Performance Comparisons of Dynamic Resource Allocation With/Without Channel De-Allocation in GSM/GPRS Networks

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***Abstract*—In this letter, we analyzed and compared the performance of dynamic resource allocation with/without channel de-allocation in GSM/GPRS networks. It is quite known that dynamic resource allocation allows communication systems to utilize their resources more efficiently than the traditional fixed allocation schemes. In GPRS, multiple channels may be allocated to a user to increase the transmission rate. In the case when there are no free channels in the system, some of these channels may be de-allocated to serve higher priority calls. The results show that with channel de-allocation mechanism, the voice blocking probability can be greatly reduced, especially at high GPRS traffic load. Besides, the scheme with channel de-allocation mechanism can achieve higher channel utilization.**

***Index Terms*—Channel de-allocation, dynamic resource allocation, GPRS.**

I. Introduction

GENERAL Packet Radio Service (GPRS) [1] provides packet-switched data transfer to efficiently utilize the radio resources. Besides, it allows a single mobile station to transmit data using multiple time slots (one to eight time slots per time-division multiple access (TDMA) frame) to increase the data transmission rate. Therefore, GPRS has been considered to be the main development step of GSM networks toward the next generation mobile communication system like UMTS [2].

Ni and Haggman showed that employing the multi-slot service in GPRS will result in higher blocking probability and longer delay than using the single-slot service, and these effects can be alleviated by implementing the resource allocation scheme with flexible, or dynamic, multi-slot service [3].

We investigated, via simulation, the performance of dynamic resource allocation with channel de-allocation mechanism in a previous work [4]. In this letter, we will focus on the analysis and comparison of the performance of the dynamic resource allocation with/without channel de-allocation. Our goal is to understand the impact of channel de-allocation on the performance of integrated voice/data service in GSM/GPRS networks.

Manuscript received July 30, 2002. The associate editor coordinating the review of this letter and approving it for publication was Prof. S. Pierre. This work was supported in part by the National Science Council under Contract NSC 90-2213-E–011-128.

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Digital Object Identifier 10.1109/LCOMM.2002.806448

II. Dynamic Resource Allocation

For a data request of M channels, the network allocates at most M channels to the request. Assume there are N available channels in the system upon a data request arrival. If $N \geq M$, M channels are allocated to the request. If $0 < N < M$, N channels are allocated to the request. If $N = 0$, the request is blocked. Throughout the paper, "slot" and "channel" are used to have the same meaning.

To simplify the analysis, we will consider the case when $M = 2$. A packet request will be allocated with two channels if there are at least two unused channels upon arrival, otherwise, it will be allocated with one channel for transmission. If no channel is available, the request will be blocked. When there are no free channels upon a voice arrival, one slot of an existing 2-slot GPRS packet is de-allocated for the voice call, and the de-allocated packet continues its transmission with one slot. When there are neither free channels nor 2-slot packets in service, the voice call request will be blocked.

III. Analytical Model

To investigate the performance of the scheme with and without channel de-allocation, further assumptions are made. The arrivals of voice call requests form a Poisson process with a mean rate of λ_v. The service time of voice calls is assumed to be exponentially distributed with a mean of $1/\mu_v$. The arrival process of GPRS packets is assumed to be Poisson with a mean rate of λ_d. The service time of each GPRS packet is exponentially distributed with a mean of $1/\mu_d$. The total number of channels in the system is C. Let the state (i, j, k) denote that there are i voice calls, j 1-slot GPRS packets, and k 2-slot GPRS packets in the system. P_{ijk} denotes the state probability of the system in state (i, j, k).

Performance metrics considered in this work include the blocking probabilities of voice and GPRS, respectively, the mean transmission time of GPRS packets, and the channel utilization.

A. Without Channel De-Allocation

The voice call requests and GPRS packet requests will be blocked when there are no channels available upon arrival. Fig. 1

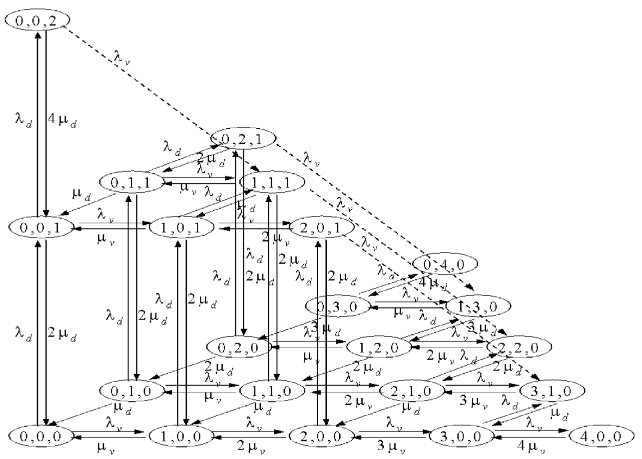

Fig. 1. The state transition diagram of an example with $C = 4$, without de-allocation.

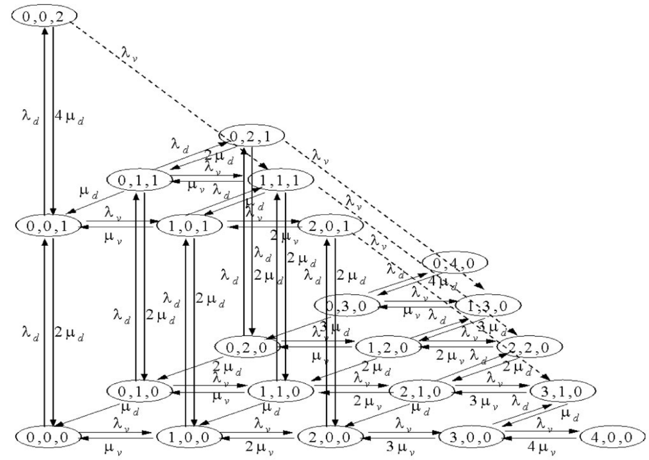

Fig. 2. The state transition diagram of an example with $C = 4$, with de-allocation.

shows an example of the state transition diagram assuming $C = 4$. Let S be the set of feasible states in the case that de-allocation is not employed

$$S = \{(i,j,k) \mid 0 \le i+j+2k \le C, 0 \le i \le C,$$
$$0 \le j \le C \text{ and } 0 \le k \le \lfloor C/2 \rfloor\}. \quad (1)$$

To handle the infeasible states, an indicator function $\varphi(i,j,k)$ is used to indicate whether the state (i,j,k) is feasible or not, i.e., $\varphi(i,j,k) = 1$ if $(i,j,k) \in S$. For all $(i,j,k) \in S$, the balance equations can be expressed as

$$\begin{aligned}
&P_{ijk}(\lambda_v \varphi(i+1,j,k) + \delta_1 \lambda_d \varphi(i,j+1,k) \\
&\quad + \delta_2 \lambda_d \varphi(i,j,k+1) + i\mu_v \varphi(i-1,j,k) \\
&\quad + j\mu_d \varphi(i,j-1,k) + 2k\mu_d \varphi(i,j,k-1)) \\
&= \lambda_v P_{i-1,j,k} \varphi(i-1,j,k) + \delta_3 \lambda_d P_{i,j-1,k} \varphi(i,j-1,k) \\
&\quad + \delta_4 \lambda_d P_{i,j,k-1} \varphi(i,j,k-1) \\
&\quad + (i+1)\mu_v P_{i+1,j,k} \varphi(i+1,j,k) \\
&\quad + (j+1)\mu_d P_{i,j+1,k} \varphi(i,j+1,k) \\
&\quad + 2(k+1)\mu_d P_{i,j,k+1} \varphi(i,j,k+1), \qquad (2)
\end{aligned}$$

where

$$\delta_1 = \begin{cases} 1, & \text{if } i+j+2k = C-1 \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

$$\delta_2 = \begin{cases} 1, & \text{if } i+j+2k \le C-2 \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

$$\delta_3 = \begin{cases} 1, & \text{if } i+(j-1)+2k = C-1 \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

$$\delta_4 = \begin{cases} 1, & \text{if } i+j+2(k-1) \le C-2 \\ 0, & \text{otherwise.} \end{cases} \quad (6)$$

Applying the constraints $\sum_S P_{ijk} = 1$ to the set of balance equations, we can obtain the steady-state probability P_{ijk} to evaluate the performance metrics. The blocking probability of both voice calls, P_{vb}, and GPRS packets, P_{gb}, can be expressed as

$$P_{vb} = P_{gb} = \sum_{i+j+2k=C} P_{ijk}. \quad (7)$$

The mean transmission time of GPRS packets, W, is

$$W = \frac{1}{\lambda_d(1-P_{gb})} \cdot \sum_{(i,j,k)\in S} (j+k) \cdot P_{ijk}. \quad (8)$$

The channel utilization, U, can be expressed as

$$U = \frac{\left(\sum_{(i,j,k)\in S} (i+j+2k) \cdot P_{ijk} \right)}{C}. \quad (9)$$

B. With Channel De-Allocation

Channel de-allocation is applied upon voice arrivals, i.e., when there are no free channels, one slot of an existing 2-slot GPRS packet is de-allocated for a voice arrival. When there are no free channels and no 2-slot packets in service, the voice call request will be blocked. GPRS packet requests will be blocked when there are no free channels upon arrivals.

Fig. 2 shows an example of the state transition diagram assuming $C = 4$. The dash line in the figure represents the state transition caused by de-allocating a 2-slot packet upon a voice arrival. Applying the similar approach described in the previous subsection, the steady-state probability P_{ijk} can be obtained to evaluate the performance metrics. The blocking probability of voice calls, P_{vb}, can be expressed as

$$P_{vb} = \sum_{i+j=C} P_{ij0}. \quad (10)$$

The expressions of blocking probability of GPRS packets, P_{gb}, mean transmission time of GPRS packets, W, and channel utilization, U, are the same as (7)–(9).

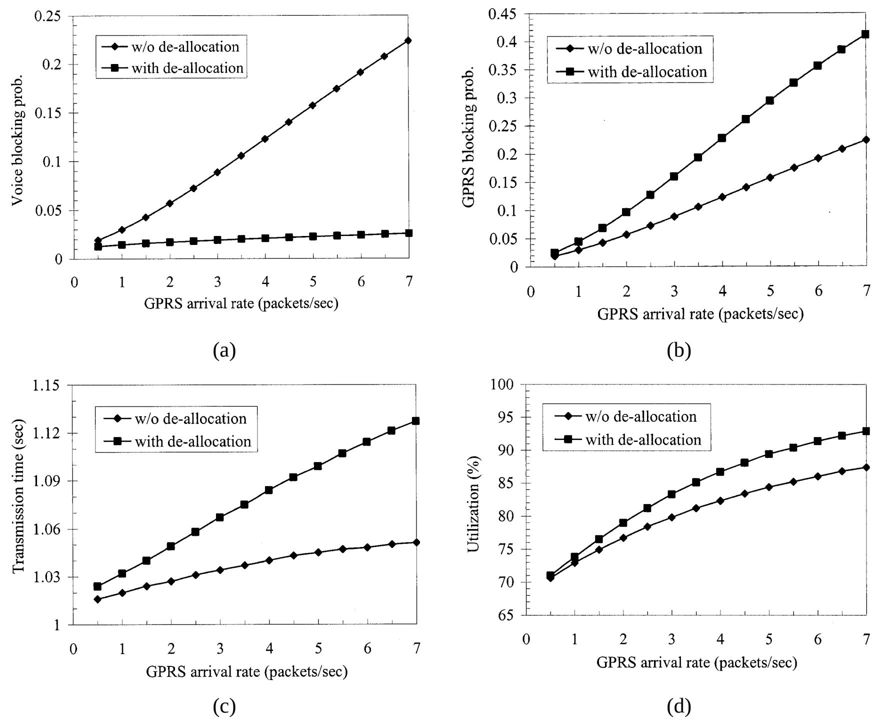

Fig. 3. Performance comparisons. (a) Voice blocking probability. (b) GPRS blocking probability. (c) Mean transmission time. (d) Channel utilization.

IV. Numerical Results

For the performance evaluation and comparison of the scheme with and without channel de-allocation, the total number of channels is set to be 32. The mean arrival rate of voice calls is taken to be 0.122 45 calls/s, and the mean service time of voice calls is 180 s. The voice traffic load is chosen to be 22.04 Erlang corresponding to 1% blocking probability for 32 channels. The mean arrival rate of GPRS packets is a system parameter and is chosen to be in the range of 0.5 to 7 packets/s. The mean service time of GPRS packets is taken to be 2 s if one channel is allocated.

Fig. 3 shows the performance comparisons of the scheme with and without channel de-allocation. As can be seen in Fig. 3(a) that although the voice blocking probability of both schemes increase with increasing GPRS traffic load, the scheme with de-allocation gives lower blocking probability, especially at high GPRS traffic load. For example, the improvement is nearly 90% at GPRS arrival rate being 7 packets/s. The reason is that as the GPRS load increases, there will be more packets that are allocated with two channels. Therefore, there will be more opportunity to de-allocate a 2-slot packet upon voice arrivals. In addition, the channel utilization is better when de-allocation mechanism is employed as shown in Fig. 3(d)

Since the de-allocated 2-slot packet continues its transmission using a single channel, the packet transmission time will be longer when de-allocation is exploited as shown in Fig. 3(c). However, the increment in packet transmission time is not tremendous even at high GPRS traffic load, e.g., the increment is less than 7% at GPRS arrival rate being 7 packets/s. The longer transmission time will also cause the forthcoming GPRS packets to have less chance obtaining services, thus resulting in higher blocking probability as can be seen in Fig. 3(b).

V. Conclusions

GPRS allows a single mobile station to transmit data using multiple time slots to increase the transmission rate. It has been demonstrated that using dynamic scheme efficient and flexible utilization of the available spectrum for packet data can be obtained. In this letter, we analyze and compare the performance of dynamic resource allocation with/without channel de-allocation in GSM/GPRS networks. The results show that with channel de-allocation mechanism, the voice blocking probability can be greatly reduced, especially at high GPRS traffic load, to an extent of nearly 90%. Besides, higher channel utilization can be achieved at the expense of increased GPRS blocking probability and longer packet transmission time. However, the increment in packet transmission time is less than 7% at high GPRS traffic load.

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