On the Influences of Enlarging or Shrinking the Soft Handoff Coverage for a Cellular CDMA System*

TSANG-LING SHEU AND JAW-HUEI HOU+
Department of Electrical Engineering
National Sun Yat-Sen University
Kaohsiung, 804 Taiwan
E-mail: sheu@ee.nsysu.edu.tw
+*Department of Electronic Engineering*
Kao Yuan University
Kaohsiung, 821 Taiwan
E-mail: houjh@cc.kyu.edu.tw

This paper is concerned with the influences of enlarging or shrinking the soft handoff coverage on the new-call blocking and the handoff-call dropping probabilities in a cellular CDMA system. In the proposed analytic model, we assume a cell is in hexagonal shape with two parameters, *a* and *b*, representing the soft handoff region between the outer and the inner cell. In the traffic model, we assume mobile stations are uniformly distributed over the service area and the new-call generation rate per unit area is a Poisson process. Enlarging the soft handoff region may significantly increase the blocking and the dropping probabilities, while shrinking the soft handoff region can reduce the two probabilities slightly. The effect of activating a call admission control is also discussed. As new-call generation rate per unit area is small, reserving 40% of code channels for handoff calls can reduce the handoff-call dropping probability from 10^{-4} to 10^{-8}, while the new-call blocking probability is increased form 10^{-3} to 10^{-1}. Finally, the analytical model is compared with a previous work and a simulation is performed to validate the accuracy of our proposed model.

Keywords: cellular CDMA, soft handoff, cell coverage, blocking, dropping, Markov model

1. INTRODUCTION

Soft handoff is widely known to be a decisive feature in a CDMA-based cellular network. Soft handoff is processed by a *make-before-break* method to provide macro-diversity. For real-time traffic, a base station involved in soft-handoff communications permits handoff delay of no longer than the residual time in soft-handoff region. Soft handoff can increase system capacity because it can largely reduce interference by transmitting data signals at the minimum power level required by base stations (BSs) [1, 2]. Nevertheless, soft handoff may unexpectedly increase handoff traffic and it could hold a code channel unnecessarily longer than the traditional hard handoff.

In this paper, we propose an analytical model to study the impact of changing soft handoff coverage on the new call blocking and the handoff call dropping probabilities for

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a cellular CDMA system. In the work, a cell is in hexagonal shape with two parameters, *a* and *b*, representing the soft handoff region between the outer and the inner cell. Since these two parameters are tightly related to the thresholds of pilot signals, the adequate adjustment of the soft handoff region can improve system performance. The assumption of changeable soft handoff area makes our analytic model more realistic and more accurate. Additionally, since the new-call generation rate may be affected once the size of service area is changed, we investigate the new call blocking and the handoff call dropping probabilities by first enlarging and then shrinking the soft handoff region. To provide higher priority for handoff calls, the proposed model employs a call admission control to limit the percentage of new calls.

Previous works in soft handoff have been focused on the investigation of handoff delay versus cell coverage. Viterbi, *et al*. [1] demonstrated that soft handoff could result in a larger cell coverage area and a subsequent increase in reverse link capacity. By investigating channel resources of soft handoff in a limited field environment, Cho, *et al*. [3] proposed an analytical model for a DS-CDMA mobile system. Lee and Steel [4] analyzed the capacity loss on the forward link. They claimed that a small percentage of capacity loss might not adversely affect the overall system capacity, if the forward link capacity is higher than the reverse link capacity. In [5], Narrainen and Takawira proposed a traffic model for a DS-CDMA cellular network. In their scheme, the teletraffic behavior was investigated by taking into account CDMA soft capacity and soft handoff among cells. Kim and Sung [6] derived equations for handoff traffic and introduced a methodology to calculate the capacity increase due to soft handoff. However, their model assumed that cell coverage is square, which obviously simplifies the numerical analysis but it does not meet the realistic requirements of a cellular system. In [7], Kim proposed an algorithm of traffic management for multicode CDMA systems based on the same assumption that cell coverage is in square shape. Network capacity versus cell coverage was studied in [8]. Their analysis shows that there exists an explicit relationship between the cell coverage and the number of active users in the cell. This relationship may be useful for capacity planning, since the maximum amount of users admitted to a cell could be statistically determined. In [9], Avidor *et al*. investigated the effect of two control parameters, the soft handoff threshold and the maximum number of active base stations. Their results demonstrated that the outage probability could be largely increased as the soft handoff threshold is increased and the number of active base stations is decreased.

The rest of this paper is organized as follow. Section 2 describes the basic traffic model of soft handoff used to build the analytic model. In section 3, Markov models with and without call admission control are built to evaluate the average blocking probability of new calls and the average dropping probability of handoff calls. In section 4, we present the analytical results and compare the results with a previous work and a simulation. Finally, section 5 contains concluding remarks.

2. SOFT HANDOFF MODEL

2.1 Soft Handoff

The pilot signal strength of base station (BS) that a mobile station (MS) can detect is

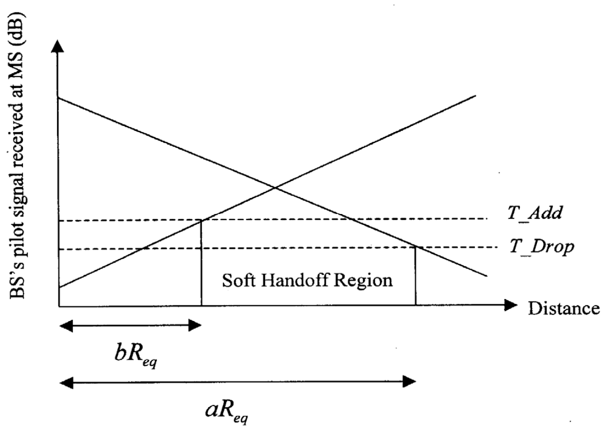


Fig. 1. Soft handoff model of a CDMA system.

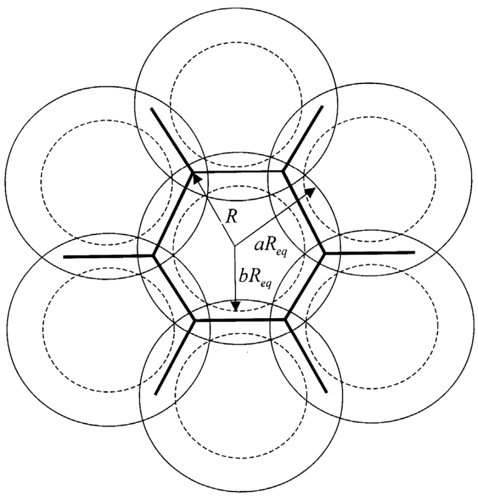


Fig. 2. The hexagonal cell structures and their soft handoff boundaries.

inversely proportional to the distance between MS and BS. When pilot signal from a new BS is stronger than a threshold value, *T_Add*, a new link to the new BS is established while the old link to the old BS is still maintained. As shown in Fig. 1, a call is said to be in its *soft handoff* in this situation. An MS in soft handoff can communicate with two BS through two strong pilot signals, respectively. In a normal operation, if a pilot signal from the third BS becomes stronger than either of the two existing pilot signals, a handoff may occur and the call will drop the weakest link, so that only two links are available in any given time interval. For simplify, in our model, we do not consider the handoff effect from the third pilot signal. When the pilot signal from either the old BS or the new BS becomes weak and drops below a threshold value, *T_Drop*, the bad connection is released. The hexagonal cell structure with soft handoff region for a mobile CDMA cellular system is shown in Fig. 2. In the figure, *R* is defined as the distance from the hexagon center to any vertex, and R_{eq} is defined as the equivalent radius of the hexagon cell. From [3], we know the equivalent radius can be derived as $R_{eq} = \sqrt{\frac{3\sqrt{3}}{2\pi}}R \approx 0.91R$. For convenience, the two thresholds of a pilot signal can be defined as a function of R_{eq}. That is, $T\_Drop = P_i - PL(aR_{eq})$ and $T\_Add = P_i - PL(\sqrt{3}R - bR_{eq})$, where $1 \le a \le 2$, $0 \le b \le 1$, P_i (in dBm) is the pilot signal transmitted from BS, and $PL(d)$ is a function of path loss with the distance d between MS and BS. Soft handoff region may vary as the two parameters, a and b, change. Throughout this paper, the circle with radius bR_{eq} is referred to as the inner cell. The circle with radius aR_{eq} is referred to as the outer cell, and the hexagonal cell with equivalent radius R_{eq} is referred to as the original cell.

The soft handoff rate is the frequency of soft handoff attempts that a call makes before the call terminates in the cellular system. The soft handoff rate can be determined by a number of factors, such as the size and the shape of a cell, the call density, and the moving speed of MS. Under the assumption that traffic is homogeneous and is in statistical equilibrium, the average handoff rate incoming to a cell is equal to the average handoff rate outgoing from the cell [10]. The derivation of the average outgoing handoff rate (λ) can be referred to Thomas's formula [11, 12]. Thus, we have

$$\lambda = \frac{\rho \bar{V} L}{\pi}, \tag{1}$$

where ρ, $\bar{V}$ and L, respectively, denote the call density per unit area, the average moving speed of MS, and the perimeter of the cell area.

2.2 Traffic Model

In the traffic model, we assume new call generations are uniformly distributed over the service area according to Poisson process with a mean rate per unit area (λ_a), *i.e.*, λ_a is defined as the average number of new call generations per second per unit area. Although mobile call generations, in realistic, may be non-uniformly distributed over a service area, and the speed and the direction of a mobile call may vary during its call interval, for simplicity, we make some assumptions for the sake of analytical tractability [10, 13, 14]. That is, the speed and the direction of mobile calls are uniformly distributed in the interval [0, $V_{\max}$], and in the interval [0, 2π], respectively. In addition, in our model, the speed and the direction of a generated mobile call will remain unchanged during its call interval. The call duration time varies with a random variable, T_{cd}, and it is assumed to be exponentially distributed with a mean $1/\mu_{cd}$. Thus, the probability density function of T_{cd} can be expressed as

$$f_{T_{cd}}(t) = \begin{cases} \mu_{cd} e^{-\mu_{cd} t}, & \text{if } t \ge 0 \\ 0, & \text{otherwise} \end{cases}. \tag{2}$$

2.3 System Capacity

In a cellular CDMA system, the call quality is proportional to the signal to interference ratio (*SIR*). *SIR* is directly affected by a number of factors, such as the system bandwidth, the code chip rate, the voice activity factor, *etc*. System capacity of a cellular CDMA system has been widely discussed in the previous literatures [1, 2, 8, 15]. In a cellular CDMA system, the signal to interference ratio of the *j*th user can be expressed as

$$(SIR)_j = \frac{\frac{S_j}{R_b}}{\sum_{i:i\neq j} \frac{v_i S_i}{W} + N_0 + I}, \tag{3}$$

where S_j is the power from the *j*th user received at BS, v_i is the voice activity factor of *i*th user, R_b denotes the information bit rate, W denotes the system bandwidth, N_0 is the background noise power spectral density and I is interference density of other cells. The transmitted power (in decibel) of the *j*th user can be expressed as

$$(S^*_{trans})_j = S^*_j + PL(d) + Z_j \tag{4}$$

where $S^*_j = 10\log S_j$, $PL(d)$ is the path loss at distance d from the BS and Z_j is a random variable represented by shadow fading. From [16], the path loss at distance d is modeled as

$$PL(d) = K_1 + K_2 \log d \tag{5}$$

where K_1 and K_2 is path loss constant. There are two situations for the outage to occur. One occurs when the received *SIR* at the BS is smaller than the required minimum *SIR*. The other occurs when the received *SIR* at the BS is greater than the required minimum *SIR* and the transmitting power of MS exceeds its maximum (S_{max}). The worst case occurs at the edge of a cell, *i.e.* $d = aR_{eq}$. Thus, referring to [8], the system capacity can be derived as a function of cell coverage under the maximum outage probability (p_m).

3. PERFORMANCE EVALUATION MODEL

3.1 System-Level Description

When a call is generated in a certain cell, the cell is referred to as the original cell, and the call is categorized as a new call. When the new call moves to the soft handoff region between the inner cell (with radius bR_{eq}) and the outer cell (with radius aR_{eq}), it may issue a handoff request to a new BS that is selected based on the strongest strength of pilot signals. If the selected new BS can offer a free channel to the mobile call, we say the handoff is successful. Within the soft handoff area, a successful handoff call can transmit data through either the old or the new BS. When this handoff call continues to pass through beyond the outer cell, the services from the old BS will be disconnected.

Based on section 2.3, we know the system capacity, C, can be determined if the distance of cell coverage, aR_{eq}, is given. In the model, we assume that the new call generation rate is a Poisson process with a mean, λ_n, and the channel holding time is exponentially distributed with a mean, $1/\mu_{ch}$. The performance metrics of our interests include the average blocking probabilities of new calls and the average dropping probabilities of handoff calls. A Markov model is then built to evaluate these two probabilities. A Markovian state, E_j, represents that there are exactly j code channels in use in a cell. Note that an admission control is activated if the number of occupied code channels exceeds a predefined threshold, C_{ac}. In other words, an arriving new call is blocked and only handoff calls are admitted if the number of unused code channels is smaller than $C - C_{ac}$.

3.2 Transition Probability of the Markov Model

Assuming that the channel distributions and the cell structures are all identical as shown in Fig. 3, the mean new-call generation rate per cell, λ_n, can be expressed as

$$\lambda_n = \lambda_a A_{or} = \lambda_a \pi R_{eq}^2, \tag{6}$$

where A_{or} is the area of original cell and λ_a is the new call generation rate per unit area.

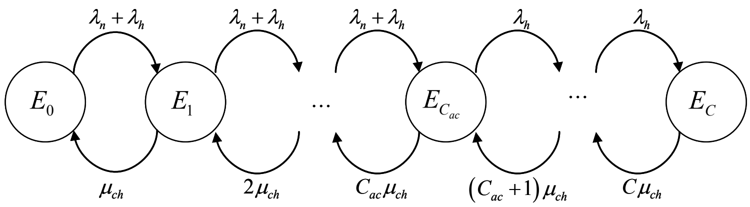


Fig. 3. State transition diagram of the Markov model.

Handoff attempts may occur in the following two cases. In the first case, we consider that mobile calls are generated only in the soft handoff region, where two neighboring cells have an overlapped area. Since we have assumed that new call generation rate is uniformly distributed over this overlapped area, only half of the new calls generated in one neighboring cell may issue handoff attempts to the other neighboring cell. Let the handoff attempt rate be denoted as λ_{h1}, we have

$$\lambda_{h1} = \frac{1}{2}\pi\lambda_a (a^2 - b^2) R_{eq}^2 (1 - P_B), \tag{7}$$

where P_B is the new call blocking probability. In the second case, we consider that mobile calls are generated within the inner cell. Handoff attempts can occur if the generated mobile calls are passing the inner cell boundary and entering the soft handoff region. This handoff attempt rate is denoted as λ_{h2}. Refer to Thomas's formula as shown in Eq. (1), we have $\lambda = \lambda_{h2}$, $L = 2\pi b R_{eq}$ and $\overline{V}$ is the average speed of mobile calls. Therefore, if the overall handoff attempt rate issued to the neighboring cells is denoted as λ_h, we have,

$$\lambda_h = \lambda_{h1} + \lambda_{h2}. \tag{8}$$

Since ρ is defined as the call density per unit area, it can be expressed as

$$\rho = \frac{(\lambda_{nc} + \lambda_{hc})}{\mu_{ch}} \times \frac{1}{A_{ot}}, \tag{9}$$

where λ_{nc} and λ_{hc} are, respectively, defined as the successful generation rate of new calls and the successful handoff attempt rate of handoff calls. They can be expressed as

$$\lambda_{nc} = \lambda_n \times (1 - P_B), \tag{10}$$

$$\lambda_{hc} = \lambda_h \times (1 - P_f), \tag{11}$$

where P_f is the failure probability of handoff attempts. The value of $1/\mu_{ch}$ denotes the mean channel holding time. The value of A_{ot} represents the area of outer cell and it is given by

$$A_{ot} = \pi(aR_{eq})^2. \tag{12}$$

When a mobile call is terminated within a cell or when it passes beyond the boundary of the outer cell, the occupied channel is released. Thus, the channel holding time, T_{ch}, is a random variable and can be expressed as

$$T_{ch} = \min(T_{cd}, T_{ot}), \tag{13}$$

where the two random variables, T_{cd} and T_{ot}, are denoted as the call duration time and the call residual time, respectively. Assume that T_{cd} and T_{ot} are exponentially distributed with two mean numbers, $1/\mu_{cd}$ and $1/\mu_{ot}$, respectively. The mean channel holding time can be obtained by [14]

$$\frac{1}{\mu_{ch}} = \frac{1}{\mu_{cd} + \mu_{ot}}. \tag{14}$$

Assuming that the call residual time is proportional to the radius of the outer cell, the mean call residual time ($1/\mu_{ot}$) within the outer cell is given by

$$\frac{1}{\mu_{ot}} = \frac{1}{\mu_{or}} \times a, \tag{15}$$

where $1/\mu_{or}$ represents the mean residual time in the original cell [14]. Thus, Eq. (14) becomes

$$\frac{1}{\mu_{ch}} = \frac{a}{(a\mu_{cd} + \mu_{or})}. \tag{16}$$

Since $1/\mu_{or}$ is inversely proportional to the speed of Mobile calls, without losing any generality, the mean residual time in the original cell can be expressed as

$$\frac{1}{\mu_{or}} = \frac{R_{eq}}{\overline{V}}. \tag{17}$$

When the number of occupied code channels is smaller than C_{ac}, no admission control is required for the system; the state transition probability from E_j to E_{j+1} ($j < C_{ac}$) is $\lambda_n + \lambda_h$. On the other hand, when the number of occupied code channels is larger than or equal to C_{ac}, an arriving new call will be blocked; the handoff call attempt rate becomes λ_h, and the state transition probability from E_j to E_{j+1} ($j \geq C_{ac}$) is λ_h. The analytic model is therefore divided into two cases: without and with admission control.

3.3 Without Admission Control

In this case, we assume there are C code channels in a cell and the number of occupied code channels is never greater than C. Let P_j be the steady state probability of the state E_j. P_j can be calculated as

$$P_j = \frac{1}{j!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^j \times P_0, \text{ where} \tag{18}$$

$$P_0 = \left[\sum_{k=0}^{C} \frac{1}{k!} \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^k \right]^{-1}. \tag{19}$$

If handoff calls do not posses higher priority than new calls, the blocking probability of new calls should be equal to the failure probability of handoff calls. Thus, the average blocking probability of new calls (P_B) and the average failure probability of handoff calls (P_f) are all equal to the probability that all the code channels are occupied (P_C). We have,

$$P_B = P_f = P_C = \frac{1}{C!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^C \times P_0. \tag{20}$$

If a handoff call can successfully pass the boundary of outer cell, it implies that the mobile call has obtained a code channel from a foreign cell and it has released the code channel originally assigned by the home cell. On the other hand, a handoff call will be dropped if the handoff attempt occurs at the boundary of outer cell but not any foreign cells can assign channels. Based on Eq. (1) and the average failure probability of handoff calls (P_f), we can derive the average dropping rate of handoff calls (λ_{hd}) as

$$\lambda_{hd} = \frac{\rho \overline{V} L_o}{\pi} \times P_f, \tag{21}$$

where L_o is the perimeter of outer cell. Finally, the average dropping probability of handoff calls (P_{hd}) is just the average dropping rate of handoff calls (λ_{hd}) divided by the overall handoff attempt rate (λ_h). We have,

$$P_{hd} = \frac{\lambda_{hd}}{\lambda_h} = \frac{\rho \overline{V} L_o}{\lambda_h \pi} \times \frac{1}{C!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^C \times P_0. \tag{22}$$

3.4 With Admission Control

When the number of occupied code channels exceeds C_{ac} ($C_{ac} < C$), any arriving new call will be blocked. The probability can be derived as

$$P_j = \begin{cases} \frac{1}{j!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^j \times P_0, & j \le C_{ac} \\ \frac{1}{j!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^j \times \left(\frac{\lambda_{h2}}{\lambda_n + \lambda_h} \right)^{j - C_{ac}} \times P_0, & C_{ac} < j \le C \end{cases}, \text{ where} \tag{23}$$

$$P_0 = \left[\sum_{k=0}^{C_{ac}} \frac{1}{k!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^k + \sum_{k=C_{ac}+1}^{C} \frac{1}{k!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^k \times \left(\frac{\lambda_{h2}}{\lambda_n + \lambda_h} \right)^{k - C_{ac}} \right]^{-1}. \tag{24}$$

The average blocking probability of new calls becomes

$$P_B = \sum_{j=C_{ac}}^{C} P_j = \sum_{j=C_{ac}}^{C} \frac{1}{j!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^j \times \left(\frac{\lambda_{h2}}{\lambda_n + \lambda_h} \right)^{j - C_{ac}} \times P_0, \tag{25}$$

and the average failure probability of handoff calls becomes

$$P_f = P_C = \frac{1}{C!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^C \times \left(\frac{\lambda_{h2}}{\lambda_n + \lambda_h} \right)^{C - C_{ac}} \times P_0. \tag{26}$$

Finally, the average dropping probability of handoff calls can be expressed as

$$P_{hd} = \frac{\rho \bar{V} L_o}{\lambda_h \pi} \times \frac{1}{C!} \times \left(\frac{\lambda_n + \lambda_h}{\mu_{ch}} \right)^C \times \left(\frac{\lambda_{h2}}{\lambda_n + \lambda_h} \right)^{C - C_{ac}} \times P_0. \tag{27}$$

4. ANALYTICAL RESULTS VERSUS SIMULATION

In this section, we present the analytical results based on the equations derived in section 3. A simulation model is given to validate the analytical results. The proposed model is compared to a previous work [7] under the same equivalent cell radius (R_{eq}). The parameters used in the evaluation and comparison are listed in Table 1.

4.1 Simulation Model

A 10 km × 10 km platform with each cell's equivalent radius being 0.8 km is assumed in the simulation. All the MSs are uniformly distributed in the platform with mean speed 30 km/hr and the moving direction is uniformly distributed during [0, 2π] without changing direction in the call duration. The new call generation rate in a unit area is

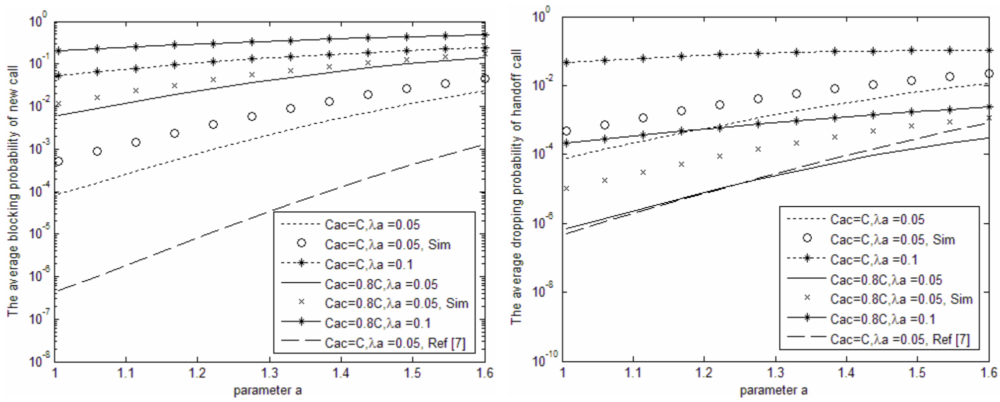
Table 1. Parameters used in the evaluation.

Parameters	Descriptions	Value
W	System bandwidth	1.25 MHz
R_b	Information bit rate	14.4 kb/s
v_i	Voice activity factor	0.45
K_1	Path-loss constant	17.3 dB
K_2	Path-loss constant	33.8 dB
p_m	Maximum of outage probability	0.05
$S_{\max}$	Maximum of mobile transmitting power	23 dBm
N_0	Thermal noise (PSD)	– 169 dBm/Hz
σ_z	Standard deviation of shadow fading	8 dB
m_ε	Medium *SIR*	7 dB
σ_ε	Standard deviation of *SIR*	2.5 dB

Poisson process. The call duration period is exponentially distributed with mean 120 sec. Other parameters used in the simulation are listed in Table 1. Similar to [17], by focusing on the central cell during 10-minute simulation time and taking the average after 100-time repetitions, we calculate the blocking number of new calls (N_B), the dropping number of handoff calls (N_D), the generating number of new calls (N_n), and the handoff-attempt number of handoff calls (N_h). Thus, the average blocking probability of new calls is equal to N_B/N_n, and the average dropping of handoff calls is equal to N_D/N_h.

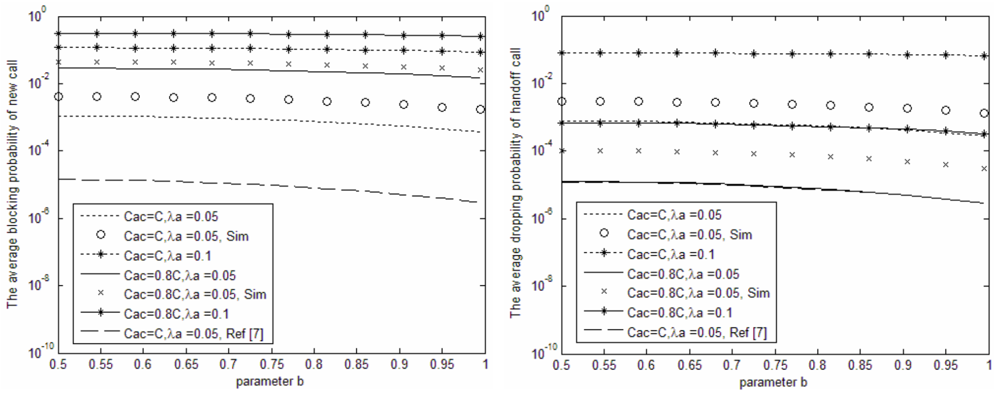
4.2 Varying the Soft Handoff Coverage

Fig. 4 (a) shows the average blocking probability of new calls (P_B), and Fig. 4 (b) shows the average dropping probability of handoff calls (P_{hd}). Here, we increase the parameter a from 1.0 to 1.6 and observe two different settings of the new call generation rate per unit area (*i.e.*, $\lambda_a = 0.05$ and 0.1). Let b be fixed to 0.8 and assume $\overline{V} = 30$ km/hr.



(a) (b)

Fig. 4. (a) Average blocking probability of new calls when a is varied and $b = 0.8$; (b) Average dropping probability of handoff calls when a is varied and $b = 0.8$.



(a) (b)

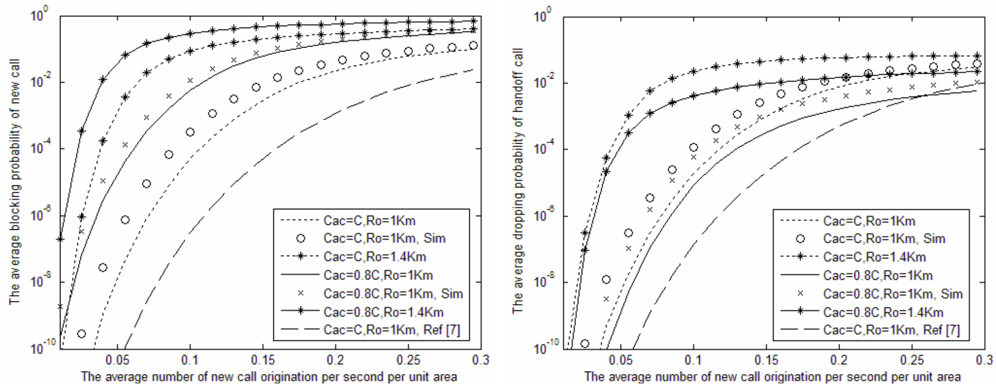
Fig. 5. (a) Average blocking probability of new calls when *b* is varied and *a* = 1.2; (b) Average dropping probability of handoff calls when *b* is varied and *a* = 1.2.

Since increasing the parameter *a* will enlarge the soft handoff area, the new call generation rate per cell (λ_n) is increased accordingly. As observed from these two figures, increasing λ_a slightly can significantly increase the average blocking probability of new calls (P_B) and the average dropping probability of handoff calls (P_{hd}). In addition, we observe that P_B and P_{hd} are all increased as the increase of the parameter *a*. Figs. 5 (a) and (b), respectively, show the variations of P_B and P_{hd}, when the parameter *b* is increased from 0.5 to 1.0. Here, we assume $a = 1.2$ and $\overline{V} = 30$ km/hr. Since increasing the parameter *b* can reduce the soft handoff area, the number of handoff attempts within that area becomes smaller. Consequently, both P_B and P_{hd} are slowly decreased as the increase of parameter *b*.

When a call admission control is activated (assuming $C_{ac} = 0.8C$), we know 20% of code channels will be reserved for handoff calls. From Figs. 4 and 5, we can easily observe that with admission control the average blocking probability of new calls is increased, as compared to the case when no admission control (*i.e.*, $C_{ac} = C$) is applied. On the contrary, the average dropping probability of handoff calls is significantly reduced when the call admission control is activated by reserving 20% of code channels for handoff calls.

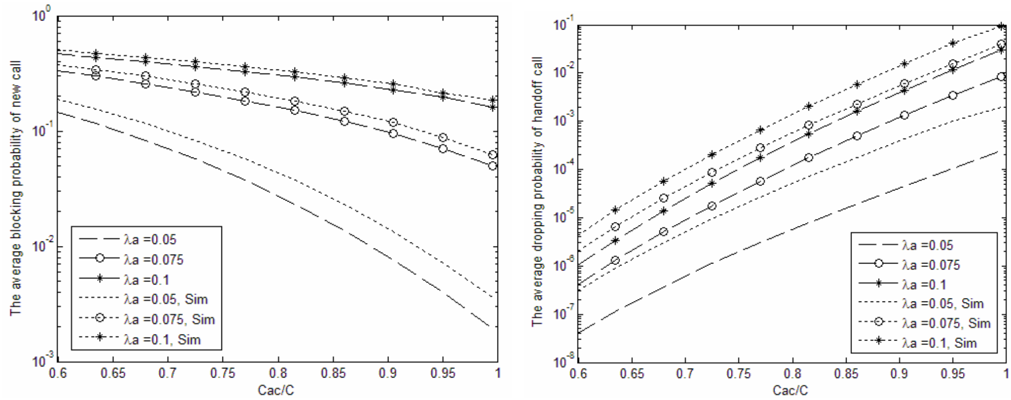
4.3 Varying the New-call Arrival Rates per Unit Area (λ_a)

Figs. 6 (a) and (b), respectively, show the variations of P_B and P_{hd}, as λ_a is varied between 0.01 and 0.3. We compare two different values of the outer cell radius, aR_{eq}, denoted as $R_o = 1$ km and 1.4 km, respectively in the figures. We also fix the parameter *b* to 0.8 and set $\overline{V} = 30$ km/hr. It is observed that as λ_a is increased, both P_B and P_{hd} are increased very quickly. Additionally, for the same value of λ_a, as the outer cell radius (R_o) is increased from 1 km to 1.4 km, the two probabilities are all increased. This is because increasing λ_a or increasing R_o can increase the number of mobile calls that contend for the code channels.



(a) (b)

Fig. 6. (a) Average blocking probability of new calls versus λ_a; (b) Average dropping probability of handoff calls versus λ_a.



(a) (b)

Fig. 7. (a) Average blocking probability of new calls versus C_{ac}/C; (b) Average dropping probability of handoff calls versus C_{ac}/C.

4.4 Varying the Number of Reserved Code Channels ($C - C_{ac}$)

In Figs. 7 (a) and (b), we discuss the impact of employing call admission control on the two probabilities under the same soft handoff coverage (a = 1.2 and b = 0.8). Note that in the figures we use the ratio of C_{ac}/C to represent the variations of code channels reserved for handoff calls. In other words, as C_{ac}/C increases, the number of code channels available to new calls is increased accordingly. Here, we observe three different new call generation rates per unit area (λ_a = 0.1, 0.075, and 0.05). As can be seen from Fig. 7, the average blocking probability of new calls is gradually decreased as C_{ac}/C increases. It is noticed that for a smaller λ_a the decrease of C_{ac}/C from 1.0 to 0.6 has brought significant reduction in the handoff-call dropping probability. Specifically, as λ_a = 0.05, by reserving 40% of code channels for handoff calls (C_{ac}/C = 0.6), the handoff-call dropping probability can be reduced from 10^{-4} to 10^{-8}, while the new-call blocking probability is increased form 10^{-3} to 10^{-1}.

4.5 Comparing with a Previous Work

From Figs. 4 to 7, we can observe that both probabilities (blocking and dropping) calculated from the model in [7] exhibits relatively smaller than the results calculated from our model. This is because when we fix R_{eq} = 0.8 km in both models, the area of square cell assumed in their model is smaller than the area of hexagonal cell assumed in our model. Therefore, the new call generation rate per unit area (λ_a) in [7] is smaller than that in our model. The larger λ_a in our model makes the two probabilities become larger. Nevertheless, as can be observed from Figs. 4 to 7, the results calculated from our model are much closer to the simulation results. This phenomenon demonstrates that our model is more accurate than [7].

4.6 Analytic Results versus Simulation

Finally, we observe that the curves of the two probabilities from simulation exhibits relatively higher than those curves calculated from the analytic model. In the simulation model, we assumed a 10 km × 10 km platform with each cell's equivalent radius being 0.8 km, which generates about 50 cells. The interference on the center cell which we observed in the simulation is much larger than that on the rest of cells. Consequently, the system capacity from simulation model becomes smaller than that from the analytic model. A smaller system capacity naturally leads to larger blocking and dropping probabilities.

Meanwhile, as the system load in terms of the new call generation rate per unit area (λ_a) is increased, the interference becomes stronger in the simulation model. Hence, we can observe that as λ_a is increased, the difference of blocking probability (and dropping probability as well), as shown in Figs. 6 (a) and (b), between the simulation model and the analytic model becomes bigger. Note that the difference seems to getting smaller in the case of heavy traffic load (*i.e.*, λ_a = 0.25 and 0.3). This is because Figs. 6 (a) and (b) were plotted in logarithmic scale rather than in linear scale.

5. CONCLUSIONS

In this paper, we have presented an analytic model to study the impact of changing soft handoff coverage on the blocking and the dropping probabilities for a cellular CDMA system. In the model, we assume a cell is in hexagonal shape with two parameters (*a* and *b*) representing the soft handoff region between the outer and the inner cell. The analytic model was built with Markov chains and Thomas's formula. By either enlarging or shrinking the soft handoff coverage, we investigated the new-call blocking (P_B) and the handoff-call dropping probabilities (P_{hd}) under different new-call generation rates per unit area (λ_a). Additionally, to provide higher priority for handoff calls, the proposed model is embedded a call admission control by limiting the percentage of new calls that can be admitted to the system.

The proposed model has made some contributions in analyzing the soft handoff coverage. First, we observe that P_B is indeed increased more quickly than P_{hd} as the increase of parameter a. Second, increasing parameter b can reduce the number of handoff attempts within that area. Consequently, both P_B and P_{hd} are slowly decreased as the increase of b. Third, by activating a call admission control, it is noticed that for a smaller λ_a the decrease of C_{ac}/C from 1.0 to 0.6 has brought significant reduction in P_{hd}. Finally, the proposed model was compared with a previous work and a simulation was performed. The simulation results not only validated the analytical results, but also demonstrated that our model is more accurate than the previous work.

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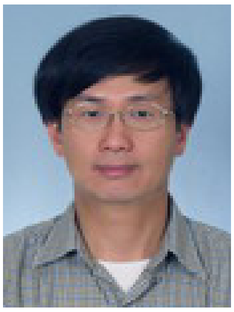

Tsang-Ling Sheu (許蒼嶺) received the Ph.D. degree in Computer Engineering from the Department of Electrical and Computer Engineering, Penn State University, University Park, Pennsylvania, U.S.A., in 1989. From Sept. 1989 to July 1995, he worked with IBM Corporation at Research Triangle Park, North Carolina, U.S.A. In Aug. 1995, he became an associate professor and was promoted to full professor in Jan. 2006, at the Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan. His research interests include wireless mobile networks and multimedia networking. He was the recipient of the 1990 IBM Outstanding Paper Award. Dr. Sheu is a member of the IEEE, and the IEEE Communications Society.

Jaw-Huei Hou (侯兆徽) received the B.S. degree in Electronic Engineering from Fu Jen Catholic University, Taipei, Taiwan in 1979, and the M.S. degree in Electrical Engineering from National Chung Cheng University, Chiayi, Taiwan, in 1981. He is currently working toward his Ph.D. degree at the Department of Electrical Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan. His current research interests include the design and analysis of personal and wireless communication networks, CDMA code scheduling, and performance modeling.