No. 865

Call Loss Probabilities in CDMA Cellular Mobile Communication Networks

by

Minoru OHMIKAWA and Hideaki TAKAGI

May 2000

Call Loss Probabilities in CDMA Cellular Mobile Communication Networks

Minoru OHMIKAWA and Hideaki TAKAGI
Institute of Policy and Planning Sciences, University of Tsukuba
1-1-1 Tennoudai, Tsukuba-shi, Ibaraki 305-8573, Japan

Abstract

We propose an analytic traffic model for CDMA cellular mobile communication networks in which the number of available channels for each cell depends on the number of conversations in progress in neighboring cells. We assume that mobiles move probabilistically across cell boundaries. The transition of state for the number of calls in each cell then forms a birth-and-death process. The generation rates of hand-over calls are determined numerically by other traffic parameters. We evaluate the probabilities of call loss, forced termination and call completion, and compare with those for FDMA networks in which the number of available channels is fixed. We have observed that the capacity of CDMA scheme is larger than that of FDMA. Our analysis results agree with those by simulation.

Keywords: Cellular mobile communication, CDMA, FDMA, hand-over, traffic analysis, loss probability, forced termination

1 Introduction

The code division multiple access (CDMA) scheme has drawn much attention among the next generation cellular phone systems. The CDMA is one of the basic multiple access schemes. It is generally said that CDMA is better than the existing frequency division multiple access (FDMA) and the time division multiple access (TDMA) in terms of quality of communication and rate of transmission under given radio propagation condition. The CDMA technique was developed in military communications due to its security and anti-jamming capability. So far the technique has been mainly used in satellite communications and in wireless LANs.

The CDMA scheme developed by QUALCOMM Incorporated was standardized as IS–95 in the U.S. in 1993. Thereafter CDMA was formally applied to cellular phone systems. The practical services of cdmaOne with IS–95 began in Hong Kong and in Korea. In Japan the DDI Cellular group and IDO Corporation started 'cdmaOne' service in July 1998. However there occur some difficulties in applying CDMA to commercial systems. Examples are the power control in the near-far effect and the hidden terminal problem owing to the straight propagation property of high frequency electromagnetic wave [1].

We evaluate the probabilities of call loss, forced termination and call completion for CDMA cellular mobile communication networks. Several Markovian models have been proposed for traffic characteristics in FDMA cellular mobile communication networks. In [2], the hand-over rate is computed from the probabilistic analysis of the movement of a mobile, and the loss probability is calculated for the models in which hand-over calls have priority over new calls in channel access and they can wait in the hand-over area. In [3], it is shown that the channel usage time in a cell has exponential distribution by analysis and simulation. These and other studies [4]–[6] are based on the assumption that all cells are statistically identical. A hierarchical model is given in [7], but the movement of users from cell to cell is not considered. Surveys of traffic models of cellular networks are given in [8]–[10]. Queueing network models are proposed in [11] and [12]. In [13], analysis and simulation for probabilities of call loss and forced termination are shown for the models in which hand-over calls probabilistically move between two cells. In [14], the performance is compared with respect to the size of a hand-over area in CDMA cellular mobile communication network in which the soft hand-over is taken into account.

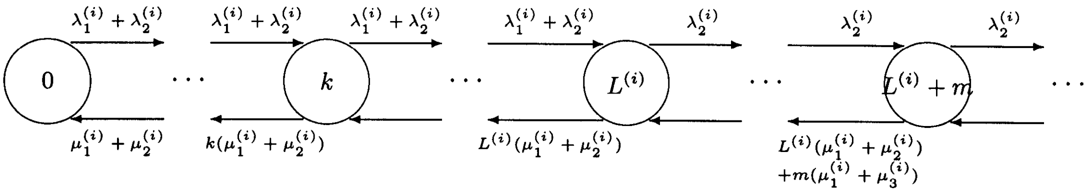


Figure 1: State transition rate diagram for cell i.

In the past study by the authors' group, the hand-over rate is approximately calculated through the solution to a set of nonlinear equations given other parameters for FDMA cellular communication networks with arbitrary traffic load. The network is composed of cells to which are allocated a fixed number of channels in advance. The performance evaluation for the entire network is conducted by matching the hand-over rate that is approximately calculated. In this paper, we conduct the performance evaluation for the entire network with CDMA in which the number of available channels in each cell depends on the number of ongoing calls in the neighboring cells.

In order to precisely evaluate the performance of a network that is composed of multiple cells, we may consider a multi-dimensional Markovian process model in which the state is the number of calls for every cell in the network. However, the more cells the network has, the more difficult it becomes to calculate the performance. In [15], a one-dimensional Markovian process is considered in which the state is the number of calls for each cell. A method is presented in which the multi-dimensional Markovian process is reduced to a set of one-dimensional Markovian processes by assuming that the movement of hand-over calls simply forms a Poisson process. In this paper we present a similar entire network model which consists of one-dimensional Markovian process models for individual cells.

The rest of this paper is organized as follows. In Section **2**, we give a traffic model for a CDMA cellular communication network. In Section **3**, we present a method of evaluating probabilities of call loss. In Section **4**, we numerically calculate and simulate performance measures for two concrete network examples and compare with those for the FDMA cellular network. We conclude in Section **5** with a summary of the present study.

2 TRAFFIC MODEL

In this section, we present our traffic model for each cell of which a network consists, and show an algorithm to calculate the hand-over rate.

2.1 Traffic model for each cell

Assume that there are N cells in the network. Calls are placed in cell i when new calls are placed in cell i and hand-over calls enter cell i from adjacent cells. We assume that they are placed in a Poisson process at rate $\lambda_1^{(i)}$ and $\lambda_2^{(i)}$, respectively. The call holding time and the residence time of a call in cell i are exponentially distributed with rate $\mu_1^{(i)}$ and $\mu_2^{(i)}$, respectively [3]. We assume that hand-over calls can wait for a new channel from the cell that they are entering by continuing to use the channel of the cell that they are leaving while they reside in the boundary of the two cells called a hand-over area. The residence time of a call in a hand-over area is also exponentially distributed with rate $\mu_3^{(i)}$.

Now, according to a model for the number of channels in CDMA [8], the maximum number $L^{(i)}$ of the available channels in cell i is given by

$$L^{(i)} = C - \sum_{j=1}^{N} \bar{L}^{(j)} \kappa_{ji} \tag{1}$$

where C is the initial number of channels given to each cell, $\bar{L}^{(j)}$ is the average number of ongoing calls in cell j, and κ_{ji} is the interference factor between cell j and cell i ($\kappa_{ji} \equiv 0$ in the case of FDMA). We should note that C is also the number of channels available in the entire system due to the availability of the same bandwidth for all cells in CDMA. Though the number of ongoing calls at a point in time chosen at random is a random variable [8], we simplify the model by assuming that the effect from adjacent cells is represented by the average number of ongoing calls in the cells to enable numerical calculation. In practice, κ_{ji} is a random variable depending on the propagation loss between cells, the variation of power control in up- and down-link, the position of a handset, and so on [16]. However, we here assume that κ_{ji} is constant as in [8] for simplicity (the same assumption is made in [17] and [18]).

If the number of ongoing calls in cell i is less than $L^{(i)}$, both a new call and a hand-over call are allocated a channel at the arrival time. If it is more than or equal to $L^{(i)}$, a new call is blocked and a hand-over call waits for an available channel in cell i while it resides in the hand-over area. In the meantime the hand-over call is actually continuing to use a channel of the previous cell. If such a call passes the hand-over area before it obtains a channel from the new cell, it is forcibly terminated.

Based on the above assumption, we find that the state transition for each cell forms a one-dimensional birth-and-death process. The state transition diagram for this process is shown in Figure 1. If we denote by $P(k)^{(i)}$ the steady-state probability that there are k calls in progress in cell i, a set of local balance equations is given by

$$\begin{cases} k(\mu_1^{(i)} + \mu_2^{(i)})P(k)^{(i)} = (\lambda_1^{(i)} + \lambda_2^{(i)})P(k-1)^{(i)} & 1 \leq k \leq L^{(i)} \\ \lambda_2^{(i)} P(k-1)^{(i)} = [L^{(i)}(\mu_1^{(i)} + \mu_2^{(i)}) + (k - L^{(i)})(\mu_1^{(i)} + \mu_3^{(i)})]P(k)^{(i)} & k > L^{(i)} \end{cases} \tag{2}$$

The solution to these equations is given by

$$P(k)^{(i)} = \begin{cases} \left(\frac{\lambda_1^{(i)}+\lambda_2^{(i)}}{\mu_1^{(i)}+\mu_2^{(i)}}\right)^k \frac{1}{k!} P(0)^{(i)} & 1 \leq k \leq L^{(i)} \\ \frac{P(0)^{(i)}(\lambda_1^{(i)}+\lambda_2^{(i)})^{L^{(i)}}}{L^{(i)}!(\mu_1^{(i)}+\mu_2^{(i)})^{L^{(i)}}} \frac{(\lambda_2^{(i)})^{k-L^{(i)}}}{\prod_{m=1}^{k-L^{(i)}} [L^{(i)}(\mu_1^{(i)}+\mu_2^{(i)})+m(\mu_1^{(i)}+\mu_3^{(i)})]} & k > L^{(i)} \end{cases} \tag{3}$$

where $P(0)^{(i)}$ is determined from the normalization condition $\sum_{k=0}^{\infty} P(k)^{(i)} = 1$.

2.2 Algorithm for calculating the hand-over generation rates

Note that the rate $\lambda_2^{(i)^*}$ of hand-over calls going out of cell i clearly depends on other parameters of the traffic model for each cell. If the number k of calls in cell i is less than or equal to $L^{(i)}$, the number of hand-over calls going out of cell i per unit time is $k\mu_2^{(i)}$. If it is more than $L^{(i)}$, the number of hand-over calls going out of cell i per unit time is $L^{(i)}\mu_2^{(i)}$, because cell i accommodates at most $L^{(i)}$ calls and $k - L^{(i)}$ calls use the adjacent cells' channels. That is, when there are k calls in cell i, $\min(k, L^{(i)})\mu_2^{(i)}$ calls go out the cell per unit time. Hence, we have

$$\lambda_2^{(i)^*} = \sum_{k=0}^{\infty} P(k)^{(i)} \min(k, L^{(i)})\mu_2^{(i)} \tag{4}$$

In addition, we assume that a call from cell i moves to cell j with probability γ_{ij}, and that the call is then placed in cell j as a hand-over call. If the call moves outside the service area with probability γ_{ie}, the following relation is held :

$$\sum_{j=1}^{N} \gamma_{ij} + \gamma_{ie} = 1, \quad \gamma_{ii} = 0 \quad 1 \le i \le N \tag{5}$$

In view of the above argument, we employ the fixed-point method to determine the value of the hand-over generation rate $\lambda_2^{(i)}$ for cell i by the following procedure in which each step is executed for all i :

1. Let $\lambda_2^{(i)} = 0$, $\bar{L}^{(i)} = 0$, and $L^{(i)} = C$ as initial values.

2. Compute $L^{(i)}$ by equation (1).

3. Compute $P(k)^{(i)}; k = 0, 1, 2, \cdots$ by equation (3).

4. Compute

$$\bar{L}^{(i)} = \sum_{k=1}^{\infty} kP(k)^{(i)} \tag{6}$$

5. Compute $\lambda_2^{(i)^*}$ by equation (4).

6. Compute

$$\lambda_2^{(i)} = \sum_{j=1}^{N} \lambda_2^{(j)^*} \gamma_{ji} \tag{7}$$

7. Repeat steps 2–6 until $\lambda_2^{(i)}$ converges.

Note that the rates $\lambda_2^{(j)}$ for all adjacent cells of cell i must converge at the same time in order that the iteration for the rate $\lambda_2^{(i)}$ converges. At present, this convergence has not been proved mathematically, but it has been obtained as a result of numerical computation.

3 PERFORMANCE EVALUATION

In this section, we show a method of evaluating the performance measures such as call loss probability, forced termination probability, and call completion probability, for homogeneous as well as non-homogeneous cells of which a network is composed.

3.1 Performance measures for each cell

We first consider the probability $Pb^{(i)}$ that a new call generated in cell i is blocked, and the probability $Ph^{(i)}$ that a hand-over call entering cell i is terminated. According to the Poisson Arrivals See Time Averages (PASTA) property because of the assumption that new calls and hand-over calls are placed as Poisson processes, we can regard the probability of the steady state of the cell as the probability of the cell state just before a call generation in equations (8) and (9).

Recall that a new call in cell i is blocked if there are $L^{(i)}$ or more calls in cell i when it is placed in that cell. Thus

$$Pb^{(i)} = \sum_{k=L^{(i)}}^{\infty} P(k)^{(i)} \tag{8}$$

The probability $Ph^{(i)}$ is the fraction of the hand-over calls that cannot get a channel of cell i before going out of the hand-over area over all the hand-over calls entering cell i. Therefore

$$Ph^{(i)} = \sum_{k=L^{(i)}+1}^{\infty} \frac{P(k)^{(i)}(k - L^{(i)})\mu_3^{(i)}}{\lambda_2^{(i)}} \tag{9}$$

3.2 Performance measures for the entire network

3.2.1 Identical treatment of all cells in a network

Consider the case in which hand-over calls never go out of the service area. If the probability of the steady state and the parameters are identical for every cell, we can equally handle all the cells in the network. Recall that the number of available channels depends on the number of ongoing calls in adjacent cells for CDMA. Hence, the model is limited for hand-over calls not going out of the service area. We cannot equally handle the cells if the number of adjacent cells is different even if the probability of the state is equal for each cell, i.e., the average number of ongoing calls is equal for each cell.

Since we handle each cell equally, the probability Pb that a new call is blocked in the entire network is equal to the probability $Pb^{(i)}$.

$$Pb = Pb^{(i)} \tag{10}$$

A call that has started with probability $(1 - Pb)$ in some cell completes in that cell with probability $\mu_1/(\mu_1 + \mu_2)$, or moves to an adjacent cell by hand-over with probability $\mu_2/(\mu_1 + \mu_2)$. Then the hand-over fails with probability $Ph = Ph^{(i)}$, or succeeds with probability $(1 - Ph)$.

Hence, a call passes through k cells without forced termination and it is terminated in the $k + 1$st cell with probability $(1 - Pb)[\{\mu_2/(\mu_1 + \mu_2)\}(1 - Ph)]^k \cdot \mu_2/(\mu_1 + \mu_2) \cdot Ph$. The probability that the call completes in the $k + 1$st cell is $(1 - Pb)[\{\mu_2/(\mu_1 + \mu_2)\}(1 - Ph)]^k \cdot \mu_1/(\mu_1 + \mu_2)$. Summing up over all k, the probability Pf that a hand-over call is forcibly terminated and the probability Pc that a call completes are respectively given by

$$Pf = (1 - Pb) \sum_{k=0}^{\infty} \left[\frac{\mu_2}{\mu_1 + \mu_2}(1 - Ph) \right]^k \frac{\mu_2}{\mu_1 + \mu_2} Ph = \frac{(1 - Pb)\mu_2 Ph}{\mu_1 + \mu_2 Ph} \tag{11}$$

$$Pc = (1 - Pb) \sum_{k=0}^{\infty} \left[\frac{\mu_2}{\mu_1 + \mu_2}(1 - Ph) \right]^k \frac{\mu_1}{\mu_1 + \mu_2} = \frac{(1 - Pb)\mu_1}{\mu_1 + \mu_2 Ph} = 1 - Pb - Pf \tag{12}$$

3.2.2 Different treatment of cells in a network

Let us now calculate the probabilities Pb, Pf, and Pc for a general network in which the parameters and the probabilities are different for each cell.

A call that has started in cell i with probability $(1 - Pb^{(i)})$ successfully completes in that cell with probability $\mu_1^{(i)}/(\mu_1^{(i)} + \mu_2^{(i)})$, or moves to adjacent cell j by hand-over with probability $\mu_2^{(i)}/(\mu_1^{(i)} + \mu_2^{(i)}) \cdot \gamma_{ij}$, or goes out of the service area with probability $\mu_2^{(i)}/(\mu_1^{(i)} + \mu_2^{(i)}) \cdot \gamma_{ie}$. The hand-over procedure by which the call enters cell j fails with probability $Ph^{(j)}$, or succeeds with probability $(1 - Ph^{(j)})$. Therefore, a call that has started in cell i successfully completes in that cell with the probability $P_e^{(i)}$, and the hand-over procedure from cell i to cell j succeeds with probability $P_j^{(i)}$, where

$$P_e^{(i)} = \frac{\mu_1^{(i)}}{\mu_1^{(i)} + \mu_2^{(i)}} \tag{13}$$

$$P_j^{(i)} = \frac{\mu_2^{(i)}}{\mu_1^{(i)} + \mu_2^{(i)}} \gamma_{ij}(1 - Ph^{(j)}) \tag{14}$$

Moreover, the probability π_i that a call which has started in cell i successfully completes somewhere in the network satisfies the following recursive equation

$$\pi_i = P_e^{(i)} + \sum_{j=1}^{N} P_j^{(i)} \pi_j \tag{15}$$

On the other hand a call which has started in cell i is forcibly terminated with probability $(1-\pi_i)$. Thus we present the following three probabilities of a call destiny.

call loss probability	$Pb^{(i)}$
forced termination probability	$(1-Pb^{(i)})(1-\pi_i)$
successful completion probability	$(1-Pb^{(i)})\pi_i$

Taking the average of the call loss probability with the weight of the new call generation rate in each cell, we obtain

$$Pb = \sum_{i=1}^{N} \frac{\lambda_1^{(i)}}{\Lambda_1} Pb^{(i)} \tag{16}$$

where $\Lambda_1 = \sum_{i=1}^{N} \lambda_1^{(i)}$ is the generation rate of new calls in the entire network. Similarly, we can obtain the average of the forced termination probability and the successful completion probability of a call with the same weight as follows :

$$Pf = \sum_{i=1}^{N} \frac{\lambda_1^{(i)}}{\Lambda_1}(1-Pb^{(i)})(1-\pi_i) \tag{17}$$

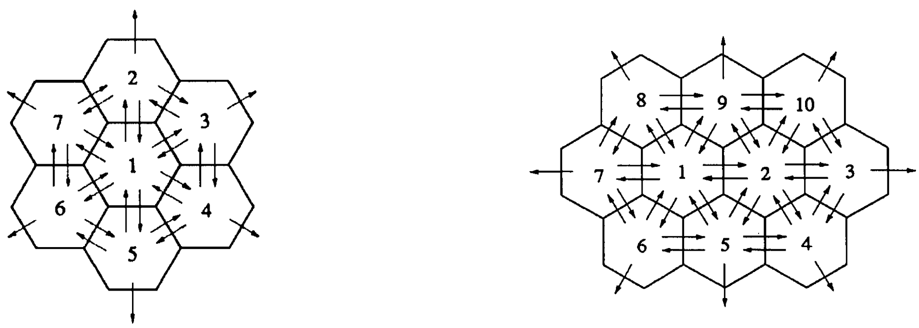
$$Pc = \sum_{i=1}^{N} \frac{\lambda_1^{(i)}}{\Lambda_1}(1-Pb^{(i)})\pi_i = 1 - Pb - Pf \tag{18}$$

If we consider the special case of identical treatment of all cells in the entire network in these equations, they reduce to the equations (11) and (12) in **3.2.1**.

4 NUMERICAL ANALYSIS

In this section, we compare the performance of CDMA with that of FDMA by using both analytic and simulation models for two simple networks.

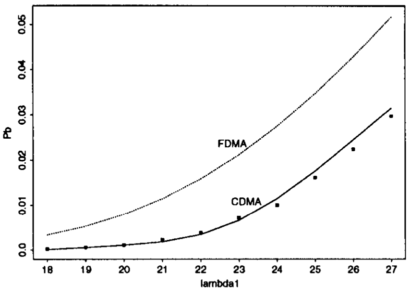
4.1 Network models



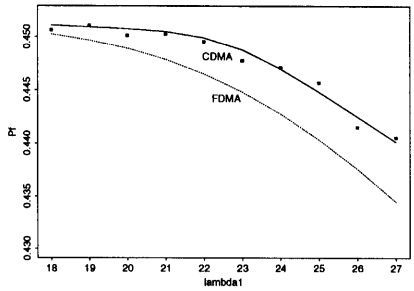
(a) Model 1 (b) Model 2

Figure 2: Models of cellular networks.

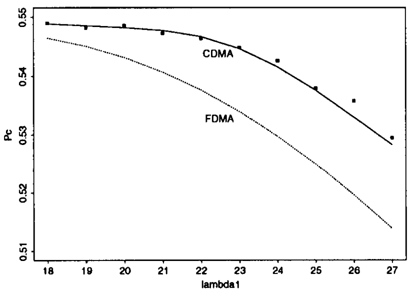
We have considered two network models that are covered with hexagonal cells as shown in Figure 2 in order to calculate the performance numerically.



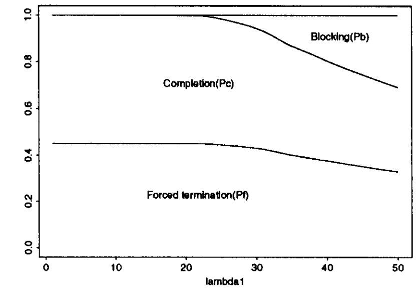
(a) Probability of call loss, Pb



(b) Probability of forced termination, Pf



(c) Probability of call completion, Pc



(d) Probabilities of the call destinies (CDMA)

Figure 3: Performance of model 1 (· :simulation).

Model 1 in Figure 2(a) is a network in which a part of calls may go out of the service area. We assume that calls that go out of the service area are always terminated. By this model, we have reflected the situation near the boundary of the service area. We assume in this model that each cell is statistically identical and the movement of handsets is homogeneous in direction. For example, a call goes out of cell 2 as a hand-over call to cell 1, 3, 7 with probability 1/6, respectively, or out of the service area to be terminated with probability 1/2.

Model 2 in Figure 2(b) is a network with an irregular topology. Calls going outside the service area are forcibly terminated. We assume that traffic parameters for each cell are different as given in Table 1. The different values for $\mu_2^{(i)}$ imply the different sizes of cells. We also assume that the movement of handsets may not be homogeneous in direction as given in Table 2. By this model, we verify that our analytic model can be applied to the service area with an arbitrary topology and an arbitrary set of parameters.

4.2 Conditions for comparison between CDMA and FDMA

In the radio frequency usage in Japan, the carrier band of 1.25 MHz is needed for a CDMA channel (in cdmaOne) and that of 6.25 kHz is needed for an FDMA channel (in analog cellular phone). Thus a CDMA channel uses two hundred times as broad as an FDMA channel does. But the channel capacity for FDMA scheme is not necessarily two hundred times as large as that for CDMA scheme. Although the same frequency cannot be used in adjacent cells for FDMA, the same frequency is reused over all cells for CDMA. For example, in a seven-cell reuse system in which each cell is initially given 20 channels, the FDMA system must contain $20 \times 7 = 140$ channels. On the other hand ,the CDMA system just contains 20 channels over the entire system.

Also, for CDMA we have to take account of the reduction of the number of available channels by the interferences in adjacent cells. Assume that the initial number of channels in a cell is chosen such that 20 channels are available in the cell when each adjacent cell has 20 ongoing calls. Then the initial number of channels in the entire system is 20×1.6=32, where the factor 1.6 comes from the assumption that the inter-cell interference factor is κ_{ji}=0.1 and that each cell is surrounded by six cells [8], [17]. In comparison of the bandwidth, the 140×6.25 kHz=8.75 kHz band is used in the FDMA system, while the 1.25 MHz band is used in the CDMA system.

4.3 Performance of model 1

Table 1: Parameters for model 2.

Cell i	1	2	3	4	5	6	7	8	9	10
$\lambda_1^{(i)}/\lambda_1^{(1)}$	1	1	2/3	1/2	2/3	2/3	3/4	1/2	3/4	2/3
$\mu_1^{(i)}$	1	1	1	1	1	1	1	1	1	1
$\mu_2^{(i)}$	2	2	1	1	1	1	1	1	1	1
$\mu_3^{(i)}$	10	10	10	10	10	10	10	10	10	10

Table 2: Matrix of probabilities for the movement of mobiles.

$i\backslash j$	1	2	3	4	5	6	7	8	9	10	e
1	0	1/4	0	0	1/6	1/6	1/6	1/12	1/6	0	0
2	1/2	0	1/6	1/12	1/12	0	0	0	1/12	1/12	0
3	0	1/2	0	1/3	0	0	0	0	0	1/12	1/12
4	0	1/3	1/12	0	1/2	0	0	0	0	0	1/12
5	1/3	1/3	0	1/12	0	1/12	0	0	0	0	1/6
6	1/3	0	0	0	1/4	0	1/4	0	0	0	1/6
7	1/2	0	0	0	0	1/4	0	1/6	0	0	1/12
8	1/4	0	0	0	0	0	1/3	0	1/4	0	1/6
9	1/3	1/5	0	0	0	0	0	2/15	0	2/15	1/5
10	0	1/3	1/4	0	0	0	0	0	1/4	0	1/6

Model 1 in which parameters for each cell are identical and calls can go outside the service area appears in Figure 2(a). In this model, we use numerical values $\mu_1 = 1$, $\mu_2 = 2$, and $\mu_3 = 10$. These parameters correspond to the situation where the mean duration of a call is 1 minute, handsets are on the cars that pass microcells of radius 250 m with the speed of 60 km/h, and the radius of the hand-over area is 25 m. It is assumed here that the movement and the interference from the first tier, i.e., only the adjacent cells, are considered. Those from the second and higher order tiers are neglected, that is, $\gamma_{ji} = 0$ and $\kappa_{ji} = 0$ for $j \neq i$. We assume that the maximum value of the state k is 50, that is, 50 calls can exist in a cell including those in the hand-over area. We conduct numerical computations by varying the call generation rate λ_1. We compare the performance of the CDMA system with that of the FDMA system under the condition that each cell first gets 32 channels for CDMA, and 20 channels for FDMA.

We have also conducted simulation. Each run is stopped at the point when one million calls are generated. The difference between the simulation model and the analytic model is as follows. In the simulation model, we create two events; one is a call that completes in cell i, and the other is a call that goes out of cell i. The durations of these events are exponentially distributed with average $1/\mu_1^{(i)}$ and $1/\mu_2^{(i)}$, respectively. If the latter occurs before the former, the hand-over procedure of a call to cell j occurs with probability γ_{ij}. In our analytic model, we assume that a hand-over call is placed as a Poisson process by aggregating the generation rates of all hand-over calls coming from adjacent cells. Furthermore, in the simulation model we have handled all cells at the same time and determined the number of available channels at each point of time in response to the instantaneous number of ongoing calls in the adjacent cells.

The results of numerical computation and simulation for model 1 are shown in Figure 3. In this model, since most of the forcibly terminated calls those are inevitably terminated by moving outside the service area, the probability of forced termination over the entire network is dominated by such calls. As the probability $\mu_2/(\mu_1 + \mu_2)$ of hand-over is constant and the number of channels is finite, the number of hand-over calls is constant when there are more calls than channels in a cell. Moreover, we also find that the number of calls that are terminated by going outside the service area is constant since the probability γ_{ie} is constant when there are more calls than channels in a cell. We observe that the probability Pf decreases more rapidly for CDMA than for FDMA as the rate λ_1 increases. It is found that there are idle channels for CDMA even when the channel capacity is saturated for FDMA. As a result, the number of calls terminated inevitably by moving outside the service area increases until the channel capacity is saturated for CDMA. In conclusion, the channel capacity of the CDMA system is larger than that of the FDMA system. We additionally find that the blocking probability starts increasing after the traffic intensity λ_1/μ_1 of new calls exceeds the number of channels given to each cell.

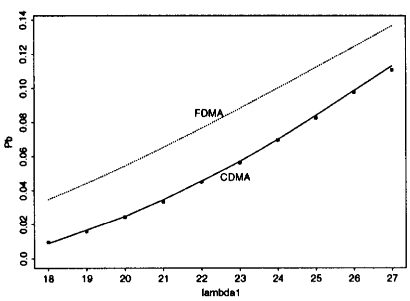
Bullets represent the results of simulation in Figure 3. As they are almost consistent with results of numerical computation, it seems reasonable to assume that hand-over calls are placed as a Poisson process and the average number of calls in adjacent cells is representative of the effect from the adjacent cells in equation (1).

4.4 Performance of model 2

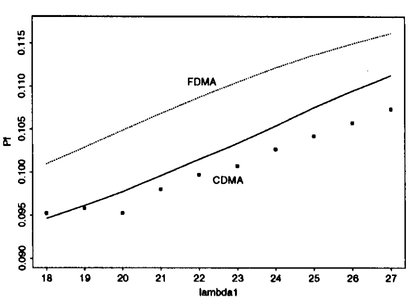
Model 2 in which parameters are arbitrarily chosen and the service area is irregular is shown in Figure 2(b). Numerical examples of parameters are indicated in Table 1 and Table 2. Here, the difference of μ_2 represents the difference in the cell size that a base station covers. For example, the diameter of cell 1 and cell 2 is half of the others. Hand-over calls always move to adjacent cells and cannot move to non-adjacent cells. Thus calls which reside in non-boundary cells of the service area cannot move outside the service area.

We have shown the results of numerical computation and simulation for model 2 in Figure 4. This model also indicates that calls can move outside the service area. We offer here a reason why the probability of forced termination increases as λ_1. Because fewer calls move outside the service area in comparison with model 1, such calls have less effect on the probability of forced termination. Therefore we can say that the calls which fail in hand-over determine the probability Pf. The CDMA system also outperforms the FDMA system in this model. In addition, the blocking probability begins to increase when the traffic intensity λ_1/μ_1 is a little smaller than the number of given channels (20) for each cell. This is why calls that remain within the service area reduce the number of available channels in adjacent cells due to the smaller probability P_e in comparison with model 1.

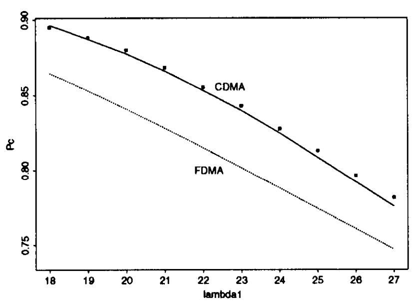
Bullets in Figure 2(b) are the results of simulation. As they almost agree with results of numerical computation, the approximation in this paper holds for an arbitrary cell configuration and an arbitrary set of parameters.



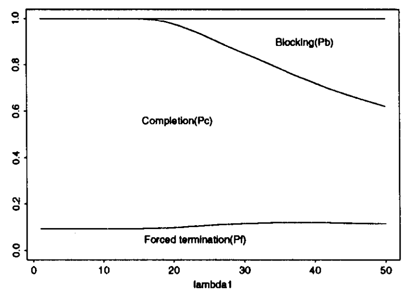
(a) Probability of call loss, Pb



(b) Probability of forced termination, Pf



(c) Probability of call completion, Pc



(d) Probabilities of the call destinies (CDMA)

Figure 4: Performance of model 2 (· :simulation).

5 CONCLUSION

In this paper, we have proposed a method to calculate the blocking probability, the probability of forced termination and the probability of successful completion of a call based on the traffic model for the CDMA cellular communication network. Compared with the FDMA system for those probabilities, we have observed that the CDMA system has a larger channel capacity than the FDMA system. In terms of the band occupancy, the CDMA system (1.25 MHz) occupies much broader band than the FDMA system (0.875 MHz) does. Hence, although the FDMA system excels with respect to the channel capacity per band occupancy, it is concluded that the CDMA system can support more users as a whole.

References

[1] Nikkei Communications, pp.130–137, April 20th 1998 (in Japanese).

[2] D. Hong and S. S. Rappaport, "Traffic model and performance analysis for cellular mobile radio telephone systems with prioritized and nonprioritized handoff procedures," IEEE Trans. Veh. Technol., vol.VT-35, no.3, pp.77–92, August 1986.

[3] R. Guérin, "Channel occupancy time distribution in a cellular radio system," IEEE Trans. Veh. Technol., vol.VT-36, no.3, pp.89–99, August 1987.

[4] C. J. Chang, T. T. Su and Y. Y. Chiang, "Analysis of a cutoff priority cellular radio system with finite queueing and reneging/dropping," IEEE/ACM Trans. Networking, vol.2, no.2, pp.166–175, April 1994.

[5] R. Guérin, "Queueing-blocking system with two arrival systems and guard channels," IEEE Trans. Commun., vol.36, no.2, pp.153–163, February 1988.

[6] C. H. Yoon and C. K. Un, "Performance of personal portable radio telephone systems with and without guard channels," IEEE J. Select. Areas Commun., vol.11, no.6, pp.911–917, August 1993.

[7] X. Lagrange and P. Godlewski, "Teletraffic analysis of a hierarchical cellular network," IEEE 45th Vehicular Technology Conf., pp.882–886, Chicago, Illinois, July 25–28 1995.

[8] D. E. Everitt, "Traffic engineering of the radio interface for cellular mobile networks," Proc. IEEE, vol.82, no.9, pp.1371–1382, September 1994.

[9] B. Jabbari, "Teletraffic aspects of evolving and next-generation wireless communication networks," IEEE Personal Commun., vol.3, no.6, pp.4–9, 1996.

[10] H. Takagi, "Traffic model for cellular mobile communication networks," Communications of the Operations Research Society of Japan, vol.43, no.5, pp.259–263, March 1998 (in Japanese).

[11] D. E. Everitt, "Product form solutions in cellular mobile communication systems," Teletraffic and Datatraffic in a Period of Change, ITC-13, A. Jensen and V. B. Iversen (editors), pp.483–488, 1991.

[12] D. McMillan, "Traffic modelling and analysis for cellular mobile networks," Teletraffic and Datatraffic in a Period of Change, ITC-13, A. Jensen and V. B. Iversen (editors), pp.627–632, 1991.

[13] K. Sakamaki and H. Takagi, "Call loss and forced termination probabilities in cellular radio communication networks," The Transactions of the Institute of Electronics, Information and Communication Engineers B-II, vol.J80-B-II, no.3, pp.231–238, March 1997 (in Japanese).

[14] S. L. Su, J. Y. Chen, and J. H. Huang, "Performance analysis of soft handoff in CDMA cellular networks," IEEE J. Select. Areas Commun., vol.14, no.9, pp.1762–1769, December 1996.

[15] H. Takagi, K. Sakamaki, and T. Miyashiro, "Call loss and forced termination probabilities in cellular radio communication networks with irregular topologies," Proc. SPIE, vol.3530, pp.66–75, Boston, Massachusetts, 2–4, November 1998.

[16] A. J. Viterbi and A. M. Viterbi, "Other-cell interference in cellular power-controlled CDMA," IEEE Trans. Commun., vol.42, no.2/3/4, pp.1501–1504, February/March/April 1994.

[17] A. J. Viterbi and A. M. Viterbi, "Erlang capacity of a power controlled CDMA system," IEEE J. Select. Areas Commun., vol.11, no.6, pp.892–900, August 1993.

[18] R. L. Pickholtz, L. B. Milstein, and D. L. Schilling, "Spread spectrum for mobile communications," IEEE Trans. Veh. Technol., vol.40, no.2, pp.313–322, May 1991.