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Uplink Practical Capacity and Interference Statistics of WCDMA Cigar-shaped Microcells for Highways in Rural Zones with Non-Uniform Spatial Traffic Distribution and Imperfect Power Control

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Abstract

The capacity (the maximum number of users per sector that the system can support) and the interference statistics (expected value and variance) of sectors composed of cigar-shaped WCDMA microcells are studied. A model of 5 microcells is used to analyze the uplink capacity and interference statistics. The microcells are assumed to exist in rural zone highways. The capacity and the interference statistics of the microcells are studied for different non-uniform spatial traffic distributions. As user density decreases away from the base station, the capacity of the sector increases due to the reduced total power transmitted by the interfering users.

Key Words: *W-CDMA, uplink capacity, shadowing.*

1. Introduction

Microcellular systems have been proposed to increase cellular capacity mainly in dense urban areas that have a large volume of wireless communication traffic, or to provide communications service along rural highway zones. It is well known that CDMA is characterized as interference-limited, so reducing the interference results in increased capacity. Three techniques are used to reduce the interference: power control (PC), which is essential in the uplink; voice activity monitoring; and sectorization. Also, well known is that urban and rural microcell shapes may approximately follow street layouts and that it is also possible to have cigar-shaped microcells [1]. Conditions that direct the design of cigar-shaped microcells for highways in rural zones are:

- each cigar-shaped microcell is formed from two directive sectors, a directive antenna signaling each sector;
- each sector should have a typical range of 1 to 1.5 km;
- user speed in rural areas can reach 120 km/h and above.

Figure 1 depicts the radiation pattern of the sector antenna and of the cigar-shaped microcell coverage. From Figure 1A notice that interference from the right side of the sector is injected through the main lobe of the antenna while interference from the left side of the antenna is injected via the side lobe.

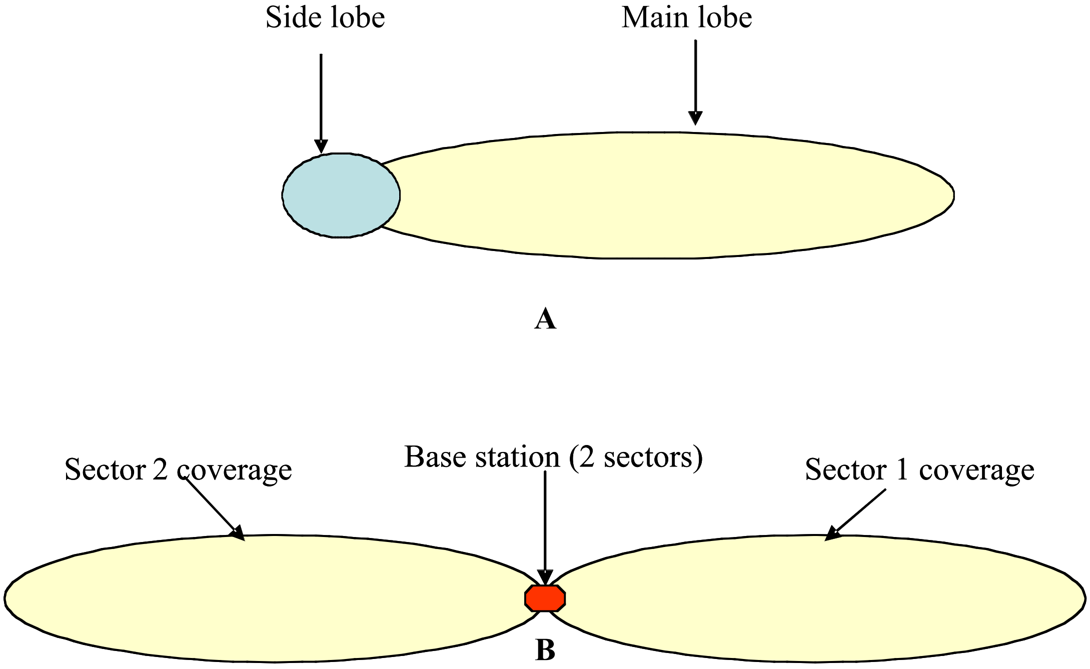

Figure 1. The sector antenna radiation pattern and microcell coverage. (a) The radiation pattern of the sector's antenna. (b) The cigar-shaped microcell coverage.

In the real world, it is rather uncommon to see spatially uniform traffic in macro- and microcells. Yet the majority of WCDMA cells have been designed to assume uniform spatial distribution: an unrealistic practice.

Min et al. studied the performance of the CDMA highway microcell using one slope propagation model and two slope propagation model without taking into account the interference variance nor the non-uniform spatial distribution of users [2]. Hashem et al. studied the capacity and the interference statistics for hexagonal cell for a propagation exponent of 4 and a uniform spatial distribution of users [3]. In [4], the capacity, the mean and variance statistics of interference of cigar-shaped microcells for highways in rural zones using wide-band code-division multiple access (WCDMA) have been studied. A general propagation exponent using a two-slope propagation model and log-normal shadowing was used. It has been assumed that users are uniformly distributed within the microcells, that the intracellular interference variance is null and that the power control is perfect.

In this work, we will use a model for cigar-shaped microcells in rural highways zones with general propagation exponent using a two-slope model and then investigate the sector capacity and interference statistics of the uplink for different spatial distributions of users and different standard deviation error in power control.

The paper has been organized as follows. In section 2, the propagation model is given. Section 3 explains the method to calculate the capacity and the interference statistics of the uplink. Numerical results are presented in section 4. Finally, in section 5 conclusions are drawn.

2. The Propagation Model

A two-slope propagation model with lognormal shadowing is used in our calculations [2]. The exponent of the propagation is assumed to be s_1 up to the break point R_b, above which it converts into s_2. In this way the path loss at a distance r from the base station is given by [4]

$$L_p(dB) \approx L_b + 10 + 10\, s_1 \log_{10}\left(\frac{r}{R_b}\right) + \xi_1 \qquad \text{for } r \leq R_b \tag{1}$$

$$L_p(dB) \approx L_b + 10 + 10\, s_2 \log_{10}\left(\frac{r}{R_b}\right) + \xi_2 \qquad \text{for } r > R_b, \tag{2}$$

where r is the distance between the microcell base station and the mobile; and L_b (defined as the propagation loss at R_b) and R_b are given by [5]

$$L_b(dB) = \left| 10 \log\left[\left(\frac{\lambda^2}{8\pi\, h_b\, h_m}\right)^2\right]\right| \tag{3}$$

$$R_b \approx \frac{4\, h_b\, h_m}{\lambda}. \tag{4}$$

Here, h_b is the base station antenna height; h_m is the mobile antenna height; λ is the wavelength; and ξ_1 and ξ_2 are Gaussian random variables of zero-mean and standard deviation σ_1 and σ_2, respectively. In practice, ξ_1 and ξ_2 are truncated to ±10 dB.

Typical values for s_1, s_2, σ_1 and σ_2 are:

- s_1 = 1.75 to 2.25
- s_2 = 3.50 to 4.75
- $\sigma_1 = 2$ to 3 dB
- $\sigma_2 = 4$ to 6 dB.

3. Uplink Capacity and Interference Analysis

In cigar-shaped microcells for highways, the sector range (radio) is typically 1 to 1.5 km and the highway width is 10 to 16 m. Thus, the cigar-shaped microcell can be treated as a one-dimension microcell. To assess the sector capacity, we have to calculate the expected value and the variance of the total interference (intracellular + intercellular) and then we model the total interference as a Gaussian noise. Figure 2 a model configuration of 5 collinear microcells (i.e. ten sectors) used in the analysis of the uplink sector capacity. Each microcell controls the transmitted power of its users. The sector range is assumed to be R. If the interfering user i is at a distance r_{im} from its base station (m) and at a distance r_{id} from the home microcell base station d, as shown in Figure 3, then the ratio of the interference signal $L(r_{id}, r_{im})$ due to the distance only is given as [4]

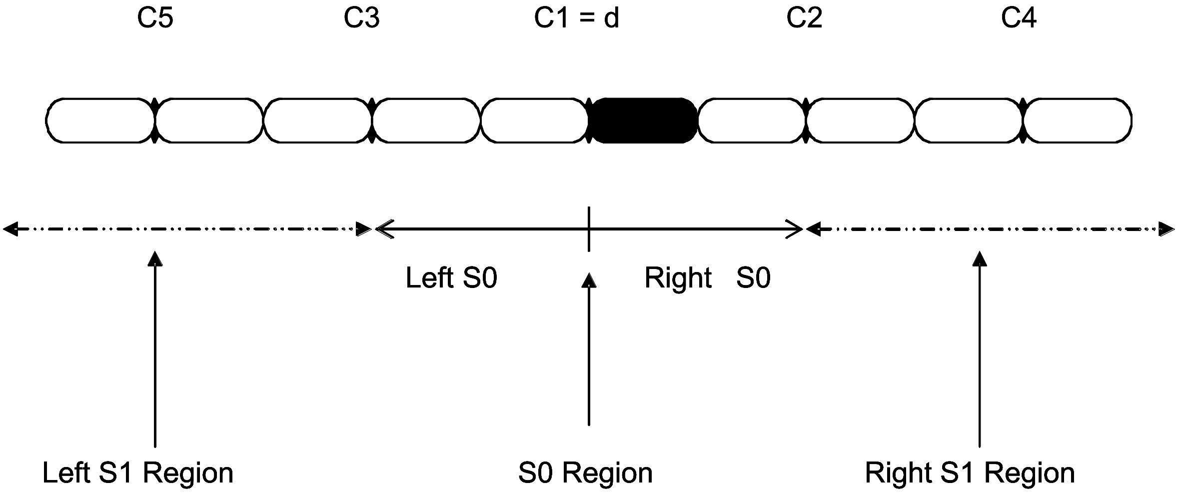

Figure 2. A model of 5 microcells showing S0 and S1 regions.

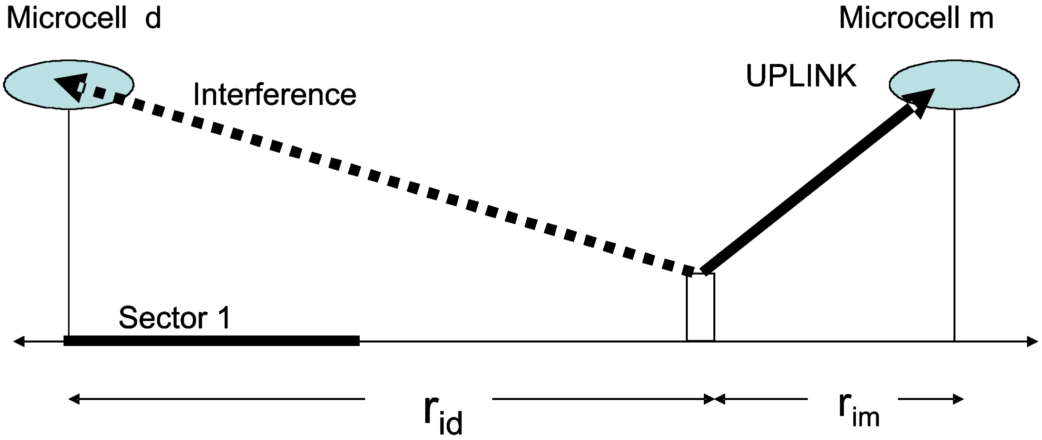

Figure 3. Schematic diagram of base stations and mobiles for highway microcells.

$$L(r_{id}, r_{im}) = r_{im}^{s_1}/r_{id}^{s_1} \qquad \text{if } (r_{id} \text{ and } r_{im} \leq R_b); \tag{5}$$

$$L(r_{id}, r_{im}) = R_b^{(s_2-s_1)} r_{im}^{s_1}/r_{id}^{s_2} \qquad \text{if } r_{id} > R_b \text{ and } r_{im} \leq R_b; \tag{6a}$$

$$L(r_{id}, r_{im}) = R_b^{(s_1-s_2)} r_{im}^{s_2}/r_{id}^{s_1} \qquad \text{if } r_{id} \leq R_b \text{ and } r_{im} > R_b; \tag{6b}$$

$$L(r_{id}, r_{im}) = r_{im}^{s_2}/r_{id}^{s_2} \qquad \text{if } (r_{id} \text{ and } r_{im} > R_b). \tag{7}$$

Now the ratio of the interference signal $I(r_{id}, r_{im})$ due to the distance and shadowing is given by:

$$I(r_{id}, r_{im}) = 10^{(\xi_{id}-\xi_{im})/10} L(r_{id}, r_{im}) \tag{8}$$

and ξ_{id} and ξ_{im} are given as:

$\xi_{id} = \xi_1$ and $\xi_{im} = \xi_1$ if $r_{id} \leq R_b$ and $r_{im} \leq R_b$;
$\xi_{id} = \xi_2$ and $\xi_{im} = \xi_1$ if $r_{id} > R_b$ and $r_{im} \leq = R_b$;
$\xi_{id} = \xi_1$ and $\xi_{im} = \xi_2$ if $r_{id} \leq R_b$ and $r_{im} > R_b$;
$\xi_{id} = \xi_2$ and $\xi_{im} = \xi_2$ if $r_{id} > R_b$ and $r_{im} > R_b$.

We will divide the total intercellular interference I_{inter} into interference from users in the S_0 region (I_{S_0}) and interference from users in the S_1 region (I_{S_1}). These regions are shown in Figure 2. We will find the interference at the right sector (sector1) of the central base station C1 assuming it to be microcell d. Users in the region S_0 will connect with the best of the two nearest microcells (with the microcell with lower path loss). In the S_1 region we assume that users communicate with the nearest base station [3]. Thus, users within the S_1 region cannot communicate with the central base station C1 and their signals will be always interfering signals.

Let the desired signal level at the base station be P_r. A user i in the region S_0 will *not* communicate with the home base station d but rather with base station m, if $\phi(\xi_{id} - \xi_{im}, r_{id}/r_{im}) = 1$, where

$$\phi(\xi_{id} - \xi_{im}, r_{id}/r_{im}) = \begin{cases} 1, \text{ if } L(r_{id}, r_{im}) 10^{(\xi_{id}-\xi_{im})/10} \leq 1 \\ 0, \text{ otherwise.} \end{cases} \tag{9}$$

The function $\phi(\xi_{id} - \xi_{im}, r_{id}/r_{im})$ is an indicator function to show the zones of the sector that are excluded in the calculation of the intercellular interference, since the mobile users in this zone are not power controlled by the base station of the microcell m, but by the base station of the microcell d.

We will study the case of different spatial distribution $f(r)$ of the users. The ideal case of users spatial distribution is the uniform distribution, for which $f(r) = 1/R$. Assuming that the number of users in each sector is N_u and that the activity factor of the users (the percentage of users in a sector that are actively communicating with the base station) is α, then for the right part of S_0 (two sectors, $n = 1$ and 2) the expected value of I_{S_0} is given as:

$$E[I_{S_0}]_r = \alpha\, N_u \sum_{n=1|S_{0r}}^{2} \int_0^R L(r_{id}, r_{im})\, f(r)\;\; f(\frac{r_{id}}{r_{im}})\;\, dr \;= k_1\, N_u\;, \tag{10}$$

where

$$k_1 = \alpha \sum_{n=1|S_{0r}}^{2} \int_0^R L(r_{id}, r_{im})\, f(r)\;\; f(\frac{r_{id}}{r_{im}})\;\, dr \tag{11}$$

and

$$f(\frac{r_{id}}{r_{im}}) = E\Big[10^{(\xi_{id}-\xi_{im})/10}\phi(\xi_{id}-\xi_{im}, r_{id}/r_{im})\Big] \tag{12}$$

$$= e^{(\beta\sigma)^2/2}Q\Big[\beta\sqrt{\sigma^2} - \frac{10}{\sqrt{\sigma^2}}\log_{10}\{1/L(r_{id}, r_{im})\}\Big]. \tag{13}$$

Here, $\beta = \frac{1}{10}\log 10$ and $Q(x)$ is given by

$$Q(x) = \int_x^\infty e^{-v^2/2}dv/\sqrt{2\pi}. \tag{14}$$

In equations (10)–(13), r_{im} and r_{id}has the following values when the user is in the left and right sectors:

$$r_{im} = \begin{cases} r & \text{when the user is in left sector C2} \\ 2R - r & \text{when the user is in right sector C1} \end{cases}$$

$$r_{id} = \begin{cases} 2R - r & \text{when the user is in left sector C2} \\ r & \text{when the user is in right sector C1} \end{cases}.$$

σ_{id} and σ_{im} are given as:

$$\sigma_{id} = \begin{cases} \sigma_1 when: \ r_{id} \le R_b \\ \sigma_2 when: \ r_{id} > R_b \end{cases} \tag{15}$$

$$\sigma_{im} = \begin{cases} \sigma_1 when: \ r_{im} \le R_b \\ \sigma_2 when: \ r_{im} > R_b \end{cases} \tag{16}$$

The general value of σ^2 is given as:

$$\sigma^2 = \begin{cases} 2(1-C_{dm})\sigma_1^2 & when: \ r_{id} \le R_b \text{ and } r_{id} \le R_b \\ (\sigma_1-\sigma_2)^2 + 2(1-C_{dm})\sigma_1\sigma_2 & when: \ r_{id} \le R_b \text{ and } r_{im} > R_b \ or \ r_{id} > R_b \text{ and } r_{im} \le R_b \\ 2(1-C_{dm})\sigma_2^2 & when: \ r_{id} > R_b and r_{im} > R_b \end{cases} \tag{17}$$

where C_{dm} is the correlation coefficient between the random variable ξ_{id} and ξ_{im} (shadowing correlation between base stations).

The expected value of I_{S1} due to the right part of the S1 region (summed over the three sectors on the right, $n = 1, \ldots, 3$) is given as

$$E[I_{S1}]_r \approx \alpha\, N_u \sum_{n=1|S_{1r}}^{3} \int_0^R L(r_{id}, r_{im})\; f(r)\; E\Big[10^{(\xi_{id}-\xi_{im})/10}\Big]\; dr = k_2\, N_u, \tag{18}$$

where we define

$$k_2 \approx \alpha \sum_{n=1|S_{1r}}^{3} \int_0^R L(r_{id}, r_{im})\; f(r)\; E\Big[10^{(\xi_{id}-\xi_{im})/10}\Big]\; dr \tag{19}$$

In the integrand of (18), r_{im} takes the value r while r_{id} assumes the value $R(2+n)-r$.

The expected value of the intercellular interference from the right side of the regions S_0 and S_1 is

$$E[I]_r = E[I_{S_0}]_r + E[I_{S_1}]_r. \tag{20}$$

For the left part of S_0 (two sectors, numbered $n = 1, 2$), the expected value of I_{S_0} is given as

$$E[I_{S_0}]_l = \alpha\; S_{ll}\; N_u \sum_{n=1|S_{0l}}^{2} \int_0^R L(r_{id}, r_{im}) f_s(r)\; f(\frac{r_{id}}{r_{im}})\; dr \;= k_3\, N_u, \tag{21}$$

where S_{ll} is the side lobe level of the directive antenna used in each sector and k_3 is given by

$$k_3 = \; S_{ll}\; \alpha \sum_{n=1|S_{0l}}^{2} \int_0^R L(r_{id}, r_{im}) f(r)\; f(\frac{r_{id}}{r_{im}})\; dr \tag{22}$$

The expected value of I_{S1} due to left part of the S_1 region (three sectors, $n = 1, \ldots, 3$) is given as:

$$E[I_{S1}]_l \approx \alpha\; Sll\; N_u \sum_{n=1|S1l}^{3} \int_0^R L(r_{id}, r_{im})\; f(r)\; E\Big[10^{(\xi_{id}-\xi_{im})/10}\Big]\; dr = k_4\, N_u \tag{23}$$

where

$$k_4 \approx Sll\; \alpha \sum_{n=1|S1l}^{3} \int_0^R L(r_{id}, r_{im})\; f(r)\; E\Big[10^{(\xi_{id}-\xi_{im})/10}\Big]\; dr. \tag{24}$$

Thus the expected value of the total intercellular interference from the left and right sides is given as

$$E[I]_{inter} = E[I_{S0}]_r + E[I_{S1}]_r + E[I_{S0}]_l + E[I_{S1}]_l. \tag{25}$$

The expected value of the total intercellular interference power is given as

$$E[P]_{inter} = P_r \; E[I]_{inter}. \tag{26}$$

The expected value of the intracellular interference power is given by

$$E[P]_{intra} \approx \; P_r \; E[I]_{intra} \; \approx \alpha \;\; N_u(1+Sll) \; P_r \; = k_5 \; N_u \; P_r. \tag{27}$$

Taking into account an imperfect power control with standard deviation error of σ_c (dB), the expected value of the total interference power P_t will be

$$E[P]_t = e^{\beta^2\sigma_c^2/2}(E[P]_{intra} + E[P]_{inter}) = k_{pc} \; (E[P]_{intra} + E[P]_{inter}), \tag{28}$$

where k$_{pc}$ is the power control error factor given by

$$k_{pc} = e^{\beta^2\sigma_c^2/2}. \tag{29}$$

In the uplink, only $\varepsilon \, P_r$ of P$_r$ is used in the demodulation (ε = 14/16 = 0.875 or ε = 15/16 = 0.9375) [7]. Thus, the expected value of the uplink carrier-to-interference ratio (C/I) is given as

$$[C/I] = \frac{\varepsilon \; P_r}{E[P]_t} \tag{30}$$

and the value of the energy per bit to noise ratio (E$_b$/ N$_o$) is given as

$$[E_b/N_o] = [C/I] * G_p, \tag{31}$$

where G_p is the processing gain. That is,

$$[E_b/N_o] = \frac{\varepsilon \; G_p}{N_u \; k_{pc} \; (k_1 + k_2 + k_3 + k_4 + k_5)} \tag{32}$$

$$\bar{N} = \frac{\varepsilon \; G_p}{[E_b/N_o]_{req} \; k_{pc} \; (k_1 + k_2 + k_3 + k_4 + k_5)}, \tag{33}$$

where $\bar{N}$ is the expected value of the number of users per sector (expressed as the average capacity) and $(E_b/N_o)_{req}$ is the required (E_b/N_o) to get a given bit error rate for a given service.

Assuming a user traveling at 120 km/h and transmitting/receiving at 9.6 kbit/sec, the signal-to-nose ratio $(E_b/N_o)_{req}$ must be ≥7 dB. For a bit rate of 144 kbit/sec, the relation (E$_b$/N$_o$)$_{req}$ has to be ≥3 dB [6].

The variance in I_{S_0} at the right part of S$_0$ (two sectors) is computed as

$$var[I_{S0}]_r = \ N_u \sum_{n=1|S0r}^{2} \int_0^R [L(r_{id}, r_{im})]^2 \ [f(r)] \left\{ p\alpha\, g(\frac{r_d}{r_m}) - q\alpha^2 f^2(\frac{r_d}{r_m}) \right\} dr, \tag{34}$$

where

$$g(\frac{r_d}{r_m}) = E\Big[10^{(\xi_{id}-\xi_{im})/10}\phi(\xi_{id}-\xi_{im}, r_{id}/r_{im})\Big]^2 \tag{35}$$

$$= e^{2(\beta\sigma)^2} Q\left[\sqrt{\sigma^2}\ln 10/5 - \frac{10}{\sqrt{\sigma^2}}\log_{10}\{1/L(r_{id}, r_{im})\}\right] \tag{36}$$

$$p = e^{2\beta^2\sigma_c^2} \tag{37}$$

$$q = e^{\beta^2\sigma_c^2}. \tag{38}$$

The variance of I$_{S1}$ due to right part of S1 (three sectors) is given as

$$var[I_{S1}]_r \approx N_u \sum_{n=1|S1r}^{3} \int_0^R [L(r_{id}, r_{im})]^2 \ [f(r)] \ \cdot \ \left\{ p\alpha\, E\Big[(10^{(\xi_{id}-\xi_{im})/10})^2\Big] - q\alpha^2 E^2\Big[10^{(\xi_{id}-\xi_{im})/10}\Big] \ \right\} dr \tag{39}$$

The variance of I$_{S0}$ due to left part of S0 (two sectors) is given as

$$var[I_{S0}]_l = Sll \ \ N_u \sum_{n=1|S0l}^{2} \int_0^R [L(r_{id}, r_{im})]^2 \ [f(r)] \left\{ p\alpha\, g(\frac{r_d}{r_m}) - q\alpha^2 f^2(\frac{r_d}{r_m}) \right\} dr. \tag{40}$$

The variance of I$_{S1}$ due to left part of S1 (three sectors) is given as:

$$var[I_{S1}]_l \approx Sll \ N_u \sum_{n=1|S1l}^{3} \int_0^R [L(r_{id}, r_{im})]^2 \ [f(r)] \ \cdot \ \left\{ p\alpha\, E\Big[(10^{(\xi_{id}-\xi_{im})/10})^2\Big] - q\alpha^2 E^2\Big[10^{(\xi_{id}-\xi_{im})/10}\Big] \ \right\} dr \tag{41}$$

Thus the sum of intercellular variance due to regions S0 and S1 is given by

$$var[I]_{inter} = \{\ var[I_{S0}]_r + var[I_{S1}]_r\ \} + \{var[I_{S0}]_l + var[I_{S1}]_l\ \}. \tag{42}$$

The intracellular interference variance is calculated as

$$var[I]_{intra} \approx N_u\ (1 + Sll)\ \left(p\alpha - q\alpha^2\right). \tag{43}$$

The total interference variance is given by the sum

$$var[I]_t = var[I]_{inter} + var[I]_{intra}. \tag{44}$$

The total interference power variance is given by the relation

$$var[P_{intf}]_t = P^2 var[I]_t. \tag{45}$$

Finally, we calculate the probability for outage, that is, the probability that the signal-to-noise ratio of a percentage of users does not reach the required E_b/N_o threshold. To do so, we need the medium value of the interference, i.e. the interference when the number of users per sector is $\bar{N}$, the expected value and the variance of the interference when the number of users per sector is N_u. The outage probability is given by the relation

$$P_r = Q\left[\frac{E(I)_t|_{\bar{N}} - E(I)_t|_{N_u}}{\sqrt{var(I)_t|_{N_u}}}\right]. \tag{46}$$

This Gaussian approximation is valid when the number of users $N_u \geq 20$, the number we assume for this work.

We calculate the F factor, which expresses the ratio of interference from other microcells to the interference of the microcell under consideration, as

$$F = \frac{IntercellularInterference}{IntracellularInterference} = \frac{E[P]_{inter}}{E[P]_{intra}} \tag{47}$$

and the effective interference power as

$$[P_{intf}]_{eff} = E[P]_t\ + \gamma\sqrt{var[P]_t}, \tag{48}$$

where γ is the deviation factor and is a function of the accepted outage probability. The practical values of γ are 2.06 (2% outage, since $Q(2.06) = 0.02$) to 2.33 (1% outage, since $Q(2.33) = 0.01$).

4. Numerical Results

Our calculations assume a W-CDMA chip rate of 3.84 Mcps/sec [7], plus the application of other reasonable figures. The antenna azimuth side lobe level is assumed to be –15 dB, the correlation coefficients $C_{dm} = 0.5$ [7], $s_1 = 2$, $s_2 = 4$, $\sigma_1 = 3$ dB, $\sigma_2 = 6$ dB, $R_b = 300$ m, R = 1000 m, $\varepsilon = 0.9375$ [7] and $\sigma_c = 1.5$ dB, unless otherwise expressly stated. We assume that the accepted outage probability is 1% and that the capacity of the sectors is calculated at this probability.

Hereafter we study the case of voice users (9.6 kbits/sec.). For the voice service, the activity factor α is assumed to be 0.63 [7].

We consider three cases of spatial distribution; each defined to have a normalized probability distribution within $0 \leq r \leq R$:

case 1: $f(r) = \frac{1}{R}$, uniform density of users within the sector;

case 1: $f(r) = \frac{2}{R}\left(1 - \frac{r}{R}\right)$, where the density of users is higher near the base station;

case 1: $f(r) = \frac{2}{R}\left(\frac{r}{R}\right)$, where the density of users is lower near the base station.

Figure 4 shows the spatial distribution, and Table 1 gives $E[I]_{inter}$, $\mathrm{var}[I]_{inter}$ and F when $\sigma_c = 1.5$ dB, for cases 1–3.

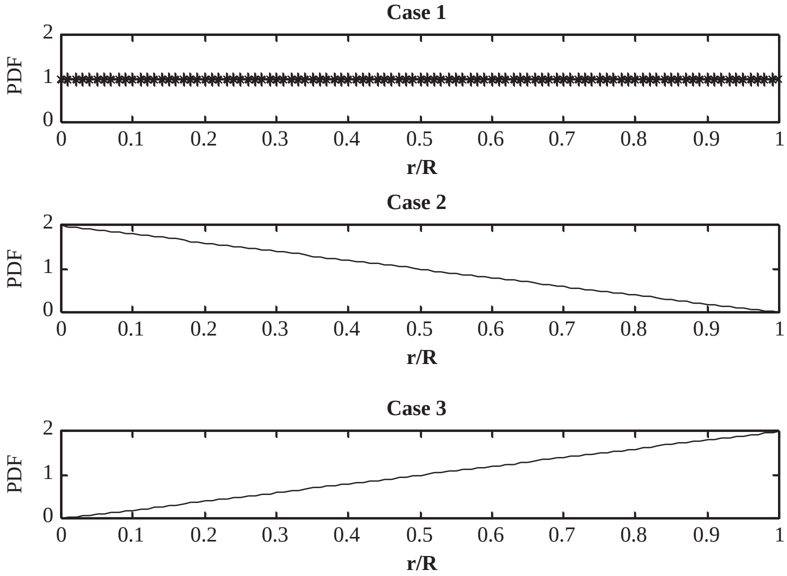

Figure 4. The normalized PDF of the users for cases 1, 2 and 3.

Table 1. $E[I]_{inter}$, $\mathrm{var}[I]_{inter}$ and F for spatial distribution cases 1–3.

Distribution Case	$E[I]_{inter}$	$var[I]_{inter}$	F
1	0.0903 N_u	0.0407 N_u	0.1308
2	0.0320 N_u	0.0136 N_u	0.0464
3	0.1485 N_u	0.057 N_u	0.2153

Figure 5 shows the outage probability of the sector as a function of capacity for each of the above three distributions, 1–3. Associated with an outage probability of 1%, the capacity of the sector for the first, second and third cases is 82, 90 and 75 voice users, respectively. Thus as the users move away from the base station, decreasing their density, the capacity of the sector increases due to less total power transmitted by the competing users.

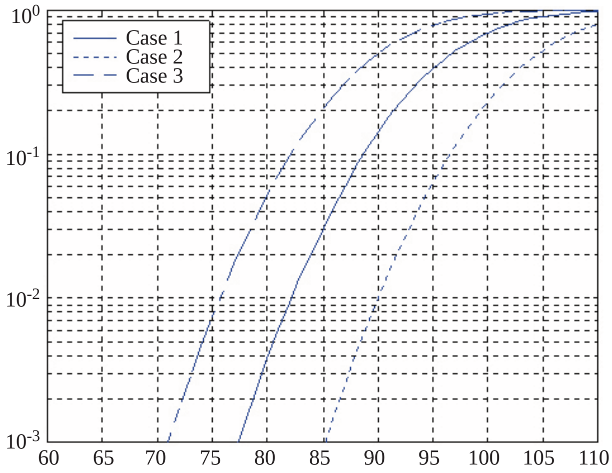

Figure 5. The outage probability of the sector, case 1, 2 and 3 for voice when $\sigma_c = 1.5$ dB.

We now consider two additional spatial distributions, each also defined to have a normalized probability distribution within $0 \le r \le R$:

case 4: $f(r) = \frac{4}{\pi R}\left[\frac{R^2-r^2}{R^2}\right]^{0.5}$, where the density of users is higher near the base station.

case 5: $f(r) = \frac{4}{\pi R}\left[\left(\frac{2r}{R}\right) - \left(\frac{r}{R}\right)^2\right]^{0.5}$, where the density of users is lower near the base station.

Figure 6 shows the spatial distribution, and Table 2 gives $E[I]_{inter}$, $\text{var}[I]_{inter}$ and F when $\sigma_c = 1.5$ dB, for cases 4 and 5.

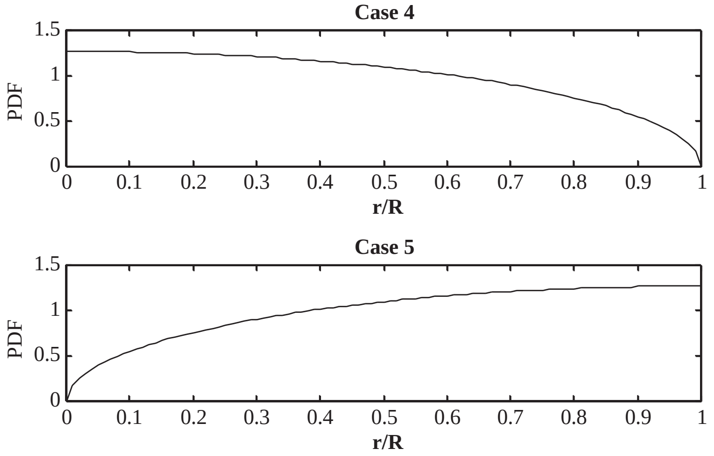

Figure 6. The normalized PDF of the users for cases 4 and 5.

Table 2. $E[I]_{inter}$, $\text{var}[I]_{inter}$ and F for spatial distribution cases 4 and 5.

Case	$E[I]_{inter}$	$var[I]_{inter}$	F
4	0.0594 N_u	0.0267 N_u	0.0861
5	0.1623 N_u	0.0479 N_u	0.1623

Figure 7 shows the outage probability of the sector as a function of capacity for distributions 4 and 5. For an outage probability of 1%, the capacity of the sector is 86 and 79 voice users, respectively. Thus, as was also observed for cases 1–3, as users move away from the base station, decreasing their density, the capacity of the sector increases due to less total power transmitted by the competing users.

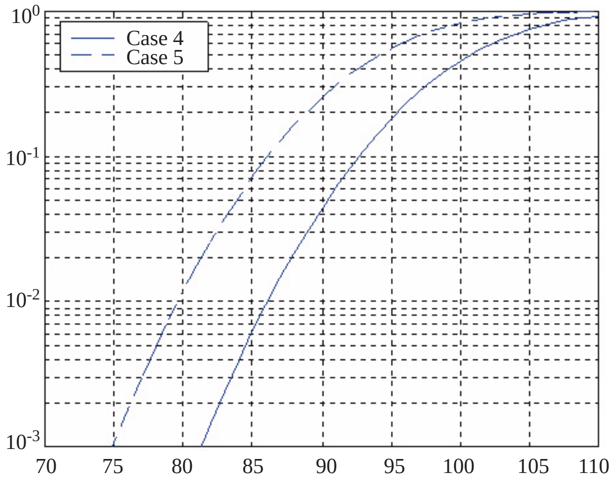

Figure 7. Outage probability of the sector, case 4 and 5 for voice service when $\sigma_c = 1.5$ dB.

To study the effect of the variation of σ_c, we consider cases 1, 2 and 3 with $\sigma_c = 0$ dB (Perfect Power Control). Figure 8 shows the outage probability of the sector for the three distributions. For an outage probability of 1%, the capacity of the sector for the first, second and third case is 90, 98 and 83 voice users, respectively. Thus, imperfect power control leads to reduction of capacity by about 10%.

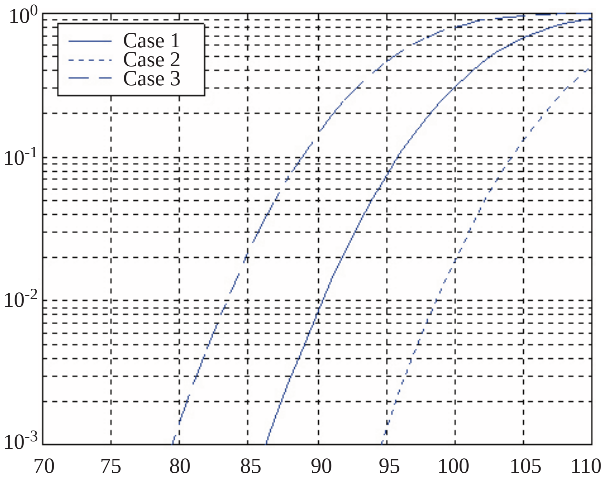

Figure 8. Outage probability of the sector, case 1 and 2 and 3 for voice service when $\sigma_c = 0$ dB.

Then we study the effect of the sector range on the sector capacity. Figure 9 shows the effect of increasing the sector range on the sector capacity. Notice that the capacity increases with sector range R up to 600m, beyond which it remains constant.

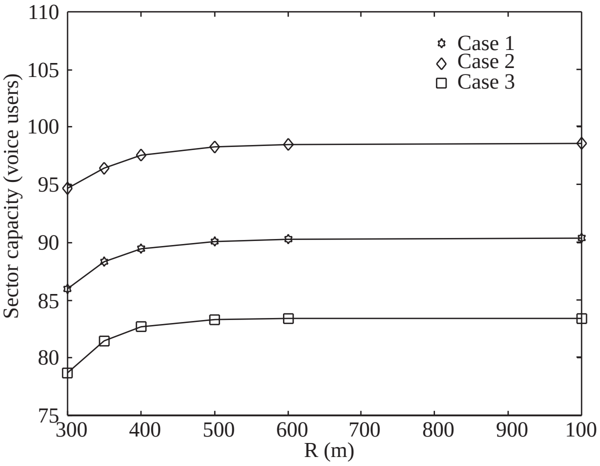

Figure 9. Sector capacity as a function of the sector range R when $\sigma_c = 1.5$ dB.

Finally, we study the effect of the side lobe level on the sector capacity. Figure 10 shows the effect of reducing the side lobe level on the sector capacity. It can be noticed that the capacity increases with decrease of the side lobe relative gain. An antenna with side lobe level of -15 dB is a good choice.

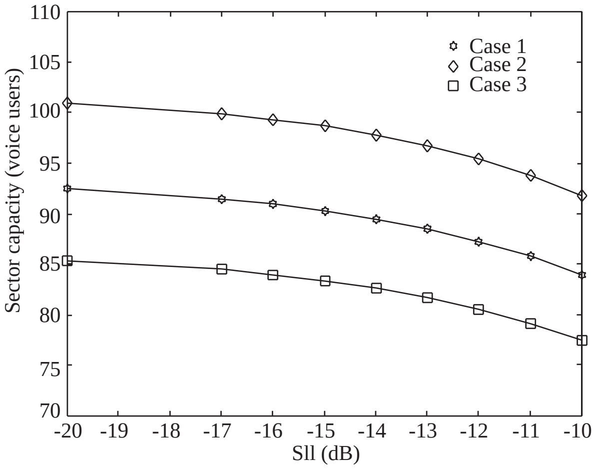

Figure 10. Sll effect on the sector capacity when $\sigma_c = 1.5$ dB.

Numerical calculations show that about 97% of the interference is due to the S_0 region. Thus the error due to the approximations in the calculation of the interference from the S_1 region is negligible.

We must mention that not one of the five distributions can exist in practice; however it gives an idea about the effect of a concentration of users on the sector capacity.

5. Conclusion

We have presented a model that give the capacity and interference statistics of a W-CDMA rural highway cigar-shaped microcells. The capacity of the sector is studied for a general two-slope propagation model with lognormal shadowing for different spatial distribution of users and different standard deviation of power control error. As the users move away from the base station, decreasing their density, the capacity of the sector increases due to the lower total power transmitted by competing users. Also, it has been found the capacity reduces with increase in the standard deviation of power control error.

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