Number of Elements in Smart Antenna System effects on both Perfect and Imperfect Power Control for Reverse Link of CDMA Cellular System

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Abstract: Power control (PC) on the reverse link of CDMA cellular system is important to increase system capacity. PC eliminates fluctuations in the received signal level and hence reduces the required signal-to-interference ratio. However, both perfect PC and imperfect PC depend on number of interferences as number of users, which by using smart antenna system can decrease number of interferences in any directions except interferences from the main beam direction. In this paper, number of elements in smart antenna system, which directly relates to the main beam pattern, is studied to find the effects on the outage probability, bit energy-to-interference density ratio (Eb/Io) and the capacities of both perfect and imperfect PC.

1. Introduction

Code Division Multiple Access (CDMA) is more attractive than any other candidates for cellular system[1]. CDMA cellular system is characterized as being interference-limited and reducing the interference results in increasing the capacity. Through any factors, PC is considered the most important system requirement for CDMA systems. PC increases the capacity on the reverse link by overcoming the near-far problem. Signals received from far users are generally weak compared to signals received from near users. Low carrier-to-interference ratio (CIR) results in high bit-error rate (BER), while high signal levels result in high interference to other users. The system capacity is maximized when all the signals are received with the minimum required CIR (CIReq). Thus, PC in the reverse link is essential to mitigate the near-far problem and to increase system capacity. PC is also necessary for the forward link, but this paper concentrates in the reverse link.

The effect of PC on system capacity was investigated in many works and was found that many parameters can affect the capacity such as PC algorithm [2][3][4] [5], soft handoff [4] ,mobile velocity [2]. However, PC performance depends on number of interferences as number of users in surrounding cells [6] which have closely related to the antenna pattern of interested cell. The smart antenna system is a novel antenna which yields an increment in the reverse link capacity, because each element of array antenna has an adaptive weighting element in order to steer main beam to specific user and reduce interference in the other directions [7]. Physical pattern of smart antenna depend on the number of array elements, so this paper concentrates to study the effect of numbers of array element on CDMA cellular system with perfect and imperfect power control.

The remainder of this paper is organized as the following. Section II presents the system model including with the smart antenna model and the interference model. In Section III, the effect of number of elements in smart antenna system on CDMA cellular system capacity is analyzed . Next, simulated results are discussed in Section IV. Lastly, Section V provides conclusions of this paper.

2. System Model

The simplified model of reverse link CDMA system without affecting of delay time in PC is considered because the target of this paper is focusing on variation of interferences from elements of smart antenna system , so the real-time process of PC and smart antenna system are ignored.

2.1 Smart Antenna Model

CDMA cellular system requires PC algorithm to ensure that all of the signals arriving at base station are at approximately the same power level which are particularly sensitive to the geographical distribution of users. Smart antenna can provide robustness to increasing capacities and reducing interferences because smart antenna can focus only coverage pattern to deal with specific user. The block diagram of smart antenna system in CDMA cellular system is shown in Figure1. The ith Mobile unit is the specific user and the n th mobile unit and k th are the interference of the i th mobile unit from the same cell and other cells respectively . Hence, the received signal of the ith mobile unit at base station can be expressed by

$$Pr_i(r,\theta) = \sum_{j=1}^{L} \left(Pr_{ij}(r,\theta) + Pr_{nj}(r,\theta) + Pr_{kj}(r,\theta)\right) \cdot w_j \qquad (1)$$

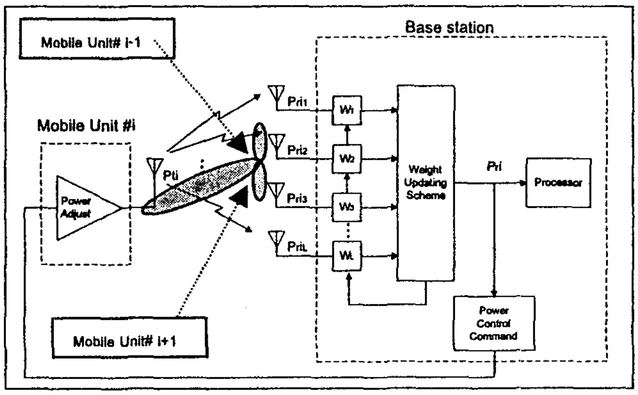

Figure 1. Block diagram of reverse link smart antenna system

where $Pr_i(r,\theta)$ is received power which is adjusted by weighting scheme, $Pr_{ij}(r,\theta)$ is received power at j th element of array antenna from the i th mobile unit, $Pr_{nj}(r,\theta)$ is received power at j th element of array antenna from the nth mobile unit, $\Pr_{kj}(r,\theta)$ is received power at j th element of array antenna from the k th mobile unit, L is total number of elements in array antenna, w_j is weighting element at j th element of array antenna

By successful adjusting the set of weighting scheme, logical pattern of array antenna is possible to direct at the maximum of the main beam in directions which the i th mobile unit is locating. Equation (1) is reduced into

$$\Pr_i(r,\theta)=\sum_{j=1}^{L}\Pr_{ij}(r,\theta)\cdot w_j \tag{2}$$

2.2 Interference Model

The geometry of the interference model is shown in Figure2. This model based on the distance from home cell has been carried out only for users at the cell boundary with 6 surrounding cells which rely on an uniform hexagonal cellular system. The users are assumed to be uniformly distributed. By successful weighting scheme in smart antenna system, only the C/I of users within the shaded main beam pattern of array antenna needs to evaluated.

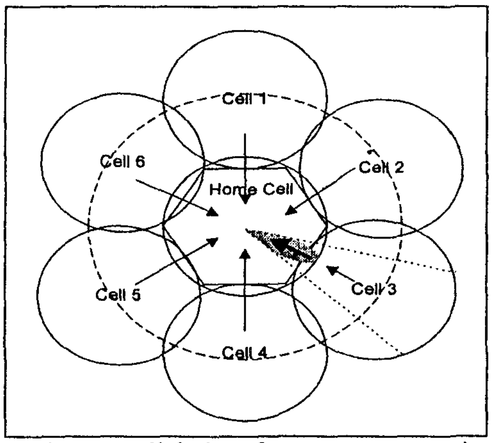

Figure 2. Reverse link interference geometry in CDMA cellular system

The C/I can be obtained by

$$\frac{C}{I}=\frac{\sum_{j=1}^{L}\Pr_{ij}(r,\theta)\cdot w_j}{\sum_{j=1}^{L}\left\{\sum_{n=1}^{N}\Pr_{nj}(r,\theta)\cdot w_j-\Pr_{ij}(r,\theta)\cdot w_j+\sum_{k=1}^{K}\Pr_{kj}(r,\theta)\cdot w_j\right\}} \tag{3}$$

where N is total number of users in home cell, K is total number of users in 6 surrounding cells

In properly adjusted, weighting scheme can cancel almost interferences for the i th mobile unit. The rest of interference will be limited in the coverage area of main beam, then Equation (3) can be rewritten as

$$\frac{C}{I}=\frac{\Pr_i(r,\theta)}{\sum_{n=1}^{N'}\Pr_n(r,\theta)-\Pr_i(r,\theta)+\sum_{k=1}^{K'}\Pr_k(r,\theta)} \tag{4}$$

where N' is number of users in home cell within $\theta_i-\frac{\theta_{BW}}{2}\le\theta\le\theta_i+\frac{\theta_{BW}}{2}$, θ_i is angle at the i th mobile unit, θ_{BW} is beam width of main beam which illustrated in Figure 3 , K' is number of users in surrounding cells within $\theta_i-\frac{\theta_{BW}}{2}\le\theta\le\theta_i+\frac{\theta_{BW}}{2}$

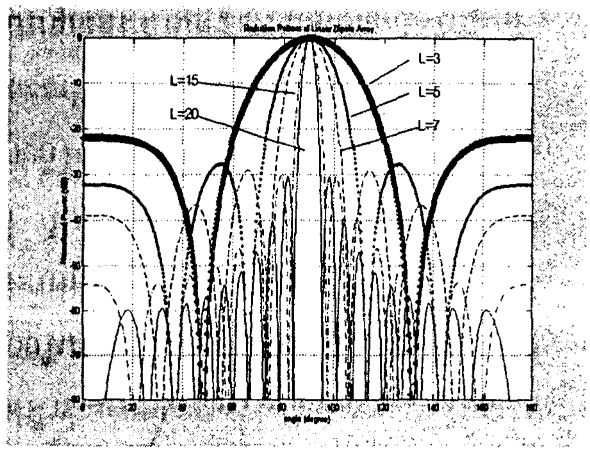

Figure 3. Radiation Pattern versus number of elements in linear dipole array system

3. Effect of number of elements in smart antenna system on CDMA cellular system

This section will be separated into 2 cases. Case A is the perfect PC and case B is imperfect PC, which both cases are limited in non-real time processing and slow-speed mobile. The cellular layout consists of only the first tiers of surrounding cells centrally located base stations. By following the IS-95 standard, the bandwidth of each channel is assumed to be 1.23 MHz, data rate is set at 9.6 kbps and the bit error rate is targeted to be no more than 10^{-3} or the required Eb/Io = 7 dB.

Case A: Perfect Power Control

In this case, all received power from mobile units to their own cell is approximately the same power level (perfect PC). Hence, equation (4) can be transformed into

$$\frac{C}{I}=\frac{Pc}{\sum_{n=1}^{N'}Pc-Pc+\sum_{k=1}^{K'}Pc\cdot\left(\frac{r_k}{x_k}\right)^m} \tag{5}$$

where r_k is distance from the kth mobile unit to its base station, x_k is distance from the kth mobile unit to base station of the ith mobile unit, m is path loss law exponent (m=2,3,4) which N' can be calculated by

$$\sum_{n=1}^{N'}Pc=\int_{\theta_i-\frac{\theta_{BW}}{2}}^{\theta_i+\frac{\theta_{BW}}{2}}\int_0^R pdf(\Pr_i)\cdot Pc\cdot r\,dr\,d\theta \tag{6}$$

where $pdf(\Pr_i)=\frac{N}{\pi R^2}$ (uniform distribution)

assume that every cell has the same uniform distribution, so K' can be calculated by

$$\sum_{k=1}^{K'}Pc\cdot\left(\frac{r_k}{x_k}\right)^m=\int_{\theta_i-\frac{\theta_{BW}}{2}}^{\theta_i+\frac{\theta_{BW}}{2}}\int_R^{3R}\frac{N}{\pi R^2}\cdot Pc\cdot\left(\frac{r}{\sqrt{r^2+(3R)^2+6rR\cos\theta}}\right)^m\cdot r\,dr\,d\theta \tag{7}$$

given

$$K'' = \int_{\theta_i-\frac{\theta_{BW}}{2}}^{\theta_i+\frac{\theta_{BW}}{2}} \int_R^{3R} \frac{N}{\pi R^2} \cdot \left(\frac{r}{\sqrt{r^2+(3R)^2+6rR\cos\theta}} \right)^m \cdot r dr d\theta \quad (8)$$

we can rewrite Equation (5) as

$$\frac{C}{I} = \frac{1}{N'-1+K''} \quad (9)$$

given $K'' = N'K'''$ and CIReq is target of systems so we can find N' in Equation (10)

$$N' = \frac{\text{CIReq}+1}{\text{CIReq}(1+K''')} \quad (10)$$

If without smart antenna and K''' is near zero, which is depend on other surrounding cell. We will see that Equation (10) is the same formula of conventional CDMA formula.

Case B : Imperfect Power Control

In practically, the received power from all users is not the same level which is disturb by multipath fading and noise. Power control error is evaluated by condition that the probability density function of power control error is Rayleigh fading and log-normal distribution. Hence, we will restart with equation (4) by adding error probability. The received power of the i th mobile unit can be expressed by

$$\Pr_i(r,\theta) = Pt_i(r,\theta) \cdot r_i^{-m} \cdot 10^{\frac{\gamma_i}{10}} \quad (11)$$

where Pt_i is the transmitter power of the i th mobile unit, r_i is distance from the ith mobile unit to home cell, γ_i is zero-mean Gaussian random variable with a standard deviation of σ, which denoted the power control error. When σ=0 dB, the case is corresponding to perfect power control. If power control is not perfect, σ is assumed to be 1-4 dB. The probability density function (pdf) of the received power is expressed by

$$pdf(\Pr_i) = \frac{1}{\sqrt{2\pi}\sigma} \cdot \exp\left\{ \frac{-\left[10\log_{10}(\Pr_i) - 10\log_{10}(\overline{\Pr}_i)\right]^2}{2\sigma^2} \right\} \quad (12)$$

and the mean received power for the i th mobile unit is given by

$$\overline{\Pr}_i = Pt_i \cdot r^{-m} \quad (13)$$

The $\frac{C}{I}$ becomes

$$\frac{C}{I} = \frac{Pt_i(r,\theta) \cdot r_i^{-m} \cdot 10^{\frac{\gamma_i}{10}}}{\left[\begin{array}{l} \sum_{n=1}^{N'} Pt_n(r,\theta) \cdot r_n^{-m} \cdot 10^{\frac{\gamma_i}{10}} - Pt_i(r,\theta) \cdot r_i^{-m} \cdot 10^{\frac{\gamma_i}{10}} \\ + \sum_{k=1}^{K'} Pt_k(r,\theta) \cdot x_k^{-m} \cdot 10^{\frac{\gamma_k}{10}} \end{array} \right]} \quad (14)$$

from perfect PC, we can defined $Pt_i(r,\theta) \cdot r_i^{-m} = Pc$

$$\frac{C}{I} = \frac{Pc \cdot 10^{\frac{\gamma_i}{10}}}{\left[\begin{array}{l} \sum_{n=1}^{N'} Pc \cdot r_n^{-m} \cdot 10^{\frac{\gamma_i}{10}} - Pc \cdot 10^{\frac{\gamma_i}{10}} \\ + \sum_{k=1}^{K'} Pc \cdot \left(\frac{r_k}{x_k}\right)^m \cdot 10^{\frac{\gamma_k}{10}} \end{array} \right]} \quad (15)$$

Outage probability can be calculated by

$$\text{Prob}\left[C/I \langle \text{CIReq}\right] = \frac{1}{2} + \frac{1}{2} erf\left[\frac{\text{CIReq} - m_{CI}}{2\sigma_{CI}} \right] \quad (16)$$

where

$$m_{CI} = 10\log_{10}(\Pr_i) - 10\log_{10}(I) \quad (17)$$

$$\sigma_{CI}^2 = \sigma_C^2 + \sigma_I^2 \quad (18)$$

Outage probability can be obtained by

$$P_o = \int_{\theta_i-\frac{\theta_{BW}}{2}}^{\theta_i+\frac{\theta_{BW}}{2}} \int_0^R \text{Prob}[C/I \langle \text{CIReq}] \cdot pdf(\text{Prob}[C/I \langle \text{CIReq}]) \cdot r dr d\theta \quad (19)$$

4. Results and Discussions.

Case A : Effect on Perfect Power Control

Perfect power control and imperfect power control are applied in this model. We propose the derived general formula which shows obviously the relations between number of array elements and outage probability in Equation (19). In the course of a simulation run, more than 100,000 slow-speed mobile units were generated randomly and their holding time were a poison distribution, which should be sufficient for good simulation results. The performance of systems measured with Eb/Io is shown in Figure 4. It is observed that as the number of elements of array antenna increases from L=1 to L=15, there is a significant improvement in system performance (Eb/Io) for all N. This is due to the number of interference with in the main beam region is reduced when the beam width is sharpened by increasing elements of array antenna.

Case B : Effect on Imperfect Power Control.

In our analysis and simulation, has been plotted in Figure 5(a) to Figure 5(b) as σ=1 and 4 dB respectively. For the same capacity; outage probability decreases with an increase in L. When N =50 users/cell and σ=4dB, Po=0.89 for L=1, Po=0.6 for L=3, Po=0.35 for L=5, Po=0.2 for L=7 and Po=0.15 for L=11. Obviously, increment in number of element of array antenna can help system performance to achieve a required outage probability.

In Figure 6. , we compare outage probability between using smart antenna at 3 array elements and without smart antenna system. The results show clearly that the capacity increase at the same level of outage probability with using smart antenna; moreover, this trend is clarity in all standard deviation of σ (0,1,2,3,4 dB)

In our study of effect of number of elements, we try to create relation between L and Po by fixing N=50 users/cell as shown in Figure 7. It strongly confirm that to increase the number of elements will improve the system performance and this improvement is slightly small if standard deviation of σ is so high.

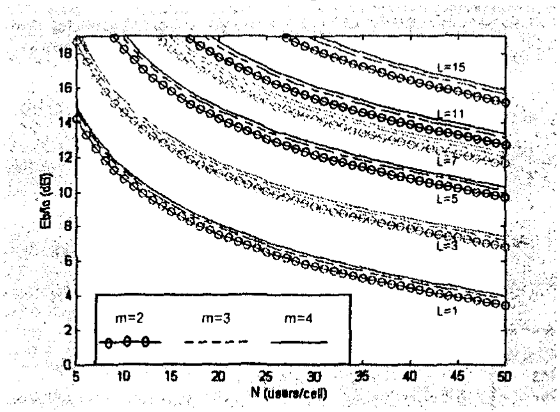

Figure 4. The reverse link capacity N versus Eb/Io in case of perfect PC for L=1,2,3,5,7,11 and 15.

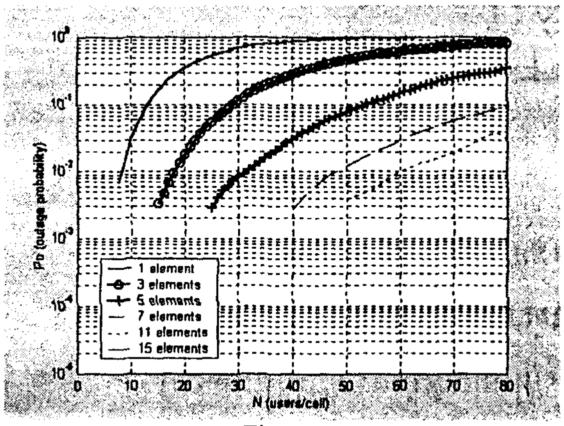

Figure 5(a)

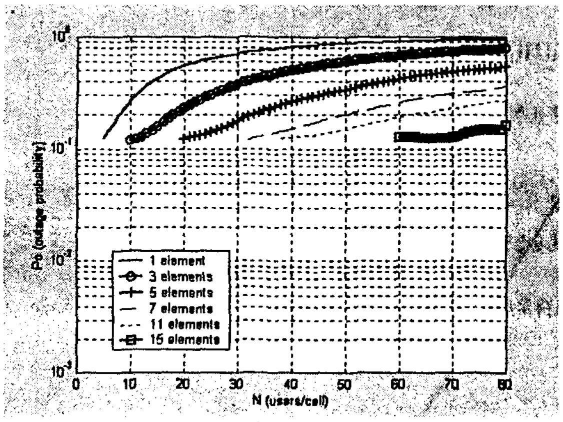

Figure 5(b)

Figure 5. Outage probability versus capacity (a) σ=1 dB (b) σ=4 dB

5. Conclusions

In this paper, the relation between number of elements in smart antenna system and performance of reverse link of CDMA system has been analyzed in addition to both perfect and imperfect power control are applied. The reverse link capacity has also been increased when number of elements of array antenna increases. In the same way, the outage probability can be improved by using more elements in smart antenna system.

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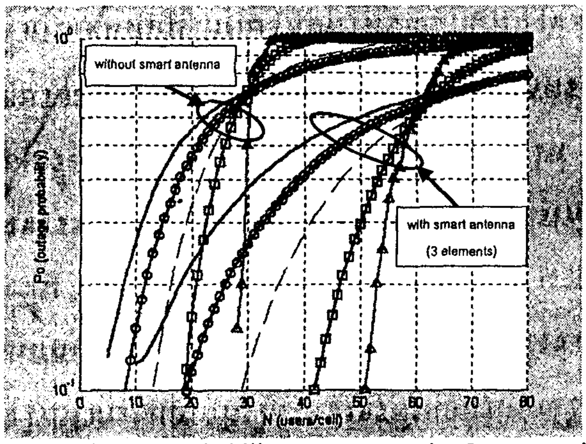

Figure 6. Outage probability versus capacity for comparing system with and without smart antenna

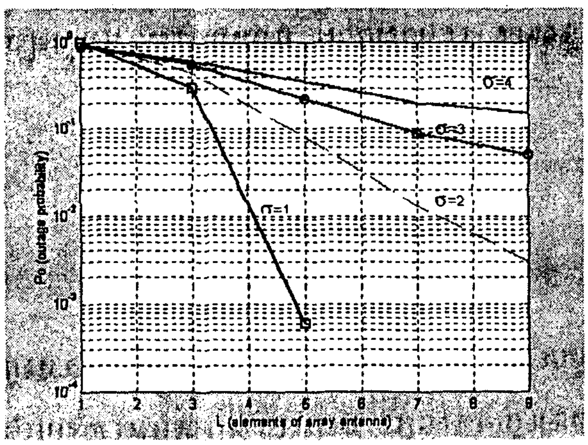

Figure 7. Outage probability versus elements of array antenna at N=50 users/cell.