The CDMA Network engineering handbook*, vol, Nov. 1992.

[4] K. S. Gilhousen, et al, "On the capacity of a cellular CDMA system," *IEEE Trans. on Veh. Tech.*, vol. 40, no.2, pp. 303-312, May 1991.

[5] Hyoung-Goo Jeon, Sung-Moon Shin, Taewon Hwang and Chang Eon Kang, "Reverse Link capacity analysis of a CDMA cellular system with mixed cell sizes," *IEEE Trans. on Veh. Tech.*, vol. 49, no.6, pp. 2158-2163, Nov. 2000.

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