Computer Networks 54 (2010) 1707–1725

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

Performance analysis for hierarchical resource allocation in multiplexed mobile packet data networks

Kai-Wei Ke [a,*], Chen-Nien Tsai [b], Ho-Ting Wu [a]

[a] Department of Computer Science and Information Engineering, National Taipei University of Technology, Taipei, Taiwan, ROC
[b] Institute of Computer Science and Information Engineering, National Taipei University of Technology, Taipei, Taiwan, ROC

ARTICLE INFO

Article history:
Received 20 September 2008
Received in revised form 25 October 2009
Accepted 19 January 2010
Available online 28 January 2010
Responsible Editor: W. Wang

Keywords:
GPRS
Hierarchical resource allocation
Markov chain
Cellular network
Radio block

ABSTRACT

The general packet radio service (GPRS) can be thought of as an overlay network above a Global Systems for Mobile (GSM) network. In cooperation with the GSM system, GPRS supports both voice and packet data services. Obviously, combining voice and data traffic implies the nature of contending with finite radio resources. The paper focuses on voice/data integrated GPRS downlink traffic and proposes two hierarchical resource allocation strategies by considering time slots and radio blocks simultaneously with two different TDMA frame configurations. The radio block based resource allocation can characterize the multiplexing scheme of the practical GPRS operation. The performance of the proposed strategies were evaluated analytically by multidimensional Markov chain and verified through intensive computer simulations. Based on both the analytical and simulation results, it showed that the proposed allocation strategies can offer high utilization of transmission resource, as well as low blocking probability to GPRS users. The results of the study provide not only a practical thinking for implementation but also a guideline for analysis.

1. Introduction

With the development of mobile technologies and the increase of user demands, the market of mobile communication has grown rapidly in recent years. It is manifested that mobile users would not satisfy the pure and traditional voice service any more. Offering data services for multimedia applications to public mobile subscribers has drawn much attention from service providers. The mobile data service allows a user to access packet data networks (for example, the Internet) from the handy cellular phone through underlying mobile communication infrastructures. Taking GPRS as an example, it is not only the proposed solution to provide mobile data service over the existing GSM (Global Systems for Mobile Communications) cellular systems [1–3], but the intermediate system between 3G and 2G systems. Similar to other packet data services (such as Asynchronous Transfer Mode (ATM) networks), the incentive of GPRS is to efficiently accommodate burst data sources and dynamically share physical resources to users; even so, the radio resources are still limited as usual. Since the same air interface is shared by voice and data traffic in the integrated system, it implies the nature of contention with finite radio resources. The issues that to fulfill user demands and allocate resources efficiently at the same time have received lots attentions from researchers.

Resource allocation strategies for cellular network commonly can be categorized into fixed resource allocation and dynamic resource allocation. Many efforts have been made with these two strategies to efficiently make use of the scarce radio channels shared by voice and data subscribers. In [4–6], the fixed resource allocation was assumed. In these studies, the system allocates a fixed number of channels (resources) for each admitted request to meet the nature of the system architectures they

* Corresponding author. Tel.: +886 2 2771 2171x4233.
E-mail addresses: kwk@csie.ntut.edu.tw (K.-W. Ke), s3419009@ntut.edu.tw (C.-N. Tsai), htwu@csie.ntut.edu.tw (H.-T. Wu).

1389-1286/$ - see front matter
doi:10.1016/j.comnet.2010.01.011

concerned. The fixed resource allocation may not be suitable for systems with bursty data traffic because it reveals inefficient use of channel. For the GPRS system, whose incentive is to efficiently accommodate burst data traffic, dynamic resource allocation are frequently employed [7–17]. Moreover, various techniques have been proposed to improve the performance of a cellular system. Examples were queueing or buffering [4,12,18], cut-off priority [4,5,19], reservation [6,13,20], and preemption [6,9,21]. In [16] and [17], the authors devised various dynamic resource allocation schemes by combining the above-mentioned techniques including buffering, priority, channel reservation and deallocation, preemption, and channel threshold control. Through extensive numerical experiments, the authors concluded that the proposed schemes can outperform many allocation schemes proposed in other literatures. However, the high complexity is the expense.

While the performance is concerned, some analytical/numerical models can also be found in many publications [7,9,11,12,17,22], and the multidimensional Markov chain approach has come into wide use. For instance, in [22], the authors modeled the air interface of GSM/GPRS multiservice networks as a multidimensional Markov chain. They also proposed an admission control policy and investigated three channel-partitioning strategies: complete sharing, complete partitioning, and partial sharing. With the proposed admission control policy, a new request is accepted by the system if after accepting the request, the sum of all occupied resources is no greater than the total capacity. The numerical results in connection with the proposed admission control policy showed that the complete sharing strategy gives the best performance regarding the utilization since no particular resources are dedicated to particular users; hence, the scarce radio resources can be effectively utilized.

The physical layer of the GSM system applies the time-division multiple access (TDMA) mechanism. Under a given carrier frequency, there are eight time slots of 577 μs each. The basic resource unit is a time slot with no sharing to multiple voice sources. The GPRS system shares with the GSM system in the same TDMA frame structure and modulation techniques. Unlike the voice transmission in GSM, however, GPRS adopts the 52-multiframe structure and multiplexes multiple data packets from various sources. A 52-multiframe consists of 52 successive TDMA frames and partitions into 12 radio blocks. The radio blocks are the basic transmission units for practical GPRS traffic (see Section 2). As voice and data services are concerned simultaneously, both time slots and radio blocks will be shared by different users. Therefore, in a GPRS network, the time slots as well as the radio blocks should be considered the resources of transmission.

The above-mentioned studies were done on time slot basis; the allocation units were the time slots underlying a certain carrier frequency, without considering the practical radio blocks in transmission for GPRS. In that way, a time slot at any time instant can only be allocated to one user, while the GPRS characteristic of flexible use of transmission resource by multiplexing data sources were misled. That is, if a time slot basis resource allocation was performed in a GPRS system, then, every time slot can be only assigned to one GPRS user at a time. Practically, a GPRS resource allocation runs on a radio block basis resource allocation, and thus every time slot can be shared by multiple GPRS users. We will explain this concept in detail in the next section.

The contributions of this study are twofold. First, to accommodate the transmission resources in practical, the proposed hierarchical allocation strategies take both time slots and radio blocks into account. Each strategy will apply a specific time slot assignment to fulfill a mobile station/user (MS)'s demand and then fully share the radio blocks under each time slot to all MSs. Second, to propose a mathematical model to analyze the performance of the proposed hierarchical allocation strategies, as a general guideline for system operation.

This paper focuses on integrated voice/data (i.e., GSM and GPRS traffic respectively) downlink traffic and proposes hierarchical resource allocation strategies, and analyzes and compares their performance. The performance metrics used for evaluation are resource utilization and blocking probability. We provided analytical models with two types (or multislot classes) of MS, class 1 "(1 + 1)" and class 2 "(2 + 1)", where a class 1 MS requests one downlink time slot while a class 2 MS asks for two downlink time slots. In addition, the effect of different traffic conditions on the performance of proposed allocation strategies is also examined.

The rest of the paper is organized as follows. Section 2 provides the basic knowledge of the GPRS system, especially the GPRS multiplexing scheme of transmission resources. Section 3 explains the proposed strategies based on both time slot and radio block allocation. Section 4 defines the system model and derives analytical approaches for finding the theoretical performance metrics. Section 5 evaluates and compares the performance of the proposed schemes through intensive simulation and computational results. Finally, Section 6 draws the conclusion of the paper.

2. Radio resources and multiplexing scheme of GPRS

In addition to voice services, an ongoing goal of cellular networks is to make its data rate higher enough to enable Internet access and multimedia services. To efficiently achieve high-data rate transmission, an appropriate multiple access scheme plays an important role. There are currently various multiple access schemes existed, for example, TDMA and frequency-division multiple access (FDMA) schemes used for most GSM/GPRS systems, code-division multiple access (CDMA) adopted by most 3G systems and some 2G systems, and orthogonal frequency-division multiple access (OFDMA) used in the mobility mode of WiMAX (Worldwide Interoperability for Microwave Access) and 3GPP Long Term Evolution downlink access [23]. Among these schemes, TDMA has kept its dominance in wired and wireless systems for many years. A right choice of multiple access technique may significantly enhance the service quality delivered to end users [24].