A Numerical Method Computing Performance of Call Admission Control under a Mobility Model

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***Abstract*— The effects joined by vehicular mobility are investigated in the performance analysis of cellular network. The channel holding times induced from mobility and call holding time are approximately modeled by general distribution to reflect an actual situation. We propose an iterative numerical algorithm to compute the performance values of the CAC as the values for a handoff call dropping probability, new call blocking probability, and handoff arrival rate. Numerical experiment shows that numerical analysis results equal to the results of simulation.**

Keywords: Mobility, Call admission control, Cellular network, Performance analysis, Numerical algorithm.

I. Introduction

Various handoff priority-based call admission control(CAC) schemes have been proposed [1] [2], and they can be broadly classified into two categories : Guard Channel (GC) Schemes and Queueing Priority (QP) Schemes. The GC Schemes have been proposed by Hong and Rappaport [3]. In their scheme, a number of channels in each cell are reserved for exclusive use by handoff calls and remaining channels are shared by both new and handoff calls. In the QP scheme, when all channels are occupied, either new calls are queued while handoff calls are dropped [4], or new calls are dropped while handoff calls are queued [5] [6], or both calls are queued and rearranged [7]. In this paper, a handoff prioritization strategy with guard channel and queue is considered. In this scheme, any handoff request arriving at a cell when there are no available channels can be queued for a fixed maximum time.

We note that there are some rough approximation in cellular system modelling in recent research literature. First, the channel holding times for new calls and handoff calls have been assumed to independent, exponentially distributed, and have the same average values [3] [8]. The mobility model is important for different issues in cellular network problems. The mobility model should includes the effects from both direction and speed of mobile [9] [10]. They showed that the distribution of the cell dwell time of mobile users has been characterized by the a generalized Gamma distribution, when it is assumed that they are moving in a random movement pattern in a cellular network with hexagonal layout. Orlik and Rappaport proposed that the sum of exponential distribution can be approximated to the dwell time distribution [11] [12]. Second, if all calls are identically distributed, then the one-dimensional Markov chain is used to obtain the blocking and dropping probabilities for new calls and handoff calls, respectively [1]. However, the new call's distribution is different from the handoff call's [3] [8]. Hence, the multidimensional Markov chain may be needed.

In this paper, we develop a numerical algorithm computing a performance of a CAC using a channel reservation and handoff queueing, when there are different mobility patterns of users. We note that the mobility of wireless users impacts the performance, such as the blocking probability and the mean of delay. Thus, more realistic analytical model of the mobility and service rate is needed. General distribution model has computation complexity problems due to the exponential increase of dimension. Thus we propose a novel numerical method to compute the performance values of the CAC as the values for a handoff call dropping probability, new call blocking probability, and handoff arrival rate, when new call arrival rates are known.

The remainder of this paper is structured as follows. In section II, we consider a model of mobility, and the computation method for the M/E_k/C/K queueing model. The matrix solution of the analytical model for Channel guard scheme with handoff buffer is presented and the numerical algorithm is discussed in section III. In Section IV, the numerical results of the analytical model is verified by some numerical examples. Finally, conclusions are drawn.

II. Traffic model in mobile networks

A. Preliminary of CAC

The probability that a new call is blocked is denoted by new call blocking probability (CBP)(P_{nb}) and the probability that a handoff call is dropped is denoted by Handoff Call Blocking Probability (CDP) (P_{hd}). These quantities are most significant QoS metrics in CAC scheme. When new calls and handoff calls are competing for the usage of a finite channel resource in a cell, their claims for QoS are different. From users' point of view, a call forced to terminate during service is more annoying than the new call blocked at its start. Therefore, handoff calls commonly given a higher priority in accessing the wireless channel. This can be realized by handoff priority-based Call Admission Control (CAC) Schemes. We note that the mobility patterns of mobile user such as slow or fast speed influence to the QoS in wireless networks. The mobility plays an important role in the performance of a cellular networks.

B. The Effects of Mobility

The cell dwell times are modeled as exponential distributions, but real fast user's ones are not [8]. We can reasonably assume that the holding channel times of the static user is a exponential distribution. The average cell dell times for high speed users depend on the speed of the users. The users are moving in a random movement pattern in a cellular network. We assume that the speed of users is known to the base station and, furthermore, that classes of vehicular (fast) user and pedestrian (slow) user can be distinguished by measurement. The cell dwell time of mobile user has been characterized by a generalized gamma distribution. The Gamma distribution does not have a specific distribution shape. Depending on the parameters, Gamma distribution can be used to model the exponential, the Erlang and the Chi-square distributions. The distribution of cell dwell time can be modeled by the Erlang function given by

$$f(x) = \frac{\mu k (k\mu x)^{k-1}}{(k-1)!} e^{-k\mu x}, \quad x \geq 0. \tag{1}$$

We denote k by Erlang Index. The average of this density function is $1/\mu$ independent of k. The standard deviation is $\sigma = \frac{1}{\mu\sqrt{k}}$. For simplicity, we assume that the distribution can be approximately identified by its mean and derivation of mobile users' speed. Let λ_n be the arrival rate for new calls and λ_h be the arrival rate for handoff call. λ_h depends on λ_n and the distribution $f(t)$ of cell dwell time. A mobile can move through several cells while being involved in a call as shown in 1.

We discuss how the distributions of the cell dwell time and the call holding time influence the distributions of the new and handoff call channel holding times in Figure 1. Let T_c denote the lifetime of the call holding that is the length from the instant of admission to the base station to the instant when the connection is terminated in the cell or in another cell after several more handovers. If the call holding time has a negative exponential distribution with mean $\frac{1}{\mu_0}$, denoted by $f_c(x)$, then the residual call length of the handover also has the same distribution, due to the memoryless property. Figure 1 shows diagram for our study similar to that in [13]. Let T_c be the call holding for a new call, t_i for $2 \leq i \leq m$ be the typical cell dwell time in a cell for a handoff user, r_1 be a residence time in the first cell for a new call, and r_f be the residual time when the call finishes m-th handoff successfully. The typical cell dwell time is generally distributed depending on the velocity of a mobile user with mean $\frac{1}{\mu}$.

The number of handoff times H that a mobile crosses different boundaries during a call holding time is a random variable dependent on the cell size, call holding time and mobility parameter [9]. From [13], it is known that the probability $Pr(H = l)$ that a call made k handoffs before it is

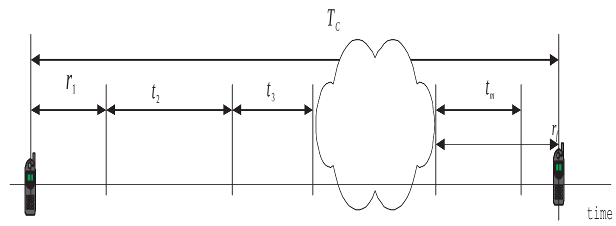


Fig. 1. The time diagram for call holding time and cell residence time

completed or forced-terminated can be computed as follows:

$$Pr(H=0) = \frac{1-P_{nb}}{2\pi j}\int_{\sigma-j\infty}^{\sigma+j\infty} \frac{1-f_r^*(s)}{s} f_c^*(-s)ds$$

$$Pr(H=l) = \frac{(1-P_{nb})(1-P_{hd})^{l-1}}{\pi j}\int_{\sigma-j\infty}^{\sigma+j\infty} \frac{f_r^*(s)[1-(1-P_{hd})f^*(s)][f^*(s)]^{l-1} f_c(-s)}{s} ds$$

where $f^*(s)$ defined by a Laplace transformation of $f(t)$ and $f_r(t)$ is a distribution function of r_1.

If the density function of the independent identical distribution calling holding times has a general distribution, then the handoff rate for a nonblocking call is given by

$$E[H] = \frac{(1-P_{nb})}{2\pi j}\int_{\sigma-j\infty}^{\sigma+j\infty} \frac{\gamma[1-f^*(s)]}{s^2[1-(1-P_{hd})f^*(s)]} f_c^*(-s)ds, \tag{2}$$

where $f_c(t)$ is defined by the distribution of call holding time and $f(t)$ is defined by the distribution of cell dwelling time. When it is assumed that the cell dwell time has a Erlang distribution with index k and mean $\frac{1}{\mu}$ and the call holding time has a exponential distribution with mean $\frac{1}{\mu_0,}$ it is expected that the handoff rate λ_h is

$$\begin{aligned}\lambda_h &= \lambda_n(1-P_{nb})E[H] \\ &= \lambda_n(1-P_{nb})\frac{\gamma[1-\left(\frac{k\mu}{\mu_0+k\mu}\right)^k]}{1-(1-P_{hd})\left(\frac{k\mu}{\mu_0+k\mu}\right)^k}\end{aligned} \tag{3}$$

where $1/\mu_0$ is the average of call holding time. We can see that the handoff call arrival rate λ_h depends on the user mobility (μ) and the new call arrival rate (λ_n). The steady state values for λ_h and λ_n have a relation as the equation (3).

C. $M/E_k/C/K$ Modeling

The Erlang distribution provides much more modeling flexibility than the exponential distribution. We will compute the blocking and dropping probabilities by using model $M(\lambda)/E_k/C/K$, where arrival process is a Poisson process with arrival rate of customers λ. If customer waiting for service in the queue does not receive service within the timeout interval, then the customer impatiently leaves the system. We assume that the timeout interval is a random variable and exponentially distributed with mean $1/\eta$. Erlang distribution can be modeled by a tandem of k exponential processes. The dimension of the state-space descriptor vector increases. For k processes, we require a $k+2$ component vector $(n;n_q,n_k,n_{k-1},\cdots,n_1)$ to describe the state of the system where n is the total number of customers in the system, the remaining i components n_i for $0\le i\le k$ represent the distribution of customers in various phases of service, and n_q is the number of customers in the queue. We can simplify the notations as follows:

$$\begin{aligned}(n;j) =&\quad (n;n_q,n_k,\cdots,n_1)\\ (n;i^+) =&\quad (n;n_q,n_k,\cdots n_i+1,\cdots,n_1)\\ (n;i^-) =&\quad (n;n_q,n_k,\cdots n_i-1,\cdots,n_1)\\ (n;i^-,j^+) =&\quad (n;n_q,n_k,\cdots,n_i-1,\cdots,n_j+1,\cdots,n_1),\end{aligned}$$

where n_q is specially denoted by the number of customers in the queue. A lexicographic set $\mathcal{M}_n$ is defined by

$$\mathcal{M}_n=\{(n;n_q,n_k,\cdots,n_1)\} \tag{4}$$

where $n-n_q=\sum_{i=1}^{k} n_i$. Here, $n_q=0$ if $n\le C$. $n_q=n-C$ if $n>C$. Let us define a lexicographic ordering relation on the set $\mathcal{M}_n$. Let us define the ordering relation ($\prec$) of the lexicographic labeling by $(n;n_q,n_k,\cdots,n_1)\prec(n;n'_q,n'_k,\cdots,n'_1)$ if it satisfies one of the following statements:

1) there is a first j from the left side such that $n_j<n'_j$,and $n_i=n'_i$ for all $i>j$ if $0\le n\le c$ $(n_q=n'_q=0)$
2) there is a first j from the left side such that $n_j<n'_j$, $n_q=n'_q$ and $n_i=n'_i$ for all $i>j$ if $n\ge C$.

The cardinality of a lexicographic ordering set $\mathcal{M}_n$ for n customers is defined by m_n ($|\mathcal{M}_n|=m_n$). Accordingly, the cardinality of $\mathcal{M}_n$ can be computed by

$$m_n=\begin{cases}\frac{(n+k-1)!}{n!(k-1)!}, & \text{when } 1\le n\le C;\\ \frac{(C+k-1)!}{C!(k-1)!}, & \text{when } N\ge n>C.\end{cases} \tag{5}$$

where $n!$ is a factorial of n. This gives the number of the total elements of the state space, $T=1+\sum_{n=1}^{K} m_n$. There is an one-to-one mapping such that $(n;n_q,n_k,n_{k-1},\cdots,n_1)$ corresponds to (n,l) for $1\le l\le m_n$ with the same order. The state probability $p_{n;n_k,n_{k-1},\cdots,n_1}$ represents the probability for which there are n customers in system and n_i customers in the phase i of service for $i=1,\cdots k$, where $n_k+n_{k-1}+\cdots+n_1=\min\{n,C\}$. If there is no ambiguity, we use the simplified notation $p_n(l)=p_{n;n_q,n_k,n_{k-1},\cdots,n_1}$. Equating flow in to flow out yields the global balance equations in (6).

Using a truncated system, due to the finite buffer length K, for $n\ge K$, we can see that $p_{n;n_q,n_k,n_{k-1},\cdots,n_1}=0$. We can use numerical techniques for solving these equations, since we have a finite set of linear algebraic equations [14]. Seelen proposed an algorithm for calculating steady-state probabilities in practical $Ph/Ph/C$ queueing models [15]. The Erlang distribution (E_k) is a special case of phase-type distributions (Ph). Using the above ordering relation, the vector-valued balanced equation can be written by

$$\begin{aligned}D_0\vec{p}_0&=V_0\vec{p}_0+W_0\vec{p}_1\\ D_n\vec{p}_n&=U_n\vec{p}_{n-1}+V_n\vec{p}_n+W_n\vec{p}_{n+1}\\ D_N\vec{p}_N&=U_N\vec{p}_{N-1}+V_N\vec{p}_N,\end{aligned} \tag{7}$$

where m_n is the number of the possible states when there are n customers, $\vec{p}_n=\begin{bmatrix}p_{n,1} & p_{n,2} & \cdots p_{n,m_n}\end{bmatrix}^t$ is a column vector with dimension m_n, and the i-th steady state probability $p_{n;n_q,n_k,\cdots,n_1}$ is denoted by $p_{n,i}$ for $i=1,\cdots,m_n$. Hence, the normalization equation is satisfied as follows: $\sum_{n=0}^{N}\sum_{i=1}^{m_n} p_{n,i}=1$. D_n is a diagonal matrix whose (i,i) entry equals the sum of all the entries in the i-th columns of the matrices U_{n+1}, V_n and W_{n-1}, i.e.

$$D_n(i,i)=\sum_{j=1}^{m_{n+1}} U_n(j,i)+\sum_{j=1}^{m_n} V_n(j,i)+\sum_{j=1}^{m_{n-1}} W_n(j,i).$$

Then, we obtain the detailed balance equations $u_n\vec{p}_n=w\vec{p}_{n+1}$ with $u_n=eU_n$ and $w_n=eW_n$, where $e=\begin{bmatrix}1 & \dots & 1 & 1\end{bmatrix}$ is the unity vector with length m_n. The state probability p_n with respect to n customers can be computed by $p_n=\sum_{i=1}^{m_p} p_{n,i}$.

III. Analysis of Call admission control Scheme

A. CAC with Guard channel and Handoff Queueing

We will analyze the performance of a CAC scheme with handoff queueing and guard channels. We assume that the channel holding times for new calls and handoff calls are independent and have different distribution [3] [9] [11]. The one-dimensional Markov chain model for CAC schemes assuming that cell dwell times of new calls and handoff calls are identically distributed may not be appropriate. Therefore, the multi-dimensional Markov chain model is needed.

Let us consider the channel holding time. There are two kinds of channel holding times : a new call channel holding and handoff call channel holding time. Let t_{nh} and t_{hh} denote the new call channel holding time and the handoff call channel holding time, respectively. The new call channel holding time is $t_{nh}=\min\{T_c,r_1\}$ and the handoff call channel holding time is $t_{hh}=\min\{r_f,t_m\}$. Applying the Laplace transform of the probability density function of new call channel holding time, we obtain

$$f^*_{nh}(s)=\frac{\mu}{s+\mu_0}+\frac{s}{s+\mu_0}f^*_r(s+\mu_0). \tag{8}$$

The Laplace transform of the probability density function of the handoff call channel holding time is given by

$$f^*_{hh}(s)=\frac{\mu_0}{s+\mu_0}+\frac{s}{s+\mu_0}f^*(s+\mu_0). \tag{9}$$

We separated calls into new calls and handoff calls when considering the channel holding time. We need to consider the channel holding time for merged traffic of new calls and handoff calls. From (8) and (9), we can see that channel holding times depend on the cell dwelling time and call holding time. For simplification of analysis, we assume that the distributions of channel holding times is approximated by Erlang distribution. We study the multi-dimensional Markov chain under the assumption that some random variable, such as dwell time may be modeled by the Erlang distribution.

Therefore, the multi-dimensional Markov chain may be needed. We study the multi-dimensional Markov chain under the assumption that some random variable, such as cell dwell

$$
\begin{cases}
\lambda p_{0;0} = \mu p_{1;1^+} & \text{if } n = 0 \quad \text{(6a)} \\
(\lambda + n\mu) p_{n;j} = \lambda p_{n-1;k^-} + (n_1+1)\mu p_{n+1,1^+} + \sum_{i=1}^{k-1} (n_{i+1}+1)\mu p_{n;(i+1)^+,i^-} & \text{if } 0 < n < C \quad \text{(6b)} \\
(\lambda + C\mu) p_{n;j} = \sum_{i=1}^{k-1} (n_{i+1}+1)\mu p_{n;(i+1)^+,i^-} + \lambda p_{n-1;k^-} + \eta p_{n+1;n_q^+} + (n_1+1)\mu p_{n+1,k^-,1^+} & \text{if } n = C \quad \text{(6c)} \\
(\lambda + C\mu + n_q\eta) p_{n;j} = \lambda p_{n-1;j} + (n_q+1)\eta p_{n+1;n_q^+} + (n_1+1)\mu p_{n+1;k^-,1^+} + \sum_{i=1}^{k-1} (n_{i+1}+1)\mu p_{n;(i+1)^+,i^-} & \text{if } K > n > C \quad \text{(6d)} \\
(C\mu + n_q\eta) p_{n;j} = \lambda p_{n-1;j} + \sum_{i=1}^{k-1} (n_{i+1}+1)\mu p_{n;(i+1)^+,i^-} & \text{if } n = K \quad \text{(6e)}
\end{cases}
$$

time may be modeled by the generalized Erlang distribution [9] [11]. We develop an algorithm that computes the blocking probability of new calls and the dropping probability of handoff calls. We develop an algorithm that computes the blocking probability of new calls and the dropping probability of handoff calls.

We assume that each base station has a finite buffer size B. Let C be the total number of channels in a cell and M and N be the number of channels only assigned for new calls and handoff calls, respectively. There are $C - M - N$ shared channels that can be used by either type of call. All channels are employed in a first-come first-serve manner. The queue model can be described by a two-dimensional (i, j) Markov chain, where i and j denote the number of existing new calls and handoff calls in a cell, respectively. The state space is given by

$$
\begin{aligned}
\mathcal{S} = \{(i,j) | & 0 \le i < M, 0 \le j \le C - M + B \quad \text{or} \\
& M \le i \le C - N, 0 \le j \le C - i + B\}.
\end{aligned}
$$

The state (i, j) transits to $(i+1, j)$ with rate λ_n if channels for new call become available (i.e., $i < C-N$or $i+j < C$) and to $(i, j+1)$ with transition rate λ_h if the handoff buffer is not full. When one of the channels occupied by i new calls is released with rate $i\mu_n$, the state (i, j) transits to $(i-1, j)$ with rate $\imath\mu_n$. Two kinds of processes will contribute to the transition from (i, j) to $(i, j-1)$. If $i < M$ and $j < C - M$ or $i \ge M$ and $j \le C - i$ (i.e., no queued handoff calls), the transition from (i, j) to $(i, j-1)$ occurs with rate $j\mu_h$. When $i < M$ and $j > C - M$ and $i \ge M$ and $j > C - i$, the transition from (i, j) to $(i, j-1)$ occurs with rate $(C-i)\mu_h + (j - (C-i))\eta$ and $(C-M)\mu_h + (j - (C-M))\eta$, respectively. The region of the two-dimensional Markov chain can be divided into three parts, as follows:

$$
\begin{aligned}
\mathcal{S}_1 = & \{(i,j) | i + j < C, 0 < i \le C - N, 0 < j \le C - M\} \\
\mathcal{S}_2 = & \{(i,j) | i \le M, C - M \le j \le C - M + B\} \\
\mathcal{S}_3 = & \{(i,j) | i + j \ge C, M \le i \le C - N\}.
\end{aligned}
$$

Figure 2 shows an example for $C = 6$, $M = 2$, $N = 1$ and $B = 3$. Let p_{n_1,n_2} denote the steady-state probability that there are n_1 new calls and n_2 handoff calls in the cell. Let us consider the two-dimensional steady-state probability $p(n_1, n_2)$ occurring in the $M/E_k/C/K$ queueing system. The Poisson interarrival and Erlang distributions in $M/E_k/C/K$ queueing system can model two-dimensional Markov chain as a generalized version of two-dimensional Markov chain proposed in [16].

Let us define a vector $\vec{n}_i = (n_{i,q}, n_{i,k} \cdots, n_{i,1})$. For c servers, we require a $k+2$ component vector to describe the state of the system, which is defined by $(n_i; \vec{n}_i) = (n_i; n_{i,q}, n_{i,k}, \cdots, n_{i,1})$ in (4) where $n_i = n_{i,q} + \sum_{j=1}^{k} n_{i,j}$ for $i = 1, 2$. The new call and handoff states can be re-ordered by lexicographical labeling. Let p_{n_1,n_2} denote the state probability that there are n_1 new calls and n_2 handoff calls in the call. The probability p_{n_1,n_2} can be divided into

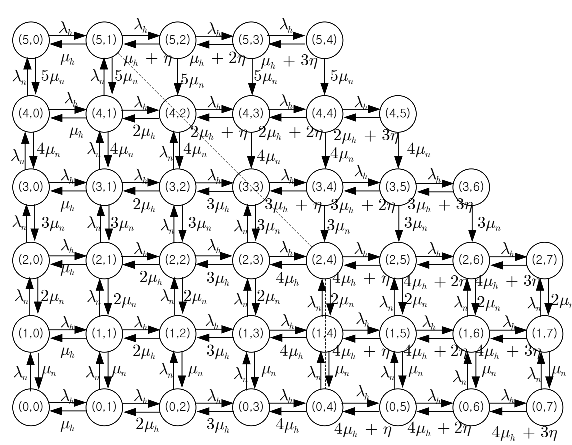


Fig. 2. Two dimension Markov Chain

$\vec{p}_{n_1,n_2}$ by lexicographical ordering. The transition diagram for the new and handoff call bounding schemes with buffers for handoff is modeled by the two-dimensional Markov chain. Define $p_{n_1,n_2}(l_1,l_2)$ such that $p_{n_1,n_2}(l_1,l_2) = p_{n_1;\vec{n}_1,n_2;\vec{n}_2}$ where $\vec{n}_i$ is l_i elements of $\mathcal{M}_{n_i}$ for $i = 1,2$. The state vector $\vec{p}_{n_1,n_2}$ can be defined such that $s = m_{n_1}s_1 + s_2$ element is $p_{n_1,n_2}(s_1,s_2)$. In order to handle the total state probability easily, we define a vector $\vec{P}_n$ such that $\vec{P}_n = \begin{bmatrix}\vec{p}_{0,n} & \vec{p}_{1,n-1} & \cdots & \vec{p}_{n-1,1} & \vec{p}_{n,0}\end{bmatrix}$ where the total number of new calls and handoff calls is n. Then, we can obtain a global balance equation, as follows:

$$\mathcal{U}_n\vec{P}_{n-1} + (\mathcal{V}_n - \mathcal{D}_n)\vec{P}_n + \mathcal{W}_n\vec{P}_{n+1} = 0, \qquad (10)$$

for $0 \le n \le K$. The detail derivation is omitted for the space saving. We solve the following equations

$$\begin{aligned} \mathcal{Q}\vec{P} &= 0 \\ E\vec{P} &= 1 \end{aligned} \qquad (11)$$

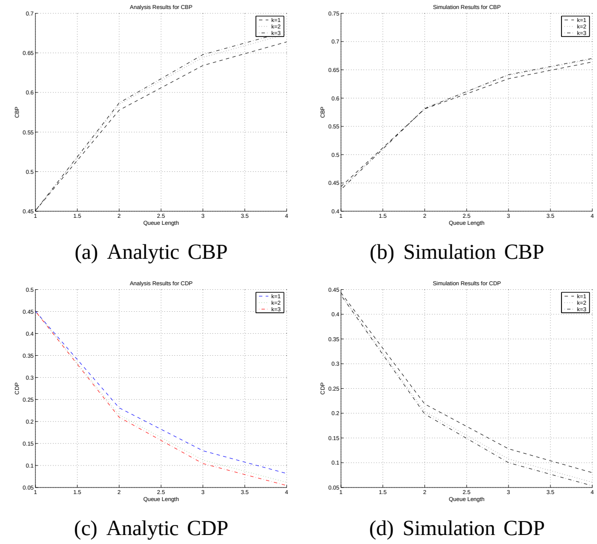
where $E = \begin{bmatrix}1 & 1 & \cdots & 1\end{bmatrix}$. Using the results, let us compute the new call dropping probability, the terminated handoff call probability, and queueing delay as QoS metrics. A new call arrival is blocked when it arrives at the state $(i,j) \in \mathcal{S}_3$. Therefore, the new call blocking probability P_{nb} is the sum of the conditional state probabilities when a new call arrives in the state $(i,j) \in \mathcal{S}_1$, such as $P_{nb} = \sum_{(i,j)\in\mathcal{S}_3} p_{i,j}$. The dropping probability of a handoff call can be calculated as the fraction of the incomplete handoff calls whose mobile leave the handoff area prior to their coming into the first queue position and getting a channel. The dropping probability $P_{hd|(i,j)}$ is defined by $P_{hd} = \sum_{(i,j)\in\mathcal{HD}} p_{i,j}$ where $\mathcal{HD} = \{(i,j) \in \mathcal{S} | j = C - M + B, \text{or } i + j = C\}$.

B. The total cellular system

We want to compute the CAC parameters as the values for a handoff call dropping probability P_{hd}, new call blocking probability P_{nb}, and handoff arrival rate λ_h, when new call arrival rates λ_n are known. These values can not computed by using local information in a single cell, but need the global information. However, it is impossible to know the global information, because the total cellular system is very large and dynamics. The values for λ_h depends on the integration on each the drop or blocking probability of the total cellular system. So, we believe that a local value of λ_h measured in single cell is not a steady state value and is a dynamical value depending on instant state. Therefore, the values for P_{hd}, P_{nb}, λ_h, and λ_n should be predicted by an iterative method under the simplified model similar to [17] [3]. Beginning with an proper initial guess for the unknowns, the equations are solved numerically using an iterative method. This section shows how to use an iterative technique to compute P_{nb}, and P_{hd} using the equations derived in Sec. III-A. The iterative algorithm is as follows:

Algorithm 1 (Iterative algorithm): Compute P_{nb}, and P_{hd}:

- *Input parameters:* the new call arrival rate λ_n, the number of channels C, and the mean and derivation of the cell dwell time.



(a) Analytic CBP (b) Simulation CBP

(c) Analytic CDP (d) Simulation CDP

Fig. 3. The loss probabilities(CBP and CDP) for Guard channel with respect to queue length

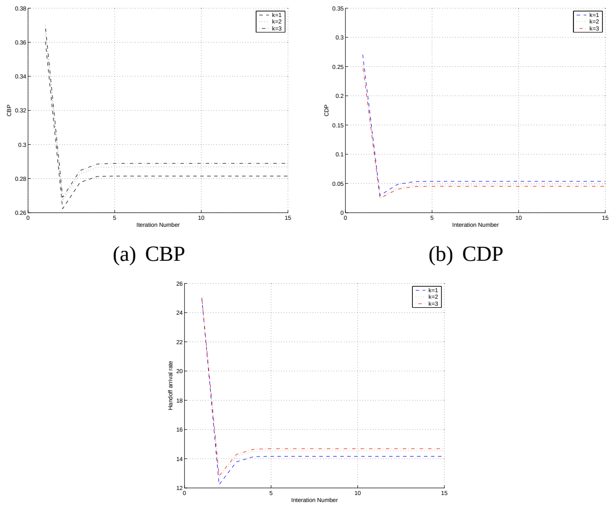
- *Output values:* the handoff call arrival rate λ_h, the new call blocking probability P_{nb}, and the handoff dropping probability P_{hd}.
  1) Select initial values for P_{nb} and P_{hd}.
  2) Compute the handoff call rate λ_h as (3) (the instant value can directly be measured).
  3) Update old values:
  $$\begin{aligned} P_{nb,old} &\leftarrow \alpha P_{nb,old} + (1-\alpha)P_{nb} \\ P_{hd,old} &\leftarrow \alpha P_{hd,old} + (1-\alpha)P_{hd}, \end{aligned}$$
  where $0 \le \alpha < 1$.
  4) Compute the new-call-blocking and handoff-call-dropping probabilities (P_{nb} and P_{hd}, respectively) by using the results in Sec. III-A.
  5) If $|P_{nb,old} - P_{nb}|$ and $|P_{hd,old} - P_{hd}|$ are larger than the given thresholds, then go to step 2. Otherwise, go to the final step
  6) The values for λ_h, P_{nb} and P_{hd} converge.

In Step 3, α is an exponential moving average factor. The convergence rate depends on α.

IV. Numerical Results

In this section, the numerical computation results obtained with our analytical model are discussed. We compare the performance QoS metrics of CAC with guard channel and finite queueing and reneging for various parameter settings to find the critical parameters of the performance under the assumption that the cell dwell time distribution is an Erlang distribution.

Figure 3 illustrates the effects of the change of Erlang index on the new-call-blocking and handoff-call-dropping probabilities, depending on queue length with respect to each Erlang index. We set $\lambda_n = 10$, $\lambda_h = 10$, $C = 3$, $M = 0$, $N = 0$, $\mu_h = \mu_n = 5$, and $0 \le B \le 5$. We compare the different



(a) CBP

(b) CDP

(c) Handoff arrival rate

Fig. 4. The CDP and CBP probabilities with respect to Erlang Index k

Erlang distributions with same mean $\frac{1}{\mu}$, but different variances $\frac{1}{(k\mu^2)}$, when guard channel schemes with queue is used. We can see that there is some differences in the blocking and dropping probabilities for different Erlang Indices. We can verify that the results of our analysis are almost equal to the results derived by the event-driven simulation in Fig 3. Here, arrival process in each cell is generated with identical independent distribution. However, it is known as Erlang loss that the steady state probabilities for an $M/G/C/C$ is the same as those of an $M/M/C/C$ with the same arrival process and the channel number [17]. Here, we can also see that there are some differences of the dropping and blocking probabilities for $M/E_k/C/K$ with respect to the Erlang index k.

Figure 4 shows differences of the new-call-blocking probability and the handoff-dropping-probability, with respect to k. Consider the effects of both the mobility and traffic types on the network performance for different Erlang Indexes. We set $\lambda_n = 20$, $C = 6$, $M = 2$, $N = 3$, $\mu_h = \mu_n = 5$, $\eta = 2.5$, and $B = 5$. In this example, the handoff arrival rate λ_h is computed by using (3). The computation of the handoff arrival rate λ_h is derived under the one-dimensional movement assumption. However, under multi-dimension movement, the derivation of λ_h is complex and more researched in the future. λ_h, P_{nb}, and P_{hd} are computed by Algorithm 1. In numerical experiment, we can see that α is closely related to the convergence of the algorithm. When $\alpha = 0$, algorithm does not converge but rather, it oscillates. Thus, in order to prevent the divergence of the algorithm, we use the exponential moving average filter. Figure 4 also shows the convergence of P_{hd}, P_{hb}, and λ_h. There is a trade-off between the convergence and the stability of the algorithm in choosing α.

V. Conclusion

We have developed an analytical model for a cellular system that utilizes CAC with guard channel and handoff queueing under the assumption that cell residence time has a Erlang distribution. We have made CAC performance analysis reflected mobility effect. We have proposed a numerical algorithm to compute the QoS metrics, such as the new-call-blocking probability and the handoff-call forced-terminated probability when the distribution of channel holding times is an Erlang distribution. The complexity of the computation increases exponentially as the Erlang index increase. By numerical experiment results, we have verified that there should be a tradeoff between the exactness of the performance model and the computational complexity. We have verified the analysis reliance by using event-driven simulation. In future works, the multidimensional mobility should be researched.

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