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Modeling and analysis of mobility management state of packet-switched (PS) services in GPRS

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Abstract

There has been an increasing demand for wireless data services due to the popularity of Internet services and circuit-switched (CS) systems are not appropriate for accommodating bursty data traffic. The wireless data services can be efficiently supported in the packet-switched (PS) system and General Packet Radio Service (GPRS) is a representative PS system which is being serviced widely. In GPRS, three mobile station (MS) mobility management states, i.e., *idle*, *ready*, and *standby* are defined in order to accommodate bursty traffic characteristics of data services, and thus, GPRS results in efficient management of radio resources and signaling networks. In order to analyze the performance of GPRS mobility management, we develop an analytical model to derive the steady-state probability of the MS states, which is essential in the performance analysis. The analytical model is validated by using a simulation model. The effect of various input parameters on the steady-state probability and the effect of variances of cell residence time, RA residence time, and packet transmission time are analyzed. Then, location update signaling and paging signaling loads are investigated based on the steady-state probability. Our study provides guideline for proper selection of PS system parameters and can be used to analyze the performance of mobility management schemes for PS systems.

Keywords: Packet-switched services; General Packet Radio Service; Mobility management; Mobile station state management; Location update; Paging

1. Introduction

Mobility management, which consists of location registration and call delivery, has been considered as one of the most important issues in mobile communication networks and there have been numerous studies in the literature [1–8]. The location registration notifies the network of the location of mobile stations (MSs), allowing the network to maintain the latest location information of the MSs. In call delivery, this location information is interrogated and the call is delivered to the called MS after paging. For both location registration and call delivery there is a tradeoff between the use of radio resources and signaling network resources. Most previous studies have focused on analysis of location registration signaling and paging signaling loads.

Recently, there has been an increasing demand for wireless data services due to the popularity of Internet services [9]. Second generation (2G) mobile communication systems such as global system for mobile communications (GSM) do not meet this demand because data services are provided based on circuit-switched (CS) radio transmission, where a channel is exclusively allocated for a single user for the entire call duration, even if the user does not transfer data packets at the moment [9]. This results in highly inefficient use of resources for data services with bursty traffic characteristics. In order to overcome this problem, packet-switched (PS) systems have been proposed.

In cellular systems, General Packet Radio Service (GPRS) [9–14] is a representative PS system which is being

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serviced widely. In GPRS, a channel is allocated when needed and is released immediately after the transmission of packets is completed and thus multiple users can share the same channel. In GPRS, MSs are defined to have three states: *idle*, *ready*, and *standby*. In the *idle* state, the MS is not reachable and the GPRS network does not have any location information. In the *ready* and the *standby* states, cell and routing area (RA) (i.e., a group of cells) information of the MS is managed, respectively.

If the packet transmission rate is high and the MS is expected to receive packets in short intervals, the MS stays in the *ready* state. In the *ready* state, network can deliver packets to the MS without paging all cells in an RA. On the other hand, if the packet transmission rate is low, the MS stays in the *standby* state and does not update its location frequently. In the *standby* state, paging all cells in the RA is required to deliver packets to the MS.

The GPRS state model accommodates the properties of PS data services, while GSM state model is appropriate only for CS voice services. In GSM, location update occurs as MS moves across location areas (LAs) and paging all cells in an LA is performed if any incoming call arrives. The GSM MS state, whether it is *idle* or *busy*, does not affect to obtain location update signaling and paging signaling loads. In GPRS, however, cell updates occur in the *ready* state and RA updates occur in the *standby* state, and paging is performed only in the *standby* state. Thus, signaling load by location update and paging depends on the probability of the *ready* and the *standby* states, and derivation of the steady-state probability of MS states is essential to analyze the performance of GPRS mobility management.

The study of steady-state probability of MS states is also essential in the performance analysis of PS micro-mobility protocols which are considered as one of the promising candidate protocols for fourth generation (4G) IP-based mobile networks. In these protocols, two MS states for PS services are defined to accommodate bursty traffic characteristics of data services and the concept of paging area (PA) is proposed. For example, *active* and *idle* states are defined in P-MIP [15]. In the *active* state, registration occurs whenever the MS changes its cell. On the contrary, registration occurs only if the MS changes its PA in the *idle* state. If there is any incoming data for the *idle* MS, paging is performed to find the exact location of the called MS. In [16], the performance of the P-MIP was analyzed based on the steady-state analysis. In the IETF seamoby working group [17], [18], the concept of *active* and *dormant* modes have been proposed.

Similar to the P-MIP protocol, MS performs cell-based location update in the *active* mode and PA-based location update in the *dormant* mode. Also, in HAWAII [19], *active* and *standby* states are defined and paging is needed in the *standby* state, where PA-based location update occurs.

As described above, most PS systems have two distinct MS mobility management states for the registered MS (i.e., *ready* and *standby* states for GPRS). In one state (i.e., *ready*), MS updates its location upon every cell change. In the other state (i.e., *standby*), MS updates its location when the MS changes its RA or PA and paging is needed in this state in order to deliver incoming packets. The state transition from *active* to *idle* states is controlled by a timer (i.e., *active* timer in GPRS).

In order to analyze the performance of these PS systems, the derivation of the probability of the MS states is essential. Since the analysis of the state management of CS voice services [20–23] is not valid for PS services, a study on the state management for PS data services is required. In our previous study [24], we derived the steady-state probability of GPRS MS states based on simple exponential distribution assumptions on cell residence time, RA residence time, and packet transmission time. In this paper, as an extension of our previous study, we develop an analytical model to derive the steady-state probability of the GPRS MS states based on more practical distributions, i.e., Erlang distribution on cell and RA residence times and Gamma distribution on packet transmission time, and the derived analytical results are validated by using the simulation results. Then, the effect of various input parameters on the steady state probability and the effect of variances of cell residence time, RA residence time, and packet transmission time are analyzed. Finally, location update signaling and paging signaling loads are investigated based on the steady-state probability. These analysis results provide guideline for proper selection of PS system parameters and can be used to analyze the performance of any mobility management schemes for PS systems. Although we are only concerned with GPRS system in this paper, the analytical model itself can be applied to other PS systems easily, which has similar MS mobility management states.

This paper is organized as follows: Section 2 presents a GPRS network architecture and MS state management. The steady-state probability of the MS states is then derived in Section 3. In Section 4 numerical examples are provided in order to show the effects of various input parameters on the steady-state probability, and the signaling load of location update and paging is also analyzed. Finally, conclusions are presented in Section 5.

2. GPRS network architecture and mobile station state transition model

2.1. GPRS network architecture

GPRS can be thought of as a network overlay on top of a GSM network. GPRS network architecture is illustrated in Fig. 1. A cell is formed by the radio coverage area of a base transceiver station (BTS). Several BTSs together are controlled by one base station controller (BSC). Aggregate BSC traffic for CS services is routed through a switch, called the mobile switching center (MSC). In each administration of an MSC there is at least one LA, which consists of one or more cells. Home location register (HLR) stores permanent mobile user data such as the user service profile