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Performance Evaluation of Wireless Cellular Networks with Guard Channel Reservation
蜂巢式無線網路的性能分析

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Abstract

In this chapter, we apply the matrix-analytical approach to explore the performance measures of the drop and block probabilities of wireless cellular networks with guard channel reservation handoff scheme. We apply the Markovian Arrival process (MAP) to model new call and handoff call. We examine the bursty nature of handoff call drops by means of conditional statistics with respect to alternating block and non-block periods. Five related performance measures are derived from conditional statistics, including the long-term new call block and handoff call drop probabilities, and the three short-term measures of average length of a block period and a non-block period, as well as the conditional handoff call drop probability during a block period. These performance measures greatly assist the guard channel reservation handoff mechanism in determining a proper threshold guard channel in the cell. Furthermore, we derive the handoff call drop probability from the short-term performance measures of average length of a block period and a non-block period, as well as the conditional handoff call drop probability during a block period. The results presented in this paper can provide guidelines for designing adaptive algorithms to adjust the threshold in the guard channel reservation handoff scheme.

Key Words: handoff, Markovian Arrival process (MAP), drop probability

摘 要

本論文運用矩陣分析方法，以遺失機率來探索無線蜂巢網絡切換程序的性能。通話的模式以馬可夫到達程序模擬，對突發的切換資料遺失的探討，是以交替性的有(無)資料周期的平均值表示。推導出五項性能指標中，包含兩項穩

態的遺失機率及三項暫態的遺失機率，這些參數用以決定蜂巢中該保留多少預備通道。進而，我們也從暫態的性能推導出穩態性能。從這些結論可以證明本論文對無線網路在切換時，能提供最佳的調整方針。

關鍵詞：切換、馬可夫到達過程、遺失機率

1. Introduction

Handoff basically involves change of radio resources from one cell to an adjacent cell. It is well known that if an new call is blocked, it is not as disastrous as a handoff call being dropped. Therefore, it is important to provide a higher priority to handoff calls so that ongoing calls can be maintained [8] [22]. One way of assigning priority to handoff requests is by assigning guard channels to be used exclusively for handoff calls from among the available channels in a cell. This guard channel reservation handoff scheme has a tunable threshold for guard channel configuration. With a selected threshold, a block period is defined the interval of time during which the channel occupancy in a cell is at or above the threshold value, and a non-block period is the complementary interval of time. The available channels at or below the threshold is shared by new calls and handoff calls. Arriving new calls are blocked by the control scheme during a block period. Handoff calls are dropped only when the channel is full.

Choosing an appropriate threshold for the guard channel for handoff calls is the most significant design issue for wireless mobile networks. If a relatively low threshold is chosen, new calls will be excessively blocked, causing a low utilization of the channel capacity in a cell. On the other hand, if a fairly high threshold is chosen, handoff calls will be dropped more than expected because of the occupancy of the channel by new calls. This phenomena prevents the system from being able to meet the required drop probability for handoff for handoff calls. Performance analysis of a threshold policy is therefore necessary and desirable in order to assist the system in choosing a proper threshold.

The guard channel reservation handoff scheme has increasingly been receiving attention in cellular network design due to its simplicity in the implementation. Several performance evaluations have been conducted by examining the new call block and handoff call drop behavior of a cell with a guard channel reservation handoff scheme. Performance analysis of wireless cellular systems with Poisson handoff arrivals that specifically adopt the guard channel scheme has been carried out by a number of authors [12] [14]. In [26] [29], they made a successful drop analysis of a preemptive and priority reservation handoff scheme by considering both real-time and non-real-time service originating calls, and real-time and non-real-time handoff service request calls as Poisson arrival processes. All of these papers considered only the Poisson handoff call arrival process case.

So far, much research has been focused on exploring handoff call arrival processes. Orlik and Rappaport [18] addressed the issue of the handoff arrival process by considering a neighborhood of cells where all but one, the cell under study, is assumed to generate handoff arrivals according to either a Poisson or a two-state Markov-Modulated Poisson Process. Rajaratnam and Takawira [20] empirically showed that handoff traffic is a smooth process under negative exponential channel holding times. They characterize handoff traffic as a general traffic process and represent it using the first two moments of its offered traffic. Zeng and Chlamtac [28] have shown that the cell residence time distribution influences the handoff traffic statistics. They used a Gamma distribution for the cell residence times and showed that, for a large cell residence time variance in a non-blocking environment, handoff traffic cannot be characterized by a Poisson process. From the above we can conclude that there is significant evidence that the handoff traffic cannot always be modeled as a Poisson process. The distribution type of the handoff interarrivals is still an open issue. Consequently, there is a need to develop performance models that allow for general distributions in handoff interarrivals. So far, several performance models with general distributions for handoff interarrivals have been conducted. Alfa and Li [1] derived a performance analysis method based on the Markovian arrival process(MAP) for arriving calls, and under the conditions that both the cell's residence time and the requested call holding time possess the general phase type(PH) distribution. Therefore, Li and Alfa [11] proposed the queueing model with MAP arrival calls to investigate the related performance measures of the priority reservation handoff scheme. Dharmaraja, Trivedi and Logothetis [4] successfully analyzed new call block and handoff call drop probabilities of a queue with a priority channel allocation scheme by considering new calls as Poisson processes and handoff call as renewal processes. Rajaratnam and Takawira [19] derived a performance analysis method based on Poisson new call arrivals, generalized handoff call arrivals, and using channel holding-time distributions that are more suitable and flexible than the simple negative exponential distribution. Wang et. al. [27] derived a matrix-analytical method based on PH distribution handoff call and new call to analyze the long-term new call block and handoff call drop probabilities and the short-term handoff call drop probability during block period.

The strategy and mathematical model used here to examine the performance measures of a guard channel reservation handoff scheme are different from those in the literature in one or more respects. In this paper, we use a MAP to model handoff call arrival processes due to the following conditions: 1) it is simple but good enough to fit field data, and 2) the resulting queueing system model is tractable. A main advantage of using Markovian models for traffic description of queues is that there are efficient numerical analysis methods, commonly referred to as matrix analytic methods, for the evaluation of a Markovian queue. Based on the above investigation, we use a MAP instead of general distributions to model handoff call and new call arrival process so that the the performance measures can be solved exactly using matrix-analytic techniques.

In addition to the evaluation of the new call block and handoff call drop probabilities, we examine the conditional handoff call drop during the block period. The threshold used to determine the block period splits the state space in two, allowing the use of two hypothesized Markov chains to describe the alternating renewal process. The distributions of various absorbing times in the two hypothesized Markov chains are derived to compute the average durations of the block period and the conditional handoff call drop probability during a block period. These performance measures will significantly assist the guard channel reservation handoff mechanism for determining a proper threshold. The overall analysis in this paper is based on the matrix-analytic approach [15] [16]. It is simple and efficient to compute the numerical results by any efficient mathematical tool.

This paper is organized as follows. In Section 2, the MAP as the new and handoff call model is briefly introduced. In Section 3, the new call block probability and handoff call drop probability are analyzed. Numerical results are computed and discussed in Section 4 to reveal the computational tractability of our analysis and to gain insight into the design of a guard channel reservation handoff scheme in wireless mobile networks. Some concluding remarks are given in Section 5.

2. Traffic Model

Many analytically tractable models have been proposed to describe new call and handoff call traffic in the literature. However, although the Markovian based traffic model requires the estimation of a large number of parameters to describe the network traffic [7], much research has focused on parameter estimation and application of MAP to model network traffic. Buchholz [3] presented an algorithm to fit the parameters of MAP according to measured data. In [6], Heyman and Lucantoni provided evidence that Markov-modulated Poisson process (MMPP) which is a special case of MAP is a good model for Internet traffic at the packet/byte level. In [10], Kang et al. provided evidence that MAP yielded very good estimation of the cell loss ratio for common superpositions of voice and VBR video sources. In [24], Salvador et al. proposed a parameter fitting procedure using superposed two-state MMPP that leads to accurate estimates of queueing behavior for network traffic exhibiting long-range dependent behavior. Telek [25] derived the minimal presentation of MAP and developed effective fitting models. Based on those studies, we can state that the MAP process is able to model a wide variety of new and handoff call traffic streams. In this paper, the arrival process of new and handoff call traffic is modeled by a MAP. A brief exposition of MAP is given in the rest of this section.

The MAP is a generalization of the Poisson arrival process by allowing for non-exponential inter-arrival times, while still preserving an underlying Markovian structure [13]. It is a marked point process with arrivals generated at the transition epochs of a particular type of m-state Markov renewal process [17]. A MAP can be more easily described by a two-dimensional continuous-time Markov chain $\{(N(t), J(t)), t \geq 0\}$, on the state space $\{(n, j) | n \geq 0, 1 \leq j \leq m\}$, with infinitesimalg enerator Q_{MAP} having the structure

$$Q_{MAP} = \begin{bmatrix} D_0 & D_1 & 0 & \cdots \\ 0 & D_0 & D_1 & \cdots \\ 0 & 0 & D_0 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

where $N(t)$ stands for a counting variable, $J(t)$ represents an auxiliary phase variable, and D_K 's are $m \times m$ matrices, called parameter matrices. The Markov chain then defines an arrival process where the transition from state (n, i) to state $(n + 1, j)$, $n \geq 0$, and $1 \leq i, j \leq m$, corresponds to an arrival and a phase change from phase i to phase j. The matrix D_1 with elements $(D_1)_{ij}$, $1 \leq i, j \leq m$, governs state transitions which correspond to an arrival, and the matrix D_0 governs state transitions which correspond to no arrivals. The sojourn time in phase i with n accumulated packets, i. e. , in the state (n, i), is exponentially distributed with parameter $-(D_0)_{ii}$, which is independent of n. At the end of that sojourn time, a state transition will occur. With probability $-(D_0)_{ij}/(D_0)_{ii}$, there will be a transition to phase j without any new arrival, i. e. , to state (n, j), for $1 \leq j \leq m$ and $j = i$. With probability $-(D_1)_{ij}/(D_0)_{ii}$, there will be a transition to phase j with an arrival, i. e. , to state $(n + 1, j)$, for $1 \leq j \leq m$. Note that in this case, j may be equal to i. The sum of both parameter matrices

$$D = D_0 + D_1 \qquad (1)$$

is an $m \times m$ matrix which is the infinitesimal generator of the underlying Markovian structure $\{J(t), t \geq 0\}$ with respect to the MAP. We assume that the underlying Markovian structure is stable and irreducible. Thus the Markov chain $\{J(t), t \geq 0\}$ has a unique stationary probability vector $\boldsymbol{\pi}$,

$$\boldsymbol{\pi} D = 0,\ \boldsymbol{\pi} \geq 0 \text{ and } \boldsymbol{\pi} \boldsymbol{e} = 1 \qquad (2)$$

here e is assumed in this paper to be an all-1 column vector with compatible dimension. We also assume that D_0 is nonsingular such that the sojourn time at any state of the state space$\{(n, j)|n \geq 0, 1 \leq j \leq m\}$is finite with probability one for guaranteeing the process never terminates. The fundamental arrival rate λ of this MAP is defined as

$$\lambda = \boldsymbol{\pi} D_1 \boldsymbol{e}. \qquad (3)$$

where $\boldsymbol{\pi}$ and $\boldsymbol{e}$ are in (2).

Now let us observe $J(t)$ immediately after $t = t_n$ when the nth packet arrival occurs. Then the discrete time sequence $\{J(t_n)\}$ is an embedded Markov chain. Consider the interarrival time $X_n = t_n - t_{n-1}$, $n \geq 1$, and define the transition probability density function $f_{ij}(x)$ by

$$f_{ij}(x)dx = P[x < X_n \leq x + dx, J(t_n) = j \mid J(t_{n-1}) = i].$$

Let $F(x)$ be a $m \times m$ matrix with its ij-th entry being $f_{ij}(x)$. Then, we can find

$$F(x) = e^{D_0 x} D_1 .$$

Then the distribution function matrix for the interarrival time can be obtained [9] by

$$\tilde{F}(x) = \int_0^x f(u)du = (I - e^{D_0 x})(-D_0^{-1})D_1 \qquad (4)$$

where the matrix $-D_0^{-1}$ is nonnegative definite.

An example of the MAP process is a MMPP, in which the Poisson arrival rate is governed by the state of an underlying continuous-time Markov chain. In an MMPP, packets arrive according to a Poisson process whose instantaneous rate is a function of the state of a continuous-time finite Markov chain. Arrivals of an MMPP occur according to a Poisson process of rate λ_i, while the system is in phase *i*. In referring to the MAP model, the MMPP model corresponds to the special case. Consider a continuous time Markov chain $J(t)$ which assumes a finite number of phases $\{1, \cdots, m\}$. Its infinitesimal generator is D. When $J(t) = i$, packets are generated with Poisson rate λ_i. Then the infinitesimal generator of this MMPP $(N(t), J(t))$ takes the following structure

$$Q_{MMAP} = \begin{bmatrix} D_0 & D_1 & 0 & \cdots \\ 0 & D_0 & D_1 & \cdots \\ 0 & 0 & D_0 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

where

$$D_1 = D_{iag}[\lambda_1 \ldots \lambda_m]$$

and

$$D_0 = D - D_1$$

In this paper we propose to model both new and handoff call traffic by a MAP. We assume that new call traffic is characterized by a sequence $\{D_i^{(n)}\}_{i=0,1}$ of parameter matrices and handoff call traffic by a sequence $\{D_i^{(h)}\}_{i=0,1}$ of parameter matrices. $D_i^{(n)}{}'s$ and $D_i^{(h)}{}'s$ are $m_n \times m_n$ and $m_h \times m_h$ matrices, respectively. The sequence $\{D_i\}_{i=0,1}$ of the defining parameter matrices for the superposed new and handoff call traffic can be obtained by

$$D_i = D_i^{(n)} \oplus D_i^{(h)}, \forall i = 0, 1 \qquad (5)$$

where $\oplus$ is the Kronecker sum [2] [5]. Note that each D_i is of dimension$(m_n m_h) \times (m_n m_h)$ [17].

3. Performance Analysis

New arrival call will be modeled using a MAP with a sequence $\{D_i^{(n)}\}_{i=0,1}$ of parameter matrices and handoff call will be modeled using a MAP with a sequence $\{D_i^{(h)}\}_{i=0,1}$ of parameter matrices as described inSection 2. We assume that ongoing call (new or handoff) connection times are exponentially distributed with parameter u_c . The time spent in a given cell, before handing off, is called the cell dwell time. We assume this time is also exponentially distributed with parameter u_d . Note that new calls that find all S−S_g channels busy will leave the system and handoff calls which find all S channels busy will leave the system.

3.1 Queueing Model

Consider the embedded continuous-time Markov chain $\{(L(t), J(t)), t \geq 0\}$ of the queuing system on the two-dimensional state space ({0, 1, ..., S} × {(1, 1), (1, 2), ..., ($m_n m_h$)}), where $L(t)$, and $J(t)$ denote the channel occupancy, and the phase of the underlying MAP of superposition of handoff call and new call, at time t respectively. For convenience, the queuing system is said to be at a level *j* if its channel occupancy is equal to *j*. The embedded Markov chain now has an infinitesimal generator of the following block form

$Q=$

$$
\begin{bmatrix}
D_0 & D_1 & 0 & \cdots & 0 & 0 & 0 & \cdots & 0 & 0 \\
uI & D_0(1) & D_1 & \cdots & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 2uI & D_0(2) & \ddots & 0 & 0 & 0 & \ddots & 0 & 0 \\
\vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\
0 & 0 & 0 & \cdots & E_0(S-S_g) & I_{mn} \oplus D_1^{(h)} & 0 & \cdots & 0 & 0 \\
0 & 0 & 0 & \cdots & (S-S_g+1)uI & E_0(S-S_g+1) & I_{mn} \oplus D_1^{(h)} & \cdots & 0 & 0 \\
0 & 0 & 0 & \vdots & 0 & (S-S_g+2)uI & E_0(S-S_g+2) & \vdots & 0 & 0 \\
\vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\
0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & E_0(S-1) & I_{mn} \oplus D_1^{(h)} \\
0 & 0 & 0 & \cdots & 0 & 0 & 0 & \cdots & SuI & -SuI+D
\end{bmatrix} \quad (6)
$$

3.2 New Call Block and Handoff Call Drop Probabilities

Let $\boldsymbol{x} = (\boldsymbol{x}_0, \boldsymbol{x}_1, \ldots, \boldsymbol{x}_S)$ be the stationary probability vector of the Markov chain Q, i. e.

$$\boldsymbol{x}Q = \boldsymbol{0}, \quad \boldsymbol{x} \geq 0 \text{ and } \quad \boldsymbol{x}\boldsymbol{e} = 1, \qquad (7)$$

where $\boldsymbol{x}_k = (\boldsymbol{x}_k(1, 1), \ldots, \boldsymbol{x}_k(m_n, m_h))$, $\forall\, 0 \leq k \leq S$. Since Q is stable, we have $\boldsymbol{x}_k(j_n, j_h) = \lim_{t\to\infty} P\{L(t) = k, J(t) = (j_n, j_h)\}$, for all k, (j_n, j_h), and the vector $\boldsymbol{x}_k$ corresponds to steady state probabilities of states of the Markov chain Q at level k.

Now let $X_{block}^{(n)}$ be the number of new call blocking in the interval $[0, t)$. Then the expected value of $X_{block}^{(n)}(t)$ denoted by $E[X_{block}^{(n)}(t)]$, is given by

$$E\left[X_{block}^{(n)}(t)\right] = \sum_{S-S_g}^{S} x_i \left(D_1^{(n)} \oplus I_{mn}\right) et$$

Consequently, the new call blocking probability, denoted by $P_{block}^{(n)}$, can be calculated by

$$P_{block}^{(n)} = \frac{E\left[X_{block}^{(n)}(t)\right]}{\lambda^{(n)} t} = \frac{\sum_{i=S-S_g}^{S} x_i \left(D_1^{(n)} \oplus I_{mn}\right) e}{\lambda^{(n)}}$$

where $\lambda^{(n)}$ is the fundamental arrival rate of the new call and can be calculated by (3) with the sequence $\{D_i^{(n)}, i = 0, 1\}$ of parameter matrices. Consequently, the handoff call dropping probability, denoted by $P_{block}^{(h)}$ can be calculated

$$P_{block}^{(n)} = \frac{E\left[X_{block}^{(h)}(t)\right]}{\lambda^{(h)} t} = \frac{x_S \left(I_{mn} \oplus D_1^{(h)}\right) e}{\lambda^{(h)}}$$

where $\lambda^{(h)}$ is the fundamental arrival rate of the new call and can be calculated by (3) with the sequence $\{D_i^{(h)}, i = 0, 1\}$ of parameter matrices.

3.3 Distribution of Block and Non-block Periods

The queueing system passes through alternating block and non-block periods. The patterns of block and non-block period are then studied by decomposing the state space $\{0, 1, \ldots, S\} \times \{(1, 1), (1, 2), \ldots, (m_n, m_h)\}$ into two subsets

$$\Omega_{nb} = \{0, 1, \ldots, S - S_g - 1\} \times \{(1, 1), (1, 2), \ldots, (m_n, m_h)\}$$

$$\Omega_{b} = \{S - S_g, \ldots, S\} \times \{(1, 1), (1, 2), \ldots, (m_n, m_h)\}$$

according to the block threshold $S - S_g$. With this partition of the state space, the infinitesimal generator Q of the embedded Markov chain of the queuing system can be partitioned as

$$Q=\begin{bmatrix} U_{nb} & A_{nb} \\ A_b & U_b \end{bmatrix} \quad (8)$$

where

$$U_{nb}=\begin{bmatrix} D_0 & D_1 & \cdots & 0 & 0 \\ uI & D_0(1) & \cdots & 0 & 0 \\ 0 & 2uI & \ddots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots & (S-S_g+1)uI & D_0(S-S_g-1) \end{bmatrix}$$

$$A_{nb}=\begin{bmatrix} 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \ddots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ D_1 & 0 & \cdots & 0 & 0 \end{bmatrix}$$

$$U_b=\begin{bmatrix} E_0(S-S_g) & I_{mn}\oplus D_1^{(h)} & \cdots & 0 & 0 \\ (S-S_g+1)uI & E_0(S-S_g+1) & \cdots & 0 & 0 \\ 0 & (S-S_g+2)uI & \ddots & 0 & 0 \\ \vdots & \vdots & \cdots & \vdots & \vdots \\ 0 & 0 & & SuI & -SuI+D \end{bmatrix}$$

$$A_b=\begin{bmatrix} 0 & 0 & \cdots & 0 & (S-S_g)uI \\ 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \ddots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & 0 \end{bmatrix}$$

Matrices U_{nb}, A_{nb}, U_b and A_b are transition rate submatrices governing transitions from Ω_{nb} into itself, from Ω_{nb} into Ω_b, from Ω_b into itself and from Ω_b into Ω_{nb}, respectively. The sojourn time in each non-block period and block period is characterized by a transient Markov chain, with respect to U_{nb} and U_b for transitions on Ω_{nb} and Ω_b. Non-block and block periods are characterized by deriving the steady state probabilities for the initial state of each transient Markov chain, as denoted by vector α_{nb} for non-block and vector α_b block periods. By definition

$$\alpha_{nb}=\alpha_{nb}((-U_{nb})^{-1}\ A_{nb}(-U_b)^{-1}\ A_b),\alpha_{nb}e=1 \quad (9)$$

$$\alpha_b=\alpha_b((-U_b)^{-1}\ A_b(-U_{nb})^{-1}\ A_{nb}),\alpha_b e=1 \quad (10)$$

Let L_{nb} and L_b be the lengths of non-block and block periods, respectively. Obviously, L_{nb} and L_b are the life times of the two transient Markov chains, with respect to U_{nb} and U_b for transitions on Ω_{nb} and Ω_b. Thus, F_{nb} (t) and F_b (t) represents the distributions of all absorbing times of the transient Markov chains, with respect to U_{nb} and U_b for transitions on Ω_{nb} and Ω_b. According to the transient Markov chain theory, the Laplace transforms of the respective probability density functions of f_{Lnb} and f_{Lb} are

$$f_{Lnb}(s)=\alpha_{nb}F_{nb}(s)e=\alpha_{nb}(SI-U_{nb})^{-1}\ A_{nb}e$$

$$f_{Lb}(s)=\alpha_b F_b(s)e=\alpha_b(SI-U_b)^{-1}\ A_b e$$

The average lengths of non-block and block periods are

$$E[L_{nb}]=-\frac{d}{ds}f_{Lnb}(s)_{s=0}=\alpha_{nb}(-\frac{d}{ds}F_{nb}(s)_{s=0})e$$

$$=\alpha_{nb}(U_{nb})^{-2}\ A_{nb}e$$

$$E[L_b]=-\frac{d}{ds}f_{Lb}(s)_{s=0}=\alpha_b(-\frac{d}{ds}F_b(s)_{s=0})e$$

$$=\alpha_b(U_b)^{-2}\ A_b e$$

by $(-U_{nb})^{-1}\ A_{nb}e=e$, $(-U_b)^{-1}\ A_b e=e$, we have

$$E[L_{nb}]=\alpha_{nb}(-U_{nb})^{-1}e \quad (11)$$

$$E[L_b]=\alpha_b(-U_b)^{-1}e \quad (12)$$

3.4 Handoff Call Drop Probability During a Block Period

To investigate the drop behavior during a block period, submatrix U_b is written as

$$U_b = U_b^{(h)}(0) + U_b^{(h)}$$

The matrix $U_b^{(h)}(0)$ comprises the probabilities that make state transitions within Ω_b without any handoff call drops. However, the matrix $U_b^{(h)}(1)$, comprises the probabilities that make state transitions within Ω_b with a handoff call drop. and

$U_b^{(h)}(0)=$

$$\begin{bmatrix} E_0(S-S_g) & I_{mn}\oplus D_1^{(h)} & \cdots & 0 & 0 \\ (S-S_g+1)uI & E_0(S-S_g+1) & \cdots & 0 & 0 \\ 0 & (S-S_g+2)uI & \ddots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots & SuI & E_0(S) \end{bmatrix}$$

$$U_b^{(h)}(1) = \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \ddots & 0 & 0 \\ \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & I_{mn}\oplus D_1^{(h)} \end{bmatrix}$$

Notably, the behavior of the queuing system during a block period can be described by the transient Markov chain, U_b for transitions on Ω_b. For a state $(i, (j1, j2))$ in Ω_b, let $P_{(i,(j1,j2)),b}^{(h)}(\ell,t)$ be the probability hat the state of transient Markov process enters $(i, (j1, j2))$ with a total of ℓ handoff call dropped during $[0, t)$. Let $P_b^{(h)}(\ell,t)$ be an $|\Omega_b|$-vector whose $(i, (j1, j2))$-th element dropped probability is $P_{(i,(j1,j2)),b}^{(h)}(\ell,t)$.Furthermore, the initial vector $P_b^{(h)}(0,0)$ can be determined based on the behavior of the queuing system during a previous non-block period as

$$P_b^{(h)}(0,0) = \int_0^{\infty} \alpha_{nb} \exp(U_{nb}t)\ A_{nb}dt = -\alpha_{nb} U_{nb}^{-1} A_{nb}$$

Additionally, the vecto r $P_b^{(h)}(\ell,t)$, $t > 0$, $\ell \geq 0$, can be obtained by the differential equation

$$\frac{\partial}{\partial t} P_b^{(h)}(\ell,t) = P_b^{(h)}(\ell,t)\, U_b^{(h)}(0) + P_b^{(h)}(\ell-1,t)\, U_b^{(h)}(1) \qquad (13)$$

Let $P_b^{(h)}(z,t)$ be the generating function of $P_b^{(h)}(\ell,t)$, then by (13)

$$\frac{\partial}{\partial t} P_b^{(h)}(z,t) = P_b^{(h)}(z,t)\, U_b^{(h)}(z)$$

$$P_b^{(h)}(z,0) = -\alpha_{nb} U_{nb}^{-1} A_{nb}$$

Where $U_b^{(h)}(z) = U_b^{(h)}(0) + z\, U_b^{(h)}(1)$ is the generating function of the sequences $\{U_b^{(h)}(\ell), \ell = 0,1\}$. Sloving the above differential equation gives

$$P_b^{(h)}(z,t) = P_b^{(h)}(z,0) \exp\left(U_b^{(h)}(z)t\right) = -\alpha_{nb} U_{nb}^{-1} A_{nb} \exp\left(U_b^{(h)}(z)t\right) \qquad (14)$$

Next, let $X_{drop,b}^{(h)}$ be the number of handoff call drops during a block period and $P_{drop,b}^{(h)}(\ell,t) = \Pr\{X_{drop,b}^{(h)} = \ell, L_b \leq t\}$ be the probability that there are ℓ handoff call drops during a block period of length no greater than t. Then

$$\frac{\partial}{\partial t} P_{drop,b}^{(h)}(\ell,t) = P_b^{(h)}(\ell,t)\ A_b e$$

Which means that the probability density function of L_b with $X_{drop,b}^{(h)} = \ell$, is $P_b^{(h)}(\ell,t)\ A_b e$. Let $P_b^{(h)}(z,t)$ be the generating function of

$P^{(h)}_{drop,b}(\xi,t)$. Then

$$\frac{\partial}{\partial t}P^{(h)}_{drop,b}(z,t) = P^{(h)}_{b}(z,t)\ A_b e$$

Let $P^{(h)}_{drop,b}(z,s)$ be the Laplace-Stieltjes transform of $P^{(h)}_{drop,b}(z,t)$, Then

$$P^{(h)}_{drop,b}(z,s) = P^{(h)}_{b}(z,s)\ A_b e_{=}$$

$$-\ \alpha_{nb} U_{nb}{}^{-1} A_{nb}(sI - U^{(h)}_{b}(z))^{-1}\ A_b e \qquad (15)$$

By(14). Now the average total number of call drop during a back period, denoted, can be calculated as

$$E\left[X^{(h)}_{drop,b}\right] = \frac{\partial}{\partial z} P^{(h)}_{drop,b}(z,s)_{z=1,s=0}$$

$$= \alpha_{nb} U_{nb}{}^{-1}(-\ A_{nb} U_b{}^{-1}\frac{d}{dz}U_b(z)_{z=1})U_b{}^{-1}\ A_b e$$

$$= -\alpha_b U_b{}^{-1} U^{(h)}_{b}(1) e \qquad (16)$$

By $\alpha_b = -\alpha_{nb} U_{nb}{}^{-1}\ A_{nb}$ and $-U_b{}^{-1}\ A_b e = e$. Drop probability during a block period can be obtained by

$$P^{(h)}_{drop,b} = \frac{E\left[X^{(h)}_{drop,b}\right]}{\lambda^{(h)} E[L_b]} \qquad (17)$$

By the renewal reward theorem [21], the long-term handoff call drop probability of a cycle(a non-block period and a block period)is

$$P^{(h)}_{drop} = \frac{E\left[X^{(h)}_{drop,b}\right]}{E[L_{nb}] + E[L_b]}\frac{1}{\lambda^{(h)}} \qquad (18)$$

where $E[L_{nb}] + E[L_b]$is the average length of a cycle, from (17) we have

$$P^{(h)}_{drop} = \frac{E[L_b]}{E[L_{nb}] + E[L_b]}\ P^{(h)}_{drop,b} \qquad (19)$$

Thus the handoff call drop probability is obtained from short-turm performance measures $E[L_{nb}], E[L_b], P^{(h)}_{drop,b}$.

4. Numerical Results and Discussion

In this section, we will investigate the numerical results under MAP new call and handoff call. In experiments, the numerical values of the MAP parameters of handoff call used:

$$D^{(h)} = \begin{bmatrix} -0.521906066 & 0.0037279 & 0.518178166 \\ 0.00434921 & -0.005591851 & 0.00042634 \\ 2.259107688 & 0.006213167 & -2.265320855 \end{bmatrix}$$

$$D^{(h)}_1 = \eta^{(h)} \begin{bmatrix} 0.020503453 & 0 & 0.518178166 \\ 0 & 0.017396869 & 0.000621317 \\ 2.259107688 & 0.004970534 & 0.004349217 \end{bmatrix}$$

$$D^{(h)}_0 = D^{(h)} - D^{(h)}_1$$

and the numerical values of the MAP parameters of new call used:

$$D^{(n)} = \begin{bmatrix} -0.521906066 & 0.0037279 & 0.518178166 \\ 0 & 0.017396869 & 0.00042634 \\ 2.259107688 & 0.006213167 & -2.265320855 \end{bmatrix}$$

$$D^{(n)}_1 = \eta^{(n)} \begin{bmatrix} 0.020503453 & 0 & 0.518178166 \\ 0 & 0.017396869 & 0.000621317 \\ 2.259107688 & 0.004970534 & 0.004349217 \end{bmatrix}$$

$$D^{(n)}_0 = D^{(n)} - D^{(n)}_1$$

We set $1/u_c$=200 sec. We consider the case corresponding to a macrocell of radius 10 km and we assume vehicles travel at the average speed 60km/hr. Average dwell time $1/u_d$=940sec. Probability of a handoff isP_h= $u_d/(u_c+u_d)$= 0.17. Then the relation between the two traffic intensities is obtained [23]

$$\lambda^{(h)} \approx \frac{P_h}{1-P_h}\lambda^{(n)} = 0.2048\lambda^{(n)}$$

Here we used the parameter $\rho^{(n)} = \lambda^{(n)}/S(u_c+u_d)$The new call arrival rate is adjusted so that the queue will have a different traffic condition. The channel capacity S is taken to be 50.Consider the guard channel handoff reservation scheme to the macrocell examples. Recall that the intensity $\rho^{(h)}$ of handoff call in terms of the new call arrival intensity was 0.2048$\rho^{(n)}$. The performance measures are shown in Figures 1–4 for a number of values of the newcall arrival intensity and for various values of S_g. As shown in Figure 1, results are as expected:for a given new call intensity $\rho^{(n)}$, the handoff call drop probability does decrease as S_g increase, with the new call block probability increasing at the same time. Figure 1 also show the expected increase of both the new call block probability and the handoff call drop probability with increasing traffic intensity $\rho^{(n)}$. They also show that there is a trade-off between the new call block and the handoff call drop probabilities. As the number $S_g$of guard channel reserved for handoff calls increases, the new call block probability $P_{drop}^{(n)}$ increases while its handoff call counterpart $P_{drop}^{(h)}$decreases, as expected. But the increase rate of $P_{drop}^{(n)}$is not as high as the the decay rate of $P_{drop}^{(h)}$.

It is apparent that the relative improvement in handoff call drop probability in this case is substantially greater than the relative increase in new call block probability. Note that with $\rho^{(n)}$ =0.6, the two probabilities at the values of 1.66×10^{-2} and 0.2, respectively, with one of the fifty channels as a guard channel. With ten guard channels assigned, the handoff call drop probability decreases further to 7.12×10^{-8}, a factor of about 10^{6} decrease, while the new call block probability increase to0.4, a much smaller increase. Further increases in the number of guard channels are possible, but the resultant new call block probability becomes quit high. Note that with guard channels S_g from 1 to 10, the handoff call drop probability drops to extremely small values, ranging from1.66×10^{-2}to7.72×10^{-8}over the range of traffic intensity $\rho^{(n)}$ = 0.6. The corresponding new call block probability ranges from 0.2 to 0.4. The resultant new call block probability becomes quit high in these cases. Increasing the number of channels would reduceboth probabilities. The introduction of guard channels therefore have the desired effect: on-going calls are much less likely to be dropped during handoff. What would a good design choice be for this macrocell example with S=50 channels assigned per cell?It would appear that operating at a new call traffic intensity of $\rho^{(n)}$= 0.6 would provide tolerable performance. A five channels allocated to handoff calls would provide a handoff call drop probability of about 5.89×10^{-5}, while the corresponding new call block probability would be about 0.3.

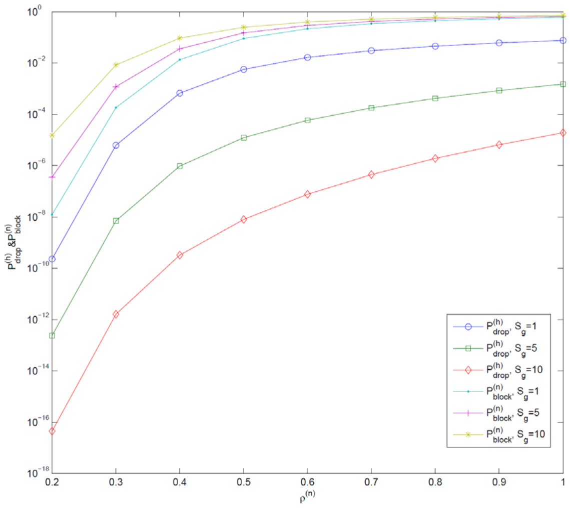

Figure 1: Handoff call drop probability and new call block probability with cell capacity S=50, and guard channel S_g =1,5,10.

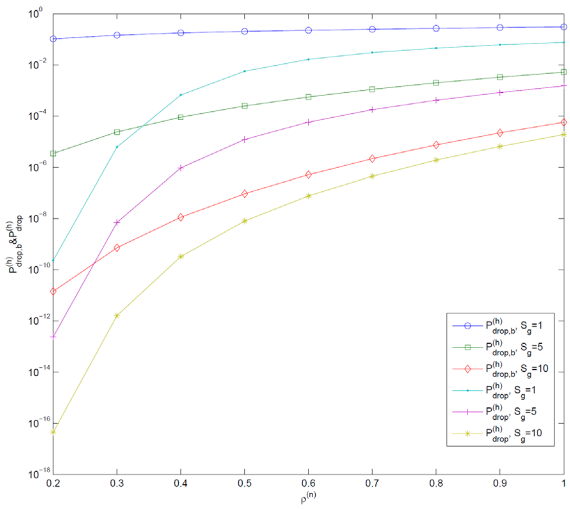

Figure 2: Comparison of handoff call drop probability and conditional handoff call drop probability with cell capacity S=50, and guard channel S_g =1,5,10.

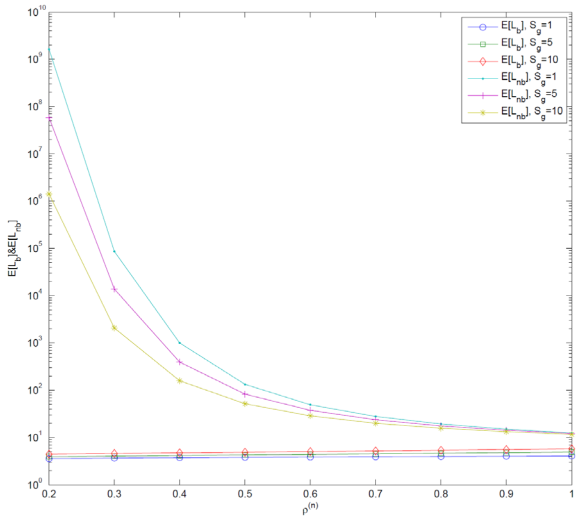

Figure 3: Average length of block and non-block periods with cell capacity S =50, and guard channel S_g =1,5,10.

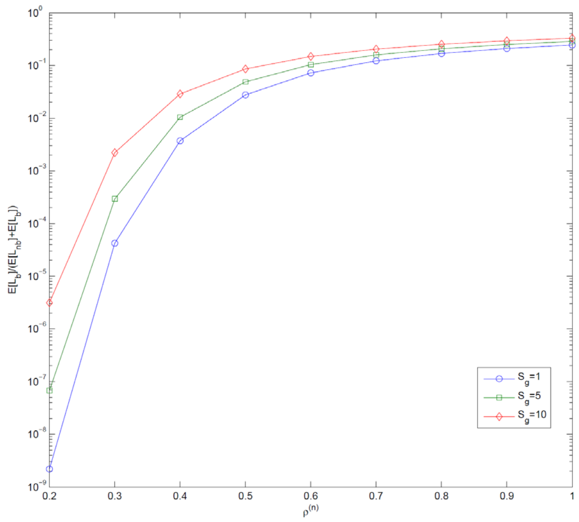

Figure 4: Probability that cell remains in block period with cell capacity S =50, and guard channel S_g =1,5,10.

The discussion above confirms that the guard channel reservation handoff scheme is an effective mechanism to guarantee the drop probability for handoff calls by adjusting the guard channel value S_g as follows. When the value of $P^{(h)}_{drop}$ is too high to satisfy the drop probability of the handoff call, the threshold value S^{-S_g} is decreased to reserve more guard channel for the handoff calls. And when the value of $P^{(h)}_{drop}$ is lower than the drop probability guaranteed value, the threshold value S^{-S_g} is increased to increase channel sharing among all arriving calls, both handoff and new. As a result, not only is the drop probability for handoff calls maintained but also near-optimum utilization of the capacity for new calls is provided.

The conditional handoff call drop probability $P^{(h)}_{drop,b}$ is shown in Figure 2 for a number of values of the new call arrival intensity and for various values of S_g. As shown in Figure 2, results are as expected: for a given new call intensity $\rho^{(n)}$, the conditional handoff call drop probability does decrease as S_g increase. Figure 2 also show the expected increase of the conditional handoff call drop probability with increasing traffic intensity $\rho^{(n)}$. In Figure 2, it can be seen that conditional handoff call drop probability $P^{(h)}_{drop}$ is higher than handoff call drop probability $P^{(h)}_{drop}$. The difference is more import in light-to-moderate load conditions than in heavy load condition. This confirms to our general expectation.

It is apparent that the conditional handoff call drop probability in this case is substantially greater than the handoff call drop probability. Note that with $\rho^{(n)}$= 0.6, the two probabilities start off at the values of 0.23 and 0.17, respectively, with one of the fifty channels as a guard channel. With five guard channels assigned, the conditional handoff drop probability decreases further to 5.65×10^{-4} , while the handoff call drop probability decrease to 5.89×10^{-5} , a much larger decrease. Further increases in the number of guard channels are possible, but the resultant drop probability becomes quit low. Figure 2 shows that with S_g=1, 5, 10, the difference between the conditional handoff drop probability and handoff call drop probability is extremely large values, over the range of traffic intensity $\rho^{(n)}$ from 0.2 to 0.6. The difference between the conditional handoff drop probability and handoff call drop probability is extremely small values, over the range of traffic intensity $\rho^{(n)}$ from 0.7 to 1.Increasing the number of channels would increase the distance between both probabilities.

Figure 3 summarizes the numerical results of the average lengths of a block period $E[L_b]$ and non-block period $E[L_{nb}]$with respect to a number of values of the new call arrival intensity $\rho^{(n)}$and for various values of S_g. As expected, the average length $E[L_{nb}]$of a non-block period is much longer than that of a block period under a light-to-moderate load condition, and $E[L_{nb}]$ decreases as S_g increases. The decay is more import in a light-to-moderate load condition than in a heavy load condition. As expected, $E[L_{nb}]$increases as

S_g increases. The increase is more import in a moderate-to-heavy load condition than in a light load condition. Because a block period and a non-block period consist of a cycle, decreases the average length of the non-block period by a larger factor would reduce the length of the cycle. This effect causes the system to frequently alternate block periods and non-block periods. Because the system alternates between non-block periods and block periods, increasing the new call arrival intensity $\rho^{(n)}$ increases the probability that the system remains in the block period.

As shown in Figure 3, note that with the range of guard channels S_g from 1 to 10, the average length of block period increases to extremely small values, ranging from 3.6 to 5.8 over the range of traffic intensity $\rho^{(n)}$ from 0.2 to 1.As shown in Figure 3, note that with $\rho^{(n)} = 0.4$, the average length of non-block period at the value of 1.0×10^{3}, with one of the fifty channels as a guard channel. With ten guard channels assigned, the average length of non-block period reduce further to 1.6×10^{2}, a factor of about 10 decrease. Because the block period and the non-block period consist of a cycle, it increases the probability of staying in the block period in this case. Increasing the number of channels would reduce the average length of block period and increase the average length of non-block period.

5. Conclusion

In this paper, we have presented an matrix-analytical performance model to study new call block and handoff call drop for MAP. The proposed model may be of great interest in the design of 3G cellular mobile networks. We have investigated the handoff call drop probability during block period by means of conditional statistics with respect to block and non-block periods that occur in an alternating manner, in addition to the evaluation of the handoff call and new call probabilities. This shows that the application of the matrix-analytical approach to the performance measures of guard channel reservation handoff scheme is computationally tractable. We also compute and discuss numerical results to confirm our expectation of the guard channel reservation handoff scheme as an effective mechanism not only to provide the drop probability guarantee for the handoff call, by adjusting the threshold value of the guard channel, but also to provide the near-optimum utilization of the channel capacity for the new call.

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