Optimum cell boundary with power ratio control and tilted antenna arrays in a cellular wireless communications

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Optimum Cell Boundary with Power Ratio Control and Tilted Antenna Arrays in a Cellular Wireless Communications

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ABSTRACT

In this paper, we propose the soft boundary concept achieved by dynamic titled antenna to solve the issue of traffic congestion occurred in cellular wireless systems. The tilted antenna array can provide the merit of traffic balance and also achieve the optimization of the signal-to-interference ratio (SIR) at receivers by automatically tilting the antenna and implementing the soft boundary among cells, corresponding to the variation of traffic.

I. Introduction

The capacity of a CDMA cellular system is determined by a volume of the interference including the internal interference and multi-cross interference. Any decrease in the interference will directly result in the increase in the system capacity. From K.C.Whang's research results[1][2][3], a tilted antenna array can be used to reduce the interference in hierarchical macrocell/microcell systems, in two tiers sharing the same spectrum.

In real cellular environments, that is non-uniform radio environments, non-uniform user distributions dominate and thus, the performance characteristics differ among cells, and communication quality varies rapidly[4]. Given these backgrounds, we propose the soft boundary concept achieved by dynamic titled antenna to solve the issue of traffic congestion occurred in cellular wireless systems. The tilted antenna array can provide the merit of traffic balance and also achieve the optimization of the signal-to-interference ratio (SIR) at receivers by automatically tilting the antenna and implementing the soft boundary among cells, corresponding to the variation of traffic.

II. System Model and a Tilted Antenna Pattern

A) Tilted antenna array: Figure 1 depicts the 60-degree directional antenna pattern that covers a sector with the same antenna gain in the horizontal direction (i.e., $x-y$ plane) shown in Figs.1 and 2(a). Of primary concern here is the horizontal antenna pattern when the antenna is tilted down by a angle θ in the vertical plane (i.e., $x-y$ plane). If the vertical pattern of the tilted antenna array is known, the horizontal pattern with tilted angle can be got as shown in Fig.2(b). Then, the normalized vertical antenna gain of the main lobe can be approximately expressed by[1][2]

$$G(\phi,\gamma) = \begin{cases} 1-(\frac{\phi}{BW})^2, & 0 \leqq \phi \leqq BW \\ \gamma & otherwise \end{cases} \qquad (1)$$

where BW is the beam-width of the used tilted antenna array that is assumed to be 10 degrees as an example to be investigated. γ is 0.1 (or -10 dB) and ϕ is the angle drifted off by 0 degree in vertical plane and increasing up to BW, which corresponds to -10 dB in antenna gain. In Fig.2(b), the solid line denotes the vertical pattern for an un-tilted antenna (i.e., $\theta = 0$ degree). When the antenna is tilted by a θ, the vertical pattern will subsequently shift right as the dashed line.

B) Non-uniform user distribution models: For simplicity, we consider the simple one-dimensional models in which users are located continuously over the whole cell area (sector area). The number of users at a point is defined as traffic density that is considered as only the function of distance r (the distance between a point to base station) that means it is non-uniform distribution to r and uniform distribution to the angle α. Then, three types of user distribution functions,

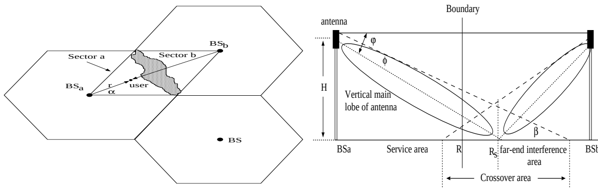

Fig. 1 Cellular geometry and tilted antenna

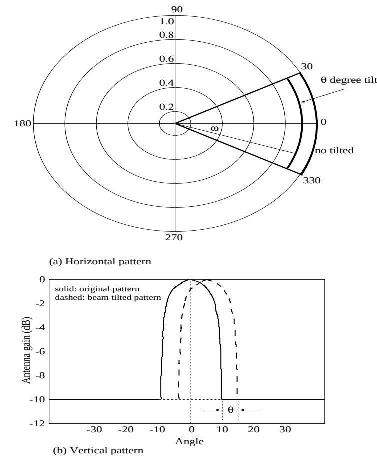

Fig. 2 Radiation pattern of a tilted antenna array

$T(r)$ are assumed as follows[3]

$$Case\ 1: \quad T(r) = \frac{N}{R^2}\cdot r \qquad (2)$$

$$Case\ 2: \quad T(r) = \frac{2N}{e^{2R}-2R-1}\cdot(e^r-1) \qquad (3)$$

$$Case\ 3: \quad T(r) = \frac{N}{R}[1-m\cdot sin\ \ (\frac{\pi}{R}r)] \qquad (4)$$

III. Performance Evaluation

A) Modified formula of SIR in the reverse link: A careful investigation must be focused on the evaluation of boundary shift point, R_s, and the impact of tilted angle, θ, in respective user distribution models. For BS_a and BS_b, SIR_a and SIR_b are given as follows[3]

$$SIR_a = \frac{1}{\upsilon(N_a-1)+I_{ba}^{ext}/S_a}$$
$$SIR_b = \frac{1}{\upsilon(N_b-1)+I_{ab}^{ext}/S_b} \qquad (5)$$

where N_a and N_b are the total number of users in sector a and b, respectively. I_{ba}^{ext} is the external interference from the adjacent sector b to BS_a. I_{ba}^{ext} is the external interference from the adjacent sector a to BS_b.

B) Modified formula of SIR in the forward link: For the forward link, since the in-cell transmissions are synchronous and hence can be made orthogonal[3], multiuser interference can be made to reduce significantly. We note that some amount of multi-path propagation degrades the orthogonality. It will result in some in-cell interference, but this will be small compared with the out-cell interference. This is especially true if RAKE receivers are adopted and some scrambling codes are used for improving cross correlations of the orthogonal sequence. We define the orthogonal factor, F_O ($0 \leqq F_O \leqq 1$), in the investigation to express the degree of orthogonality loss due to the multi-path effects[3]. By taking into account of all contributions, $SIR_a(i)$ for i-th user in sector a can be expressed as

$$SIR_a(i) = \frac{P_{Ta}(i) \cdot L(i)}{(1 - F_O)P_a L(i) + \upsilon P_b L_j(i) G(\gamma, \beta, \theta)} \quad (6)$$

where, $P_{Ta}(i)$ is the signal power sent from BS_a to user i. The first part of interference, $(1 - F_O)P_a L(i)$ in Eq.(6) is generated by the other users located at the same cell and is not the interference generated by itself code because of multi-path.

In this paper, the CDMA signal is assumed to be based on QPSK modulation/coherent demodulation format with Gold codes. In an AWGN channel, the BER of a CDMA system with the multi-cells[4] can be investigated.

IV. Numerical Results and Discussion:

The calculation parameters are listed as follows
·Bandwidth $W = 1.25MHz$, Bit rate $R_b = 9.6kbps$
·Radius of cell $R = 10km$, VAF $\upsilon = 3/8$
·$(\frac{E_b}{N_0})_{req} = 7dB$ for reverse link
·$(\frac{E_b}{N_0})_{req} = 5dB$ for forward link
·$0 \leqq \theta \leqq 1.5$ degrees, Height of the antenna $H = 50m$
·$m = 1/2$, Path loss exponent $\kappa = 3.5$

The dependence to the tilted angle of a used antenna and

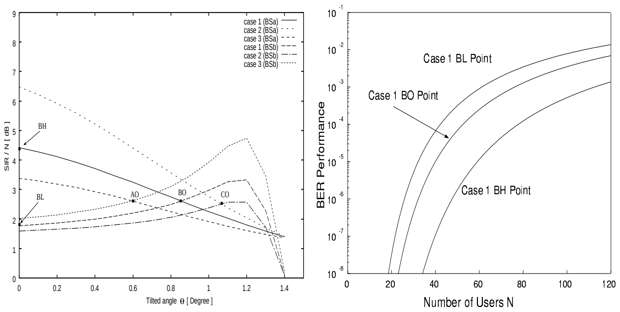

Fig. 3 $SIRs$ of BS_a and BS_b in the reverse link versus different tilted angle θ and BER performance versus the number of users N for SIR Lower point BL, Higher point BH and optimization point BO ($\frac{S_a}{S_b} = 1$, $m = 0.5$, $BW = 10$ degrees)

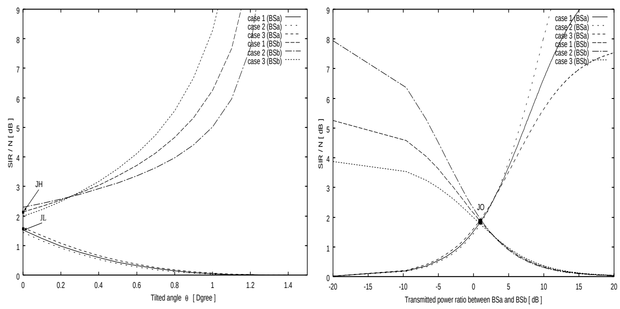

Fig. 4 $SIRs$ of the users located at the soft boundary between the sectors in the forward link versus different tilted angle θ and $SIRs$ of the users located at the soft boundary between sectors versus different power ratio $\frac{P_a}{P_b}$ ($\frac{P_a}{P_b} = 1$, $m = 0.5$, $BW = 10$ degrees, $F_O = 0.5$)

$SIRs$ of BS_a and BS_b are shown in Fig.3. From the figure, one can see whether the users are uniformly or non-uniformly distributed in the coverage service area. The tilted antenna is capable of releasing a serious hot area by shifting the boundary (also termed as soft boundary). It is also expectable to provide a better balance of services, which is especially important in the multi-service wireless systems. We also classify the radiation pattern of the antenna array by defining a ridge of balance as $SIR_a = SIR_b$. AO, BO and CO are the best points in terms of balance of services.

Figure 3 also shows the BER results for the three example points, BH,BL and BO described above. Curves labelled "Case 1 BL Point, Case 1 BH Point" were calculated with tilted angle $\theta = 0$ degree for BS_b and BS_a, respectively. These results show there are great difference of BER performance for the sector a and b because of non-uniform user distribution. The service balance (same ISR and BER) can be achieved by shifting the soft boundary using dynamic titled antenna shown as the optimization point BO. Its BER performance can be seen by the curve labelled "Case 1 BO Point". It is true that the tilted antenna array can provide the merit of traffic balance and also achieve the optimization of SIR by automatically tilting the antenna and implementing the soft boundary among cells, corresponding to the variation of traffic.

For the forward link, the situation is somewhat different, because the reference target is the mobile user who travels any area in the system. The worst case happens when the reference user is located at the boundary. Figure 4 shows $SIRs$ of reference users located at the soft boundary of BS_a and BS_b against various tilted angle when the transmitted power ratio $P_a/P_b = 1$ and orthogonal factor $F_O = 0.5$. As shown in the plots, it is impossible to find the same $SIRs$, because there are no intersection points between SIR_a and SIR_b. This implies that, once again, the balancing ridge in SIR_a and SIR_b cannot be obtained, as long as only the tilted angle control other than else is involved with finding a solution.

Now we are going to treat the problem in such a way that the power ratio arrangement and the tilted angle control are combined to investigate those effects to the system. Figure 4 also shows the relationship between SIR and transmitted power ratio when $\theta = 0$. There are almost the same three ridge points of the balance in SIR, which are marked with JO in the figure, when P_a/P_b is around 1.5 dB. Note that lower P_a/P_b will be beneficial to those users around the soft boundary in sector b, and higher P_a/P_b benefits the users around the soft boundary in sector a.

V. Conclusions

According to the numerical results, it is quite effective for user congestion relief. Especially, it is suitable for the reverse link in which the user congestion problem is treated with various user distributions to address the balance of services. In this paper, we also see the approach by tilted antenna array may be combined with the power ratio allocation control to optimize problems for implementing service balance.

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