Channel Allocation for Priority Packets in the GPRS Network

Chung-Yung Chia and Ming-Feng Chang

***Abstract*— As the General Packet Radio Service (GPRS) network begins to provide such as "push-to-talk" (PTT) service, delay-sensitive packets should be given higher priority in transmission. In this paper, we study two channel allocation schemes that implement priority queues for priority packets in the GPRS network: Bitmap Channel Allocation (BCA) and Uplink State Flag Channel Allocation (USFCA). Our study shows that the transmission delay of priority packets in the GPRS network can be better guaranteed using USFCA.**

***Index Terms*— Bitmap Channel Allocation (BCA), Uplink State Flag (USF), USF Channel Allocation (USFCA).**

I. Introduction

General Packet Radio Service (GPRS) has been developed to provide packet data services based on the circuit-switching Global System for Mobile Communications (GSM) network. Much research has been done on analyzing the performance of fixed or dynamic channel (i.e., timeslots) allocation to support multiple-slot data transmission [1-2]. However, very few studies considered special treatments to priority packets in the GPRS network. In [3], Chew and Tafazolli give priority to mobility management packets to ensure minimal delay. Their results indicated that the priority queue provides shorter Routing Area Upate (RAU) completion time and higher packet throughput than the others. However, the way in which the priority queue is implemented in the GPRS network has not been thoroughly studied.

In addition to the mobility management packets, some data services, such as "push to talk" (PTT) are delay-sensitive; the transmission latency of voice packets is very important to the quality of the communications. In this paper, we study two channel allocation schemes [4], Bitmap Channel Allocation (BCA) and Uplink State Flag Channel Allocation (USFCA), that implement priority queues to give transmission priority to packets requiring shorter transmission latency. We also present analytic models to analyze their performance in terms of packet transmission delay. Chunghwa Telecom is planning to provide USFCA scheme before the middle of 2007.

II. The Methods of BCA and USFCA

A GSM/GPRS Time Division Multiple Access (TDMA) frame consists of eight timeslots, numbered 0-7, which can be used for data or voice transmission. Channel allocation in the GPRS network can be performed in unit of radio blocks. A radio block consists of four identical timeslots from four successive TDMA frames. Uplink packet requests from a mobile station (MS) can specify different priorities for special treatment by the GPRS network [4]. In this paper, we assume only two types of packets: priority packets that are sensitive to delay, and non-priority packets that are not.

A. BCA Method

For an uplink "Packet Channel Request" message from a MS, the GPRS network may return a "Packet Uplink Assignment" message with the *allocation-bitmap* element indicating the allocated radio blocks to the uplink packet request. To reduce the number of messages exchanged between the MS and the network, the network allocates radio blocks in full amount requested by the MS. As a result, when all timeslots of the network are assigned out, new uplink packet requests need to wait until a transmitting packet completes. The transmitting packets cannot be interrupted during transmission.

B. USFCA Method

For an uplink "Packet Channel Request" message from a MS, the GPRS network may return a "Packet Uplink Assignment" message with the *USF-for-each-timeslot-number* element indicating the specific USF value for each timeslot allocated to the uplink packet request. For USFCA, the network broadcasts a USF value at each downlink radio block. In the next uplink radio block, the MS assigned with the same USF value can transmit for one radio block. In this way, the network can schedule an uplink packet to transmit at the next radio block on a radio block by radio block basis. As a result, a transmitting packet can be suspended at the end of a radio block. The way in which multiple packets share a timeslot is controlled by the network; the network can use various scheduling schemes, such as priority-packet-first. Fig. 1 shows a USFCA example using priority-packet-first scheme, a non-priority packet 1 is assigned with USF value 1 and a priority packet 2, which needs m radio blocks to transmit, is assigned with USF value 2 by network. Packet 1 is transmitting when packet 2 arrives at radio block n. The network suspends the transmission of packet 1, and instructs packet 2 to transmit at downlink radio block n+1. Packet 1 can resume transmission after packet 2 completes transmission.

III. The Analytic Models

Let C denote the number of GPRS timeslots reserved for transmission of data packets. When all the GPRS timeslots

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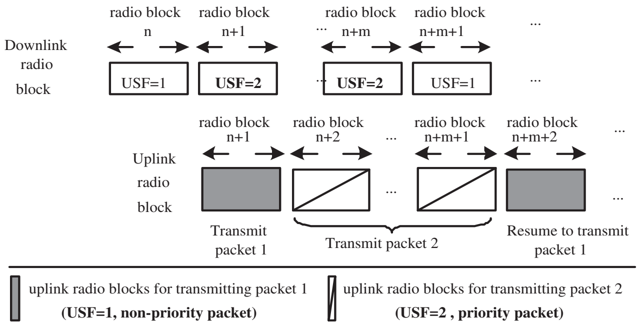

Fig. 1. A USFCA example using priority-packet-first scheme

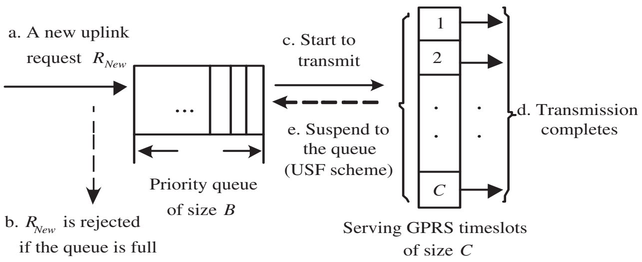

Fig. 2. The queuing model for BCA and USFCA schemes

are assigned, additional uplink packet requests are put in a priority queue of size B maintained by the network. In the priority queue, packets of the same priority will be served on a First Come, First Served (FCFS) basis. The queuing model of BCA and USFCA schemes is depicted in Fig. 2. Using BCA, the network cannot suspend the transmission of a packet under service, but using USFCA, the network can suspend the transmission of a non-priority packet, put it back to the priority queue, and start transmitting a new priority packet. This difference is depicted in Fig.2 by dotted line,e.

To analyze the performance of the schemes, we made the following assumptions. The arrivals of priority and non-priority packets form Poisson processes with mean λ_p and λ_{np} respectively. The service time of priority and non-priority packets is assumed to be exponentially distributed with mean $1/\mu_p$ and $1/\mu_{np}$ respectively. We can use the M/M/C/B Markov process to model BCA and USFCA.

A. BCA Method

In this process, state (i, j, k) denotes that there are i priority packets transmitting in the network, j priority packets waiting in the priority queue, k non-priority packets transmitting in the network or waiting in the priority queue. Let $P_{i,j,k}$ denote the steady-state probability of the network in state (i, j, k) and S_{bm} be the set of existing states for this process.

$S_{bm} = \{(i, j, k)|\ 0 \le (i + j + k) \le (C + B),\ 0 \le i \le C,\ 0 \le j \le B,\ 0 \le k \le (C + B)$ and $[(i + k) \ge C$ or $(j = 0)]\}$

To handle the non-existing states, an indicator $\theta_{i,j,k}$ is used to indicate whether state (i, j, k) exists or not, i.e., $\theta_{i,j,k}$=1 if state (i, j, k) belongs to S_{bm}. In addition, δ_1 - δ_5 indicators are used to indicate whether a specific transition exists or not. The balance equations for this process and the parameters used for BCA method can be expressed as follows.

$$P_{i,j,k}\{\delta_1\lambda_p\theta_{i+1,j,k} + (\sim \delta_1)[M_{np}(i,j,k)\theta_{i+1,j-1,k-1} + \lambda_p\theta_{i,j+1,k}] + \delta_2 M_p(i,j,k)\theta_{i-1,j,k} + \delta_3 M_p(i,j,k)\theta_{i,j-1,k} + \delta_4 M_{np}(i,j,k)\theta_{i,j,k-1} + \lambda_{np}\theta_{i,j,k+1}\}$$
$$= (\sim \delta_1)[P_{i,j-1,k}\lambda_p\theta_{i,j-1,k} + P_{i-1,j+1,k+1}M_{np}(i-1, j+1, k+1)\theta_{i-1,j+1,k+1}] + \delta_2 P_{i+1,j,k}M_p(i+1,j,k)\theta_{i+1,j,k} + \delta_3 P_{i,j+1,k}M_p(i,j+1,k)\theta_{i,j+1,k} + \delta_4 P_{i,j,k+1}M_{np}(i,j,k+1)\theta_{i,j,k+1} + \delta_5 P_{i-1,j,k}\lambda_p\theta_{i-1,j,k} + P_{i,j,k-1}\lambda_{np}\theta_{i,j,k-1}$$

$$M_p(l, m, n) = l * \mu_p$$

$$M_{np}(l, m, n) = \begin{cases} (C - l) * \mu_{np} \text{ , if } n \ge (C - l); \\ n * \mu_{np} \text{ , otherwise} \end{cases}$$

$\delta_1 = 1$, if $(i + k) < C$; 0 , otherwise.
$\sim \delta_1 = 1$, if $(i + k) \ge C$; 0 , otherwise.
$\delta_2 = 1$, if $(j = 0)$; 0 , otherwise.
$\delta_3 = 1$, if $(i + k) \ge C$ and $(i \ne 0)$; 0 , otherwise.
$\delta_4 = 1$, if $(j = 0)$ and $(i \ne C)$; 0 , otherwise.
$\delta_5 = 1$, if $(i + j + k) \le C$; 0 , otherwise.

From the balance equations and the constraints $\sum_{(i,j,k)\epsilon S_{bm}} P_{i,j,k}$=1, the steady-state probability $P_{i,j,k}$ can be obtained by an iterative algorithm [5]. The blocking probability of packets ($P_{\_bm}$) ; the mean waiting time and system time of priority packets (W_{p_bm} and T_{p_bm}) ; the mean waiting time and system time of non-priority packets (W_{np_bm} and T_{np_bm}) can be expressed as (1)-(5).

$$P_{\_bm} = \sum_{(i+j+k)=(C+B)} P_{i,j,k} \quad (1)$$

$$W_{p\_bm} = \frac{1}{\lambda_p * (1 - P_{\_bm})} * \sum_{(i+j+k)\in S_{bm}} j * P_{i,j,k} \quad (2)$$

$$T_{p\_bm} = \frac{1}{\lambda_p * (1 - P_{\_bm})} * \sum_{(i+j+k)\in S_{bm}} (i + j) * P_{i,j,k} \quad (3)$$

$$W_{np\_bm} = \frac{1}{\lambda_{np} * (1 - P_{\_bm})} * \sum_{\substack{(i+j+k)\in S_{bm} \\ ,k>(C-i)}} [k - (C - i)] * P_{i,j,k} \quad (4)$$

$$T_{np\_bm} = \frac{1}{\lambda_{np} * (1 - P_{\_bm})} * \sum_{(i+j+k)\in S_{bm}} k * P_{i,j,k} \quad (5)$$

B. USFCA Method

In this process, state (i, j) denotes that there are i priority packets and j non-priority packets transmitting in the network or in the priority queue. Let $P_{i,j}$ denote the steady-state probability of the network in state (i, j) and S_{USF} be the set of existing states for this process.

$S_{USF} = \{(i, j)|\ 0 \le (i + j) \le (C + B),\ 0 \le i \le (C + B)$ and $0 \le j \le (C + B)\}$

To handle the un-existing states, an indicator $\theta_{i,j}$ is used to indicate whether state (i, j) exists or not, i.e., $\theta_{i,j}$=1 if state (i, j) belongs to S_{USF}.The balance equations for this process and the parameters used for USFCA method can be expressed as follows.

$$P_{i,j}[\lambda_p\theta_{i+1,j} + \lambda_{np}\theta_{i,j+1} + M_p(i,j)\theta_{i-1,j} + M_{np}(i,j)\theta_{i,j-1}]$$
$$= (P_{i-1,j}\lambda_p\theta_{i-1,j} + P_{i,j-1}\lambda_{np}\theta_{i,j-1} + P_{i+1,j}M_p(i+1,j)\theta_{i+1,j} +$$

$P_{i,j+1}M_{np}(i,j+1)\theta_{i,j+1}$

$$M_p(m,n) = \begin{cases} C * \mu_p \text{ , if } m \geq C; \\ m * \mu_p \text{ , otherwise.} \end{cases}$$

$$M_{np}(m,n) = \begin{cases} 0 \text{ , if } m \geq C; \\ (C-m) * \mu_{np} \text{ , if } (m+n) \geq C; \\ n * \mu_{np} \text{ , otherwise.} \end{cases}$$

From the balance equations and the constraints $\sum_{(i,j)\epsilon S_{USF}} P_{i,j}$=1, the steady-state probability $P_{i,j}$ can be derived by an iterative algorithm. The blocking probability of packets ($P_{\_USF}$) ; the mean waiting time and system time of priority packets (W_{p_USF} and T_{p_USF}) ; the mean waiting time and system time of non-priority packets (W_{np_USF} and T_{np_USF}) can be expressed as (6)-(10).

$$P_{\_USF} = \sum_{i+j=C+B} P_{i,j} \tag{6}$$

$$W_{p\_USF} = \frac{1}{\lambda_p * (1 - P_{\_USF})} * \sum_{(i+j)\in S_{USF}, i>C} (i-C) * P_{i,j} \tag{7}$$

$$T_{p\_USF} = \frac{1}{\lambda_p * (1 - P_{\_USF})} * \sum_{(i+j)\in S_{USF}} i * P_{i,j} \tag{8}$$

$$W_{np\_USF} = \frac{1}{\lambda_{np} * (1 - P_{\_USF})} * [\sum_{(i+j)\in S_{USF}, i\geq C} j * P_{i,j} + \sum_{(i+j)\in S_{USF}, i<C, (i+j)>C} (i+j-C) * P_{i,j}] \tag{9}$$

$$T_{np\_USF} = \frac{1}{\lambda_{np} * (1 - P_{\_USF})} * \sum_{(i+j)\in S_{USF}} j * P_{i,j} \tag{10}$$

IV. Numeric Analysis

The total number of data channels (C) is set to be 4 ,used in Chunghwa Telecom's GPRS network , and the queue size (B) is set to be 4, same with the size of C. We compare three channel allocation schemes. The first two are BCA and USFCA schemes described in the previous section. The third one is a simple FCFS channel allocation scheme with a First In, First Out (FIFO) queue of the same size (B). The simple FCFS scheme,not mentioned in this paper,can also be modeled as a M/M/C/B Markov process. Let $W_{\_FCFS}$ and $T_{\_FCFS}$ denote the mean waiting time and system time of packets.

The mean service time of one packet ($1/\mu_p$ and $1/\mu_{np}$) is assumed to be 0.0625 seconds with one timeslot allocated. This represents approximately an average 105 bytes per packet under the GPRS CS-2 coding scheme and is near the average uplink packet sizes we observed in Chunghwa Telecom's GPRS network. For packet arrival, λ_{np} is fixed at 32 packets/second and λ_p varies in the range of 8-32 packets/second.

In Fig. 3, the results indicate both BCA and USFCA schemes provide shorter mean waiting time and system time for priority packets than the simple FCFS scheme at the cost of longer mean waiting time and system time for non-priority packets. The improvement and the cost become more significant as the priority traffic increases. In addition, the improvement and the cost of USFCA scheme are more significant than those of BCA scheme. This is because when there is no free channel, USFCA scheme can suspend the transmission

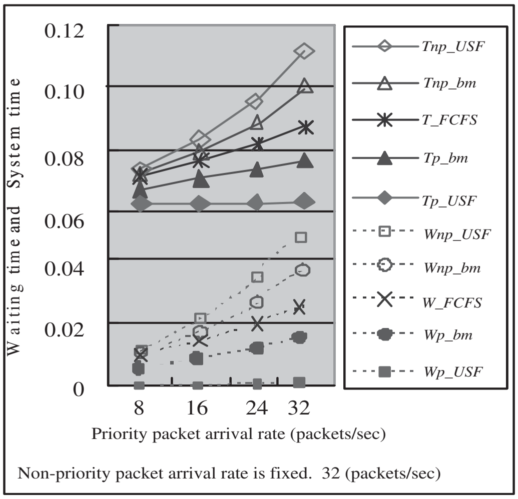

Fig. 3. The mean waiting time and system time(seconds) of uplink packets for λ_{np} = 32 packets/second and λ_p = 8-32 packets/second

of a non-priority packet and start transmitting a new priority packet, but BCA scheme cannot. The improvement on mean waiting time and system time for priority packets over the simple FCFS scheme can be as large as 0.025 seconds when the priority packet arrival rate is the 32 packets/sec, the transmission delay can be greatly reduced to an extend of nearly 72%. This 0.025 seconds difference could be critical for real-time voice communications. We have also performed the numeric analyses for a wider variety of traffic mixtures using different parameters (i.e., C and B), we get the same results.

V. Conclusion

This paper studied BCA and USFCA schemes that implement priority queues in the GPRS network. Both schemes provide shorter mean waiting time and system time for priority packets than the simple FCFS scheme at the cost of longer mean waiting time and system time for non-priority packets. In addition, the transmission delay of priority packets using USFCA can be better guaranteed than that of BCA especially when the GPRS traffic is heavy.

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