Performance Evaluation of GSM/GPRS Networks With Channel Re-Allocation Scheme

Yan Zhang and Boon-Hee Soong, *Member, IEEE*

***Abstract*—Previous work studying the channel allocation schemes in GSM/GPRS network commonly assume that one or two channels are required by a GPRS data for the sake of analytical simplicity. In this letter, we remove the assumption and generalize the GPRS data channel requirement (M channels). Additionally, we propose a channel re-allocation scheme (RAS), executed upon the channel release, by re-allocating the idle channels to the GPRS data which is currently using less than M channels. The example findings show that RAS can significantly decrease the voice call blocking probability and GPRS packet transmission time with slight channel utilization increase and negligible expense on GPRS packet blocking probability. Small M (e.g.$M = 2$) will underestimate the performance achievements of the prior channel allocation scheme as well as RAS.**

***Index Terms*—Dynamic channel allocation, GSM/General Packet Radio Service (GSM/GPRS).**

I. Introduction

THE integration of General Packet Radio Service (GPRS) [1] with the popular GSM network represents a major development toward the next generation wireless multimedia network. Due to the diverse quality-of-service (QoS) requirements of voice and data and the motivation for efficient bandwidth utilization, the channel allocation scheme in the voice/data integrated GSM/GPRS network is one of the most crucial issues to achieve the best system performance.

The adaptive characteristics implied by the mutli-slot capability, one of the key features of GPRS network providing a flexible mechanism for voice/data sharing the precious radio resources, has been investigated by a few works. Lin *et al.*[3], [4] employed the multi-slot service to assign channels to a GPRS data under the condition of insufficient resources. Chen *et al.*[2] recently proposed de-allocation scheme (DAS) specifically employing the multi-slot property upon voice call arrival to prevent the voice call from rejection. For the sake of analytical simplicity and tractability, the aforementioned studies assume that only 1, 2, or 3 maximum channels are required by GPRS data request. In this letter, we relax this assumption, i.e. generalize the channel requirement by GPRS data as M channels.

Referring to prior studies, upon channel release, the freed channels are left idle. We argue that these idle channels can be re-allocated to the *degraded GPRS call*, terming the GPRS data using less than M channels, with the potential to reduce the GPRS packet transmission duration and to fully utilize the available resources, which is called as channel re-allocation scheme (RAS). On the other hand, the general channel requirement of GPRS data considerably complicates DAS as well as RAS. When $M = 2$, only the GPRS calls using two channels should be de-allocated upon voice call arrival, while only those GPRS calls using one channel should be re-allocated upon channel release. For general case, since the possible utilizing channels by a GPRS call vary from 1 to M, two natural problems arise: which GPRS call should be selected to de-allocate a channel for a voice call connection request and which one should be chosen to re-allocate in RAS. The channel allocation policies corresponding to these two questions will be described in the next section.

Manuscript received October 2, 2003. The associate editor coordinating the review of this letter and approving it for publication was Prof. S. Pierre.

The authors are with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore (email: yanzhang@pmail.ntu.edu.sg; ebhsoong@ntu.edu.sg).

Digital Object Identifier 10.1109/LCOMM.2004.827379

II. Traffic Model and Channel Allocation Scheme

Consider a base station (BS) with C channels for the voice call and GPRS packet sharing in a homogeneous GSM/GPRS network. We term the GPRS packet using m $(m = 1, 2, \cdots, M)$ channels as *type-m GPRS call*. We assume that the voice new call, voice handoff call and GPRS packet follow the Poisson Process with the arrival rate λ_{vn}, $\lambda_{\rm vh}$ and λ_g, respectively. Let $\lambda_v = \lambda_{vn} + \lambda_{\rm vh}$ be the total voice call arrival rate. The call holding time and the cell residence time of voice call are exponentially distributed with service rate μ_c and $\mu_{\rm crt}$, respectively. Hence, the channel holding time of voice call is exponential distribution with the parameter $\mu_v = \mu_c + \mu_{\rm crt}$. The service time of each GPRS packet with one channel is exponentially distributed with mean $1/\mu_g$.

The state transition can be triggered by the following events: voice call arrival, voice call normal completion, voice call handoff, GPRS data arrival and GPRS data completion. Upon a GPRS data arrival (denoted as ARR_g), if the number of idle channels $C_{\rm idle} \geq M$, M channels are allocated to ARR_g. If $0 < C_{\rm idle} < M$, $C_{\rm idle}$ channels are allocated to ARR_g. Otherwise, i.e., $C_{\rm idle} = 0$, ARR_g is blocked.

For a voice call arrival (denoted as ARR_v), if $C_{\rm idle} > 0$, one channel is assigned to ARR_v. If $C_{\rm idle} = 0$, DAS is extended for general case. We adopt the following method: type-m GPRS call can be degraded if and only if type-q $(q = M, M-1, \cdots, m+1)$ have been already degraded to type-1. Let $j_m(t)$ be the number of type-m GPRS call at time t. Denote $j_{\alpha(t)}(t)$ as the first nonzero value in the ordered sequence $(j_M(t), j_{M-1}(t) \cdots j_2(t))$. The nonexistence of $\alpha(t)$ implies that no GPRS call exists or all GPRS calls are type-1. Hence, if $C_{\rm idle} = 0$ and $\alpha(t)$ exists, we de-allocate a channel from a type-$\alpha(t)$ GPRS call and then assign this channel to

ARR_v, and the type-$\alpha(t)$ GPRS call becomes type-$(\alpha(t)-1)$. If $C_{\text{idle}}=0$ and $\alpha(t)$ does not exist, ARR_v is blocked.

Next, we describe the RAS. Upon the channel release, if there are degraded GPRS calls, the released channel will be re-allocated to upgrade such calls. We adopt the worst degraded first upgrading policy, i.e., type-m GPRS call can be upgraded if and only if type-q $(q=1,2,\cdots,m-1)$ have been already upgraded. In upgrading a specific type-m GPRS call, it will attempt to upgrade to type-M if sufficient channels are available. Otherwise, the type-m GPRS call will expand to the possible type by using up the idle channels. If there are remaining channels after all type-m GPRS calls have been successfully upgraded to type-M, the type-$(m+1)$ will attempt to upgrade to type-M, this process will be repeated till the released channels are used up for re-allocation or all degraded GPRS calls are fully upgraded to type-M.

III. Performance Analysis

Let the BS state denote as $\mathbf{x}=(i,j_1,j_2\cdots j_M)$ with i representing the number of voice call in service, $j_m(m\in\mathcal{M}\equiv\{1,2\cdots M\})$ the number of type-m ongoing GPRS call. The state space of BS, $\mathcal{X}$, is defined as

$$\mathcal{X}\equiv\left\{\mathbf{x}=(i,j_1,j_2\cdots j_M)|0\le i+\sum_{m=1}^{M} m\cdot j_m\le C;\right.\\ \left. 0\le j_m\le\left\lfloor\frac{C}{m}\right\rfloor,\qquad m=1,2\cdots M\right\} \quad (1)$$

with $\lfloor z\rfloor$ standing for the maximum integer less than or equal to z. Let $r_{\mathbf{x}\to\mathbf{x}'}(\mathbf{x}\in\mathcal{X},\mathbf{x}'\in\mathcal{X})$ be the transition rate from the current legal state $\mathbf{x}=(i,j_1,j_2\cdots j_M)$ to the destination legal state $\mathbf{x}'=(i',j_1',j_2'\cdots j_M')$. If $\mathbf{x}\notin\mathcal{X}$ or $\mathbf{x}'\notin\mathcal{X}$, then $r_{\mathbf{x}\to\mathbf{x}'}=0$. In state $\mathbf{x}$, denote $\xi=C-i-\sum_{m=1}^{M} m\cdot j_m$ as the number of free channels in the BS. Define the indicator function $\mathbf{1}_E$ equal to 1 when the event E is true, zero otherwise. Let j_α denote the first nonzero value in the ordered sequence $(j_M,j_{M-1},\cdots,j_2)$. Let j_β denote the first nonzero value in the sequence $(j_1,j_2,\cdots,j_{M-1})$. If α does not exist, then all GPRS calls (if available) are type-1. If β does not exist, then all GPRS calls (if available) are type-M.

Upon a type-m GPRS call completion, the number of type-q $(q\in\mathcal{M})$ GPRS data becomes $(j_1,j_2,\cdots,j_m-1,\cdots j_M)$ and m free channels are available to upgrade the degraded GPRS call. Denote the index q^* $(1\le q^*\le M-1)$ satisfying

$$\sum_{q=1}^{q^*-1} j_q(M-q)\le m<\sum_{q=1}^{q^*} j_q(M-q). \quad (2)$$

The inequality shows that the type-1 to type-(q^*-1) can be fully upgraded to type-M, and the type-q^* can be partially upgraded to type-M under the condition of m channel availability. In the special case $\sum_{q=1}^{M-1} j_q(M-q)\le m$, showing that all the degraded GPRS calls in service can be fully upgraded to type-M GPRS call, we designate $q^*=M$. Non-existence of q^* in the set $\mathcal{M}$ suggests that there is no GPRS call or all GPRS calls are type-M after the type-m GPRS call completion.

The transition rate is given by (3) at the bottom of the page, where the component in the destination state $\mathbf{x}'_{MU,\text{GPRS complete}}=(i',j_1',j_2'\cdots j_M')$ due to a type-m GPRS call completion is expressed as follows.

1) $1\le q^*\le M-1$:

$$i'=i,j_q'=0(q=1,2\cdots q^*-1),j'_{q^*}=j_{q^*}-\Delta-1$$
$$j'_{q^*+\Delta_r}=j_{q^*+\Delta_r}+1,j_M'=\sum_{q=1}^{q^*-1} j_q+\Delta+j_M$$
$$j_q'=j_q \quad \text{(other index } q \text{ in the set } \mathcal{M})$$

where

$$\Delta=\left\lfloor\frac{(m-\sum_{q=1}^{q^*-1} j_q(M-q))}{(M-q^*)}\right\rfloor$$

is the maximum number of type-q^* GPRS data that can be upgraded. $\Delta_r=m-\sum_{q=1}^{q^*-1} j_q(M-q)-\Delta(M-q^*)$ represents the number of channels to upgrade one type-q^* GPRS call to type-$(q^*+\Delta_r)$.

2) $q^*=M$:

$$i'=i,j_q'=0\,(q=1,2\cdots M-1),j_M'=j_1+j_2+\cdots+j_M.$$

From this, the generator matrix $\mathbf{R}$ governing the evolution of the multidimensional Markov chain, can be easily obtained. The steady-state probability of the state $\mathbf{x}$ is denoted as $\pi(\mathbf{x})$. Let $\mathbf{\Pi}$ be the stationary state probability vector of the system and be ordered in the lexicographic order based on the state $\mathbf{x}$. Then, $\mathbf{\Pi}$ is the solution of linear equation $\mathbf{\Pi R}=0$ and $\mathbf{\Pi e}=1$ with $\mathbf{e}$ representing the column vector with all ones.

The voice handoff call arrival rate is described as

$$\lambda_{\text{vh}}=\left(\sum_{\mathbf{x}\in\mathcal{X}} i\cdot\pi(\mathbf{x})\right)\cdot\mu_{\text{crt}}. \quad (4)$$

Note that since the voice handoff call arrival rate and steady state probability is mutually related, an iterative algorithm should be used.

$$r_{\mathbf{x}\to\mathbf{x}'}=\begin{cases}\lambda_v\cdot\mathbf{1}_{\xi>0} & i'=i+1,j_q'=j_q(q\in\mathcal{M})\\ \lambda_v\cdot\mathbf{1}_{\xi=0}\mathbf{1}_{(\text{exist }\alpha)} & i'=i+1,j'_{\alpha-1}=j_{\alpha-1}+1,j'_\alpha=j_\alpha-1,j_q'=j_q\,(q\in\mathcal{M}-\{\alpha-1,\alpha\})\\ \lambda_g\cdot\mathbf{1}_{\xi\ge M} & i'=i,j_M'=j_M+1,j_q'=j_q\,(q\in\mathcal{M}-\{M\})\\ \lambda_g\cdot\mathbf{1}_{1\le\xi<M} & i'=i,j'_\xi=j_\xi+1,j_q'=j_q\,(q\in\mathcal{M}-\{\xi\})\\ i\mu_v\cdot\mathbf{1}_{(\text{exist }\beta)} & i'=i-1,j'_\beta=j_\beta-1,j'_{\beta+1}=j_{\beta+1}+1,j_q'=j_q\,(q\in\mathcal{M}-\{\beta,\beta+1\})\\ i\mu_v\cdot\mathbf{1}_{(\text{not exist }\beta)} & i'=i-1,j_M'=j_M,j_q'=0\,(q\in\mathcal{M}-\{M\})\\ j_m(m\mu_g)\cdot\mathbf{1}_{(\text{exist }q^*)} & \mathbf{x}'_{MU,\text{GPRS complete}};\quad m\in\mathcal{M}\\ j_m(m\mu_g)\cdot\mathbf{1}_{(\text{not exist }q^*)} & i'=i,j_M'=j_M,j_q'=0\,(q\in\mathcal{M}-\{M\});\quad m\in\mathcal{M}\end{cases} \quad (3)$$

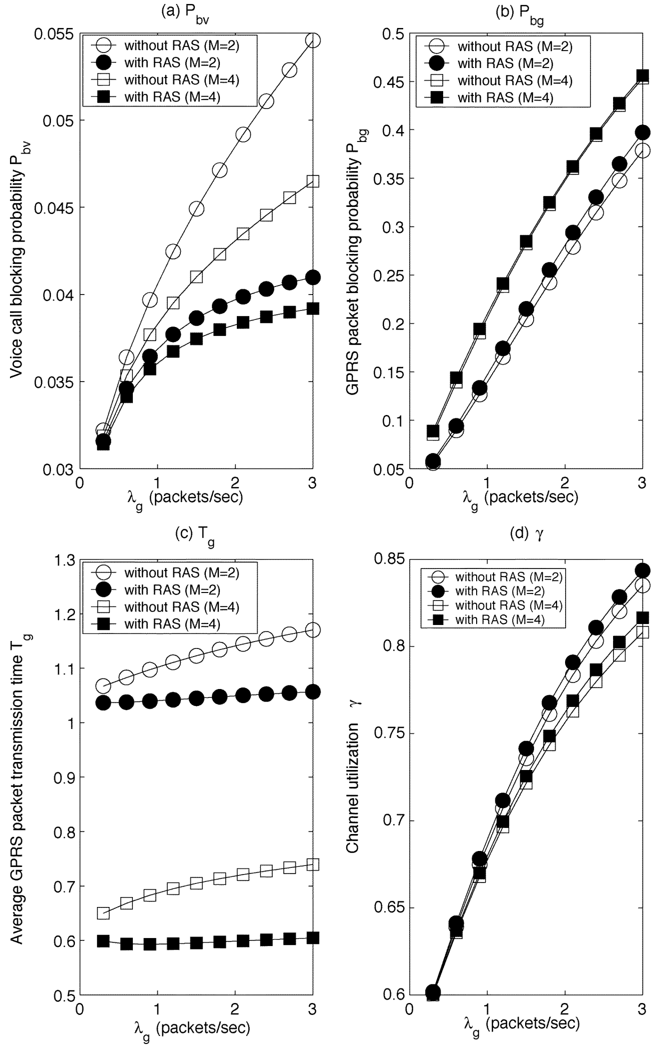

Fig. 1. Performance metrics in terms of the GPRS packet arrival rate.

Denote $P_{bv}, P_{bg}, T_g, \gamma$ as the voice call blocking probability, GPRS packet blocking probability, average GPRS packet transmission time and channel utilization, respectively.

$$P_{bv} = \sum_{i+j_1=C, j_2=0, j_3=0, \cdots, j_M=0} \pi(\mathbf{x}) \tag{5}$$

$$P_{bg} = \sum_{i+\sum_{q=1}^{M} q \times j_q = C} \pi(\mathbf{x}) \tag{6}$$

$$T_g = \frac{\sum_{\mathbf{x}\in\mathcal{X}} \left(\sum_{m=1}^{M} j_m\right) \cdot \pi(\mathbf{x})}{\lambda_g(1-P_{bg})} \tag{7}$$

$$\gamma = \frac{\sum_{\mathbf{x}\in\mathcal{X}} \left(i + \sum_{m=1}^{M} m \cdot j_m\right) \cdot \pi(\mathbf{x})}{C}. \tag{8}$$

IV. Numerical Results

We choose the following set of parameters: $C = 12$, $\mu_c = 1/180.0$, $\mu_{\text{crt}} = 1/120.0$, $\mu_g = 1/2.0$, $\lambda_{vn} = 0.04$ calls/s. Fig. 1 shows the performance metrics in terms of GPRS packet arrival rate. It is evident that RAS can substantially decrease P_{bv} and T_g. This is because, when using RAS, more channels are accessible for GPRS packet, leading to the great reduction in the GPRS packet transmission time. As a consequence, in a fixed interval, more GPRS packet can complete the service and more channels are available for voice call connection, which results in smaller P_{bv} and T_g. In addition, there is a slight increase in the channel utilization when using RAS due to the tendency of RAS to fully utilize all idle channels. We can observe that the penalty on P_{bg} is negligible. From the perspective of GPRS data request, RAS reduces its available channels. Hence, P_{bg} becomes larger with the involvement of RAS. However, the substantially reduced GPRS packet transmission time, leading to more available channels for GPRS packet access, compensates such deterioration and makes this issue insignificant. Furthermore, better performance can be achieved with larger M and such benefit becomes more apparent with burstier GPRS packet. Hence, the commonly used assumption, i.e. two channels requirement by a GPRS data, underestimates the actual achievement of DAS as well as RAS.

V. Conclusion

In this paper, we generalize the channel requirement of GPRS data and propose the channel RAS in GSM/GPRS network with the emphasis on employing the adaptive characteristics implied by multi-slot capability. The result shows that RAS can considerably reduce the voice packet blocking probability and GPRS packet transmission time with negligible expense on GPRS packet blocking probability. Moreover, the assumption for two channels requirement of GPRS data underestimates the performance of DAS as well as RAS.

Acknowledgment

The authors thank the anonymous reviewers for their helpful suggestions.

References

[1] 3GPP TS 23.060, *General Packet Radio Service (GPRS)*, service description; stage 2; release 5, v5.0.0, 2002.

[2] W.-Y. Chen, J.-L. C. Wu, and L.-L. Lu, "Performance comparisons of dynamic resource allocation with/without channel de-allocation in GSM/GPRS networks," *IEEE Commun. Lett.*, vol. 7, pp. 10–12, Jan. 2003.

[3] P. Lin, "Channel allocation for GPRS with buffering mechanisms," *Wireless Networks*, vol. 9, pp. 431–441, 2003.

[4] P. Lin and Y. B. Lin, "Channel allocation for GPRS," *IEEE Trans. Veh. Technol.*, vol. 50, no. 2, pp. 375–387, 2001.