Radio Resource Allocation in GSM/GPRS Networks

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Abstract. GPRS is a packet switched access mode for GSM system to improve wireless access to the Internet. In this paper, we study the design of radio resource allocation for GPRS and GSM services by allowing guard channels to be temporarily allocated to GPRS users to increase channel utilization. The call admission controller and channel allocation controller are employed to achieve good channel utilization and preserve the QoS of GSM services. Simulation results show that at low voice traffic load, there is no need to apply admission control to GPRS connections. While at high voice traffic load, applying call admission control to GPRS connections can guarantee the performance of voice service, but result in high GPRS connection blocking and low channel utilization. Furthermore, the QoS of voice service not being affected by the introduction of GPRS can be obtained by allowing voice arrivals to preempt the ongoing GPRS connections.

1 Introduction

General Packet Radio Service (GPRS) [1], initiated in 1994, is an European Telecommunications Standard Institute (ETSI) standard for packet data transmission using the core GSM (Global System for Mobile Communications) radio access network. Consequently, GPRS shares the GSM frequency bands with telephone and circuit-switched data traffic, and makes use of many properties of the physical layer of the original GSM system. Since radio resources of a cell are shared by both the GPRS and GSM voice services, how to efficiently allocate radio resources between these two services and at the same time not degrading the QoS of voice service is an important issue.

Brasche *et al.* [2] first introduced GPRS, described the GPRS protocol and demonstrated its performance. Different scheduling strategies were proposed by Sau *et al.* [3,4] to guarantee the QoS in GPRS environment. The performance analysis of radio link control and medium access control (RLC/MAC) protocol of GPRS was investigated by Ludwig *et al.* [5]. The performance of integrated voice and data for GPRS was analyzed in [6,7]. However, the above researches focused on the performance of GPRS traffic, none has discussed the impact of accommodating GPRS traffic on the performance of voice services. In this paper, we will study the interaction of resource allocation between voice traffic and GPRS traffic and the impact on the system performance.

Static guard channel scheme [8] is commonly used to prioritize GSM voice handoff calls because of its low implementation complexity. These guard channels can be temporarily allocated to GPRS to increase channel utilization, and will be de-allocated to handoff calls when necessary.

The rest of this paper is organized as follows: In section 2, we will briefly introduce the radio interface of GPRS. The channel de-allocation and call admission control mechanisms are described in section 3. Section 4 provides the simulation results of the proposed scheme and section 5 concludes this paper.

2 Radio Interface

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 service. The physical channel dedicated to packet data traffic is called the packet data channel (PDCH). The basic transmission unit of a PDCH is called a radio block. To transmit a radio block, four time slots in four consecutive TDMA frames are used [9]. Four different coding schemes, CS-1 to CS-4, are defined for the radio blocks [10] and are shown in Table 1.

Table 1. GPRS coding schemes

Coding scheme	Code rate	Payload	Data rate (kbits/s)
CS-1	1/2	181	9.05
CS-2	~2/3	268	13.4
CS-3	~3/4	312	15.6
CS-4	1	428	21.4

Radio blocks can be sent on different PDCHs simultaneously, thus reducing the packet delay for transmission across the air interface. The allocated channels may vary by allocating one to eight time slots in each TDMA frame depending on the number of available PDCHs, the multi-slot capabilities of the mobile station, and the current system load [11]. With coding scheme and multi-slot allocation, higher date rate can be achieved.

To support the packet-switched operation of GPRS, PDCHs are assigned temporarily to mobile stations. The base station controller (BSC) controls the resources in both the uplink and downlink directions. We will focus on the uplink data transfer to investigate the radio resource allocation. To avoid access conflicts in the uplink direction, the BSC transmits in each downlink radio block header an uplink state flag indicating which mobile station is allowed to transmit on the corresponding uplink PDCH.

3 The Proposed Radio Resource Allocation Scheme

The proposed scheme employs the channel allocation and admission control mechanism to guarantee the QoS and improve the channel utilization. Each GPRS connection request can be associated with two bandwidth parameters: the requested bandwidth (*b_req* Kbps) and the minimum required bandwidth (*b_min* Kbps). Each GPRS connection request demands for a bandwidth of *b_req* Kbps, and the minimum bandwidth to be guaranteed is *b_min* Kbps once this connection request is admitted. The bandwidth allocated to each GPRS connection can vary between *b_req* and *b_min* Kbps.

Upon the arrival of a GPRS connection request, the call admission controller has to figure out the number of channels required. Let *c_req* denote the number of channels allocated for GPRS to offer a bandwidth of *b_req* Kbps if it is admitted, and *c_min* denote the minimum number of channels required to offer a bandwidth of *b_min* Kbps for an admitted GPRS connection. Assume each PDCH can provide a bandwidth of I Kbps. Then *c_req* and *c_min* can be obtained as follows:

$$c\_req = \left\lceil \frac{b\_req}{I} \right\rceil, \text{ and } c\_min = \left\lceil \frac{b\_\min}{I} \right\rceil, \qquad \textbf{(1)}$$

where $\lceil x \rceil$ is the ceiling function of x.

The channel allocation model is depicted in Fig. 1 where GSM voice service and GPRS share the same common pool of the physical channels. A number of guard channels are reserved for prioritized voice handoff calls. C denotes the total number of channels of the common pool, C_G denotes the number of guard channels reserved for voice handoff calls which can be temporarily allocated for GPRS. C_{voice} denotes

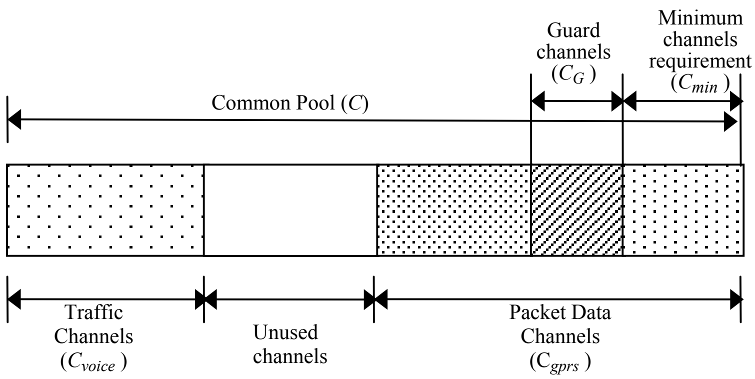


Fig. 1. The channel allocation model

the number of channels used by voice calls. C_{gprs} denotes the number of channels used by GPRS connections. C_{min} denotes the number of channels guaranteed for admitted GPRS connections. The number of available channels for voice service denoted as C_{avail} can be expressed as $C_{avail} = C - C_{min}$.

3.1 The channel allocation controller

The channel allocation controller is employed to dynamically adjust channels allocated for both services to achieve better channel utilization. When the network is congested, the channel allocation controller is responsible for de-allocating some channels of the existing GPRS connections to fulfill the minimum bandwidth requirement for the admitted GPRS connections and voice calls.

When a new voice call is admitted, the channel allocation controller will allocate one channel to this voice call from the unused channels. If there are no unused channels, it will try to de-allocate one PDCH from the existing GPRS connections whose allocated bandwidth is larger than its minimum bandwidth requirement. The remaining PDCHs should still provide bandwidth for the ongoing GPRS connections to maintain their minimum bandwidth requirement. If a handoff call arrives and all the guard channels are used up by voice handoff calls and GPRS connections, the guard channels temporarily allocated to GPRS as PDCH must then be de-allocated for voice handoff calls.

3.2 The call admission controller

The call admission controller is employed to control the number of GPRS to guarantee the QoS of voice service and admitted GRPS connections. A GPRS connection request will be admitted under two conditions. Firstly, the admission of a GPRS connection can still maintain the blocking probability of new and handoff calls below P_{tnb} and P_{thd}, where P_{tnb} is the target blocking probability of new calls, and P_{thd} is the target blocking probability of handoff calls. Secondly, the network should have enough bandwidth to guarantee a bandwidth of *b_min* Kbps for this request, that is, $c\_min \le C - C_{voice} - C_{min}$.

To find the blocking probability of new and handoff calls after having admitted a GPRS connection, the traffic model for personal communication system [12] is used. Fig. 2 shows the state-transition diagram for the static guard channel scheme. The mean arrival rate of new call requests and handoff call requests are denoted as λ_n and λ_h, respectively. The mean residence time of a mobile unit in a cell is denoted by $1/\mu$. Having admitted a GPRS connection request, the system needs to allocate *c_min* channels to guarantee its minimum QoS requirement. Then the number of available channels for voice service, $\widetilde{C}_{avail}$, can be expressed as $\widetilde{C}_{avail} = C - (C_{min} + c\_min)$.

Let i be the system state corresponding to the number of voice calls in the system. $P(i)$ denotes the steady-state probability of a total of i voice calls in the system, and the probability can be easily obtained from the M/M/c/c queueing model as

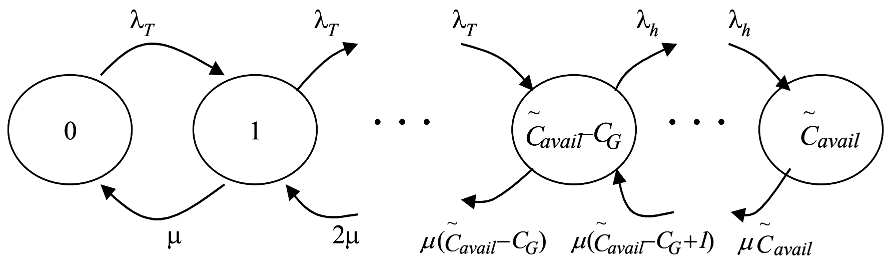


Fig. 2. The state-transition diagram for the static guard channel scheme

$$P(i)=\begin{cases}(\frac{\lambda_T}{\mu})^i\frac{P(0)}{i!}, & \text{if } i\le\tilde{C}_{avail}-C_G\\ (\frac{\lambda_T}{\mu})^{\tilde{C}_{avail}-C_G}(\frac{\lambda_h}{\mu})^{i-(\tilde{C}_{avail}-C_G)}\frac{P(0)}{i!}, & \text{if } \tilde{C}_{avail}-C_G<i\le\tilde{C}_{avail}\end{cases} \quad (2)$$

$$P(0)=\left[\sum_{i=0}^{\tilde{C}_{avail}-C_G}\frac{(\frac{\lambda_T}{\mu})^i}{i!}+(\frac{\lambda_T}{\mu})^{\tilde{C}_{avail}-C_G}\sum_{i=\tilde{C}_{avail}-C_G+1}^{\tilde{C}_{avail}}\frac{(\frac{\lambda_h}{\mu})^{i-(\tilde{C}_{avail}-C_G)}}{i!}\right]^{-1} \quad (3)$$

where $\lambda_T = \lambda_n + \lambda_h$. The new call blocking probability P_{nb} and handoff call blocking probability P_{hb} can be expressed respectively as

$$P_{nb}=\sum_{i=\tilde{C}_{avail}-C_G}^{\tilde{C}_{avail}}P(i)\text{, and } P_{hb}=P(\tilde{C}_{avail}) \quad (4)$$

The call admission controller then compares these two values with the target values P_{tnb} and P_{thb}, respectively. If both P_{nb} and P_{hb} are smaller than the target values respectively, and the available channels are enough to guarantee the minimum bandwidth requirement, the GPRS connection requests will be accepted. On the other hand, GSM new call requests will be accepted if $C_{avail} - C_G > 0$, and handoff call requests will be accepted if $C_{avail} > 0$.

4 Simulation Assumptions and Results

The total number of channels, C, is assumed to be 100. For simplicity, we assume the arrival of new and handoff calls form a Poisson process with rate λ_n and λ_h, respectively, and let $\lambda_n = \lambda_h = \lambda$. According to the study of the effect of different number of guard channels to voice call blocking probability for C =100, the number of guard channel being 2 is chosen. Let the new call arrival rate be 0.20 calls/sec for low voice traffic load and 0.23 calls/sec for high voice traffic load. The call holding time, new or handoff, is assumed to be exponentially distributed with a mean of 180 seconds.

The arrivals of GPRS connection requests are assumed to form a Poisson process with rate λ_{gprs}. In the simulation, CS-2 coding scheme is used and its corresponding transmission rate is 13.4 *Kbps* per PDCH. Assume the packet length of each GPRS connection is exponentially distributed with a mean of 2×13.4 *Kbits*, corresponding to the mean service time of 2 seconds if one PDCH is allocated.

We also assume that the mobile station has the multi-slot capability and the maximum number of PDCHs that can be allocated to one mobile station is 4. In other words, 1 to 4 time slots per TDMA frame can be allocated to one mobile station. For simplicity, the allocated channels are not restricted to be in the same frame. Referring to the call blocking probabilities given in [13], the target new call blocking probability P_{tnb} is chosen to be 0.05 and the target handoff call blocking probability P_{thb} is 0.005.

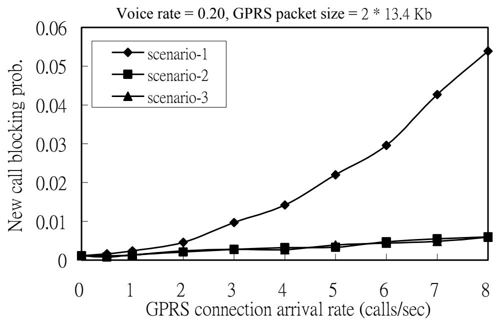
To investigate the performance of the proposed scheme, three scenarios are considered:

scenario-1 : GPRS traffic shares the radio resources with GSM voice traffic without resource management.

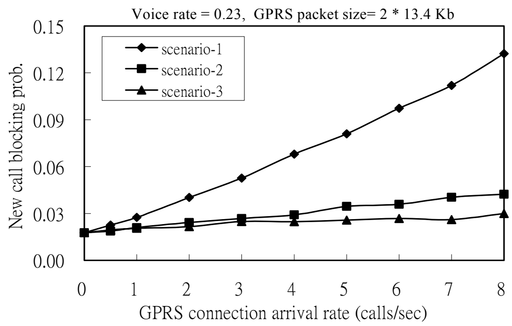
scenario-2 : GPRS traffic shares the radio resources with GSM voice traffic with channel de-allocation mechanism, *i.e.*, the channels of existing GPRS connections will be de-allocated to voice calls when no resources are available in the system.

scenario-3 : GPRS traffic shares the radio resources with GSM voice traffic, and both channel de-allocation and call admission control mechanism are employed.

Performance of the three scenarios with increasing GPRS mean arrival rate under different voice traffic load are studied. Performance measures of interest are blocking probability of new and handoff voice calls, GPRS connection rejection ratio, and channel utilization. Fig. 3 and Fig. 4 show the comparison of the blocking probability of new voice call and handoff call respectively with GPRS mean packet size being 2×13.4 *Kbits*. It can be seen that accommodating GPRS without any resource management, *i.e.,* scenario-1, would severely degrade the performance of voice service. Besides, at low voice traffic load, admission control on GPRS arrivals is not necessary. Scenario-2 gives almost the same performance as scenario-3. At high voice traffic load, the blocking probability of voice service for scenario-2 becomes worse with increasing GPRS traffic load. The blocking probability of voice calls, new and handoff call, for scenario-3 still maintains below certain value in despite of the increasing GPRS traffic load. The reason for handoff call blocking probability exceeds P_{thb} at high voice traffic load is that although the guard channels temporarily used by GPRS connections can be de-allocated to handoff calls, the amount of bandwidth of the de-allocated GPRS connection must still be greater than or equal to its minimum bandwidth requirement. If all the GPRS connections are admitted with minimum required bandwidth and the guard channels have been used up by handoff calls or GPRS connections, handoff arrivals would be blocked.



(a) low voice traffic load

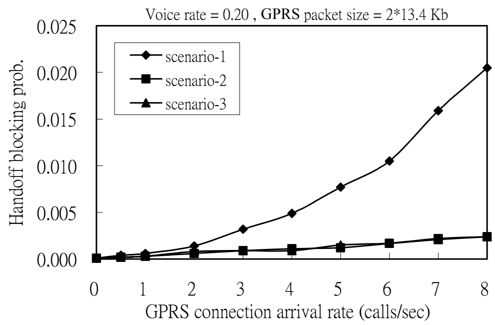


(b) high voice traffic load

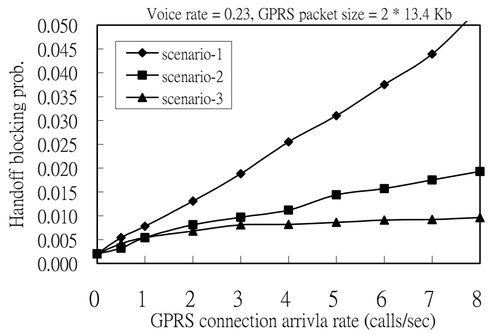
Fig. 3. Comparison of new call blocking

Fig. 5 shows the comparison of GPRS connection rejection. It shows that scenario-3 will suffer large connection rejection ratio, especially at high traffic load, compared with the other two scenarios. This is because when the traffic load increases, a GPRS connection request will most probably fail the admission control test, causing high rejection ratio. On the other hand, scenario-1 gives the lowest GPRS rejection ratio among the three scenarios.

Fig. 6 compares the channel utilization. At low voice traffic load, the channel utilization of all three scenarios are almost the same when the GPRS arrival rate is less than 3 calls/sec. With increasing GPRS arrival rate, scenario-2 will have the largest channel utilization. At high voice traffic load shown in Fig. 6 (b), the channel utilization has similar trend and characteristics as the low voice traffic load case. Scenario-3 has the lowest channel utilization. This is because a large portion of GPRS connection requests are rejected by the call admission controller at high traffic load.

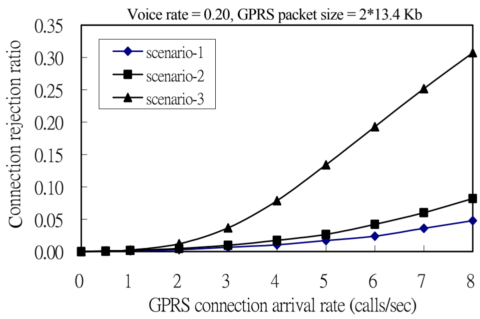


(a) low voice traffic load

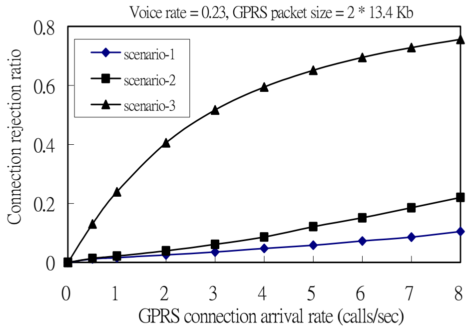


(b) high voice traffic load

Fig. 4. Comparison of handoff call blocking

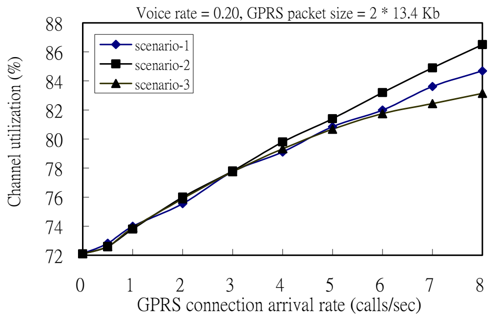


(a) low voice traffic load

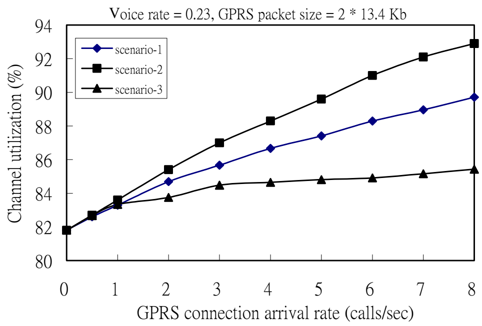


(b) high voice traffic load

Fig. 5. Comparison of GPRS connection rejection



(a) low voice traffic load



(b) high voice traffic load

Fig. 6. Comparison of channel utilization

From Fig. 3 and Fig. 4, it can be seen that the voice blocking probability will be increased with increasing GPRS traffic load even if applying channel de-allocation and call admission control mechanisms to GPRS traffic. Therefore we modified the previous scheme to guarantee the voice blocking probability not to be affected by the increasing GPRS traffic load. The modification is described as follows. When channel de-allocation mechanism can not provide channels for the arriving voice call, new or handoff, the network preempts an ongoing GPRS connection to service the arriving voice call. In addition, when a GPRS connection request arrives and there are no unused channels, the connection request is queued in the buffer. The preempted GPRS connections will also be queued in the buffer and are given higher priority to resume their services whenever there are channels available. Both kinds of connections are served in a first come first served (FCFS) manner. In this part of simulation, the buffer size is assumed to be infinite to avoid the GPRS connection request being blocked due to buffer overflow. We will investigate the mean packet delay of GPRS traffic with different multi-slot capability under different traffic load.

Fig. 7 shows the blocking probability of new call and handoff call with voice traffic load being 0.23 calls/sec and GPRS mean packet size being 2×13.4 *Kbits*. It can be seen that with voice preemption, the blocking probability of voice service is well below the target blocking probability (P_{tnb} and P_{thb}) and is independent of GPRS traffic load.

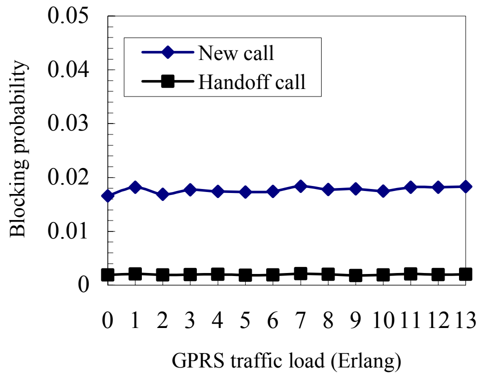
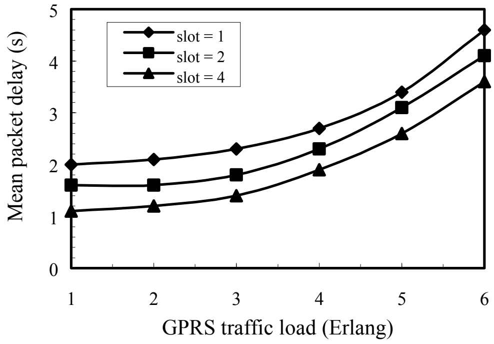
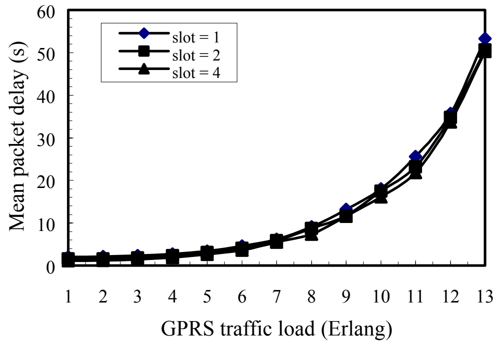


Fig. 7. Voice blocking probability of new call and handoff call

The effect of different multi-slot allocation to mean packet delay of GPRS traffic is shown in Fig. 8. In the figure, slot = 1 (or 2, 4) means that the maximum number of PDCHs that can be allocated to one mobile station is 1 (or 2, 4). It can be seen that at low GPRS traffic load, the mean packet delay can be effectively reduced with multi-slot allocation. While at high GPRS traffic load, the improvement is not obvious. The reason is that at high traffic load, a large portion of GPRS connections are allocated only one channel despite of multi-slot capability.



(a) low GPRS traffic load



(b) high GPRS traffic load

Fig. 8. The effect of multi-slot allocation

5 Conclusions

Since GPRS shares radio resources with voice service, how to allocate bandwidth between the two services is an important issue. The introduction of GPRS service should not degrade the QoS of existing voice services. Guard channels can be temporarily allocated to GPRS connections to improve channel utilization. As voice traffic load increases, the channels of some ongoing GPRS connections are de-allocated to arriving voice calls. The de-allocation must still maintain the minimum required QoS of the de-allocated connections.

Simulation results show that at low voice traffic load, there is no need to apply admission control to GPRS connections. At high voice traffic load, the call admission control guarantees the blocking probability of new and handoff calls to be below certain value. But this will result in high GPRS rejection and low channel utilization.

To guarantee the QoS of voice service not to be affected by the introduction of GPRS, voice arrivals are allowed to preempt the ongoing GPRS connections. The mean packet delay of GPRS traffic can be effectively reduced with multi-slot allocation at low GPRS traffic load.

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