The Capacity and Interference Statistics of High Car Traffic W-CDMA Street Cross-Shaped Micro-Cells (Uplink Analysis)

Bazil TAHA-AHMED, Miguel CALVO-RAMÓN, Leandro de HARO-ARIET

Departamento Sistemas, Señales y Radiocomunicaciones, ETSI Telecomunicación,
Universidad Politécnica de Madrid, Ciudad Universitaria, Madrid, 28040, Spain

bazil@gr.ssr.upm.es

Abstract. *Since interference is related to the capacity and performance of W-CDMA system, it is necessary to investigate the interference characteristics (the mean value and the variance). Thus, the uplink capacity and the interference statistics of the sectors of the cross-shaped W-CDMA microcell have been analyzed using geometry with 17 microcells. A single slope propagation model with a lognormal shadowing factor has been used in the analysis. The cells have been assumed to exist in city streets with high car traffic. The capacity and the interference statistics of the sectors have been studied for different sector ranges, and different side-lobe level. The results show that the capacity increases with the increment of the sector range and with the reduction of the side-lobe level of the antennas used.*

Keywords

W-CDMA, cell capacity, cross-shaped microcells, interference statistics.

1. Introduction

It is well known the CDMA is characterized as being interference-limited and reducing the interference results in increasing the capacity. Three factors are used to reduce the interference:

- Power control (PC) which is essential in the uplink;
- Voice activity monitoring which can increase the capacity by a factor of 1.6 to 2.5;
- Sectorization, which can increase the capacity by a factor of approximately 0.8 × the number of the cell sectors.

It is well known that urban microcells shapes may approximately follow the street pattern, and for that reason, it is possible to have cross-shaped microcells [1].

Min *et al* studied the performance of a cigar-shaped CDMA highway micro cell [2] giving the average capacity of the microcell. Hashem *et al.* studied the capacity and the interference statistics for hexagonal cell for a propagation exponent of 4.0 [3]. Ahmed *et al.* studied interference statistics for high-way microcells using two slope propagation model [4]. Ahmed *et al.* studied capacity and interference statistics for city street microcell assuming low car traffic using two-slope propagation model [5]. The electromagnetic waves propagation in city streets has been studied for the case of high car traffic [6], where it has been noticed that the two-slope propagation model is not applicable.

In this work, we introduce a model for a cross-shaped microcells in city streets with general propagation exponent using a single slope propagation model and then investigate the sector capacity and interference statistics, i.e., the expected value of the interference and the variance of the interference of the uplink.

2. Propagation Model

In daytime (high car traffic), the break point was found to disappear and the path loss could be approximated by a single-slope propagation model [6]. So, a single-slope propagation model is used in the calculations where the exponent of the propagation is assumed to be s. From (9) and (10) of [6], the path loss can be given by:

$$L_p\,[\mathrm{dB}] \approx L_S + 10 + 10\,s\log\left(\frac{d}{R_S}\right) + \xi_1,\; d \le R_S\,, \quad (1)$$

$$L_p\,[\mathrm{dB}] \approx L_S + 10 + 10\,s\log\left(\frac{d}{R_S}\right) + \xi_2,\; d > R_S\,, \quad (2)$$

where ξ_1 and ξ_2 are Gaussian random variables of zero-mean and a standard deviation of σ_1 and σ_2 respectively, d is the distance between the base station of the cell C and the mobile receiver, R_S is the distance of the point of change of ξ and L_S is the reference attenuation at a distance R_s

$$L_S\,[\mathrm{dB}] = \left|\; 20\log\left(\frac{\lambda}{2\pi R_S}\right)\right|\,. \quad (3)$$

Here, λ is the wavelength.

The shadowing factor ξ due to two different base stations m and n has a correlation coefficient C_{mn}. From (1-2), it can be noticed that the random Gaussian variable ξ has a value of ξ_1 till the point of change R_S and then it converts into ξ_2 after this point. The parameter s has a typical value of 3.0 to 3.5 [6].

3. Cell Geometry

The cross-shaped cell geometry is shown in Fig. 1. We can notice that the microcell consists of four directive sectors. Each sector uses a directive antenna with a side-lobe level *Sll.*

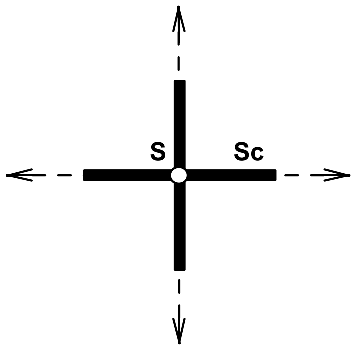

Fig. 1. The cell geometry.

Fig. 2 shows the deployment of the cells. We can notice that, there is a cross-shaped microcell in each cross point of the streets net. The sector range R has a typical value of 80 to 120 m.

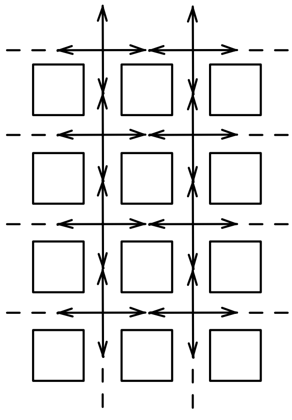

Fig. 2. The cross-shaped cells deployment.

4. Uplink Analysis

A model of 17 microcells is used to analyze the uplink interference. The interference regions are divided into the near interference zone S0 and the far interference zone S1. Fig. 3 shows the configuration of microcells that affect the capacity of the sector under consideration (Sc1). In the down given analysis, a perfect power control is assumed in the uplink and the interference from sectors that suffer from diffraction is neglected (diffraction loss ≥ 20 dB).

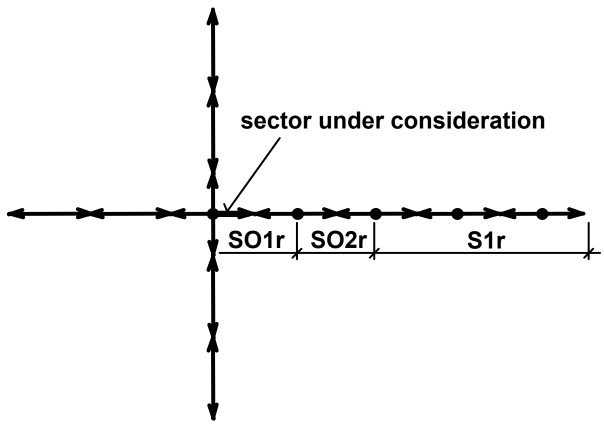

Fig. 3. Cells that affect the capacity of the sector under consideration (only 11 cells are shown).

Fig. 4 shows the configuration of the microcells interference geometry. In the uplink each cell controls the transmitted power of its users. If the interfering user is at a distance r_n from the nearest base station and at a distance r_m from the next nearest base station as shown in Fig. 4, then the ratio of the normalized interference signal $L(r_m, r_n)$ due to the distance only is given as

$$L(r_m, r_n) = (r_n / r_m)^S \quad . \tag{4}$$

Now the ratio of the normalized interference signal $I(r_m, r_n)$ due to the distance and shadowing is given by

$$I(r_m, r_n) = L(r_m, r_n)\, 10^{(\xi_m - \xi_n)/10} \tag{5}$$

When (r_m and $r_n \le R_S$) then $\xi_m = \xi_1$ and $\xi_n = \xi_1$. If $r_n > R_S$ then $\xi_0 = \xi_2$ and $\xi_m = \xi_1$ or ξ_2 for $r_m < R_S$ or $r_m > R_S$ resp.

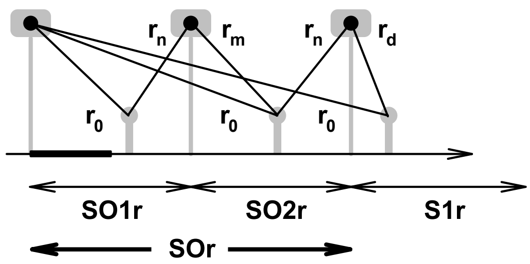

Fig. 4. The interference geometry.

We will find the statistics of the total intercellular interference $I_{inter,t}$ for the right sector Sc1 of the central cell evaluating the interference from users in S0 region I_{S0} and interference from users in the S1 region I_{S1}, where the above mentioned regions are shown in Fig. 3. In our analysis, it has been assumed that the user will connect with the best of the two nearest base stations. In the S1 region, we will approximate the distance between the user and the second closest base station by the distance between the user and the closest base station [3].

Let the desired signal level be S. The interference from an active user communicating with the home cell will be also S. A user i will not communicate with the base station m but rather with base station n, if $\phi\,(\xi_m - \xi_n,\ r_m/r_n) = 1$, where

$$\phi\left(\xi_m-\xi_n, r_m / r_n\right)=\begin{cases}1 & \text{if } L\left(r_m, r_n\right) 10^{\left(\xi_m-\xi_n\right) / 10} \leq 1 \\ 0 & \text{otherwise}.\end{cases} \tag{6}$$

Assuming a uniform density of users, the density of users in each sector is $\rho = N_u / R$ users per unit length, and that the activity factor of the user is α, then for the right part of the S01 zone, the expected value of I_{S01} is given as

$$E\{I_{S01}\}_r = \alpha\,\rho \int_{S01r} A(r_0, r_n)\, f\left(\frac{r_0}{r_n}\right) dr \;, \tag{7}$$

where

$$A(r_0, r_n) = L(r_0, r_n)\; E\left\{10^{(\xi_0-\xi_n)/10}\right\}, \tag{8}$$

$$A(r_0, r_n) = L(r_0, r_n)\; \exp\left[(\beta\,\sigma_{0n})^2 / 2\right], \tag{9}$$

and

$$f\left(\frac{r_0}{r_n}\right) = E\left\{\phi\left(\xi_0-\xi_n, r_0/r_n\right)\right\}, \tag{10}$$

$$f\left(\frac{r_0}{r_n}\right) = Q\left\{\sqrt{\sigma_{0n}^2}\;\beta - \frac{10}{\sqrt{\sigma_{0n}^2}} \log\left[1 / L(r_0, r_n)\right]\right\}, \tag{11}$$

where $\beta = 0.1 \ln 10$.

Now, the general value of $\sigma_{mn}{}^2$ is given as:

- If $r_m \leq R_s$ and $r_n \leq R_s$ then

  $$\sigma_{mn}^2 = 2\,(1 - C_{mn})\,\sigma_1^2 \;, \tag{12}$$

  where C_{mn} is the correlation coefficient between the shadowing random variable ξ_m and ξ_n due to the microcells m and n.

- If $r_m \leq R_s$ and $r_n > R_s$ or $r_m > R_s$ and $r_n \leq R_s$ then the value of $\sigma_{mn}{}^2$ is given by:

  $$\sigma_{mn}^2 = (\sigma_1 - \sigma_2)^2 - 2\,(1 - C_{mn})\,\sigma_1\,\sigma_2 \;. \tag{13}$$

- If $r_m > R_s$ and $r_n > R_s$ then

  $$\sigma_{mn}^2 = 2\,(1 - C_{mn})\,\sigma_2^2 \;. \tag{14}$$

The term $Q(x)$ is given by the relation:

$$Q(x) = \int_x^{\infty} \exp\left(-v^2/2\right) dv / \sqrt{2\pi} \;. \tag{15}$$

The expected value of I_{S02} due to the right side of the region S02 is given as

$$E\{I_{S02}\}_r = \alpha\rho\left\{\int_{S02r}\left[A(r_0, r_m)\, f\left(\frac{r_n}{r_m}\right)\right] dr + \int_{S02r}\left[A(r_0, r_n)\, f\left(\frac{r_m}{r_n}\right)\right] dr\right\} \tag{16}$$

The expected value of I_{S1} due to right part of the S1 region is given as

$$E\{I_{S1}\}_r \approx \alpha\rho \int_{S1} L(r_0, r_d)\; E\left\{10^{(\xi_0-\xi_d)/10}\right\} dr \;. \tag{17}$$

The expected value of the intercellular interference from the right side of interference regions S0 and S1 is given by:

$$E\{I\}_r = E\{I_{S01}\}_r + E\{I_{S02}\}_r + E\{I_{S1}\}_r \;. \tag{18}$$

Thus, the expected value of the total interference from the all sides is given as

$$E\{I\}_{inter,t} = E\{I\}_r\,(1 + 3\,Sll) \;, \tag{19}$$

where Sll is the side-lobe level of the directive antenna used in each sector. The expected intercellular interference power in terms of the desired power S is given as

$$E\{P\}_{inter} = S\,E\{I\}_{inter,t} \;. \tag{20}$$

The intracellular interference power is given by

$$P_{intra} \approx \alpha\,S\,N_u\,(1 + 3Sll) \;. \tag{21}$$

The total interference-to-signal ratio is given by

$$\frac{P_t}{S} = \frac{P_{intra}}{S} + \frac{E\{P\}_{inter}}{S} \;. \tag{22}$$

The uplink carrier-to-interference ratio $(C/I)_{up}$ is given as

$$(C/I)_{up} = S/P_t \tag{23}$$

and $(E_b/N_0)_{up}$ is given as:

$$(E_b/N_0)_{up} = (C/I)_{up}\;G_p \;. \tag{24}$$

The expected number of users $E\{N_u\}$ is calculated from (24). Now, the variance of I_{S01} due to right part of the region S01 is given as:

$$\operatorname{var}\{I_{S01}\}_r = \rho \int_{S01r}\left\{\left[B(r_0, r_n)\right]^2 \cdot \left[\alpha\, g\left(\frac{r_0}{r_n}\right) - \alpha^2 f^2\left(\frac{r_0}{r_n}\right)\right]\right\} dr \;, \tag{25}$$

where

$$\begin{aligned} B(r_0, r_n) &= E\left\{10^{(\xi_0-\xi_n)/10}\right\}^2 \left\{L(r_0, r_n)\right\}^2 \\ &= \exp\left[2\,(\beta\,\sigma_{on})^2\right] \left\{L(r_0, r_n)\right\}^2 \end{aligned} \;. \tag{26, 27}$$

and

$$g(r_0/r_n) = E\left\{\phi\left(\xi_0 - \xi_n, r_0/r_n\right)\right\}^2 = \tag{28}$$

$$= Q\left\{\sqrt{\sigma_{on}^2}\; 2\beta - \frac{10}{\sqrt{\sigma_{on}^2}} \log\left[\frac{1}{L(r_0, r_n)}\right]\right\} \;. \tag{29}$$

The variance of I_{S02} due to the right part of the S02 region is given as

$$\operatorname{var}\{I_{S02}\}_r = \rho \int_{S02r} \left\{ [B(r_0, r_n)]^2 \cdot \left[\alpha\, g\left(\frac{r_m}{r_n}\right) - \alpha^2 f^2\left(\frac{r_m}{r_n}\right) \right] \right\} dr + \rho \int_{S02r} \left\{ [B(r_0, r_m)]^2 \cdot \left[\alpha\, g\left(\frac{r_n}{r_m}\right) - \alpha^2 f^2\left(\frac{r_n}{r_m}\right) \right] \right\} dr \tag{30}$$

The variance of I_{S1} due to right part of the S1 region is given as

$$\operatorname{var}\{I_{S1}\}_r \approx \rho \int_{S1r} \left\{ [L(r_0, r_n)]^2 \cdot \left[\alpha\, E\left\{ \left[10^{(\xi_0-\xi_d)/10}\right]^2 \right\} - \alpha^2 E^2 \left\{ 10^{(\xi_0-\xi_d)/10} \right\} \right] \right\} dr, \tag{31}$$

Thus the total variance due to the interference regions S0 and S1 is given by

$$\operatorname{var}\{I\}_t = \left[\operatorname{var}\{I_{S0}\}_r + \operatorname{var}\{I_{S1}\}_r \right] [1 + 3\,Sll] \tag{32}$$

The variance of the number of user $\operatorname{var}\{N_u\}$ is calculated as

$$\operatorname{var}\{N_u\} = \operatorname{var}\{I\}_t \; E\{N_u\} \tag{33}$$

Finally, the outage probability (the probability that E_b/N_0 of X % of the users did not reach the required E_b/N_0) is calculated as:

$$P_r = Q\left[\frac{E(N_u) - N_u}{\sqrt{\operatorname{var}(N_u)}} \right] \tag{34}$$

5. Numerical Results

In our estimation it has been assumed that the processing gain $G_p = 400$, $\alpha = 0.5$ and the required $E_b/N_0 = 7$ dB [7]. For our calculations, some reasonable figures are applied. The antenna azimuth side lobe level is assumed to be –15 dB, the correlation coefficients $C_{nm} = 0.5$, $s = 3$, $\sigma_1 = 3$ dB, $\sigma_2 = 6$ dB and $R_s = 100$ m unless other values are mentioned. We assume that the accepted outage probability is 1 % and that the capacity of the sectors is calculated at this probability.

To get the numerical results, the integrations given in section 4 have been solved numerically.

Fig. 5 shows the outage probability when $R = 100$ m. It can be noticed that the sector capacity is 115 users (1 % outage). The average capacity of the sector is 121 users (50 % outage).

The effect of the sector range is shown in Fig. 6. It can be noticed that the sector capacity is constant for a sector range of 80 to 90 m, it increases for a sector range of 90 to 100 m and then it remains constant for larger range.

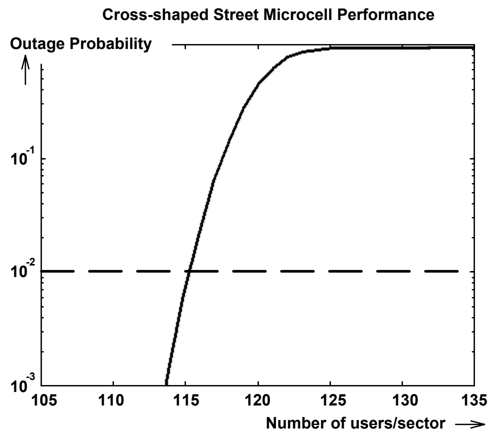

Fig. 5. The outage probability of the sector for $R = 100$ m.

The effect of the side lobe level is shown in Fig. 7 when $R = 100$ m. We can notice that reducing the side-lobe level will give a rise to a capacity increment. An antenna with side lobe level of –12 to –15 dB is a good choice.

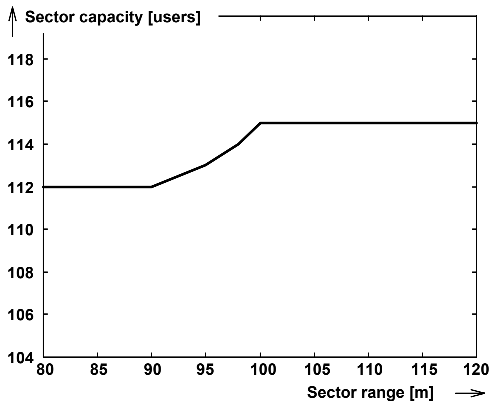

Fig. 6. The effect of the sector range on the sector capacity.

The effect of changing the distance R_1 is shown in Fig. 8. It can be seen that the capacity is constant when R_s has a value of 100 m – 250 m, it increases when R_s is in the range of 300 m – 350 m, and it remains constant for larger R_s.

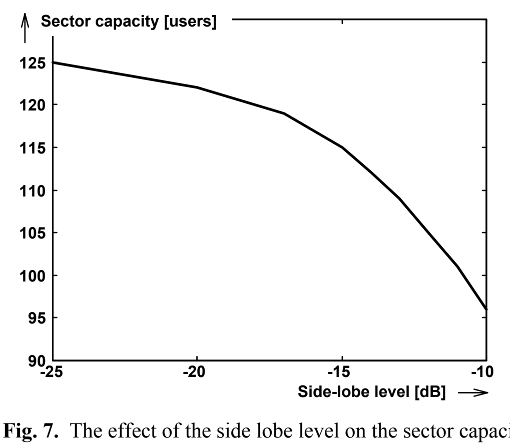

Fig. 7. The effect of the side lobe level on the sector capacity.

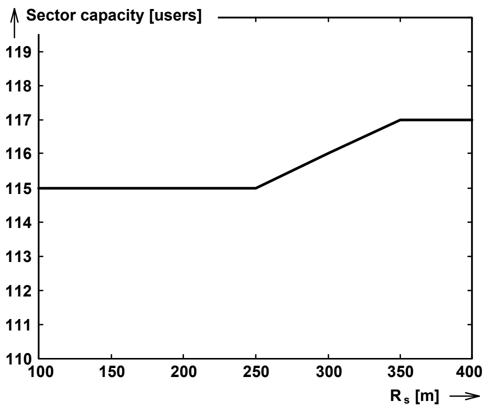

Fig. 8. The effect of changing R_s on the sector capacity.

6. Conclusions

The sector capacity and the interference statistics of the uplink were studied using a model of 17 micro-cells. The micro-cells are assumed to exist in city streets. The capacity and the interference statistics of the sectors were studied for different sector ranges, different side-lobe level and for different values of R_s. It was noticed that increasing the sector range will increase the sector capacity and that reducing the side-lobe level will increase the sector capacity and that increasing R_s increases the capacity in general.

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About Authors...

Bazil TAHA-AHMED was born in Mosul, Iraq, in 1960. He received the B.Sc. and M.Sc. degrees in telecommunication engineering from the University of Mosul, in 1982 and 1985, respectively. He got the Ph. D degree in telecommunication engineering from the Polytechnic University of Madrid in 2003. From 1985 to 1998, he was teaching at the Electrical Engineering Department at Mosul University.

Bazil has published more than 30 scientific journal and conference papers in the area of the electromagnetic propagation and CDMA systems, particularly the CDMA capacity. His research interests includes CDMA capacity and E. M. Wave propagation in micro-cellular and macrocellular environments.

Miguel CALVO-RAMON was born in Pueyo de Jaca, Huesca, Spain on June 10, 1949. He got the *Ingeniero de Telecomunicación* degree from the Escuela Técnica Superior de Ingenieros de Telecomunicación of the Universidad Politécnica de Madrid in 1974 and the *Doctor Ingeniero de Telecomunicación* degree from the same University in 1979.

He works as Professor in the *Señales Sistemas y Radiocomunicaciones* (Signals, Systems and Radiocommunications) department where he obtained the *Catedrático* (Full Professor) position in 1986.

Leandro de HARO-ARIET was born in Barcelona, Spain, on May 17, 1962. He got the *Ingeniero de Telecomunicación* degree in 1986 and the *Doctor Ingeniero de Telecomunicación* degree (Apto cum laude) in 1992 both from the Escuela Técnica Superior de Ingenieros de Telecomunicación of the Universidad Politécnica de Madrid (Dept. of Señales, Sistemas y Radiocomunicaciones).

Since 1990 he develops his professional career in the E.T.S. Ingenieros de Telecomunicación of the Universidad Politécnica de Madrid (Dept. of "Señales, Sistemas y Radiocomunicaciones") as Assistant Professor on the Signal Theory and Communications area.