Performance Analysis of Radio Resource Allocation in GSM/GPRS Networks

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Abstract--*General Packet Radio Service (GPRS) is a packet switched access mode for GSM system to efficiently utilize the radio resources. In this paper, we analyzed the performance of radio resource allocation in GSM/GPRS networks. To guarantee the QoS of voice service not being affected by the introduction of GPRS, preemptive priority is applied for voice calls to preempt GPRS data packets. Three cases of radio resource allocation are considered: no-buffer; buffer-only-for-preempted-GPRS-packets; and buffer-for-GPRS-packets. The results show that employing buffer for GPRS packets can greatly reduce its blocking probability even under the condition of voice preemption. For real-time data applications, the mechanism of buffer-only-for-preempted-GPRS-packets will be suitable since the queueing delay is relatively small.*

I. INTRODUCTION

The General Packet Radio Service (GPRS) [1] is an European Telecommunications Standard Institute (ETSI) standard for packet data transmission using the core GSM (Global System for Mobile Communications) radio access network. It provides switched packet data transfer to efficiently utilize the radio resources. The GPRS has been considered to be the main development step of GSM networks towards the next generation mobile communication system like UMTS [2].

Several analytical models have been proposed in the performance study of GSM/ GPRS networks. Lindemann *et al.* investigated the impact of the number of packet data channels reserved for the GPRS users on the performance of cellular networks based on the continuous-time Markov chain [3]. Ermel *et al*. developed partitioning strategies to divide the cell capacity between traditional GSM and the GPRS [4]. The results showed that the complete sharing strategy can achieve the highest system utilization. Ni *et al.* used the decomposition technique [5] to decompose a two-dimensional Markov chain into two one-dimensional Markov chains to analyze the performance of GPRS [6]. This technique is valid only for the case that the mean service time of one traffic class is much larger than that of the other class. Lin *et al.* proposed several resource allocation algorithms to investigate the impact of GPRS service on the GSM network [7]. In their study, buffers are designed to queue the delay-sensitive traffic only.

In this paper, we evaluate the performance of radio resource allocation in GSM/GPRS networks based on a two-dimensional Markov chain. Three cases are considered depending on whether to apply buffer for GPRS data packets or not. To guarantee the QoS of voice traffic, voice call arrivals are assumed to have preemptive priority.

II. RADIO RESOURCE ALLOCATION

In GSM/GPRS networks, the GPRS uses the same TDMA/FDMA structure as that of GSM to form physical channels. Each physical channel can be assigned to either GPRS or GSM traffic. The physical channel dedicated to packet data traffic is called the packet data channel (PDCH). One or several PDCHs can be allocated to a mobile station at a time on a demand basis.

The guard channel scheme [8] is commonly used to prioritize the GSM voice handoff calls because of its low implementation complexity and cost. It has the drawback of low channel utilization, therefore, temporarily allocating these guard channels to GPRS users can improve the channel utilization. Upon voice handoff call arrivals, the GPRS packets in service will be preempted. Because of its short transmission time, no handoff is assumed for GPRS packets throughout this paper. In addition, the radio resources are completely shared by voice calls and GPRS data packets. In other words, the complete sharing strategy [4] is adopted.

Three different cases are considered depending on whether to provide buffers for GPRS data packets or not when no channels are available or when they are preempted by voice calls. They are the no-buffer case, buffer-only-for-preempted-GPRS-packets case, and buffer-for-GPRS case.

In these three cases, voice arrivals can preempt the existing GPRS packets when no available channels are found. The preempted packets can be either buffered in queue or dropped. Being buffered in queue, the preempted packets have priority over new data packets to obtain services. The preemption mechanism is exploited to guarantee the voice performance not being affected by the introduction of GPRS.

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III. The Analytical Model

In this section, we will describe the analytical model based on a two-dimensional Markov chain. The analyses will be focused on a single cell in isolation and assume that the network is symmetric and the traffic is homogenous. Let the state (i, j) denote that there are i voice calls and j GPRS packets in the system. P_{ij} denotes the probability that the system is in state (i, j). Assume that the total number of channels in a cell is C, the number of guard channels reserved to prioritize voice handoff calls is C_G, and the buffer is with size B.

To investigate the performance of radio resource allocation, several assumptions are made in the analytical model. The arrivals of new and handoff voice call requests form Poisson processes with rate λ_n and λ_h, respectively, and $\lambda_v = \lambda_n + \lambda_h$. Here, we assume $\lambda_n = \lambda_h$ for simplicity. The service time of voice calls, new or handoff, is assumed to be exponentially distributed with a mean of $1/\mu_v$. The arrivals of GPRS data packets are assumed to be a Poisson process with rate λ_d. The service time of GPRS data packets is exponentially distributed with a mean of $1/\mu_d$.

A. No-buffer (NB) case

In this case, GPRS packet arrivals are blocked when there are no channels available. The packets preempted by voice arrivals will be dropped. Fig. 1 shows an example of the state transition diagram with $C = 3$ and $C_G = 1$. Let ψ be the set of feasible states. To handle the infeasible states, an indicator function $\varphi(i, j)$ is used to indicate whether the state (i, j) is feasible or not, *i.e.* $\varphi(i, j) = 1$ if $(i, j) \in \psi$. For all $(i, j) \in \psi$, the balance equations can be expressed as

$$\begin{aligned} &P_{ij}(\lambda_1 \varphi(i+1, j) + \lambda_d \varphi(i, j+1) + i\,\mu_v \varphi(i-1, j) \\ &\quad + j\,\mu_d \varphi(i, j-1) + \lambda_2 \varphi(i+1, j-1)) \\ &= \lambda_3 P_{i-1,j} \varphi(i-1, j) + \lambda_d P_{i,j-1} \varphi(i, j-1) \\ &\quad + (i+1)\,\mu_v P_{i+1,j} \varphi(i+1, j) + (j+1)\,\mu_d P_{i,j+1} \varphi(i, j+1) \\ &\quad + \lambda_4 P_{i-1,j+1} \varphi(i-1, j+1) \end{aligned} \quad (1)$$

where $\lambda_1 = \begin{cases} \lambda_v, & \text{if } i < C - C_G \\ \lambda_h, & \text{otherwise} \end{cases}$

$$\lambda_2 = \begin{cases} \lambda_v, & \text{if } i + j = C \text{ and } i < C - C_G \\ \lambda_h, & \text{if } i + j = C \text{ and } C - C_G \le i < C \\ 0, & \text{otherwise} \end{cases}$$

$$\lambda_3 = \begin{cases} \lambda_v, & \text{if } i \le C - C_G \\ \lambda_h, & \text{otherwise} \end{cases}$$

$$\lambda_4 = \begin{cases} \lambda_v, & \text{if } i + j = C \text{ and } i \le C - C_G \\ \lambda_h, & \text{if } i + j = C \text{ and } C - C_G < i < C \\ 0, & \text{otherwise} \end{cases}$$

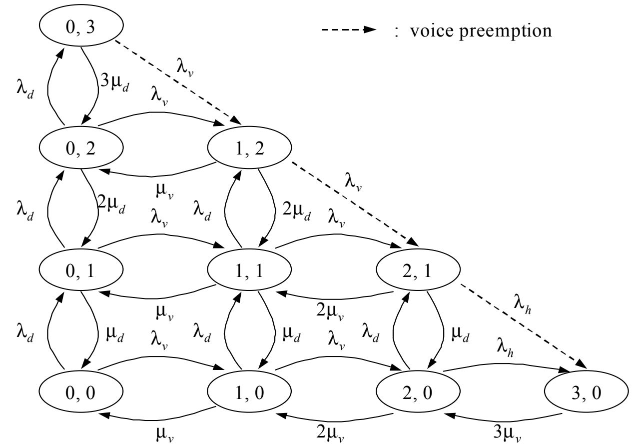

Fig. 1 The state diagram of NB case for C=3 and C_G=1

Voice preemption attributes to the last term on both sides of (1). By applying the constraints $\sum_{\psi} P_{ij} = 1$ to the set of balance equations, we can obtain the steady-state probability P_{ij} to evaluate the performance metrics of the system. The blocking probability of voice new call, P_{vb}, and the handoff dropping probability, P_{vd}, can be respectively expressed as

$$P_{vb} = \sum_{i=C-C_G}^{C} \sum_{j=0}^{C-i} P_{ij} \quad (2)$$

$$P_{vd} = P_{C0} \quad (3)$$

The blocking probability of GPRS data packets, P_{gb}, is

$$P_{gb} = \sum_{i+j=C} P_{ij} \quad (4)$$

and the preemption probability of GPRS data packets, P_{gp}, is

$$P_{gp} = \frac{1}{\lambda_d (1 - P_{gb})} \cdot \left[\sum_{\substack{i+j=C \\ \& \, i<C-C_G}} \lambda_v \cdot P_{ij} + \sum_{\substack{i+j=C \\ \& \, C-C_G \le i < C}} \lambda_h \cdot P_{ij} \right] \quad (5)$$

where the second term is contributed by voice handoff traffic.

B. Buffer-only-for-preempted-GPRS-packets (BP) case

In this case, the GPRS packet arrivals are blocked when there are no channels available and the packets preempted by voice call arrivals will be queued in the buffer. To avoid the preempted data packets being dropped by the network due to buffer overflow, the buffer size, B, is set to equal to the total number of channels. Fig. 2 shows an example of the state transition diagram assuming $C = B = 3$, and $C_G = 1$.

Exploiting the analytical approach described in the previous subsection, the performance metrics can be evaluated as follows. The blocking probability of voice new calls, P_{vb}, and the dropping probability of handoff calls, P_{vd}, are respectively

$$P_{vb} = \sum_{i=C-C_G}^{C} \sum_{j=0}^{C} P_{ij} \quad (6)$$

$$P_{vd} = \sum_{j=0}^{C} P_{Cj} \quad (7)$$

The blocking probability of GPRS data packets, P_{gb}, is

$$P_{gb} = \sum_{i+j\geq C} P_{ij} \tag{8}$$

and the preemption probability of GPRS data packets, P_{gp}, is

$$P_{gp} = \frac{1}{\lambda_d(1-P_{gb})} \cdot \left[\sum_{\substack{i+j\geq C \\ \& \, i<C-C_G}} \lambda_v \cdot P_{ij} + \sum_{\substack{i+j\geq C \\ \& \, C-C_G\leq i<C}} \lambda_h \cdot P_{ij} \right] \tag{9}$$

The mean queueing delay of GPRS data packets, W, is obtained as

$$W = \frac{\sum_{i=0}^{C} \sum_{j=1}^{C} j \cdot P_{ij}}{\lambda_d (1 - P_{gb})} - \frac{1}{\mu_d} \tag{10}$$

C. Buffer-for-GPRS-packets (BG) case

In this case, the GPRS packet arrivals will be queued in the buffer when there are no channels available. Moreover, the preempted GPRS packets will also be queued and are given higher priority than new data packets to resume their services whenever there are channels available. All data packets are served in a first come first served (FCFS) manner. Fig. 3 shows the state transition diagram assuming C=3, C_G=1, and B=2. Using a similar analytical approach described in the previous subsection, the performance metrics can be evaluated. The blocking probability of voice new call, P_{vb}, and handoff dropping probability, P_{vd}, are respectively

$$P_{vb} = \sum_{i=C-C_G}^{C} \sum_{j=0}^{C+B-i} P_{ij} \tag{11}$$

$$P_{vd} = \sum_{j=0}^{B} P_{Cj} \tag{12}$$

The blocking probability of GPRS data packets, P_{gb}, is

$$P_{gb} = \sum_{i+j=C+B} P_{ij} \tag{13}$$

The dropping probability of GPRS data packets, P_{gd}, is

$$P_{gd} = \frac{1}{\lambda_d(1-P_{gb})} \cdot \left[\sum_{\substack{i+j=C+B \\ \& \, i<C-C_G}} \lambda_v \cdot P_{ij} + \sum_{\substack{i+j=C+B \\ \& \, C-C_G\leq i<C}} \lambda_h \cdot P_{ij} \right] \tag{14}$$

The preemption probability of GPRS data packets, P_{gp}, is

$$P_{gp} = \frac{1}{\lambda_d(1-P_{gb})} \cdot \left[\sum_{\substack{i+j\geq C \\ \& \, i<C-C_G}} \lambda_v \cdot P_{ij} + \sum_{\substack{i+j\geq C \\ \& \, C-C_G\leq i<C}} \lambda_h \cdot P_{ij} \right] \tag{15}$$

The mean queueing delay of GPRS data packets, W, is obtained as

$$W = \frac{\sum_{j=1}^{B} \sum_{i=0}^{C} j \cdot P_{ij} + \sum_{j=B+1}^{C+B} \sum_{i=0}^{C-(j-B)} j \cdot P_{ij}}{\lambda_d (1 - P_{gb})} - \frac{1}{\mu_d} \tag{16}$$

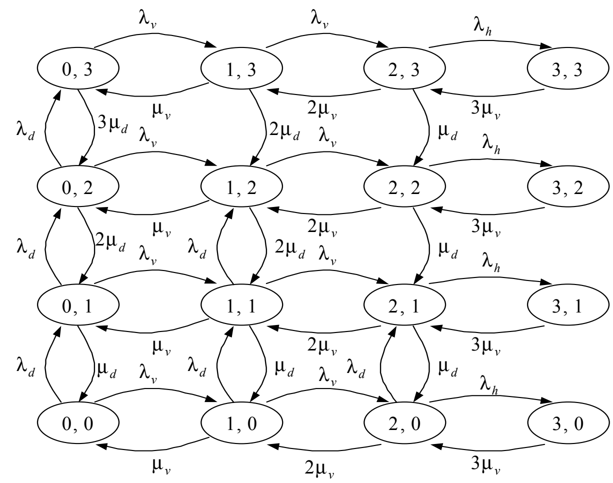

Fig. 2 The state diagram of BP case for C=B=3, and C_G=1.

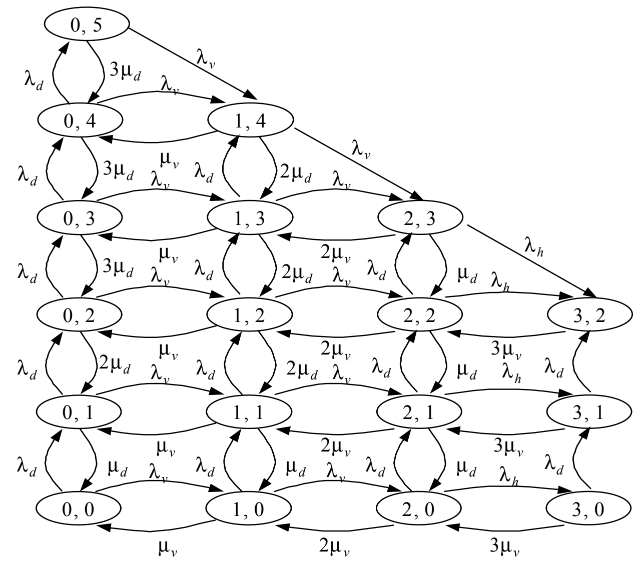

Fig. 3 The state diagram of BG case for C=3,C_G=1 and B=2.

IV. Numerical and Simulation Results

To validate the analytical results, simulation experiments are conducted. The total number of channels in a cell is set to be 32, and the number of guard channels is chosen to be 1. The mean voice arrival rate, new or handoff, is taken to be 0.0612 calls/sec, and the mean service time of voice calls is 180 seconds which results in to a load of 22.03 Erlang and is so chosen to ensure that the new call blocking probability and the handoff dropping probability are below the typical values of 2% and 0.5%, respectively. The arrival rate of GPRS data packets is a system parameter and is chosen to set the GPRS load in the range of 1 to 14 Erlang. The mean service time of GPRS data packets is taken to be 2 seconds. The buffer size is set to be 32.

With voice preemption, the new call blocking probability and handoff dropping probability will remain constant irrespective to the GPRS traffic load, and the value is 1.95 % and 0.498 %, respectively, under a voice traffic load of 22.03 Erlang.

Fig. 4 shows GPRS blocking probability for the BG case. It can be seen that the numerical results match very well with the simulation results. The results of NB case and BP case have similar characteristics as that of the BG case. Fig. 5 shows the comparison of blocking probability for the three cases. The blocking probability is almost the same for the NB case and the BP case. This is because the buffer is only used to queue the preempted data packets in the latter case. When the buffer is used to queue both new and preempted data packets, *i.e.* the BG case, the blocking probability of GPRS data packets can be significantly reduced. For example, at high GPRS traffic load, the improvement is nearly 25% compared with the other two cases.

Fig. 6 shows the comparison of GPRS dropping probability for the NB case. Fig. 7 shows the comparison of preemption probability of GPRS data packets for the BP case. Fig. 8 shows the comparisons of dropping probability and preemption probability of GPRS data packets, respectively, for the BG case. It can be seen that as the GPRS traffic load increases, there will be less chance for voice calls to find idle channels upon arrival. Therefore, the probability of preemption increases with increased GPRS traffic load, resulting in the increase of dropping probability. The reason for larger probability of preemption in the BG case than in the BP case is because of its lower blocking probability in the former.

Fig. 9 shows the mean queueing delay of GPRS packets for the BP case and BG cases, respectively. It is interesting to note that at low GPRS traffic load, the mean queueing delay of preempted GPRS data packets decreases as the traffic load increases in the BP case. The reason is that when the GPRS load is very low, once it is preempted, it must wait for a voice call completion before resuming its service. When the load increases, there will be some GPRS data packets in service, a preempted packet may wait for either a voice call or a GPRS packet completion before resuming its service. Since the mean service time of GPRS data packets is much smaller than that of voice calls, the mean queueing delay in the latter case will be smaller than that in the former one. With further increased traffic load, the queue begins to build up and the queueing delay increases with increased traffic load.

V. Conclusions

In this paper, we analyzed the performance of radio resource allocation in GSM/GPRS networks. To maximize the system utilization, the radio resources are completely shared by both GSM and GPRS traffic. The focus of our investigation is whether to provide buffer for GPRS data packets or not. Three cases are considered: no-buffer; buffer-only-for-preempted-GPRS-packets; and buffer-for-GPRS-packets. To guarantee the voice performance not being affected by the introduction of GPRS, preemptive priority is applied for voice calls to preempt GPRS data packets.

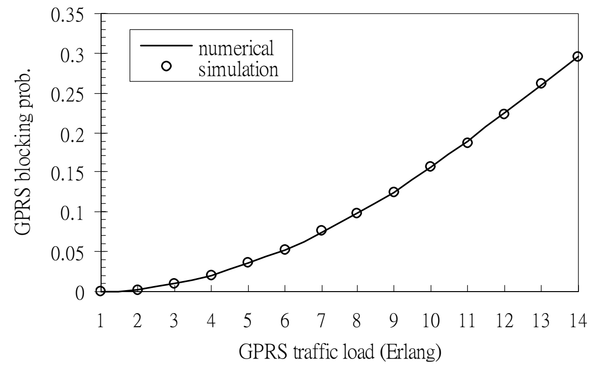

Fig. 4 GPRS blocking probability for the BG case

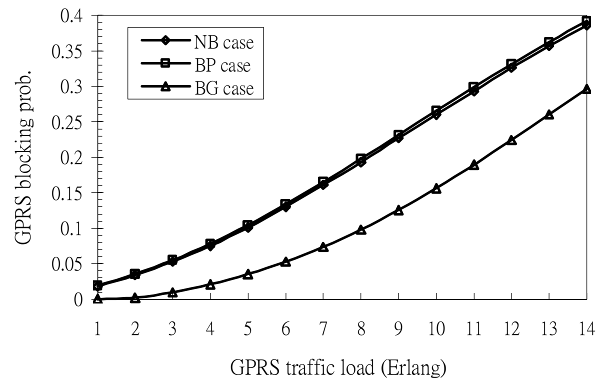

Fig. 5 Blocking probability of GPRS packets for the three cases

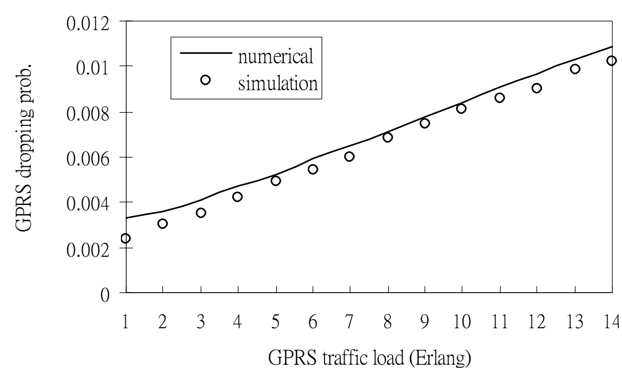

Fig. 6 Dropping probability of GPRS packets for the NB case

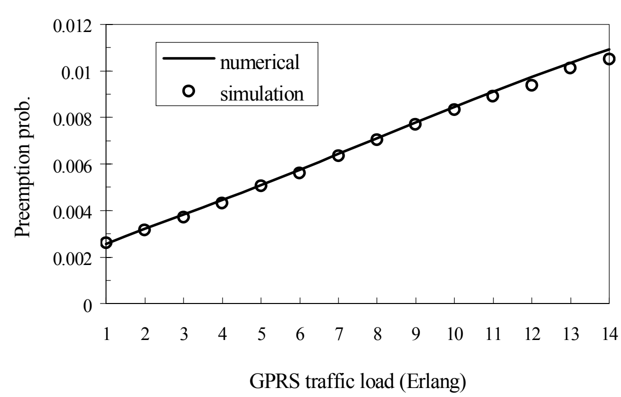

Fig. 7 Preemption probability of GPRS packets for the BP case

The results show that with preemptive priority, the new call blocking probability and handoff dropping probability remain constant irrespective to the GPRS traffic load. This is achieved at the expense of increasing preempted probability of GPRS packets as the GPRS traffic load increases. The blocking probability of GPRS packets can be effectively reduced by applying buffers for packets when no available channels are found upon arrival. Furthermore, the mechanism of buffer-only-for-preempted-GPRS-packets will be suitable for real-time data applications since the queueing delay is relatively small. The analyses are validated by the simulation experiments.

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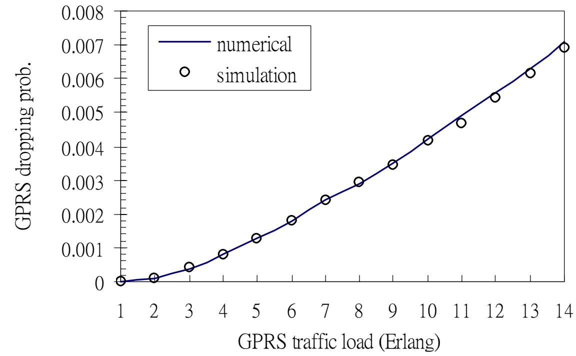
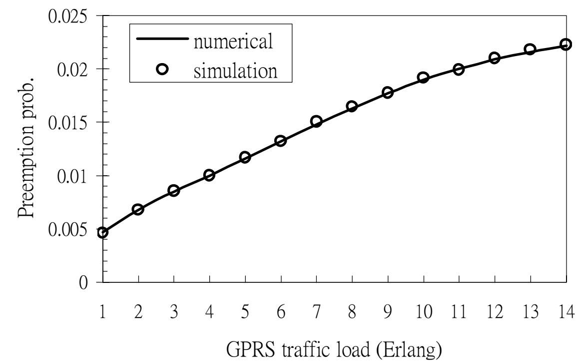
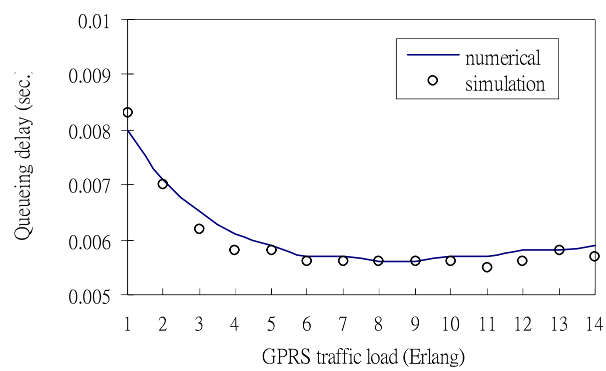


(a) Dropping probability

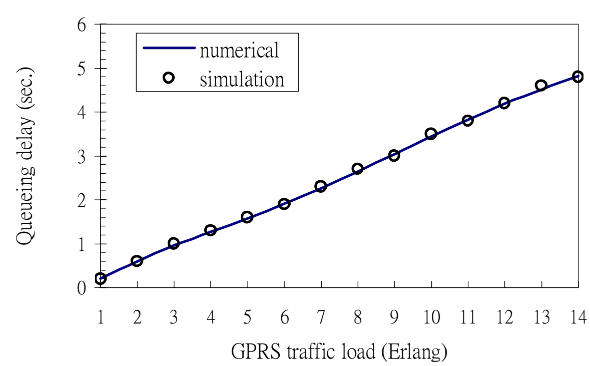


(b) Preemption probability

Fig. 8 Dropping probability and preemption probability of GPRS packets for the BG case



(a) BP case



(b) BG case

Fig. 9 The mean queueing delay of GPRS packets