도심 마이크로셀에서 CDMA 시스템을 위한 효율적인 기지국 배치를 위한 모의실험

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System-Level Simulation for Efficient Displacement of Base Station Antennas for CDMA Uplink System in Urban Microcells

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요 약

본 논문은 균일한 도심지역에서의 CDMA 시스템의 상향링크에 대하여 송신전력, 간섭전력 및 블로킹 확률 등을 최소화하는데 기지국 배치에 따라 결정되는 셀 모양의 효과를 분석하기 위하여 시스템 수준의 모의실험이 이루어진다. 도심 마이크로 셀에서 기지국에 대한 경로 손실은 단말이 위치한 거리의 방향성에 영향을 받는다. 단말로부터 기준 기지국에 대한 간섭은 2차 Tier까지 고려된다. 간섭 계산의 정확성에 대한 손실 없이 계산 복잡도를 줄이기 위한 방법으로Wrap around method가 사용된다. 모의실험 결과는 송신전력, 간섭전력 및 블로킹 확률 등이 효율적인 기지국 배치에 따른 셀의 모양에 따라 줄어들 수 있음을 보여준다.

Key Words : Cell shape, Base station deployment, Path loss model, Non-isotropic path loss model, Blocking probability

ABSTRACT

In this paper, we carry out system level simulations to investigate the effect of cell shape (i.e., different base station displacements in the two directions defined by the street grid) on minimizing transmitter power, interference power, and blocking probability for CDMA system in urban microcellular environments. In urban microcell, path loss to the base station depends on the orientation of the street where the mobile is located. Interference from mobile stations to the base station in the reference cell is considered up to second tier. The wrap around method is used to include the second tier interference with realistic computational complexity without reducing the accuracy of interference calculations. The investigation shows that the transmitter power, interference power, and blocking probability in a cell can be reduced by proper selection of the efficient cell shape.

Ⅰ. Introduction

The continuing demand for mobile communication services drives the current cellular systems to their capacity limit. Placement of base station antennas of the current cellular systems above rooftops makes the geographical cell size large. Increasing system capacity can be achieved by placing the base station

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antenna below the surrounding buildings to reduce the cell size. However, for low base station antennas the path loss is found to depend on the position and orientation of the street containing the mobile relative to the street on which the base station is located [1]-[4], so that cell shape is diamond like rather than hexagonal.

Capacity of CDMA systems is determined by uplink interference from users in the same cell, i.e., in-cell interference, and from users from other cells, i.e., out-of-cell interference [5]-[7]. The capacity of CDMA system has been studied for hexagonal cells obtained when the path loss dependence is the same in all directions from the base station [7]-[12]. The purpose of this paper is to investigate how the changes in cell shape from the hexagons of macro-cellular systems to diamonds impacts the transmitted and interference powers of CDMA systems.

In a previous study [13] we investigated the affect of the directional dependence of propagation on the out-of-cell interference for uniformly loaded CDMA systems in residential environments having a rectangular street grid. In that study we assumed the mobiles to be uniformly distributed along the streets. Based on the ratio of the out-of-cell interference to the in-cell interference, we found the most efficient displacement of base stations in the two orthogonal directions defined by the street grid for the case when the base station antennas were placed in the middle of the block.

The work reported here differs from our previous studies in that Transmitter power, interference power, and blocking probability are computed for different cell shapes (different base station antennas displacements in the two directions defined by the street grid) and as a function of the number of mobiles per cell. The transmitting power, interference power, and blocking probability of a CDMA system are evaluated using the power control method developed by Zander [21], assuming the mobiles to be randomly located along the streets and using the wrap around method to include second tier interference. As a result, we find that the transmitter power by mobile terminals, interference power, and blocking probability are different for the various displacements of base station antennas (i.e., cell shapes). The efficient cell shapes found by the power control method used in this work are consistent with those are chosen by the out-of-cell interference in [13].

This paper is organized as follows. Section Ⅱ presents definitions of cell shapes for urban microcell of a regular street grid and path loss models used in calculation channel gains. Calculation of transmitter power and interference power are discussed in Section Ⅲ. Simulation environment, parameters and results are presented in Section Ⅳ. We conclude the paper in Section Ⅴ.

Ⅱ. Urban Microcell Shape and Path Loss Model

As discussed previously [1]-[4], [13], placing base station antennas below surrounding buildings makes propagation characteristics strongly dependent on the building environment. In conventional cellular systems with high base station antennas, the equi-received power contours are circles, which lead to the hexagonal cell shape. For low base station antennas in areas having regular street grids, the equi-received power contours are irregular, but somewhat elliptical areas, leading to cells in the shape of squeezed hexagons or diamonds [1]-[4], as shown in Figure 1. For the regular street grid of Figure 1, the "horizontal" and "vertical" distances of the street grid are given by $2D$ and $2d$, respectively. For this study we assume that all base stations are regularly located at mid-block, and are displaced from each other in lattice whose displacements in the two street grid directions are M blocks and N blocks, as depicted in Figure 1. Thus the diamond shape, while not the actual cell shape defined by equi-received power contours, is still a convenience in keeping trackof the spacing between base stations. Different cell shapes are characterized by the ratio of M and N. For example, if MN=6, there are 4 shapes: MxN=1x6; 2x3; 3x2; and 6x1, which are chosen as the basis for this study. For any actual shape, the cell area is equal to the area of the diamond which

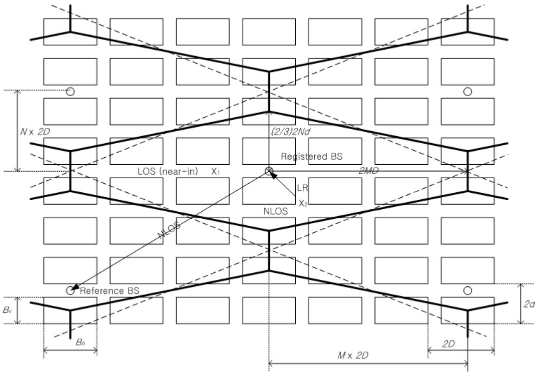


Fig. 1. Propagation types to the registered base station and the reference base station.

is given by *8MNDd*. In order to further illustrate the concept of different cell shapes, different displacements of base station antennas for the case of cell size MN=6 are shown in Figure 2 for the cases of MxN=1x6; 2x3; 3x2; and 6x1.

As indicated in Figure 1, the mobile can communicate with the registered and reference base stations through four different propagation types [22],[23]. These types are: 1) Near in LOS for distances before the break point at $R_b = 4h_b h_m / l$ 2) Far LOS for distances beyond the break point; 3) Lateral Route (LR) for mobiles on the two streets closest to the base station that are perpendicular to the LOS street of the base station; and 4) NLOS for all the remaining streets. Each propagation type has a corresponding path loss model, which takes to the form

$$P_L(R) = A + 10n\log_{10} R + \xi \qquad (1)$$

where A is the received power at a distance R=1 (units), R is the distance between the transmitter and the receiver, n is a slope index and x is a random variable of shadow loss having zero mean and

Table 1. Parameters A and $10n$ for various propagation types

Propagation Type	A	$10n$
LOS (near in)	$39.401\log_{10} f_M + 17.101\log_{10} h_b - 84.46$	$15.80 - 5.761\log_{10} h_b$
LOS (far-out)	$45.701\log_{10} f_M + (25.34 - 13.91\log_{10} R_b)$ $\log_{10} h_b - (88.72 + 32.101\log R_b)$	$32.10 + 13.901\log_{10} h_b$
Lateral Route	$-110.72+42.13\log_{10} f_M+(8.43-1.67\log_{10} f_M)$ $Sgn(\Delta h)\log_{10}(1+\lvert\Delta h\rvert)$_	$33.67-2.81 sgn(\Delta h)\log_{10}(1+\lvert\Delta h\rvert)$
Non-LOS	$-99.78+37.27\log_{10} f_M+(10.70-2.20\log_{10} f_M)$ $Sgn(\Delta h)\log 10(1+\lvert\Delta h\rvert)$	$36.89-3.57 sgn(\Delta h)\log_{10}(1+\lvert\Delta h\rvert)$

standard deviation s. The values of A and n depend on the frequency, heights of antenna, height of building and the breakpoint distance, and are listed in Table 1.

Where h_b is the base station antenna height and h_{bd} is average building height in meters, $Dh=h_b-h_{bd}$ and $\mathrm{sgn}(\Delta h) = \begin{cases} -1 & \Delta h < 0 \\ 1 & \Delta h \ge 0 \end{cases}$.

Ⅲ. Calculation of Transmitting Power and Interference Power

Assuming that there are N_C mobiles in a cell, let P_j be the power transmitted by jth mobile and L_{ij} be the path gain, which is the ratio of the received power to the transmitted power, from jth mobile to the base station of the ith mobile. For ith mobile to communicate properly with its base station, the following constraint has to be satisfied [21]

$$\frac{P_i}{\sum_{j=1}^{N} Z_{ij} P_j - P_i + \frac{\nu_i}{L_{ii}}} \ge \gamma_i \qquad (2)$$

Here ν_i is background noise power at ith demodulator and $Z_{ij} = L_{ij}/L_{ii}$ is normalized path gain matrix, $\mathbf{g}_i$ is the required signal to noise ratio for ith mobile at the registered base station.

3.1 A Matrix Method

Define the matrix

$$Z = \begin{bmatrix} \frac{L_{11}}{L_{11}} & \cdots & \frac{L_{1N_m}}{L_{11}} \\ & \ddots & \\ \vdots & \frac{L_{ij}}{L_{ii}} & \vdots \\ \frac{L_{N_m 1}}{L_{N_m N_m}} & \cdots & \frac{L_{N_m N_m}}{L_{N_m N_m}} \end{bmatrix} \qquad (3)$$

and let $\eta_i \equiv \nu_i / L_{ii}$. After some manipulation, (2) becomes

$$(ZP)_i - P_i + \eta_i \le \frac{P_i}{\gamma_i} \qquad (4)$$

Expanding the above constraint into matrix form for

$i=1,2,\cdots,N_m$, where N_m is the total number of mobiles

$$ZP - P + \eta \le \Gamma^{-1}P \tag{5}$$

where, $\eta = [\eta_1 \eta_2 \cdots \eta_N]^T$ and $\Gamma = diag[\gamma_1 \gamma_2 \cdots \gamma_N]^T$. Multiplying (5) by **G** gives

$$\Gamma(Z - I)P + \Gamma\eta \le P \tag{6}$$

To properly satisfy (6), the transmitting power matrix P must satisfy [21]

$$(I - A)P = \Gamma\eta \tag{7}$$

or

$$P = (I - A)^{-1}\Gamma\eta \tag{8}$$

where

$$A = \Gamma(Z - I) \tag{9}$$

From (8) we can directly compute the power that should be radiated by each mobile. In order to compute P, we need only to evaluate the matrices A, **G** and **h**. To do so we put A, **G**, P and **h**into submatrices organized by the cells to which the mobiles belong. The 25 cells, including the second tier, are numbered $0,1,2,\cdots,24$ as shown in Figure 2. Let $H_{(m,n)}$ be a square sub-matrix of A related to the base station m from the mobile group registered to base station n. Including the second tier, the dimension of A is $25N_C$ x $25N_C$ and has the form

$$A = \begin{bmatrix} H_{(0,0)} & H_{(0,1)} & \cdots & H_{(1,24)} \\ & \ddots & & \\ \vdots & & H_{(m,n)} & \vdots \\ & & \ddots & \\ H_{(24,0)} & H_{(24,1)} & \cdots & H_{(24,24)} \end{bmatrix} \tag{10}$$

Also

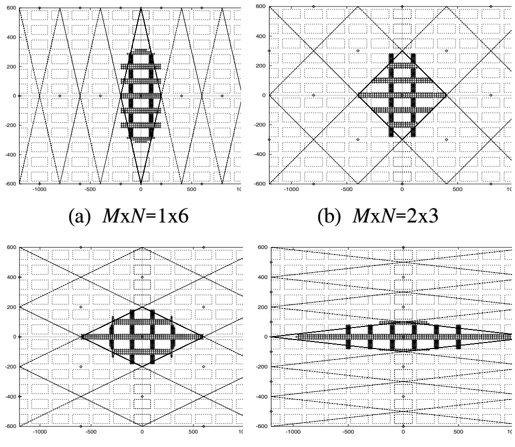
$$\Gamma = \begin{bmatrix} \Gamma_{00} & 0 & \cdots & 0 & 0 \\ 0 & \ddots & 0 & & 0 \\ \vdots & 0 & \Gamma_{mn} & \ddots & \vdots \\ 0 & & \ddots & \ddots & 0 \\ 0 & 0 & \cdots & 0 & \Gamma_{24\,24} \end{bmatrix} \tag{11}$$

$$P = [P_{BS_0} \ldots P_{BS_n} \ldots P_{BS_{24}}]^T \tag{12}$$

$$\boldsymbol{\eta} = [\boldsymbol{\eta}_o \ldots \boldsymbol{\eta}_n \ldots \boldsymbol{\eta}_{24}]^T \tag{13}$$

Here, P_{BSi} is the transmit power column vector of mobiles registered to base station i. Using (10)-(13), we rewrite (7) in the following notation

$$\sum_{m=0}^{24} (I - H_{(m,n)}) P_{BS_n} = \sum_{m=0}^{24} \Gamma_{mn} \eta_n \tag{14}$$


(a) MxN=1x6 (b) MxN=2x3

(c)MxN=3x2 (d) MxN=6x1

Fig. 2. Different displacements of base station antennas in case of cell size MN=6

3.2 Wrap Around Approximation

The wrap around method is used to reduce the computation complexity while effectively accounting for second tier interference. The average interference at the base stations computed by the A matrix method accounting for: 1) first tier interference only; 2) first and second tier using random placement of the mobiles in both tiers; 3) first and second tier interference using the wrap around method; and 4) first and second interference using duplication. It was found that accounting for the first tier only generally gives slightly less interference than methods including the second tier [25]. The wrap around method has the same computational complexity as the case of first interference tier only, and was found to give almost the same results as when the mobiles in both the first tier and second tiers are generated randomly.

Because the mobiles in the second tier are the duplicates of those in the first tier, we can assume that the transmit power vectors of the second tier are also the same. Let the similar sets S_k be the set of duplicated base stations represented by the base station $k$in the first tier base stations. Then,

$S_0=\{0\}, S_1=\{1,14,17,20\}, S_2=\{2,19\}, S_3=\{3,18,21,24\}, S_4=\{4,23\},$
$S_5=\{5,9,12,22\}, S_6=\{6,11\}, S_7=\{7,10,13,16\}, S_8=\{8,15\}$

and

$P_{BS_1}=P_{BS_{14}}=P_{BS_{17}}=P_{BS_{20}},\ P_{BS_2}=P_{BS_{19}},\ P_{BS_3}=P_{BS_{18}}=P_{BS_{21}}=P_{BS_{24}},\ P_{BS_4}=P_{BS_{23}}$
$P_{BS_5}=P_{BS_9}=P_{BS_{12}}=P_{BS_{22}},\ P_{BS_6}=P_{BS_{11}},\ P_{BS_7}=P_{BS_{10}}=P_{BS_{13}}=P_{BS_{16}},\ P_{BS_8}=P_{BS_{15}}$

Replacing P_{BS9}~P_{BS24} with P_{BS0}~P_{BS8} in (14), the mth row term can be written as

$$\sum_{j=0}^{8} W_{ij} P_{BS_j} = \sum_{j=0}^{8} \Gamma'_{ij} \eta'_j \tag{15}$$

where,

$$W_{ik} = \sum_{j \in S_k} \left(I - H_{(i,j)}\right) \quad for\ k = 0,1,\cdots,8 \tag{16}$$

$$\Gamma'_{ik} = \sum_{j \in S_k} \Gamma_{ij} \tag{17}$$

$$\eta'_k = \sum_{j \in S_k} \eta_j \tag{18}$$

Here, the sum is taken over all similar set S_k which are all duplicates of cell k and also includes the cell k.

In matrix notation (14) can be written as

$$YP^{wrap} = \Gamma^{wrap} \eta^{wrap} \tag{19}$$

$$P^{wrap} = Y^{-1} \Gamma^{wrap} \eta^{wrap} \tag{20}$$

where,

$$\begin{aligned} Y_{ij} &= \sum_{k \in S_i} W_{kj} \\ &= \sum_{k \in S_i} \sum_{m \in S_j} \left(I - H_{(k,m)}\right) \end{aligned} \tag{21}$$

$$\Gamma_{ij}^{wrap} = \sum_{k \in S_i} \sum_{m \in S_j} \Gamma_{km} \tag{22}$$

$$\eta_j^{wrap} = \sum_{k \in S_j} \eta_k \tag{23}$$

Thus, the matrix form (7) with dimensions $25N_C$ x $25N_C$ can be converted into (19) with dimensions $9N_C$ x $9N_C$ by making use of the wrap around method.

Ⅳ. Simulation Results

Mobile positions are generated inside the reference cell, and in the first and second tiers of cells shown in Figure 3 that surround the reference cell 0 where the interference is to be determined. The mobiles in the reference cell and in the first tier (stations 1~8) are randomly generated from a uniform spatial distribution along the streets. The mobiles in the second tier (base stations 9~24) shown in Figure 3 are duplicates of the mobiles in the first tier cells indicated by the number in the parenthesis. For example, cell 9 has mobiles located at the positions that are the duplicates of cell 5, and the locations in cell 10 are the duplicates of those in cell 7. The relative distances of the mobiles to the duplicated base station are same to the distances of the mobiles to the original base station.

Figure 4 shows the positions of mobiles in one embodiment for the case MxN=3x2, assuming that

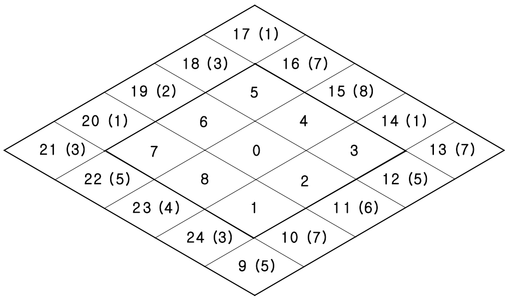


Fig. 3. Surrounding cell arrangement to generate the mobiles for the wrap-around method

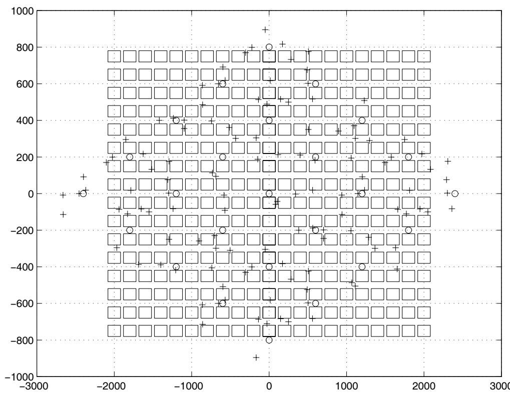


Fig. 4. Example of mobile generation up to 2 tier for the case of the number of mobiles per cell N_C=5 and the cell shape MxN=3x2

the number of mobiles N_C per cell is N_C=5. The reference base station is located at (0,0) and the mobiles in the reference cell and first tier cells are generated randomly. As previously described, the mobiles in second tier cells are duplicates of those in the first tier. As noted previously, we investigate different measures for evaluation of four different cell shapes having the same area, which are MxN=1x6, 6x1, 3x2, and 2x3, as shown in Figure 2.

4.1 Simulation Parameters

For simulation, the following environment and system parameters are assumed: horizontal block size D=200m, vertical block size d=100m, street width W_s=38m, blocking probability P_{block} = 0.01, maximum acceptable interference $1/\eta = I_o/N_o$ =10, thermal noise $N_o = -110\ dBm$. Using the path loss models in Table 1, the channel gains and the matrices **G**, Z, η and A are calculated. The dimensions of these matrices are reduced by the wrap around method. When there is no positive solution for the transmit power, the mobiles in the first and second tiers that have the greatest path loss to the registered base station are dropped, and the process is repeated until a feasible solution of the transmitted and interference powers are found. Then the ratio of the out-of-cell to the in-cell interference is calculated. The whole process is repeated for a large number of trials of mobile locations for statistical significancee.

4.2 Out-of-Cell Interference

The out-of-cell interference f_A obtained from the Amatrix method can be found from the ratio of the out of cell interference power to the in cell interference using the wrap around method. The expression for f_A is

$$f_A = \frac{\sum_{j=N_C+1}^{24*N_C} L_{0j} P_j}{\sum_{j=1}^{N_C} L_{0j} P_j} \tag{24}$$

Here, N_C is the number of mobiles in each of the 24 cells surrounding the reference cell. Also L_{0j} is the path loss from the jth mobile to the reference cell and $P_j$is the transmit power of jth mobile as found from the A matrix method. Table 2 shows average value of f_A obtained for N_C=18. It is seen from Table 2 that f_A is the least for the base station antenna displacement of MN = 3x2 cell shape. This result is the same as previously obtained for fully loaded cells [13].

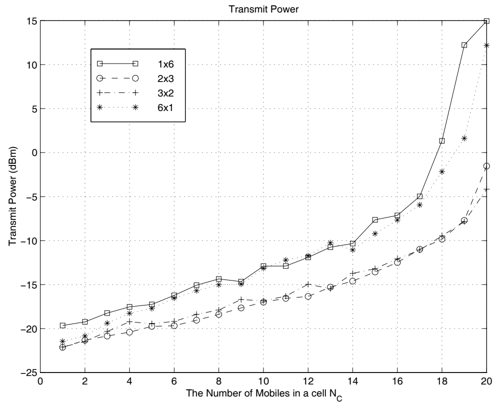
Table 2. Comparison of out-of-cell interference f_A

	$MxN=1x6$	$MxN=2x3$	$MxN=3x2$	$MxN=6x1$
f_A	2.1906	1.5610	1.4441	1.6747

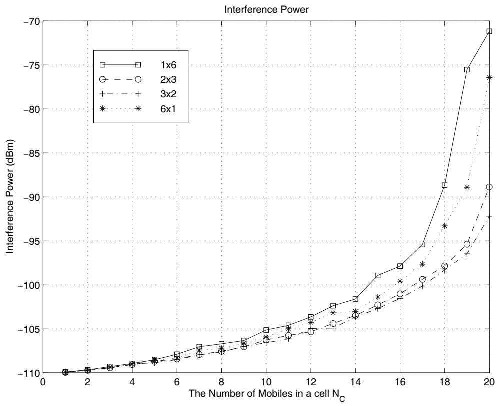
4.3 Transmitting and Interference

Different displacement of base station antennasfor the CDMA network result in different cell shapes that can be utilized to design for minimum transmitted power and minimum interference power. We compute and compare the average interference power and the average transmitted power for the different cell shapes. In this Monte-Carlo simulation, the transmit power and the interference power are obtained for many trials. The mean values of the transmit power and the interference power for 100 trials are shown in Figure 5 for each of the cell shapes having dimension MN = 6.

From the transmit power of Figure 5(a), the cell shapes 2x3 or 3x2 are seen to be more efficient than 1x6 or 6x1 because the lower transmit power implies an increases in battery life. The important factor determining the system capacity is the interference power not the transmit power. In terms of the mean interference power of Figure 5(b), there is little difference between 2x3 and 3x2 but 2x3 and 3x2 have much less interference than 1x6 and 6x1 for heavy loading (N_c large). Since CDMA systems are interference limited, more capacity is obtained using the 2x3 and 3x2 cell shape. Figure 5 shows that the mean transmit power and the mean interference power increase as the number of mobiles in a cell increases because the larger number of mobiles makes more interference. The number of mobiles allowed to communicate in a cell is limited by the single cell capacity which is calculated by considering only the mobiles in the reference cell.



(a) Transmit power



(b) Interference power

Fig. 5. Comparison of the transmit power and interference power for different cell shapes

Additional information is obtained by considering the cumulative distribution function (CDF) of the transmit power and the interference power, as shown in Figure 6 when the number of mobiles per cell N_C=15. Among the 4 cases for *MN*=6, the 2x3 cell shape has the lowest transmit power, but the 3x2 has the lowest interference among them. Thus the 3x2 shape has the greatest capacity among them.

4.4 Blocking probability

Since CDMA systems are interference limited, blocking occurs when the interference exceeds the maximum acceptable interference. To estimate the interference from the limited number of the sampled values for each trial, we assume that the interference has a normal distribution, as shown by the Gaussian fit lines *G(x)* in Figure 6(b). The Gaussian distribution is given by

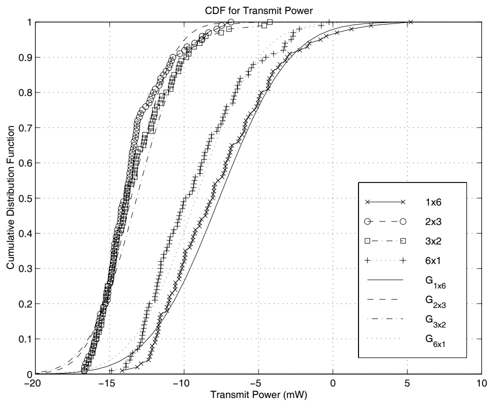
$$G\left(\frac{x-m_x(N_C)}{\sigma_x(N_C)}\right)=\begin{cases}\frac{1}{2}+\frac{1}{2}erf\left(\frac{x-\tilde{m}_x(N_C)}{\sqrt{2}\tilde{\sigma}_x(N_C)}\right) & for\ x\geq m_x\\ \frac{1}{2}-\frac{1}{2}erf\left(\frac{|x-\tilde{m}_x(N_C)|}{\sqrt{2}\tilde{\sigma}_x(N_C)}\right) & for\ x<m_x\end{cases}\qquad(25)$$

Here, *erf(.)* is error function and $\tilde{m}_x(N_C)$ and $\tilde{\sigma}_x(N_C)$ are the mean estimator and the standard deviation estimator for the number of mobiles per cell N_C respectively.

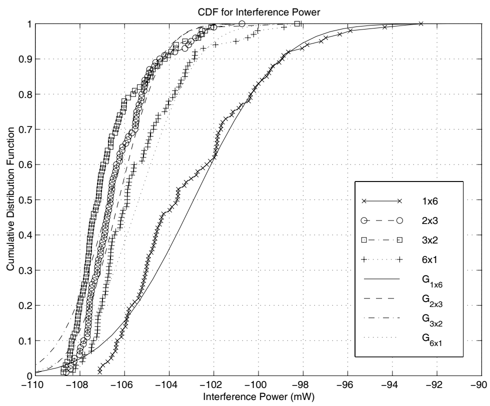
$$\tilde{m}_x(N_C)=\frac{1}{N_{trial}}\sum_{k=1}^{N_{total}}P_I(k)\qquad(26)$$

$$\tilde{\sigma}_x(N_C)=\sqrt{\frac{1}{N_{trial}}\sum_{k=1}^{N_{total}}\left(P_I(k)-m_x\right)^2}\qquad(27)$$

where, $P_I(k)$ is the interference power for *k*th trial.



(a) Transmit power



(b) Interference power

Fig. 6. Cumulative distribution function for transmit power and interference power for NC=15 based on 100 trials.

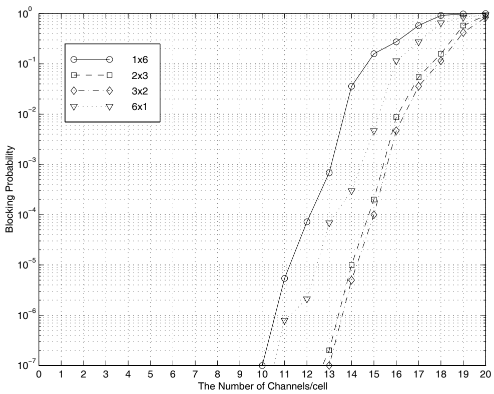


Fig. 7. Blocking probability as a funtion of the number of channels

The Gaussian CDF fit line in (25) is used to estimate the interference power, and from it the blocking probability under the criterion that blocking occurs when the total interference exceeds 10 times thermal noise [24]. We have assumed the thermal noise is –110 dBm, so that if the total interference exceeds –100 dBm, soft blocking occurs. From (25), the estimated blocking probability P_b is

$$P_b = 1 - G\left(\frac{x - \tilde{m}_x(N_C)}{\tilde{\sigma}_x(N_C)}\right)\Bigg|_{x=-100dBm} \qquad (28)$$

Figure 7 shows the blocking probability for various numbers N_c of mobiles in each cell. For the same number of mobiles in a cell, the blocking probability is seen in Figure 7 to be least for the 3x2 cell shape. Conversely, for a given blocking probability, the MN=3x2 cell shape allows the largest number of mobiles among the four possible cell shapes. This system simulation result is consistent with that of dependence of capacity on the cell shape found using the out-of-cell interference method [13].

V. Conclusions

In this study, we have carried out system simulations that give the transmit power, the interference power, and blocking probability of CDMA systems for different cell shapes. In order to reduce the computational complexity of the Mote-Carlo simulations, we used the wrap around approximation to include interference effects from second tier cells. The wrap around method has the same complexity as the method of considering the first tier only and almost same accuracy as full simulations that include the second tier. While the average transmit power for 1x6 and 6x1cell shape is about 15 dBm in the case of almost fully loaded cells, it is only –4 dBm for 3x2 cell shape. The higher transmit power causes more interference to all base stations, so that it reduces the system capacity. Thus, proper positioning of the base station antennas result in efficient cell shape that has advantages in terms of reducing the transmit power and the interference power. We have also investigated how the interference influences the cell blocking probability for different cell shapes, and which cell shape supports the least blocking probability. Through Monte-Carlo simulations we have shown that the proposed efficient cell shape is consistent with that previously found using the out-of-cell interference [13] for a uniformly loaded system, and that the cell capacity can be increased with less blocking probability by choosing an efficient cell shape.

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