Hot-Spot Traffic Relief with a Tilted Antenna in CDMA Cellular Networks

Jung-Shyr Wu, *Member, IEEE,* Jen-Kung Chung, *Student Member, IEEE,* and Chang-Chung Wen

Abstract— **Direct-sequence code-division multiple-access (DS-CDMA) cellular networks are highly promising in terms of their potential to provide more capacity than an advanced mobile phone system (AMPS). However, heterogeneous traffic loading causes traffic congestion in a CDMA hot spot. This paper presents a tilted-antenna mechanism for sectored cells in CDMA cellular networks to relieve the congestion in a hot-spot sector. The fixed antenna-tilted mechanism, which only tilts the hot-spot antenna, can provide the merit of traffic balancing. Besides, we design a dynamic antenna-tilted mechanism in which tilting the antennas of the hot spot and its adjacent cell sectors is based on varying the signal-to-noise ratio (SNR). The dynamic mechanism can automatically tilt the antenna corresponding to the variation of traffic. Consequently, more capacity can be provided than in fixed tilting mechanism, which only tilts the hot-spot antenna. Another benefit is the traffic-balancing effect with a tilted-antenna mechanism that reduces the transceivers of hot-spot base station. Therefore, extra facilities are unnecessary for the hot spot than for a normal or light traffic sector.**

Index Terms—**CDMA, hot spot, tilted antenna.**

I. INTRODUCTION

THE code-division multiple-access (CDMA) cellular network can efficiently provide more capacity to fulfill the increasing demand for mobile communication service than the AMPS system [1]–[5]. Nevertheless, the uneven traffic load in the cell may occur and exceed the predetermined capacity when a system is installed. The cell with heavy traffic is called "hot spot." This situation frequently occurs and is serious, particularly when the "personal communication service" is mature or the penetrations of mobile communication users are large.

The hot spot certainly introduces large blocking probability. Some methods have been proposed in frequency-division multiple-access (FDMA) or time-division multiple-access (TDMA) systems to alleviate the hot-spot problem [6] including cell splitting, channel borrowing [7], channel sharing, dynamic channel allocation, and cell overlaying/underlaying arrangement. The above methods are related to reassigning the channel in a hot-spot area. In CDMA cellular networks, all of the cells can operate with the same channel, and the users in a cell can access the same channel without planning the channel allocation as in TDMA and FDMA systems. Therefore, the above methods cannot adequately resolve the hot-spot problem.

The capacity for a CDMA cellular network is determined by a volume of cochannel interference including the intracell interference and adjacent cell interference. A better method for the interference control subsequently yields more capacity. From Lee's research results [6], the tilted antenna is generally used to reduce the cochannel interference in FDMA and TDMA systems, thereby yielding a better signal-to-noise ratio (SNR) and good quality of voice communication. It is also proposed to provide the steeper transmission loss for microcell in a hybrid CDMA macrocell/microcell environment with an overlay/underlay structure to maintain an acceptable capacity [8], [9]. This paper presents a method capable of tilting the antenna to increase system capacity. The proposed method can alleviate the traffic congestion in the CDMA hot spot. The paper contains two major parts. The first part investigates the relationship between fixed antenna-tilted mechanism and hot-spot relief, and the second part addresses the dynamic antenna-tilted mechanism. In the first part, the relationship between tilted-antenna and hot-spot relief is examined. In addition, the proposed method is deemed effective to relieve the hot-spot traffic congestion without degrading the performance. Section III provides a detailed description.

In the cellular environment, a hot-spot cell's location is changeable, depending on the mobile users' movement. For instance, the traffic intensity in a highway is extremely high during rush hour. After rush hour, the heavy traffic is moved from the highway to a business area. To match the variations of traffic, Section IV presents a dynamic antenna-tilted mechanism capable of adaptively adjusting the antenna angle based on different traffic loadings in the sectors. Accordingly, the congestion problem can be successfully resolved with heterogeneous traffic distributed in various sectors. This mechanism resembles the "dynamic channel allocation" in FDMA or TDMA systems.

II. NETWORK MODELS AND ASSUMPTIONS

The CDMA environments under investigation and some assumptions related are described as follows.

1) The hexagonal cell with sectorization is assumed, and all cells have the same size.
2) The capacity of CDMA system is determined by the reversed link [2]. This paper only considers the reversed link.
3) The users in each sector are uniformly distributed. The arrival process in sector k is assumed to be Poisson

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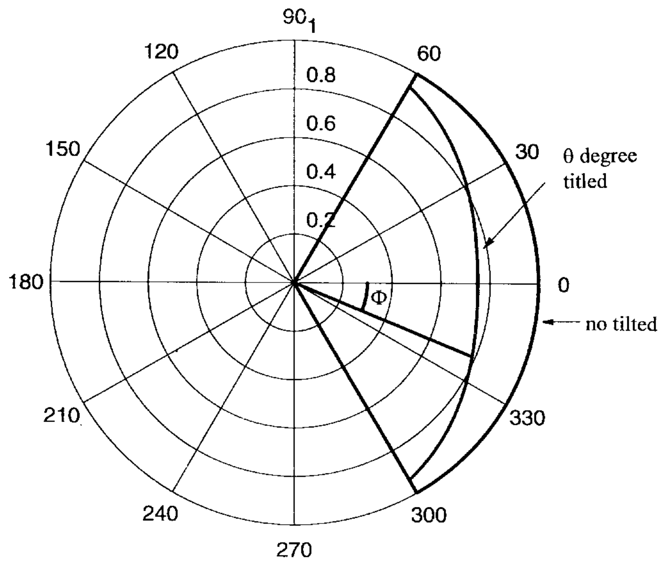


Fig. 1. Horizontal antenna pattern.

distributed with the mean arrival rates of λ_k, and the holding times of users are identically independent exponentially distributed with the mean value of $1/\mu_{\mathrm{k}}$.

4) The antenna of each sector base station is a collinear array, which is tiltable.
5) The voice activity factor is assumed to be 0.375 [2].
6) The mobility characteristics are neglected.
7) Antenna height is 0.01 R, where R is the radius of cell size.

In addition to the above assumptions, detailed characteristics of system model are described as follows.

A. Tilted-Antenna Pattern

The collinear array antenna, widely used in mobile communication, is assumed here to be used. Fig. 1 depicts the 120° directional antenna pattern that covers a sector with the same antenna gain in the horizontal direction (i.e., x–y plane). 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–z plane). If the vertical antenna pattern is known, the horizontal antenna pattern with angle tilted can be obtained [6]. We assume that the normalized vertical antenna gain of main lobe can be expressed approximately by [9]

$$G = \begin{cases} 1 - (\varphi/\mathrm{BW})^2, & 0 \le \varphi \le (\mathrm{BW} - 0.5) \\ \gamma, & \text{otherwise} \end{cases} \tag{1}$$

where the angle BW is assumed to be 10°, γ is 0.1 (or −10 dB) and φ is the angle drifted off 0° in vertical plane and increasing up to 9.5°, which corresponds to −10-dB antenna gain. The solid line in Fig. 2 denotes the vertical pattern for an untilted antenna (i.e., θ is 0°). When the antenna is tilted by a θ angle, the vertical pattern will subsequently shift right as the dashed line in Fig. 2 shows. The antenna gain at the 0° for the dashed-line curve is less than the antenna gain without being tilted. When the center beam is tilted downward by an angle of θ, the off-center beam with a Φ angle from the center is tilted downward by only a Ψ angle, which can be represented as follows [6]:

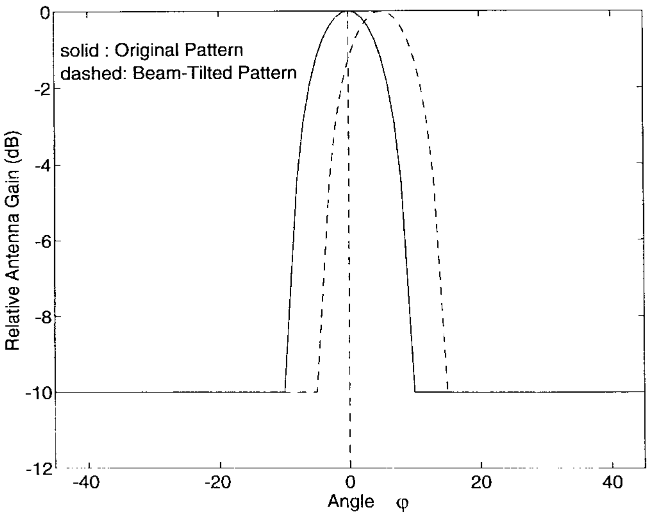


Fig. 2. Vertical antenna pattern.

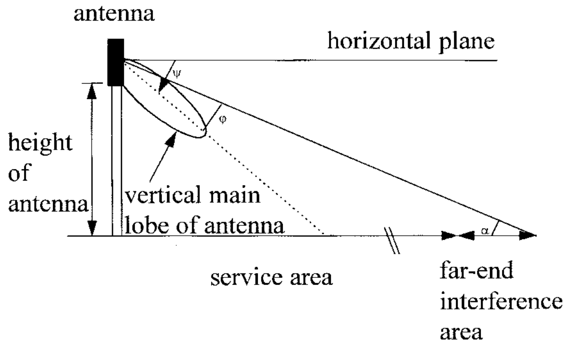


Fig. 3. Tilted antenna and cochannel interference reduction for far-end user.

$$\cos \Psi = 1 - \cos^2 \Phi (1 - \cos \theta). \tag{2}$$

Substituting the angle φ in (1) by Ψ, the horizontal pattern can be obtained.

If a mobile station is located at an angle of Φ relative to the center beam in horizontal plane (with an elevation angle of α to sector base station) and the antenna of sector base station is tilted down by a θ°, the actual tilted angle for the mobile station can be expressed as

$$\varphi = \alpha - \Psi = \alpha - \cos^{-1}[1 - \cos^2 \Phi (1 - \cos \theta)]. \tag{3}$$

For the sake of clarity, Fig. 3 depicts the relation among the angle Ψ, φ, and α. When an antenna is tilted down by a θ° and a mobile station is located with a Φ angle relative to the center beam with its elevation angle of α, according to (1), the antenna gain is defined as

$$G_{\mathrm{ANT}}(\alpha, \Phi, \theta) = \begin{cases} 1.0 - \left(\dfrac{\varphi}{\mathrm{BW}}\right)^2, & \text{if } 0 \le \varphi \le \mathrm{BW} \\ \gamma, & \text{otherwise.} \end{cases} \tag{4}$$

Two effects are caused by antenna tilting in cellular communication. First, the antenna gain for the far-end user is less than that for the near-end user. This phenomenon can be easily found in Fig. 3, causing less cochannel interference from the far end. In the CDMA cellular network, since the capacity is directly affected by the interference, less cochannel interference yields a higher system capacity. Second, the tilted antenna will shrink the coverage area. In cellular communication, the mobile station must determine which sector base station to access by measuring the pilot signal's strength. The tilted antenna causes the signal strength to be less for the mobile station on the sector boundary than that without using tilted antenna. Consequently, the mobile station on the sector boundary switches to access adjacent sectors. Due to the benefits brought by these two effects, tilted antenna is used here.

B. Propagation Model

Three factors are associated with the propagation model: path loss, lognormal fading, and short-term fading. The propagation loss is proportional to the three factors, with the most significant factors being path loss and lognormal fading. The propagation loss can be simply represented as

$$\text{Loss}(r, \xi) = r^{-n} 10^{\xi/10} \tag{5}$$

where ξ is a random variable standing for lognormal fading with a standard deviation of 5–12 dB. A typical value is 8 dB [10], and n is the propagation loss exponent with a typical value being 2.7–4.0. Here, it is assumed to be 4.0.

C. Access Determination, Call Administration, and Blocking Probability

Each mobile station in the sector must determine which sector's base station to initially access. The mobile station will access a certain sector's base station which emits the most strong pilot signal. Some factors affect the strength of received pilot signal, including transmitted power of the pilot signal, antenna gains of sector's base stations and mobile stations, propagation path loss and lognormal fading. The received power of pilot signal for a mobile is represented as

$$P_{mr} = P_p \times G_b \times G_m \times \text{Loss}(r, \xi) \tag{6}$$

where P_p is pilot power, G_b is antenna gain of base station, and G_m is antenna gain of mobile station.

The transmitted power of pilot signal for each sector's base station is the same if the sector's size is the same. The antenna gain of each sector's base station is the same for all untilted antennas. However, the gain for tilted and untilted antennas are different and follows (4). The antenna gain of every mobile station is assumed to be the same. The propagation model of path loss and lognormal fading will follow (5). Thus, important factors affecting the strength of received pilot signal for mobile stations are the tilted-antenna angle of a sector's base station and propagation model.

After a mobile station chooses to access a certain sector's base station, the sector's base station will check whether the signal-to-interference ratio (SIR) is less than the threshold of SIR_{th} or not. If the SIR is less than the threshold, the mobile station is blocked. The required E_b/N_0 of the CDMA system is about 7 dB for a bit-error rate less than 10E−3. In order to decrease the outage probability, the threshold value is defined as 7.4 dB, which is slightly larger than 7 dB [2]. The processing gain of the CDMA system is defined as "bandwidth divided by data rate" that is 21.0 dB (1.2288 MHz/9.6 kbps), so that the threshold value of SIR is −13.6 dB (i.e., 7.4 − 21.0).

The SIR-based algorithm for call administration is a distributed mechanism. It can be used by each sector's base station to determine whether or not a call is admitted to the system. The algorithm is described as follows.

1) Each sector base station i checks the measured SIR_i according to (8) (as explained in Section III) when a local mobile station k initiates a call request.
2) Then, calculate the residual capacity, which is defined as

$$R_i = \left\lfloor \frac{1}{\text{SIR}_{th}} - \frac{1}{\text{SIR}_i} \right\rfloor. \tag{7}$$

3) If $R_i > 0$, then the call request is accepted. Otherwise, the call request is rejected. The call blocking probability is defined as

$$P_{b_i} = P_r\{R_i = 0\}.$$

III. TILTED-ANTENNA MECHANISM AND HOT-SPOT RELIEF

The hot-spot relief problem based on sectored cellular environment (as shown in Fig. 4) is investigated in the following. The SIR is a good quality indicator for CDMA cellular networks, where the interference originates from users of the dedicated sector and adjacent sectors. The SIR can be formulated, as shown in (8) at the bottom of the page, where S is the signal strength received by the sector base station under the assumption of perfect power control, so that this value is the same for every mobile station in the same sector, N_i is the number of active users in the sector i, r_{ik} is the distance from mobile k to sector base station i, $G_{ik}(\cdot)$ and $G_{jk}(\cdot)$ are the antenna gains of sector base station i and sector base station j for a mobile station k, respectively. ν is the voice activity factor, and ξ_{ik} is a lognormal random variable representing the shadowing effect for mobile station k to sector base station i.

As the denominator in (8) implies, the first term represents the interference from local users while the second term represents the interference from the users of adjacent sectors.

$$(s/i)_i = \frac{S}{\nu\left\{(N_i - 1)S + \sum\limits_{j\neq i} \sum\limits_{k\in\{1,\cdots,N_j\}} S\left(\frac{r_{jk}}{r_{ik}}\right)^4 \cdot 10^{(\xi_{ik}-\xi_{jk}/10)} \frac{G_{ik}(\alpha_{ik}, \Phi_{ik}, \theta_{ik})}{G_{jk}(\alpha_{jk}, \Phi_{jk}, \theta_{jk})}\right\}} \tag{8}$$

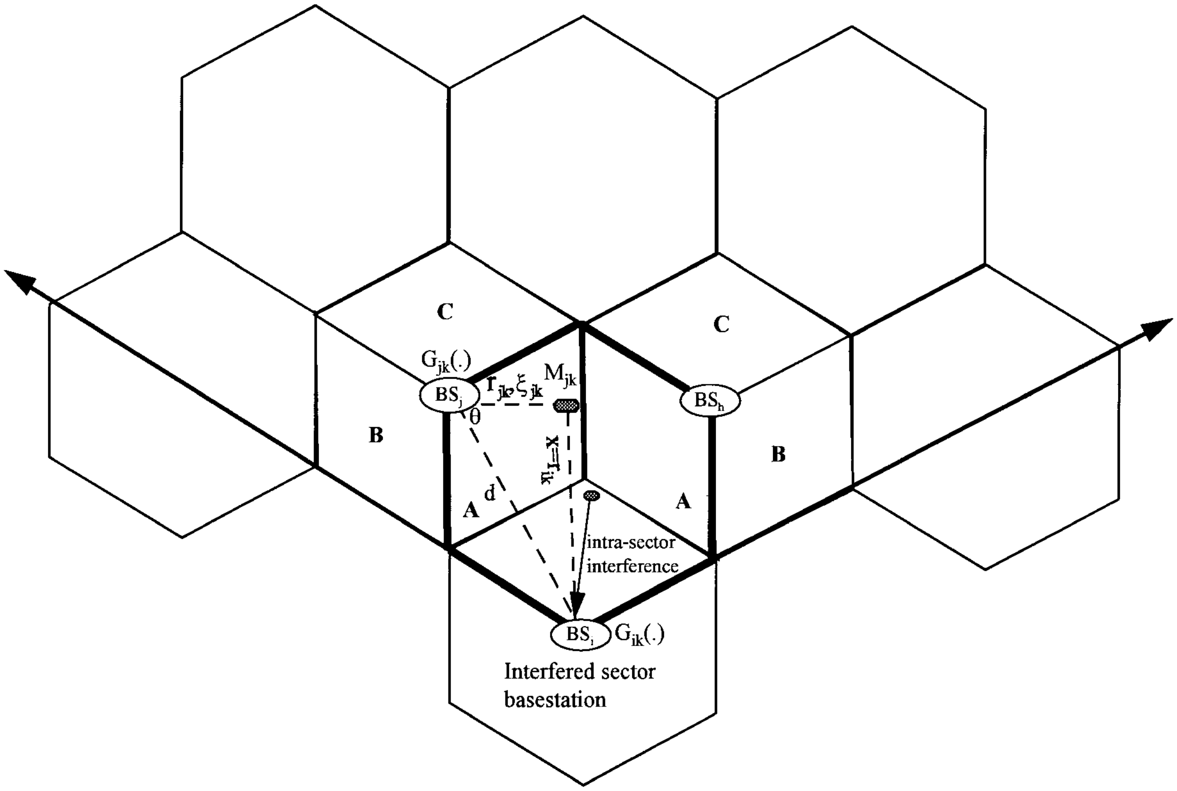


Fig. 4. Sector structure and interference source.

TABLE I
PARAMETERS OF SIMULATION

Cell Radius	R
Antenna Height	0.01R
Reverse Link SIR_{TH}	-13.6dB
Bss (Spreading BW)	1.2288MHz
Bs (Data Rate)	9600bps
Voice Activity Factor	0.375
Propagation Exponent	4.000
Lognormal Shadowing (standard deviation)	8dB

Whether a call request of mobile station is accepted by the sector's base station or not is determined by the measured SIR_i and SIR_{th} according to (7).

To assess the system's performance, the approach of event-driven simulation is adopted herein. Performance measures include blocking probability and average active users, which are related to tilted angle and offered traffic. All of the parameters used in the simulation are listed in Table I.

In the beginning, the capacity of homogeneous sectors with equal loading for all three sectors should be determined. Fig. 5 summarizes these results. The blocking probability is 1% under the SIR_{th} of -13.6 dB when every sector offers the traffic capacity of 37.2 Erls/sector, which is called full traffic (FL). In the heterogeneous traffic environment, each sector's traffic loading is different and represented in multiples of full traffic.

We study the problem with different traffic distributions in the sectors of BS0, BS1, and BS2. The BS0 is a hot-spot sector with the traffic load higher than full traffic, and the sectors BS1 and BS2 belonging to base stations 1 and 2 are adjacent to the hot-spot sector with the same traffic, but less than full traffic. If we tilt hot-spot sector BS0's antenna, this will introduce a notch of antenna gain in the horizontal direction and reduce the size of the coverage area just as mentioned in Section II-A. Fig. 4 depicts the traffic-distribution scenario. Only two sectors of adjacent cells are considered herein. The reason is given in the Appendix. Under the assumption that mobile stations are uniformly distributed in sectors, the tilted antenna covers a smaller area, and the population of mobile

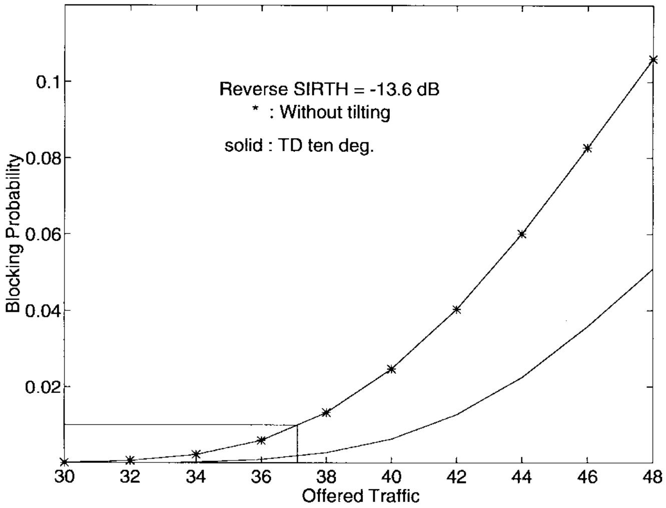


Fig. 5. Blocking probability versus homogeneous traffic loading for untilted antenna under $SIR_{th} = -13.6$ dB.

TABLE II
Tilted Antenna Angle of Hot-Spot Versus Sector Traffic

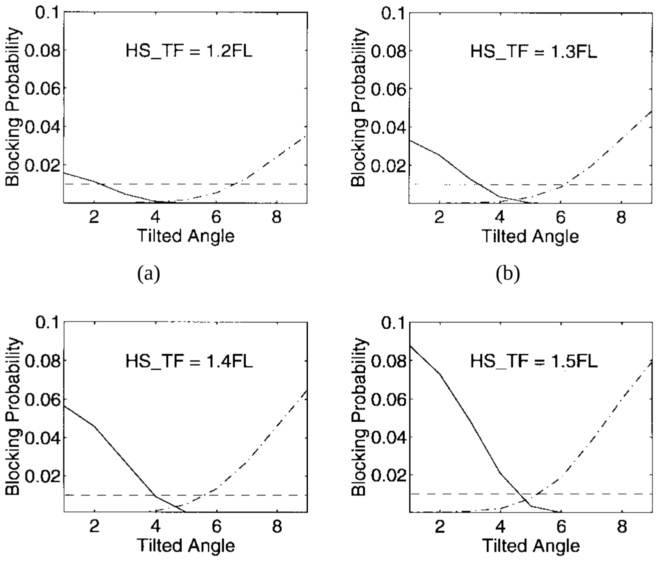
Traffic of light/normal sector(FL)	Traffic of hot-spot sector (FL)	Blocking probability of hot-spot (without tilting)	Range of tilted angle (degree) (blocking probability of all sectors are below 1%)
0.100/0.100	1.400	0.004	0.0~9.5
"	1.500	0.012	2.5~9.5
"	2.600	0.323	7.5
"	2.700	0.350	-
0.200/0.200	1.900	0.123	6.0~9.5
"	2.000	0.155	6.0~9.0
"	2.400	0.283	7.0
"	2.500	0.312	-
0.300/0.300	1.300	0.005	0.0~9.5
"	1.400	0.013	2.5~9.5
"	2.200	0.239	7.0
"	2.300	0.272	-
0.300/0.700	1.200	0.005	0.0~8.0
"	1.300	0.150	2.5~7.0
"	1.700	0.112	5.5
"	1.800	0.151	-
0.400/0.400	1.300	0.009	0.0~9.5
"	1.400	0.020	3.0~9.5
"	2.000	0.195	6.5
"	2.100	0.226	-
0.500/0.500	1.200	0.006	0.0~9.5
"	1.300	0.014	2.0~9.5
"	1.900	0.182	6.0
"	2.000	0.214	-
0.600/0.600	1.200	0.009	0.0~8.5
"	1.300	0.022	3.0~7.5
"	1.700	0.131	5.5
"	1.800	0.166	-
0.700/0.700	1.100	0.006	0.0~7.0
"	1.200	0.014	2.0~7.0
"	1.500	0.085	4.5~5.0
"	1.600	0.117	-
0.800/0.800	1.100	0.010	1.5~5.5
"	1.200	0.022	3.0~5.0
"	1.300	0.027	4.0~4.5
"	1.400	0.072	-
0.900/0.900	1.100	0.015	2.5~3.5
"	1.200	0.033	-

stations served by the BS0 decreases. Accordingly, the mobile stations in the hot-spot sector near the sector boundary switch to the sectors' base stations with light traffic (i.e., BS1 or BS2) because the strength of a pilot signal from the hot-spot sector is weaker than that from BS1 or BS2 as mentioned in Section II. Under this condition, the effect of an antenna tilted in a hot-spot sector alleviates the traffic load and maintains the blocking probability at an acceptable grade of service (GOS). The populations in BS1 and BS2 increase without significantly deteriorating the blocking probability if the overall traffic load does not exceed the full traffic. The tilted angle can hopefully be obtained for a different combination of traffic loading to derive an "optimum solution." That is, the blocking probabilities for all three sectors are under 1%, i.e., the targeted GOS.

Table I lists the simulation parameters. In the simulation, the hot-spot traffic varies in the range from 1.1 to 2.7 times of full traffic while the traffic of BS1 and BS2 changes from 0.1 to 0.9 times of full traffic, and both of them carry the same traffic. Table II presents that the simulation results of blocking probability for three sectors are below 1%. As this table reveals, an excellent performance is attained by using a tilted antenna when the traffic loading for hot spot is as high as 1.5 times of full traffic, and the traffic for BS1 and BS2 is high, up to 0.7 times of full traffic. This finding demonstrates that the tilted antenna can effectively solve the hot-spot congestion problem.

If the offered traffic of both BS1 and BS2 sectors is 0.1 times of full traffic, the corresponding traffic of hot-spot sector BS0 can be high up to 1.4 times of full traffic—its blocking probability is below 1% without antenna tilting. The hot spot can carry more traffic if the tilted antenna is adopted, and its offered traffic can reach as high as 2.6 times of full traffic. This example demonstrates that the capacity of using tilted antenna is improved by 85% [i.e., (2.6 − 1.4)/1.4]. As the traffic for BS1 and BS2 increases, the hot-spot capacity gradually decreases. Even if the traffic for BS1 and BS2 is 0.8 times of full traffic, the capacity for the hot spot is still improved by 27% [i.e., (1.4 − 1.1)/1.1].

Fig. 6 depicts the relationship between the tilted angle and blocking probability (assuming that traffic of BS1 and BS2 is 0.7 times of full traffic and hot-spot traffic varies from 1.2 to 1.5 times of full traffic). As Fig. 6(a) reveals, if the hot-spot sector's antenna is tilted down beyond 2°, the blocking probability for all sectors is below 1%. If the antenna is not tilted (i.e., 0°), the blocking probability of hot-spot sector is 0.014. This finding suggests that the tilted-antenna mechanism in a hot spot can actually improve system performance. On the other hand, if the tilted angle exceeds 4°, blocking probabilities for BS1 and BS2 apparently increase. Such an increase is owing to that hot-spot mobile stations near sector boundary will switch to access BS1 and BS2, thereby causing their traffic loading to increase. According to Fig. 6, the range of the tilted antenna angle is narrower to maintain all sectors with a blocking probability under 1% when the traffic in a hot spot becomes heavier. This phenomenon can be accounted for by two factors. First, the variation of average active users in the hot spot and BS1 and BS2 can be verified. As Fig. 7 reveals, the average active users for hot-spot decrease with an increasing tilted angle while the average active users for BS1 and BS2 increase with an increasing tilted angle. This finding suggests that the users in a hot spot near the sector boundary switch to BS1 and BS2 and access them instead of BS0. The larger tilted angle implies that more users belonging to BS0 will access BS1 and BS2. This is a kind of traffic-balancing effect. Second, the "unequal loading effect" for the CDMA system inherently exists [2]. As Table II reveals, the hot spot can have a capacity up to 1.4 times of full traffic when neighboring sectors BS1 and BS2 only carry 0.3 or 0.4 times of full traffic under a nontilted condition such that blocking



(a) (b)

(c) (d)

Fig. 6. Blocking probability versus tilted angle of hot spot (traffic of normal sector = 0.7 FL).

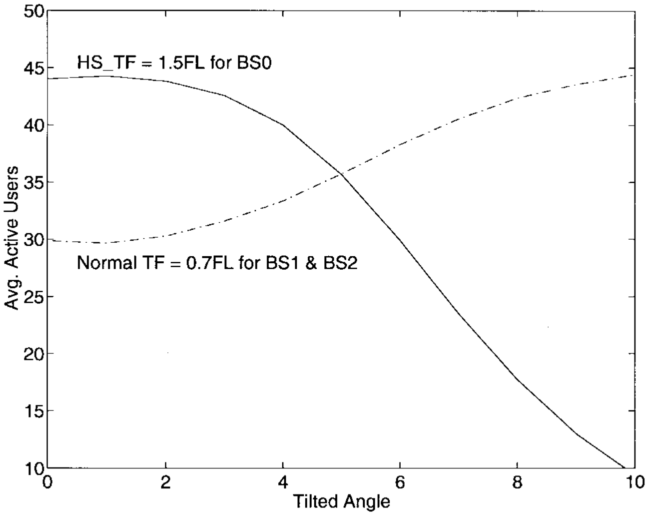


Fig. 7. Average active users in all sectors versus tilted angle of hot spot (traffic of normal sector = 0.7 FL and hot-spot traffic = 1.5 FL).

probabilities for the three sectors are all below 1%. Our results are confirmed with an unequal loading effect [2]. When the traffic loadings for BS1 and BS2 are low, the hot spot can accommodate up to 1.4 times of full traffic without tilting the antenna due to the second factor (i.e., unequal loading effect). If the traffic load for BS1 and BS2 increases more, the hot spot can accommodate less traffic load without tilting the antenna. Hence, it must be resolved with the tilted antenna for traffic balancing. Based on these two factors, we can explain why the tilted angle is more critical when the traffic in hot spot is heavier.

IV. DYNAMIC ANTENNA-TILTED MECHANISM

According to the analysis in Section III, the tilted-antenna mechanism can enhance system performance certainly. However, only discussed herein is the relationship between fixed traffic load and the tilted angle of an antenna in hot spot. How to use the tilted antenna for these three sectors to promote the system performance under variant traffic load is quite interesting. Besides, when to tilt the antenna, how to tilt the antenna dynamically for variant traffic loading, and what is the suitable tilted step size for the antenna should be studied. The following proposes a simple mechanism to verify that the tilted-antenna mechanism also works for variant traffic load.

Since the SIR value decreases with an increasing traffic load, the SIR value is a good indicator for traffic variation. The blocking probability can hopefully be attained under 1% for heterogeneous traffic sectors by controlling the measured SIR. Tilting the antenna of a local sector not only affects its own SIR value, but also other adjacent sectors' SIR value. In our mechanism, the sectors' base stations should pass the measured SIR value to a mobile telephone switch office (MTSO) and the MTSO should determine the procedure for tilting antenna according to the algorithm defined as below.

1) The MTSO chooses $\mathrm{SIR}_{\max}$ and $\mathrm{SIR}_{\min}$ from the SIR information obtained from every sector's base station. That is

$$\mathrm{SIR}_{\max} = \max_i\{\mathrm{SIR}_i\} \tag{9a}$$

$$\mathrm{SIR}_{\min} = \max_i\{\mathrm{SIR}_i\}, \qquad i \in \{0, 1, 2\}. \tag{9b}$$

2) We define

$$\delta_m = \frac{1.0}{\mathrm{SIR}_{\min}} - \frac{1.0}{\mathrm{SIR}_{\max}}. \tag{10}$$

When a new call enters the sector with $\mathrm{SIR}_{\min}$ or a call is released in the sector with $\mathrm{SIR}_{\max}$ and $\delta_m > \delta$ (margin), the MTSO executes the step 3). Otherwise, the MTSO takes no action. The margin of δ is a system parameter affecting the number of tilting operations.

3) The MTSO tilts down the antenna of a sector's base station with $\mathrm{SIR}_{\min}$ by a step size of θ_s° and elevates the antenna of sector base station with $\mathrm{SIR}_{\max}$ by the same step size. The range of the tilted-antenna angle ranges from 0° to 9.5°.

Similar as in the analysis of Section III, we first check the maximum traffic loading (full traffic) for three homogeneous sectors with the same tilted angle and equal loading. Fig. 8 summarizes these results. According to this figure, the blocking probabilities for the three sectors with a tilted angle of 5° are below 1%. The corresponding traffic for a tilted angle of 5° is 38.7 Erl, which is treated as the unit of full traffic for each sector. The reason for why tilted an angle of 5° is initially selected is that the hot spot may tilt down the antenna from 5° to 9.5°, while normal or light traffic sector may elevate its tilting angle from 5° to 0°.

Two scenarios are considered in simulation. The first is the scenario (a), in which both the traffic load for BS1 and BS2 are the same (e.g., 0.7 times of full traffic), while the traffic for BS0 change from 1.0 to 1.9 times of full traffic. The second one is the scenario (b), where the traffic for BS2 and BS1 are 0.3 and 0.7 times of full traffic, respectively, while the traffic for BS0 changes from 1.0 to 1.9 times of full traffic. Figs. 9

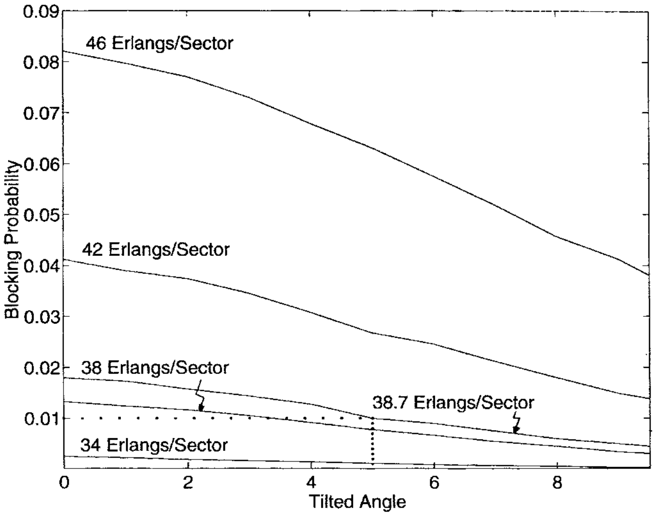


Fig. 8. Blocking probability versus tilted angle for three sectors with tilting capacity.

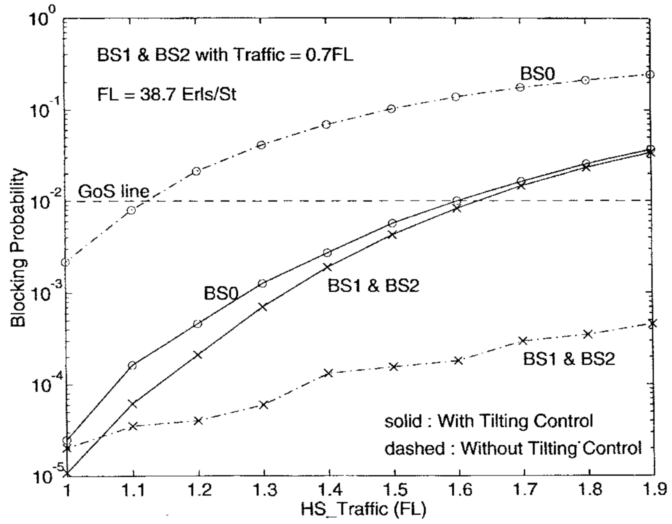


Fig. 9. Blocking probability versus hot-spot traffic scenario (a).

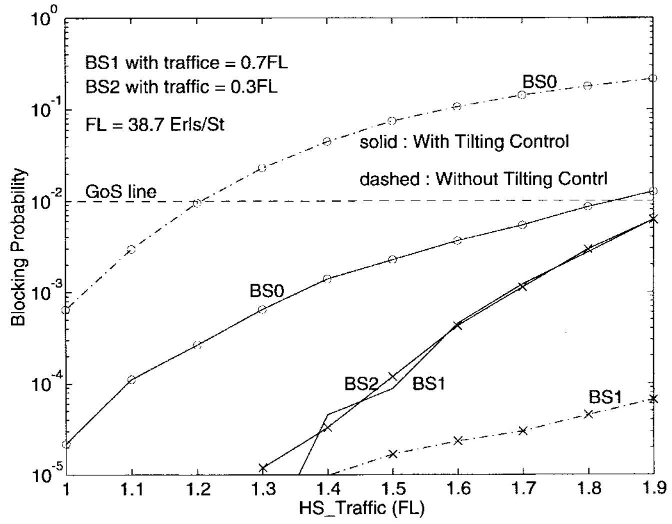


Fig. 10. Blocking probability versus hot-spot traffic scenario (b) (blocking probability of BS2 is too small to show).

and 10 summarize the results with a margin of five and the step size of the tilted angle being 0.1° for scenarios (a) and (b), respectively. In Fig. 9, the traffic for hot spot may increase up to 1.6 times of full traffic, and the blocking probability for the three sectors is below 1%. As mentioned earlier in Table II (with fixed hot-spot antenna-tilting mechanism), where BS1 and BS2 carry 0.7 times of full traffic (i.e., 37.2 Erl/sector) and only the hot-spot antenna can be tilted, the traffic of hot spot can accommodate up to 1.5 times of full traffic. The dynamic antenna-tilted mechanism is more powerful than the fixed hot-spot antenna-tilted mechanism. The hot-spot capacity of the former is 6.1 Erl (i.e., $38.7 \times 1.6 - 37.2 \times 1.5$) more than the latter's. As Fig. 10 reveals, the offered traffic for hot spot can increase up to 1.8 times of full traffic, which provides more capacity than traffic scenario (a)'s. This finding suggests that the dynamic tilted-antenna mechanism also provides good performance for the three sectors with variant traffic loading. The result is better than obtained in Section III for fixed hot-spot antenna tilting mechanism (only 1.7 times of full traffic).

The overall capacity for a dynamic antenna-tilted mechanism with traffic scenario (a) and fixed hot-spot antenna tilting with traffic loading of BS1 and BS2 being 0.7 times of full traffic are 116.1 Erl [i.e., $38.7 \times (1.6 + 0.7 + 0.7)$] and 107.88 Erl [i.e., $37.2 \times (1.5 + 0.7 + 0.7)$], respectively. The dynamic antenna-tilted mechanism has a 9.22 Erl benefit in comparison to fixed hot-spot antenna-tilted mechanism. The overall capacity for a dynamic antenna-tilted mechanism with traffic scenario (b) and fixed hot-spot antenna-tilted mechanism (with BS1 and BS2 carrying 0.3 and 0.7 times of full traffic) is 108.4 Erl [i.e., $38.7 \times (1.8 + 0.3 + 0.7)$] and 100.4 Erl [i.e., $37.2 \times (1.7 + 0.3 + 0.7)$], respectively. Applying the dynamic antenna-tilted mechanism has an 8.0 Erl benefit better than using fixed hot-spot antenna-tilted mechanism.

To account for why the margin of five and a step size of 0.1° are chosen for antenna-tilted mechanism, effects of the margin and step size on the dynamic tilting mechanism must be investigated. The blocking probabilities for the margins of one and five (with BS0 traffic being 1.4 times of full traffic and traffic of BS1 and BS2 being 0.7 times of full traffic) are shown in Fig. 11. Obviously, a large step size for a tilted angle degrades the blocking probability. The reason is that the larger the step size uses the coverage area to be more changeable for the hot spot and light sector and, subsequently, causes the blocking probability to increase. If the blocking probability is 0.01, then step sizes of adjustment for margins of one and five are 0.25° and 0.3°, respectively. These results are quite reasonable because the larger margin will make less adjustments of antenna so that the step size for a tilted angle can be slightly larger. To compare the performance results for margins of one and five, Fig. 12 presents the relative counts of adjustment (i.e., the number of adjustments/the number of admitted calls). As this figure reveals, more adjustment counts are required for a smaller margin. Frequent operation will exhaust the MTSO central processing unit (CPU) power so that a margin of five is more appropriate than a margin of

TABLE III
HANDOFF BLOCKING PROBABILITY AND AVERAGE HANDOFF PERCENTAGE

Step size	Handoff blocking probability	Average handoff percentage*						
		overall	$BS0 \to BS1$	$BS0 \to BS2$	$BS1 \to BS0$	$BS1 \to BS2$	$BS2 \to BS0$	$BS2 \to BS1$
0.1°	10^{-6} order	1.3%	0.22%	0.22%	0.21%	0.21%	0.22%	0.22%
0.2°	10^{-6} order	2.6%	0.44%	0.43%	0.42%	0.45%	0.42%	0.44%
0.3°	10^{-6} order	4.0%	0.67%	0.67%	0.66%	0.66%	0.66%	0.68%

*Average handoff percentage is defined as the ratio of handoff users to overall active users when tilting action occurs.

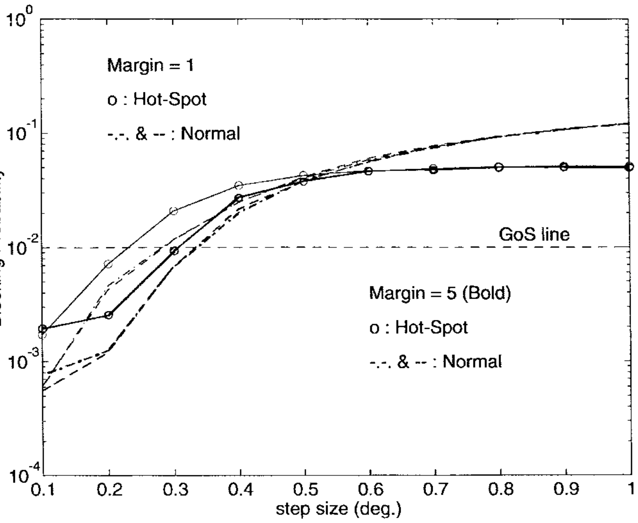


Fig. 11. Blocking probability versus step size under margin $=$ 1 and margin$=$ 5 for hot spot $= 1.4$ FL and normal sector $= 0.7$ FL.

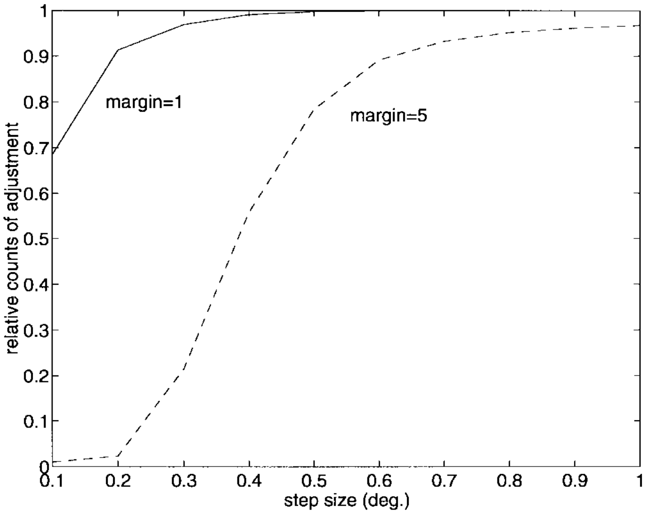


Fig. 12. Relative counts of adjustment versus step size for hot spot $= 1.4$ FL and normal sector $= 0.7$ FL.

one. Fig. 12 indicates that the relative adjustment counts for a step size of 0.1 or 0.2 are less than that for a step size of 0.3.

The tilting action causes some existing users in a hot spot to switch to access the lighter traffic sectors. This phenomenon is also called handoff. The phenomenon of handoff (with BS0 traffic being 1.4 times of full traffic and traffic of BS1 and BS2 being 0.7 times of full traffic) due to antenna tilting is shown in Table III. The handoff users probably make the quantity R_i in (7) equal to zero. Under this condition, some handoff users should be forced to be dropped or blocked until R_i is slightly larger than zero. The blocking probabilities of handoff users are listed in the second column of Table III. The value of handoff blocking probability is in the order of 10^{-6}, which is negligible. The traffic of hot spot can accommodate 1.6 times of full traffic under the traffic load of BS1 and BS2 being 0.7 times of full traffic, but here the hot spot only offer 1.4 times of full traffic. Besides, we also accumulate the data of average handoff percentage, which is defined as the ratio of handoff users to the overall active users per tilting action. Based on the results, we observe that: 1) the average handoff percentage of each sector is almost the same because the Poisson arrival assumption makes the traffic load unbalanced such that the tilting action happens randomly for each sector and 2) the average handoff percentage is less for a step size of 0.1 than for a step size of 0.2 or 0.3 because the larger step size makes more handoffs. This is another reason why we choose the step size of 0.1. The other phenomena not shown in the Table III include: 1) 58% (respectively, 42%) of the handoffs in a hot spot switch to the lightest traffic sector (resp. medium traffic sector). A small amount of users in the medium traffic sector also make handoffs to lighter traffic sector. 2) The ratio of tilting action occurs between hot-spot and light traffic sectors (i.e., between BS0 and BS1 or between BS0 and BS2) and between light traffic sectors (i.e., between BS1 and BS2) is 1.07. However, as Table III reveals, the handoff impact on the proposed dynamic antenna-tilted mechanism is still minor and can be accepted.

V. CONCLUSION

The paper presents a method to relieve congestion in a heterogeneous traffic environment with a tilted antenna mechanism. It is quite effective for hot-spot relief. The performance results demonstrate that the dynamic antenna-tilted mechanism is more powerful than the fixed hot-spot antenna-tilted mechanism. This is reasonable because the effectiveness of traffic balancing is better for a dynamic antenna-tilted mechanism. However, the dynamic antenna-tilted mechanism causes only a slight handoff impact. We think various alternative mechanisms may be combined with the “soft-handoff” characteristics to dynamically tilt the antenna. In this article, although a primitive mechanism was proposed, we still hope to find an optimum mechanism in the future.

Results in this study demonstrate that the mobile users will transfer from a hot-spot sector to access other light traffic sectors and balance the difference of traffic loading. This finding suggests that the number of average active users in each sector tends to be the same. That is another benefit because the number of average occupied transceivers in every sector remains the same, thereby reducing the amount of cost and enhancing equipment's utilization.

APPENDIX
THE INTERFERENCE EFFECT OF ADJACENT SECTORS

The interference is the dominant factor when we consider the CDMA system's capacity. We will show the interference effect of adjacent sectors to the dedicated BS0. Since the BS0 is equipped with a 120° sectorization antenna, the interference originates from sectors that are under the coverage of 120° angle. As Fig. 4 reveals, the interference from sectors A, B, and C are the most significant to BS0. We assume that N mobiles are uniformly distributed in a sector of radius R. The density of mobiles in a sector is

$$\rho = \frac{N}{\frac{1}{3}\pi R^2}.$$

Assume that the power received in the base station from each mobile is P_c with a path loss proportional to the fourth power of distance. The interference caused by the adjacent sector k ($k =$ A, B, or C) is

$$I_k = \int P_c \cdot \frac{r^4}{x^4} \cdot \rho \cdot dA$$

where r is the distance between the mobile and the dedicated sector base-station k, $x = \sqrt{d^2 + r^2 - 2dr\cos\theta}$ is the distance between the mobile in the kth sector and the interfered base-station, and d is the distance between two base stations. Therefore, we can formulate that

$$I_k = \int_\theta \int_0^R P_c \cdot \frac{r^4}{(d^2 + r^2 - 2dr\,\cos\theta)^2} \cdot \frac{N}{\frac{1}{3}\pi R^2} \cdot r \cdot dr \cdot d\theta$$

where $\theta = -\pi/6$–$\pi/2$, $\pi/2$–$7\pi/6$, $7\pi/6$–$11\pi/6$ for sectors A, B, and C, respectively. Through numerical computation, we obtain

$$\begin{aligned} I_A &= N \cdot P_c \cdot (0.1079)\\ I_B &= N \cdot P_c \cdot (0.027)\\ I_C &= N \cdot P_c \cdot (0.0071). \end{aligned}$$

The interference from the intrasector mobiles is equal to

$$I_{\text{BS}} = N \cdot P_c \cdot \left(\frac{N-1}{N}\right) = (N-1) \cdot P_c.$$

If N is large, then $I_{\text{BS0}} \cong NP_c$. Here, we can see the interference from sectors B and C are extremely small to BS0, so only sector A with interference I_A is considered.

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