Performance Analysis of a Preemptive and Priority Reservation Handoff Scheme for Integrated Service-Based Wireless Mobile Networks

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Abstract—In this paper, we propose an analytical model for integrated real-time and non-real-time service in a wireless mobile network with priority reservation and preemptive priority handoff schemes. We categorize the service calls into four different types, namely, real-time and non-real-time service originating calls, and real-time and non real-time handoff service request calls. Accordingly, the channels in each cell are divided into three parts: one is for real-time service calls only, the second is for non-real-time service calls only, and the last one is for overflow of handoff requests that cannot be served in the first two parts. In the third group, several channels are reserved exclusively for real-time service handoffs so that higher priority can be given to them. In addition, a real-time service handoff request has the right to preempt non-real-time service in the preemptive priority handoff scheme if no free channels are available, while the interrupted non-real-time service call returns to its handoff request queue. The system is modeled using a multidimensional Markov chain and a numerical analysis is presented to estimate blocking probabilities of originating calls, forced termination probability, and average transmission delay. This scheme is also simulated under different call holding time and cell dwell time distributions. It is observed that the simulation results closely match the analytical model. Our scheme significantly reduces the forced termination probability of real-time service calls. The probability of packet loss of non-real-time transmission is shown to be negligibly small, as a non-real-time service handoff request in waiting can be transferred from the queue of the current base station to another one.

Index Terms—Analytical model, blocking probability, forced termination probability, handoff, integrated service, mobile networks, preemptive reservation, priority, real-time/ non-real-time, transmission delay.

✦

1 INTRODUCTION

WIRELESS data service is not a totally new topic; some crude forms of wireless data services were present even in AMPS and GSM system [1]. However, the data service in second-generation mobile networks is limited only to short messages or very low-speed data applications (such as plain e-mail) because of the limited transmission rate and the existing billing philosophy. Table 1 shows a comparison of service types in second and third generation wireless mobile networks. However, with the increase in demand for an integrated wireless service solution, limited data service may be far from being acceptable. Business customers are very interested in an integrated mobile service if it can be provided at any time and any place, and information access is feasible to their employees and key customers. Service providers are extremely interested in supporting value-added services to maximize the utilization of their infrastructure. These value added services include, but not limited to brokerage, banking, emergency services, traffic reporting, navigating, gambling, shopping, advertising, greeting for special event, music on demand, interactive gaming and entertainment, and video subscription news. Thanks to the advances in wireless and VLSI technologies, this kind of value-added integrated service is finally becoming a reality. Several data-capable multimedia-ready cell phones, Pocket PCs, and Palms are already available in the market. With the development of next generation wireless mobile network infrastructure, customers can take full advantage of the Internet and Intranet for a seamless, boundless, effortless, and secure communication services.

In order to support a true combination of real-time service and non-real-time service and maximize the utilization of network infrastructure, Quality of Service (QoS) has to be taken into consideration while designing the infrastructure. One of the central issues characterizing the performance is how the handoff is handled [1]. Handoff primarily represents a process of changing some of the parameters of a channel (frequency, time slot, spreading code, or combination of them) associated with an existing connection. It is often initiated either by crossing a cell boundary or by a deteriorated quality of signal received on a currently employed channel. Poorly designed handoff schemes tend to generate heavy signaling traffic and, thereby, a decrease in QoS. With the introduction of next generation wireless mobile networks and personal communication systems,

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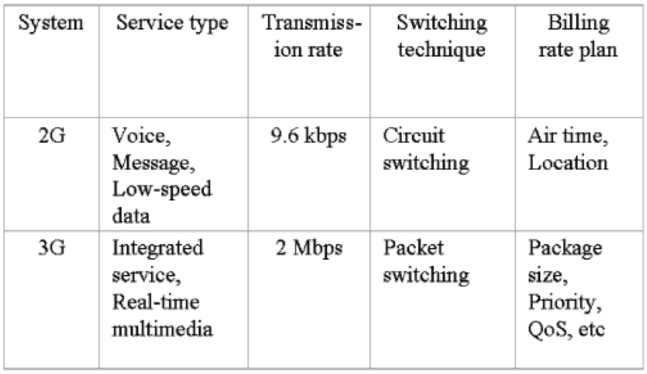
TABLE 1
Comparisons of Service Types in 2G and 3G Mobile Network



System	Service type	Transmission rate	Switching technique	Billing rate plan
2G	Voice, Message, Low-speed data	9.6 kbps	Circuit switching	Air time, Location
3G	Integrated service, Real-time multimedia	2 Mbps	Packet switching	Package size, Priority, QoS, etc

microcell, picocell, and hybrid cell structures [2] are being exploited to support a drastic increase in demand. More frequent handoffs will occur if the size of the cell is made smaller and the propagation conditions of signals do not improve drastically. Therefore, the handoff strategy should be given careful consideration, especially in next generation wireless mobile networks.

A good design of a handoff scheme anticipates the blocking probability of originating calls to be minimized as much as possible. However, from the user's point of view, handoff request traffic is more important as forced termination of an ongoing call is more annoying than blocking of a new call. In addition, attempts should be made to decrease the transmission delay of non-real-time service calls, as well as increase channel utilization in a fair manner. Unfortunately, all requirements cannot be satisfied simultaneously and there are trade offs between various parameters. In this paper, we focus on concurrent minimization of the forced termination probability of real-time service without drastically sacrificing other QoS parameters.

The study of handoff is not a new topic to the wireless communication world. The simplest way of assigning priority to handoff requests is to reserve a fixed number of channels for them, which is called a guard channel scheme [1], [3]. In a frequently referenced paper of Hong and Rapapport [4], a system with voice handoff queue has been studied. In [5], a system with queue for voice originating calls has been proposed. Both the originating calls and handoff requests are allowed to be queued in [6]. Handoff schemes with two-level priority reservation have been proposed in [7], [8]. Cellular systems that support a mixed type of platform are considered in [9], [10]. However, in all of the above studies, the research focuses on voice-based cellular systems only and multiple types of services have not been taken into consideration.

With the development of integrated wireless mobile systems, non-real-time service has to be incorporated and its effect needs to be taken into account [11]. A handoff scheme for a non-real-time wireless network only has been studied in [12]. However, future wireless networks will be required to support multiple types of services simultaneously. In order to meet future demands, a handoff strategy needs to take different features of these services into account, i.e., the ideal handoff processes have to be service-dependent. For example, transmission of real-time service is very sensitive to interruptions. On the other hand, transmission delay of non-real-time service does not have any significant impact on the performance of their service, i.e., they are delay insensitive. Therefore, a successful handoff without interruption is very important for real-time services, but not so critical for non-real-time services. A two-dimensional model for integrated service cellular mobile systems has been proposed in [13], which assigns preemptive priority to real-time service calls. However, no distinction is made between originating and handoff requests. In [14], a handoff scheme for the integrated voice/data wireless network has been introduced, while only data service handoff requests are allowed to be queued.

In this paper, we introduce a service-dependent priority handoff scheme based on channel reservation for integrated real-time and non-real-time service wireless mobile networks in Section 2. Based on whether the real-time service handoff request has the right to preempt the ongoing non-real-time service call, two different priority reservation handoff schemes have been proposed. An analytical model for proposed handoff schemes is also provided. The closed formula for blocking probabilities of both real-time and non-real-time originating calls, forced termination probability of real-time service, and average transmission delay for non-real-time service are given in Section 4. Simulation based on a general distribution of call holding time and cell dwell time is presented. Numerical results with the exponential and gamma distributions are given in Section 5. Finally, concluding remarks are given in Section 6.

2 SYSTEM MODEL

For simplicity, we consider a system with homogenous cells and a fixed number of S channels which are permanently assigned to each cell. In such a system, we focus our attention on a single cell, which we call the reference cell. When a mobile user dials the number and contacts the base station of the reference cell, an originating call is generated in the reference cell. When a real-time service mobile user holding a channel enters the handoff area of the reference cell from a neighboring cell, a real-time service handoff request is generated. There is no handoff area for non-real-time service mobile users. Instead, we use the cell boundary, which is defined by the points where the received signal strength between two adjacent cells is equal. When a non-real-time service mobile user holding a channel approaches the reference cell and crosses the cell boundary, a non-real-time service handoff request is generated.

The system model for the reference cell is shown in Fig. 1. The total number of channels S of a reference cell are divided into three groups, namely,

1. Real-time service Channels (RC) group with capacity S_R,
2. Common handoff Channels (CC) group with capacity S_C, and
3. Non-real-time service Channels (NC) group with capacity S_N,

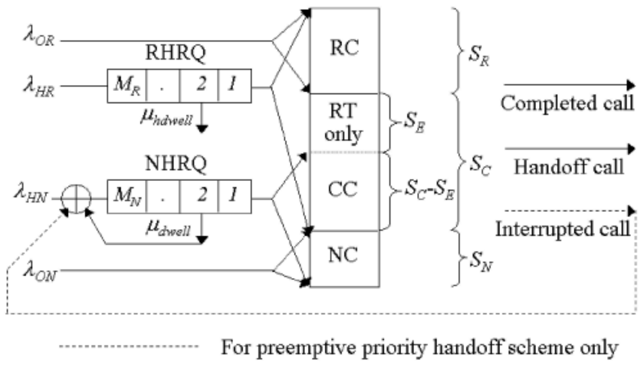


Fig. 1. System model for a reference cell.

RC is reserved for real-time service calls only, including both real-time originating calls (λ_{OR}) and handoff request calls (λ_{HR}). NC is reserved for non-real-time service calls only, including both non-real-time originating calls (λ_{ON}) and handoff request calls (λ_{HN}). CC is for the overflow of real-time and non-real-time service handoff requests from the first two groups of channels. Out of CC, a few channels are reserved exclusively for real-time service handoff requests only. We use S_E to mark the predefined number of free channel reserved before non-real-time service handoff request calls could be served in CC. There are two queues in the reference cell, real-time service handoff request queue (RHRQ) and non-real-time service handoff request queue (NHRQ). RHRQ with finite capacity M_R serves the real-time service handoff request calls and NHRQ with finite capacity M_N serves the non-real-time service handoff request calls. The originating service calls do not have their own queues.

When an originating real-time service call arrives, it can be served only if there are channels available in RC. Similarly, an originating non-real-time service call can be served only if there are idle channels in NC. An originating real-time service call (or an originating non-real-time service call) is blocked if it finds no channels available in the RC (or NC). Fig. 2 shows the flow diagram for handling originating calls in the handoff scheme proposed here.

Fig. 3 shows the flow diagram for handling handoff request calls. When a real-time service user holding a channel enters the handoff area of the reference cell, a handoff request of real-time service is generated. The real-time service handoff request call first checks whether there are channels available in RC on arrival. If RC is full, it checks whether there are channels available in CC. For the priority reservation handoff scheme, the real-time service handoff request call is put in RHRQ if both RC and CC are full. However, in the preemptive priority handoff scheme, the real-time service handoff request call has a higher priority and can be served even if there is no idle channel in both RC and CC. With preemptive procedure, the real-time service handoff request calls can get served by preempting one of the current non-real-time handoff request calls in CC if there is at least one ongoing non-real-time service call in CC and NHRQ that is not full. The interrupted non-real-time service call returns back to NHRQ and waits for an idle channel to be served based on the first-in-first-out rule. We could possibly consider another preemptive procedure, where a real-time service handoff request call can preempt non-real-time service calls irrespective of NHRQ being full or not. However, this does not cause significant difference in a very large NHRQ buffer. In both schemes, the real-time service handoff request is queued in RHRQ when it cannot get the service. When RHRQ is fully occupied by prior calls, the real-time service handoff request is blocked. The maximum allowed waiting time for the real-time service handoff requests in RHRQ is the dwell time of a real-time service mobile user in the handoff area. The real-time service handoff requests waiting in RHRQ ought to be dropped if the mobile user moves out of handoff area before it gets the service.

When a non-real-time service mobile user holding a channel crosses the cell boundary and enters the reference cell, a non-real-time service handoff request is generated. The non-real-time service handoff request call is to be served in NC if there is a channel available in NC. If NC is full, it can be served in CC only if the number of idle channels in CC is larger than the predefined reservation number S_E. Otherwise, it is put into NHRQ. A non-real-time service handoff request is blocked on arrival if NHRQ is full. The non-real-time service handoff requests in NHRQ can be transferred from the reference cell to one of the target cells when the mobile user moves out of the reference cell

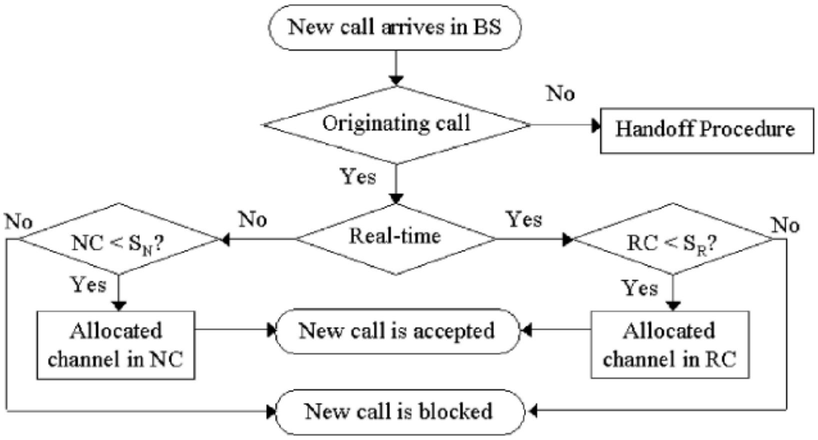


Fig. 2. Flow diagram for handling originating calls.

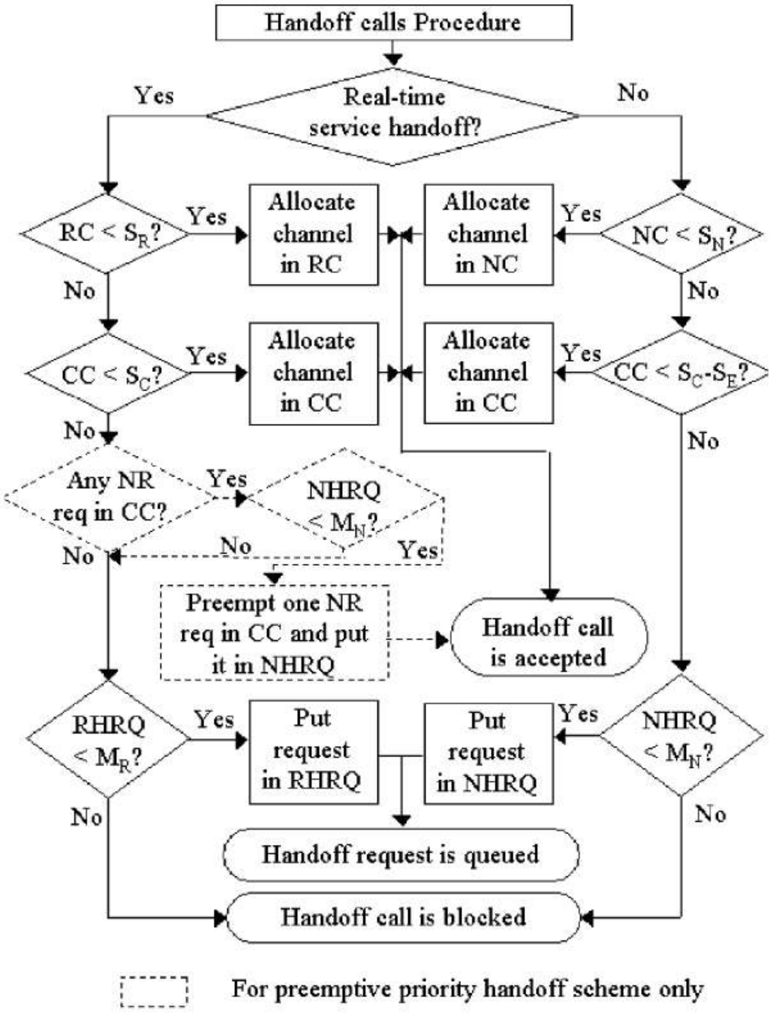


Fig. 3. Flow diagram for handling handoff request calls.

before it gets service. Therefore, if the size of NHRQ is large enough to hold all the non-real-time handoff requests, the forced termination of non-real-time service would never happen. Indeed, we do not need an infinite buffer to hold the non-real-time service handoff request because the maximum possible waiting time of non-real-time service handoff request in NHRQ is equal to the dwell time of non-real-time service subscribers in the reference cell, even if the non-real-time service user does not get service in the reference cell.

A blocked real-time service handoff request call still keep the communication via the current base station until the received signal strength goes below the receiving threshold. However, in this paper, we neglect the probability that a blocked real-time service handoff request call completes the communication before the received signal strength goes below the receiving threshold. A blocked handoff request can repeat trial handoff until the received signal strength goes below the receiving threshold. However, we do not consider repeated trials of blocked handoff requests.

3 THE TRAFFIC MODEL

To develop a detailed analytical model for the proposed handoff scheme and QoS model, a traffic model for wireless mobile networks has to be developed first. There are three characteristics of a traffic model:

1. call arrival process,
2. call holding time, and
3. cell dwell time.

A lot of research has been done to define the most suitable traffic model for wireless networks. For the call arrival process, we can safely assume that the call arrival is a Possion process. If there are enough mobile users in one cell, the call arrival at a base station is a Possion process, even if the call arrival for an individual mobile user is not. For the call holding time and the cell dwell time, two main approaches can be found in the literatures. One way is to model the call holding time and the cell dwell time as general independent identically distributed (iid) with nonlattice distribution. This approach has been intensively studied by Fang et al. [15], Lin et al. [16], Fang et al. [17], and Bolotin in [18]. After studying general iid distribution, they use models such as gamma, hyperexponential, log-normal, or hyper-Erlang distributions to compute numerical results. The second approach is based on the user's mobility, the shape and size of the cell, and exponential distribution to determine the distribution of the cell dwell time and the channel holding time. This method has been extensively used by Hong and Rappaport [4], Zeng et al. [8], and Nanda [19]. Both approaches have their own advantages, while it's important but very hard to identify the call holding time and the cell dwell time to reflect characteristics of a real system. For example, some field data show that exponential call holding time distribution assumption is reasonable [20], but other field data show that gamma and lognormal distributions provide good approximations for call holding time [15]. Since the focus of this paper is the integrated service handoff scheme and an analytical model for the QoS, instead of a traffic model, we choose the second approach and select exponential distribution for the call holding time and the cell dwell time to make the Markov model tractable in the analytical section. However, in the numerical and simulation results section, we implement the first approach as well as give a camparison between the results of these two approaches.

3.1 Cell Dwell Time

We assume that both the real-time and non-real-time service subscribers have the same probability distributions of moving speed. Let $f_V(v)$ be the probability density function (pdf) of the speed V of the mobile users with mean $E[V]$. We choose the fluid flow model, which assumes that a uniform density of users throughout the researched area and a user is equally likely to move in any direction with arbitrary distribution of moving speed as the mobility model for mobile users. For two-dimensional fluid flow model, the average outgoing rate μ_{dwell} of a mobile unit within a cell is given by

$$\mu_{dwell} = E[V]L/(\pi\ A), \tag{1}$$

where L is the length of the perimeter of a cell with arbitrary shape and A is the area of the cell. If we assume that the cell dwell time T_{dwell} has a random exponential distribution with mean $1/\mu_{dwell}$, then the average cell dwell time is given by

$$E[T_{dwell}] = \pi A/(E[V]L). \tag{2}$$

3.2 Handoff Area Dwell Time

Based on the pdf $f_V(v)$ of the speed of real-time service subscribers, the pdf $f_{V^*}(v)$ of the speed of real-time service subscribers crossing the cell's boundary V^* is given by

$$f_{V^*}(v) = v f_V(v)/E[V]. \tag{3}$$

We represent the dwell time of real-time service subscribers in the handoff area as the random variable T_h, and are given by

$$T_h = D/V^*, \tag{4}$$

where random variable D is the length of moving path of the mobile users in the handoff area. Assuming that the path length and velocity of mobile users are independent, we have

$$E\left[\frac{1}{V^*}\right] = \int_0^\infty \frac{1}{v} f_{V^*}(v)dv = \int_0^\infty \frac{f_{V^*}(v)}{E[V]}dv = \frac{1}{E[V]}. \tag{5}$$

Therefore, we can get the average handoff area dwell time $E[T_h]$ using relations (3) and (4) as

$$E[T_h] = 1/\mu_{hdwell} = E[D]/E[V]. \tag{6}$$

The random variable T_h is assumed to have an exponential distribution with the above average.

3.3 Channel Holding Time

We assume that the call holding time T_{CR} and T_{CN} of real-time service calls and non-real-time service calls have an exponential distribution with mean $1/\mu_{CR}$ and $1/\mu_{CN}$, respectively. Therefore, the channel holding time T_R (or T_N) of a service call is equal to the lesser value of T_{dwell} and T_{CR} (or T_{CN}). The memoryless property of the exponential pdf leads to

$$E[T_R] = 1/\mu_R = 1/(\mu_{CR} + \mu_{dwell}), \tag{7}$$

and

$$E[T_N] = 1/\mu_N = 1/(\mu_{CN} + \mu_{dwell}). \tag{8}$$

The channel holding time T_R and T_N are exponentially distributed with mean $E[T_R]$ and $E[T_N]$.

3.4 Arrival Process of Service Calls

We assume that the arrival rates of originating real-time service and non-real-time service calls follow Poisson processes in the reference cell. The average arrival rates of originating real-time service and non-real-time service calls are denoted by λ_{OR} and λ_{ON}, respectively. For the arrival rate of real-time service handoff requests λ_{HR}, we cannot arbitrarily assume that it is directly related to λ_{OR}. We have to compute it by the following method: If the call holding time of a mobile user is greater than the dwell time in the cell, a handoff request is initialized in the neighboring cell. Since we assume a system with homogeneous mobility pattern, the mean number of incoming calls in the reference cell is equal to that of outgoing ones from the reference cell. Therefore, the arrival rate of real-time service handoff request calls into the reference cell is equal to the departure rate of real-time service handoff calls from the cell. For the outgoing rate λ_{OUTR} of real-time handoff request in a referenced cell, we have

$$\lambda_{OUT\ R} = E[C_R]\mu_{dwell}, \tag{9}$$

where $E[C_R]$ is the average number of real-time service calls holding channels in the reference cell. Therefore, the average arrival rate of real-time service handoff requests λ_{HR} is given by

$$\lambda_{HR} = \lambda_{OUT\ R} = E[C_R]\mu_{dwell}. \tag{10}$$

Similarly, for non-real-time service users, the outgoing rate of calls without completing their communication in the reference cell is $E[C_N]\mu_{dwell}$, $E[C_N]$ is the average number of non-real-time service users holding channels in a cell. The first part of the arrival rate of non-real-time service handoff request calls is given by

$$\lambda_{HN1} = E[C_N]\mu_{dwell}. \tag{11}$$

A non-real-time service handoff request in the queue of the current cell is transferred to the queue of the target cell when the non-real-time service mobile user moves out of the cell before getting a channel. Therefore, the second part of the arrival rate of non-real-time service handoff request calls is given by

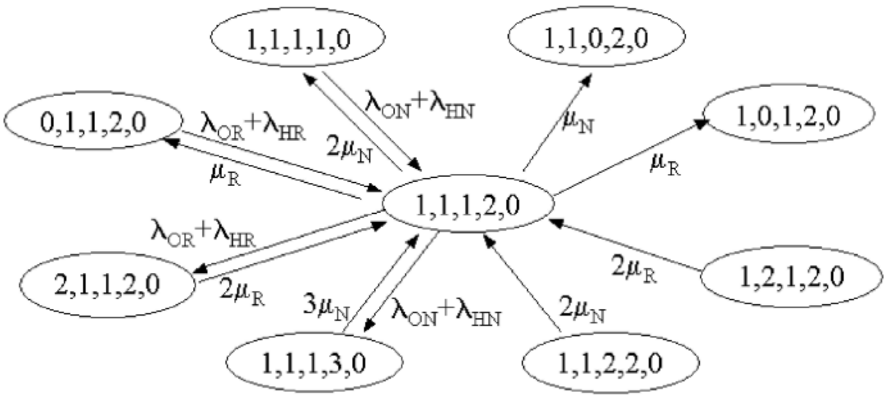


Fig. 4. Stable state transition diagram for State (i = 1, j = 1, k = 1, 1 = 2, $m = 0$).

$$\lambda_{HN2} = E[L_N]\mu_{dwell}, \tag{12}$$

where $E[L_N]$ is the average length of NHRQ. Combining (11) and (12), we can get the arrival rate of non-real-time service handoff requests λ_{HN} by

$$\lambda_{HN} = \lambda_{HN1} + \lambda_{HN2} = E[N_N]\mu_{dwell}, \tag{13}$$

where $E[N_N]$ is the average number of both non-real-time service requests and calls in the reference cell, i.e.,

$$E[N_N] = E[C_N] + E[L_N]. \tag{14}$$

We assume that the arrival time interval of each type of call is an exponential distribution with above mean. Thus, the total arrival rate of calls in a cell is given by

$$\lambda = \lambda_{OR} + \lambda_{ON} + \lambda_{HR} + \lambda_{HN}. \tag{15}$$

4 PERFORMANCE ANALYSIS

We define the state of the referenced cell by a five-tuple of nonnegative integers (i, j, k, l, m), where

- i is the number of channels used by real-time service calls (including originating calls and handoff request calls) in RC,
- j is the sum of the number of real-time service handoff request calls in both CC and RHRQ,
- k is the number of non-real-time service handoff request calls in CC,
- l is the number of non-real-time service calls (including originating calls and handoff request calls) in NC, and
- m is the number of non-real-time service handoff requests waiting in NHRQ.

The value ranges of discrete parameters are $i \in [0, S_R]$, $j \in [0, S_C + M_R], k \in [0, S_C - S_E], l \in [0, S_N]$, and $m \in [0, M_N]$.

Therefore, we represent the proposed scheme by a five-dimensional Markov chain with states (i, j, k, l, m). The total number of possible states in a Markov chain can be given by

$$\begin{aligned} N_T = {} & M_N(S_C - S_E + 1)(M_R + S_R S_E + S_R + S_E + 1) \\ & + \frac{1}{2}(S_N + 1)(S_C - S_E + 1)(2M_R + (S_R + 1) \\ & (S_C + S_E + 2)). \end{aligned} \tag{16}$$

Based on the state transition diagram, we can get N_T balance equations. For example, if we choose

$$S = S_R + S_C + S_N = 12,$$

$S_R = 6$, $S_C = 3$, $S_N = 3$, $S_E = 1$, and $M_R = 5$, $M_N = 50$ (as used in simulation section), N_T is 3,162. It is rather impractical to write all the balance equations in this paper and it is hard to summarize balance transition relations, as there are too many state boundaries for such a five-dimension Markov chain. Therefore, we would like to give an example state and its corresponding transition equations here to provide a better understanding to the readers. Consider one stable system state when there are one real-time service call in RC, one real-time, and one non-real-time service handoff request calls in CC, two non-real-time service calls in NC, and nothing in both RHRQ and NHRQ. The stable state of the reference cell can be marked as ($i = 1$, $j = 1$, $k = 1$, $l = 2$, $m = 0$) and the complete state transition diagram is given by Fig. 4. Where

- λ_{OR} is the arrival rate of real-time originating calls,
- λ_{ON} is the arrival rate of non-real-time originating calls,
- λ_{HR} is the arrival rate of real-time handoff request,
- λ_{HN} is the arrival rate of non-real-time handoff request,
- μ_R is the departure rate of real-time service, and
- μ_N is the departure rate of non-real-time service.

If the non-real-time service user in CC departs with departure rate μ_N, the state (1,1,1,2,0) becomes the state (1,1,0,2,0). If one of the two non-real-time service users in NC departs, the state (1,1,1,2,0) becomes the state (1,1,1,1,0) and the departure rate is $2\mu_N$. Those are the only two possibilities that are caused by the departure of the non-real-time service call. Thus, the departing rate of state (1,1,1,2,0) related to non-real-time service user departure, which is on the left side of the transition balance equation, is $3\mu_N$. Other departure rates and arrival rates of state (1,1,1,2,0) can be calculated in a similar way. The complete transition balance equation of state (1,1,1,2,0) is given by

$$(\lambda_{OR}+\lambda_{HR}+\lambda_{ON}+\lambda_{HN}+2\mu_R+3\mu_N)P_{(1,1,1,2,0)} = (\lambda_{OR}+\lambda_{HR})P_{(0,1,1,2,0)} + (\lambda_{ON}+\lambda_{HN})P_{(1,1,1,1,0)} + 3\mu_N P_{(1,1,1,3,0)} + 2\mu_N P_{(1,1,2,2,0)} + 2\mu_R P_{(1,2,1,2,0)} + 2\mu_R P_{(2,1,1,2,0)}. \tag{17}$$

As we see from Fig. 4, equilibrium probabilities $P(i,j,k,l,m)$s are related to each other through the state balance equations. However, notice that any of these balance equations can be obtained from other $N_T - 1$ equations because we have the normalizing condition, given by

$$\begin{aligned}&\sum_{i=0}^{S_R}\sum_{k=0}^{S_C-S_E}\sum_{j=0}^{S_C-k}\sum_{l=0}^{S_N} P(i,j,k,l,0) + \\ &\sum_{k=0}^{S_C-S_E}\sum_{j=S_C-k+1}^{S_C+M_R-k}\sum_{l=0}^{S_N} P(S_R,j,k,l,0) + \\ &\sum_{i=0}^{S_R}\sum_{k=0}^{S_C-S_E}\sum_{j=S_C-S_E-k}^{S_C-k}\sum_{m=1}^{M_N} P(i,j,k,S_N,m) + \\ &\sum_{k=0}^{S_C-S_E}\sum_{j=S_C-k+1}^{S_C+M_R-k}\sum_{m=1}^{M_N} P(S_R,j,k,S_N,m) = 1.\end{aligned} \tag{18}$$

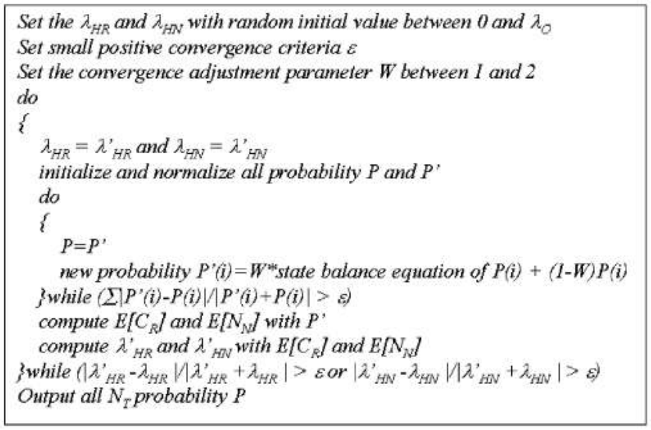
Adding the normalizing (18), we can obtain N_T independent equations with λ_{HR} and λ_{HN} as two unknown variables. Considering relations (10) and (13), we can get $N_T + 2$ nonlinear independent simultaneous equations for $N_T + 2$ unknown variables. As N_T is rather a large number, we use the SOR iteration method to solve $N_T + 2$ independent nonlinear equations and compute all the state probabilities $P(i,j,k,l,m)$s as indicated by the pseudocode given in Fig. 5.

Where $E[C_R]$, the average number of real-time service calls holding channels in the reference cell, is given by

$$\begin{aligned}E[C_R] = &\sum_{i=0}^{S_R}\sum_{k=0}^{S_C-S_E}\sum_{j=0}^{S_C-k}(i+j)\sum_{l=0}^{S_N} P(i,j,k,l,0) + \\ &\sum_{k=0}^{S_C-S_E}(S_R+S_C-k)\sum_{j=S_C-k+1}^{S_C+M_R-k}\sum_{l=0}^{S_N} P(S_R,j,k,l,0) + \\ &\sum_{i=0}^{S_R}\sum_{k=0}^{S_C-S_E}\sum_{j=S_C-S_E-k}^{S_C-k}(i+j)\sum_{m=1}^{M_N} P(i,j,k,S_N,m) + \\ &\sum_{k=0}^{S_C-S_E}(S_R+S_C-k)\sum_{j=S_C-k+1}^{S_C+M_R-k}\sum_{m=1}^{M_N} P(S_R,j,k,S_N,m),\end{aligned} \tag{19}$$

and $E[N_N]$, the average sum number of both non-real-time service requests and calls in reference cell, is given by

$$\begin{aligned}E[N_N] = &\sum_{l=0}^{S_N}\sum_{k=0}^{S_C-S_E}(k+l)\sum_{j=0}^{S_C-k}\sum_{i=0}^{S_R} P(i,j,k,l,0) + \\ &\sum_{k=0}^{S_C-S_E}\sum_{j=S_c-k+1}^{S_C+M_R-k}\sum_{l=0}^{S_N}(k+l)P(S_R,j,k,l,0) + \\ &\sum_{i=0}^{S_R}\sum_{k=0}^{S_C-S_E}\sum_{j=S_C-S_E-k}^{S_C-k}\sum_{m=1}^{M_N}(S_N+k+m)P(i,j,k,S_N,m) + \\ &\sum_{k=0}^{S_C-S_E}\sum_{j=S_C-k+1}^{S_C+M_R-k}\sum_{m=1}^{M_N}(S_N+k+m)P(S_R,j,k,S_N,m).\end{aligned} \tag{20}$$



```
Set the $\lambda_{HR}$ and $\lambda_{HN}$ with random initial value between 0 and $\lambda_O$
Set small positive convergence criteria $\varepsilon$
Set the convergence adjustment parameter W between 1 and 2
do
{
    $\lambda_{HR} = \lambda'_{HR}$ and $\lambda_{HN} = \lambda'_{HN}$
    initialize and normalize all probability P and P'
    do
    {
        P=P'
        new probability P'(i)=W*state balance equation of P(i) + (1-W)P(i)
    }while ($\sum|P'(i)-P(i)|/|P'(i)+P(i)| > \varepsilon$)
    compute $E[C_R]$ and $E[N_N]$ with P'
    compute $\lambda'_{HR}$ and $\lambda'_{HN}$ with $E[C_R]$ and $E[N_N]$
}while ($|\lambda'_{HR}-\lambda_{HR}|/|\lambda'_{HR}+\lambda_{HR}| > \varepsilon$ or $|\lambda'_{HN}-\lambda_{HN}|/|\lambda'_{HN}+\lambda_{HN}| > \varepsilon$)
Output all $N_T$ probability P
```

Fig. 5. Pseudocode to solve $(N_T + 2)$ independent nonlinear equations.

Based on the above probability set $P(i,j,k,l,m)$s, the following system performance parameters can be obtained.

Blocking probability B_{OR} of an originating real-time service call is given by

$$\begin{aligned}B_{OR} = 1 &- \sum_{i=0}^{S_R-1}\sum_{k=0}^{S_C-S_E}\sum_{j=0}^{S_C-k}\sum_{l=0}^{S_N} P(i,j,k,l,0) \\ &- \sum_{i=0}^{S_R-1}\sum_{k=0}^{S_C-S_E}\sum_{j=S_C-S_E-k}^{S_C-k}\sum_{m=1}^{M_N} P(i,j,k,S_N,m).\end{aligned} \tag{21}$$

Forced termination probability F_{HR} of real-time service handoff request calls in the reference cell consists of two parts, i.e., B_{HR} and D_R. B_{HR} is the blocking probability of real-time service handoff request calls and D_R is the dropping probability of real-time service handoff requests in RHRQ. We have

$$F_{HR} = B_{HR} + (1 - B_{HR})D_R, \tag{22}$$

where

$$\begin{aligned}B_{HR} = &\sum_{k=0}^{S_C-S_E}\sum_{l=0}^{S_N} P(S_R, S_C+M_R-k, k, l, 0) \\ &+ \sum_{k=0}^{S_C-S_E}\sum_{m=1}^{M_N} P(S_R, S_C+M_R-k, k, S_N, m),\end{aligned} \tag{23}$$

and

$$\begin{aligned}D_R = \frac{\mu_{hdwell}}{(1-B_{HR})\lambda_{HR}} \times \Bigg\{ &\sum_{k=0}^{S_C-S_E}\sum_{j=S_C-k+1}^{S_C+M_R-k}(j+k-S_C) \\ &\sum_{l=0}^{S_N} P(S_R,j,k,l,0) + \sum_{k=0}^{S_C-S_E}\sum_{j=S_C-k+1}^{S_C+M_R-k}(j+k-S_C) \\ &\sum_{m=1}^{M_N} P(S_R,j,k,S_N,m)\Bigg\}.\end{aligned} \tag{24}$$

The channel utilization is given by

$$\eta = (E[C_R] + E[C_N])/S, \tag{25}$$

where $E[C_N]$, the average number of non-real-time service calls holding channels in reference cell, is given by

$$
\begin{aligned}
E[C_N] = {} & \sum_{l=0}^{S_N} \sum_{k=0}^{S_C-S_E} (k+l) \sum_{j=0}^{S_C-k} \sum_{i=0}^{S_R} P(i,j,k,l,0) \\
& + \sum_{k=0}^{S_C-S_E} \sum_{j=S_c-k+1}^{S_C+M_R-k} \sum_{l=0}^{S_N} (k+l) P(S_R,j,k,l,0) \\
& + \sum_{i=0}^{S_R} \sum_{k=0}^{S_C-S_E} \sum_{j=S_C-S_E-k}^{S_C-k} \sum_{m=1}^{M_N} (S_N+k) P(i,j,k,S_N,m) \\
& + \sum_{k=0}^{S_C-S_E} \sum_{j=S_C-k+1}^{S_C+M_R-k} \sum_{m=1}^{M_N} (S_N+k) P(S_R,j,k,S_N,m).
\end{aligned} \tag{26}
$$

The average buffer utilization of RHRQ is given by

$$\eta_{RHRQ} = E[L_R]/M_R, \tag{27}$$

where $E[L_R]$, the average length of RHRQ, is given by:

$$
\begin{aligned}
E[L_R] = {} & \sum_{k=0}^{S_C-S_E} \sum_{j=S_C-k+1}^{S_C+M_R-k} (j+k-S_C) \sum_{l=0}^{S_N} P(S_R,j,k,l,0) \\
& + \sum_{k=0}^{S_C-S_E} \sum_{j=S_C-k+1}^{S_C+M_R-k} (j+k-S_C) \sum_{m=1}^{M_N} P(S_R,j,k,S_N,m).
\end{aligned} \tag{28}
$$

Similarly, the average buffer utilization of NHRQ is given by

$$\eta_{NHRQ} = E[L_N]/M_N. \tag{29}$$

where $E[L_N]$, the average length of NHRQ, is given by

$$
\begin{aligned}
E[L_N] = {} & \sum_{i=0}^{S_R} \sum_{k=0}^{S_C-S_E} \sum_{j=S_C-S_E-k}^{S_C-k} \sum_{m=1}^{M_N} m^* P(i,j,k,S_N,m) \\
& + \sum_{k=0}^{S_C-S_E} \sum_{j=S_C-k+1}^{S_C+M_R-k} \sum_{m=1}^{M_N} m^* P(S_R,j,k,S_N,m).
\end{aligned} \tag{30}
$$

The forced termination probability in lifetime P_{hf} of real-time service calls is defined as the probability that a real-time service call accepted by the system is forced to terminate during its whole communication period. The probability P_h that a real-time service call triggers a handoff request in the reference cell is the probability that the call holding time exceeds the dwell time of the real-time service user in the reference cell. Thus, we have

$$P_h = \Pr\{T_{CR} > T_{dwell}\}. \tag{31}$$

Assuming T_{CR} and T_{dwell} are independent, we can get

$$P_h = \mu_{dwell}/(\mu_{CR} + \mu_{dwell}). \tag{32}$$

Therefore, the P_{hf} of real-time service calls can be expressed as

$$P_{hf} = \sum_{l=1}^{\infty} P_h F_{HR} [(1-F_{HR})P_h]^{l-1} = \frac{P_h F_{HR}}{1-P_h(1-F_{HR})}. \tag{33}$$

In the proposed schemes, non-real-time service handoff requests can be transferred from the queue of the reference cell to the queue of the adjacent cell if it cannot be served in the reference cell. The lifetime transmission delay T_d of non-real-time service is the sum of transmission delay T_w of non-real-time service in every cell during its lifetime. Using Little's low, the average waiting time $E[T_w]$ of non-real-time service handoff requests in the queue Q_d is given by

$$E[T_w] = E[L_N]/[(1-B_{HN})\lambda_{HN}], \tag{34}$$

where $E[L_N]$ is the average length of NHRQ given by (30) and the blocking probability B_{ON} of originating non-real-time service call is given by

$$
\begin{aligned}
B_{ON} = 1 & - \sum_{l=0}^{S_N-1} \sum_{i=0}^{S_R} \sum_{k=0}^{S_C-S_R} \sum_{j=0}^{S_C-k} P(i,j,k,l,0) \\
& - \sum_{l=0}^{S_N-1} \sum_{k=0}^{S_C-S_E} \sum_{j=S_C-k+1}^{S_C+M_R-k} P(S_R,j,k,l,0).
\end{aligned} \tag{35}
$$

The average serving time $E[T_s]$ of non-real-time service calls is given by

$$E[T_S] = \frac{E[N_N]}{(1-B_{ON})\lambda_{ON} + (1-B_{HN})\lambda_{HN}}, \tag{36}$$

where the blocking probability B_{HN} of non-real-time service handoff request calls is given by

$$B_{HN} = \sum_{i=0}^{S_R} \sum_{k=0}^{S_C-S_E} \sum_{j=S_C-k+1}^{S_C+M_R-k} P(i,j,k,S_N,M_N). \tag{37}$$

Let us define N_h as the average number of handoff per a non-real-time service handoff request during its lifetime. We have

$$N_h = (N_h E[T_w] + E[T_{CN}])/E[T_S], \tag{38}$$

From (38), we can get

$$N_h = E[T_{CN}]/(E[T_S] - E[T_w]). \tag{39}$$

Therefore, the average transmission delay (expect average non-real-time service time) $E[T_N]$ of non-real-time service is given by

$$E[T_N] = \frac{N_h E[T_w](1-B_{HN})\lambda_{HN}}{(1-B_{ON})\lambda_{ON} + (1-B_{HN})\lambda_{HN}}. \tag{40}$$

5 NUMERICAL AND SIMULATION RESULTS

In this section, both simulation results and the analytical model numerically evaluate system characteristics. Our simulation runs over an integrated service homogenous cellular system, while originating calls are generated in every single cell, following a Possion process. The call holding time and cell dwell time for each service call is generated by the following assumptions:

- Scenario 1. The cell and handoff area dwell time are exponentially distrbuted. The call holding times follow exponential distribution.
- Scenario 2. The cell and handoff area dwell time are iid according to the Gamma distribution with parameter $\gamma = 1.5$. The call holding times are iid, according to Gamma distribution with parameter $\gamma = 2$.

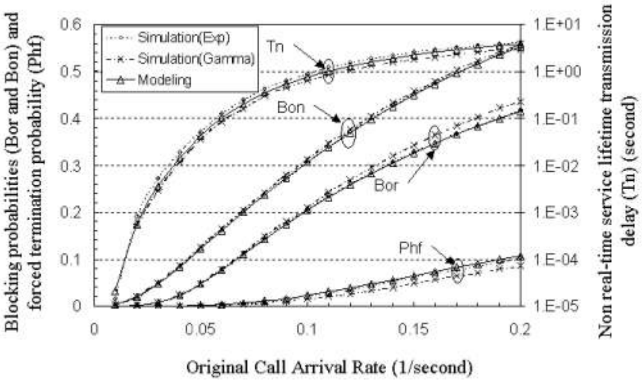


Fig. 6. Comparision of results of analytical model and simulation in two scenarios (exponential distribution and gamma distribution).

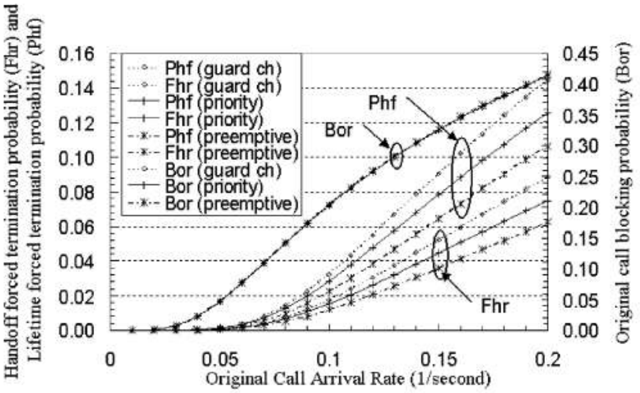


Fig. 7. Real-time service QoS parameters versus offered traffic.

Scenario 1 matches the assumptions made for our proposed analytical model, so that we can compare the numerical result of the analytical closed formula with scenario 1 simulation. Scenario 2 is widely used for wireless network modeling of the general call holding time and cell dwell time distribution such as in Fang et al. [15], [16]. Although other iid, such as hyperexponential or hyper-Erlang distribution, can also be used for call holding time, we use Gamma distribution to represent the general iid. Please note that the mean cell dwell time and call holding are made the same in both scenarios so that the results of two simulations can be compared. The cell shape is assumed to be hexagonal and one of its six neighboring cells can be picked up randomly as the target cell whenever a handoff occurs, i.e., the residue call holding time exceeds the current cell dwell time.

By assuming both real-time and non-real-time service mobile users are automobile passengers, system parameters are set as follows:

- Simulation area is a square area around 4.4 km by 4.4 km (10×10 cells),
- Cell radius $r = 400$ meter,
- Moving distance in handoff area $E[D] = 0.1r = 40$ meter,
- Moving speed $E[V] = 10$ meter/second,
- Real-time call holding time $E[T_{CR}] = 120$ seconds,
- Non-real-time call holding time $E[T_{CN}] = 60$ seconds,
- Number of channel in each cell

$$S = S_R + S_C + S_N = 12,$$

$S_R = 6$, $S_C = 3$, $S_N = 3$, and $S_E = 1$.

- Size of queuing buffer $M_R = 5$, $M_N = 50$.

Simulation stops when the convergence $\epsilon < 10^{-6}$. The ratio of originating real-time service calls and non-real-time service calls $\lambda_{OR}/\lambda_{ON}$ is set to 1. Based on the cell size and user speed, we can obtain the average cell dwell time to be 62.8 seconds and the average handoff area dwell time is 4 seconds from (2) and (6), respectively. Those numbers are used in both scenarios 1 and 2.

Fig. 6 shows the comparison of results of the analytical model and simulation. We compared several important QoS parameters, including blocking probability of originating calls for both real-time service and non-real-time service (B_{OR} and B_{ON}), forced termination probability of real-time service calls in their individual life time (P_{hf}) and transmission delay of non-real-time service calls during their life time (T_N). From the figure, we can see that the simulation results of scenario 1, which assumes the call holding time, the cell dwell time, and the handoff area dwell time follows exponential distribution, and analytical closed formula match each other very well and are consistent for all four QoS parameters. Especially, the difference between the result of simulation and analytical model for B_{OR}, B_{ON}, and P_{hf} are so small (less than 4 percent) that the solid and diamond dash lines always overlay each other in the figure. Please note that the simulation results do not depend on any transition probabilities. Therefore, we can say that our handoff analytical model in terms of its accuracy and correctness has been substantiated. Next, let's look at the simulation for scenario 1 and scenario 2. From Fig. 6, we can see the results for both exponential and gamma distributions are comparable. The forced termination probability for real-time service of Gamma distribution simulation is 20 percent less than the P_{hf} of Exponential distribution. The B_{OR} and B_{ON} of Gamma distribution simulation is 6 percent and 2 percent larger than those of Exponential distribution. The non-real-time service transmission delay T_N of Gamma distribution simulation is 28 percent less than the T_N of Exponential distribution. These differences between Gamma and Exponential distribution simulation are reasonable because the Gamma distribution has a smaller standard deviation than the Exponential distribution, although they have the same mean value. However, we can see the results of Gamma distribution and Exponential distribution have the same trend and the difference is consistent and tractable. Therefore, we believe that our analytical closed formula can present the QoS characteristics with tolerable error margins, although the call holding time and cell dwell time follow general iid distribution.

Fig. 7 shows the real-time service QoS parameters versus offered traffic λ_O for standard guard channel reservation (diamond dash line), priority reservation (solid line), and preemptive priority handoff scheme (crossing dash line). From the figure, we can see that the blocking probability B_{OR}, the forced termination probability F_{hr} for handoff request, and the lifetime forced termination probability P_{hf}

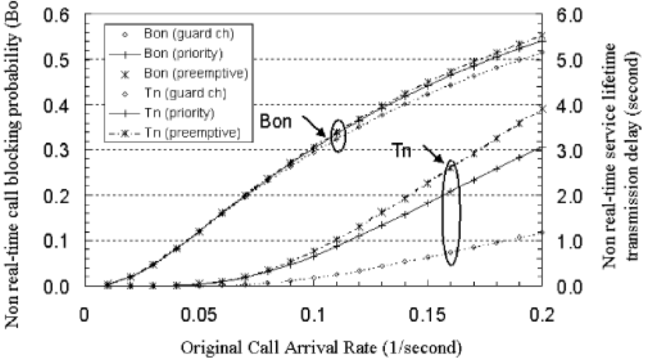


Fig. 8. Non-real-time service QoS parameters versus offered traffic.

increase as the offered traffic increases. However, the F_{hr} and P_{hf} have an on average of 14.7 percent improvement in priority reservation handoff scheme as compared to the guard channel reservation scheme when offered traffic λ_O is between 0.1 and 0.2. After implementing the preemptive procedure, the average improvement in F_{hr} and P_{hf} increase to 30.9 percent as compared to the guard channel reservation scheme when offered traffic λ_O is between 0.1 and 0.2. On the other hand, the blocking probability of originating real-time service calls in all three handoff schemes remains almost unchanged (change is less than 1 percent). Therefore, we can conclude that the priority reservation handoff scheme, especially the one with preemptive priority procedure, is effective in decreasing forced termination probability of real-time service calls.

Fig. 8 shows the non-real-time service QoS parameters versus offered traffic λ_O for standard guard channel reservation (diamond dash line), priority reservation (solid line), and preemptive priority handoff scheme (crossing dash line). We can see that the average lifetime transmission delay T_N increases as the offered traffic increases. Since the number of channels available for non-real-time service handoff requests decreases in the priority reservation scheme, T_N in priority reservation handoff scheme is larger than that in a guard channel scheme. However, the percentage weight of increased T_N is really small, considering the average call holding time for non-real-time service. For example, in preemptive priority handoff scheme, the maximum transmission delay is only 6.5 percent in the whole service time even for the largest transmission delay (3.91 second). For non-real-time service, the maximum transmission delay of 6.5 percent is not a big deal at all, but the trade off for real-time service is a 31 percent decrease in the forced termination probability. Since real-time service transmission is very sensitive to interruption, decreasing forced termination probability is more important than decreasing transmission delay of non-real-time service. On the other hand, increase in blocking probability of originating non-real-time service calls in preemptive handoff schemes remains small (7 percent). Because a non-real-time service handoff request can be transferred from the queue of one cell to another one, the forced termination probability for accepted non-real-time service is negligibly small. Therefore, we can conclude that the proposed preemptive handoff scheme is better than other handoff schemes in terms of performance of both real-time and non-real-time service calls.

6 CONCLUSIONS

The design of a handoff scheme is an important consideration for the QoS in a wireless mobile network with integrated real-time and non-real-time services. A handoff scheme with priority reservation and preemptive priority procedure has been proposed in this paper. An analytical model for the system performance has been presented. Simulation with both exponential and gamma distribution scenarios are also obtained and results are observed to match with the analytical evaluations. Blocking probability of originating calls, forced termination probability of real-time service calls, and average transmission delay of non-real-time service have been evaluated. It is seen that forced termination probability of handoff request calls of real-time service mobile users can be decreased by proposed preemptive and priority reservation handoff schemes. Moreover, non-real-time service handoff requests do not fail, except for negligibly small blocking probability, as a non-real-time service handoff request can be effectively handled by transferring it from the queue of the reference cell to an adjacent cell.

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