In Proc. 12th GI/ITG Fachtagung Kommunikation in Verteilten Systemen (KiVS), Hamburg, Germany, pp. 291-301, Feb. 2001

Evaluating the GPRS Radio Interface for Different Quality of Service Profiles

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Abstract. This paper presents a discrete-event simulator for the General Packet Radio Service (GPRS) on the IP level. GPRS is a standard on packet data in GSM systems that will become commercially available by the end of this year. The simulator focuses on the communication over the radio interface, because it is one of the central aspects of GPRS. We study the correlation of GSM and GPRS users by a static and dynamic channel allocation scheme. In contrast to previous work, our approach represents the mobility of users through arrival rates of new GSM and GPRS users as well as handover rates of GSM and GPRS users from neighboring cells. Furthermore, we consider users with different QoS profiles modeled by a weighted fair queueing scheme. The simulator considers a cell cluster comprising seven hexagonal cells. We provide curves for average carried traffic and packet loss probabilities for different channel allocation schemes and packet priorities as well as curves for average throughput per GPRS user. A detailed comparison between static and dynamic channel allocation schemes is provided.

Keywords: Wireless and mobile communication networks, performance evaluation, IP networks, discrete-event simulation.

1 Introduction

The *General Packet Radio Service (GPRS)* is a standard from the *European Telecommunications Standards Institute (ETSI)* on packet data in GSM systems [6], [14]. By adding GPRS functionality to the existing GSM network, operators can give their subscribers resource-efficient wireless access to external Internet protocol-based networks, such as the Internet and corporate intranets. The basic idea of GPRS is to provide a packet-switched bearer service in a GSM network. As impressively demonstrated by the Internet, packet-switched networks make more efficient use of the resources for bursty data applications and provide more flexibility in general.

In previous work, several analytical models have been developed to study data services in a GSM network. Ajmone Marsan et al. studied multimedia services in a GSM network by providing more than one channel for data services [1]. Boucherie and Litjens developed an analytical model based on Markov chain analysis to study the performance of GPRS under a given GSM call characteristic [4]. For analytical tractability, they assumed exponentially distributed arrival times for packets and exponential packet transfer times, respectively. On the other hand, discrete-event simulation based studies of GPRS were conducted. Meyer et al. focused on the performance of TCP over GPRS under several carrier to interference conditions and coding schemes of data [10]. Furthermore, they provided a detailed implementation of the GPRS protocol stack [11]. Malomsoky et al. developed a simulation based GPRS network dimensioning tool [9]. Stuckmann et al. studied the correlation of GSM and GPRS users with the simulator GPRSim [13].

This paper describes a discrete-event simulator for GPRS on the IP level. The simulator is developed using the simulation package CSIM [12] and considers a cell cluster comprising of seven hexagonal cells. The presented performance studies were conducted for the innermost cell of the seven cell cluster. The simulator focuses on the communication over the radio interface, because this is one of the central aspects of GPRS. In fact, the air interface mainly determines the performance of GPRS. We studied the correlation of GSM and GPRS users by a static and dynamic channel allocation scheme. A first approach of modeling dynamic channel allocation was introduced by Bianchi et al. and is known as *Dynamic Channel Stealing (DCS)* [3]. The basic DCS concept is to temporarily assign the traffic channels dedicated to circuit-switched connections but unused because statistical traffic fluctuations. This can be done at no expense in terms of radio resource, and with no impact on circuit-switched services performance if the channel allocation to packet-switched services is permitted only for idle traffic channels, and the stolen channels are immediately released when requested by the circuit-switched service.

In contrast to the models developed in [4], [9], [10], and [11], our approach additionally represents the mobility of users through arrival rates of new GSM and GPRS users as well as handover rates of GSM and GPRS users from neighboring cells. Furthermore, we consider users with different QoS profiles modeled by a weighted fair queueing scheme according to [5].

The remainder of the paper is organized as follows. Section 2 describes the basic GPRS network architecture, the radio interface, and different QoS profiles, which will be considered in the simulator. In Section 3 we describe the software architecture of the GPRS simulator, details about the mobility of GSM and GPRS users, the way we modeled quality of service profiles, and the workload model we used. Results of the simulation studies are presented in Section 4. We provide curves for average carried traffic and packet loss probabilities for different channel allocation schemes and packet priorities as well as curves for average throughput per GPRS user.

2 General Packet Radio Service

On the physical layer, GSM uses a combination of *Frequency Division Multiple Access (FDMA)* and *Time Division Multiple Access (TDMA)* for multiple access. Two frequency bands are reserved for GSM operation, one for transmission from the mobile station to the *Base Transceiver Station (BTS)* (uplink) and one for transmission form the BTS to the mobile station (downlink). Each of these bands is divided into 124 single carrier channels of 200 kHz width. A certain number of these frequency channels is allocated to a BTS, i.e., to a cell. Each of the 200 kHz frequency channels is divided into eight time slots that form a TDMA frame. A time slot lasts for a duration of 0.577 ms and carries 114 bits of information. The recurrence of one particular time slot defines a physical channel. A GSM channel is called *Traffic Channel (TCH)* and a channel allocated for GPRS is called *Packet Data Channel (PDCH)*.

In conventional GSM, a physical channel is permanently allocated for a particular user during the entire call period (whether data is transmitted or not). In contrast, GPRS allocates channels only when data packets are sent or received, and they are released after the transmission. For bursty traffic this results in a much more efficient usage of the scarce radio resource. With this principle, multiple users can share one physical channel. GPRS allows a single mobile station to transmit on multiple time slots of the same TDMA frame. This results in a very flexible channel allocation: one to eight time slots per TDMA frame can be allocated to one mobile station. On the other hand a time slot can be assigned temporarily to a mobile station, so that one to eight mobile stations can use one time slot. GPRS includes the functionality to increase or decrease the amount of radio resources allocated to GPRS on a dynamic basis. The PDCHs are taken from the common pool of all channels available in the cell. The mapping of physical channels to either packet-switched (GPRS) or circuit-switched (conventional GSM) services can be performed statically or dynamically ("capacity on demand"), depending on the current traffic load. A load supervision procedure monitors the load of the PDCHs in the cell. According to the current demand, the number of channels allocated for GPRS can be changed. Physical channels not currently in use by conventional GSM can be allocated as PDCHs to increase the quality of service for GPRS. When there is a resource demand for services with higher priority, e.g. GSM voice calls, PDCHs can be de-allocated.

Because of the scarcity of wireless channel capacity, aggressive admission control will likely be employed to fully utilize the wireless link. Therefore GPRS subscribers can choose their own QoS profile consisting of *precedence class*, *delay class*, *reliability class*, *peak throughput class* and *mean throughput class*. For a detailed description of the GPRS network architecture we refer to [14], the GPRS Radio Interface to [8], and for QoS profiles proposed by the ETSI to [6].

3 The Simulation Model

We consider a cluster comprising of sever hexadiagonal cells in an integrated GSM/GPRS network, serving circuit-switched voice and packet-switched data calls. The performance studies presented in Section 4 were conducted for the innermost cell of the seven cell cluster. We assume that GSM and GPRS calls arrive in each cell according to two mutually independent Poisson processes, with arrival rates λ_{GSM} and λ_{GPRS}, respectively. GSM calls are handled circuit-switched, so that one physical channel is exclusively dedicated to the corresponding mobile station. After the arrival of a GPRS call, a *GPRS session* begins. During this time a GPRS user allocates no physical channel exclusively. Instead the radio interface is scheduled among different GPRS users by the *Base Station Controller (BSC)*. Every GPRS user receives packets according to a specified workload model. The amount of time that a mobile station with an ongoing call remains within the area covered by the same BSC is called *dwell time*. If the call is still active after the dwell time, a handover toward an adjacent cell takes place. The *call duration* is defined as the amount of time that the call will be active, assuming it completes without being forced to terminate due to handover failure. We assume the dwell time to be an exponentially distributed random variable with mean $1/\mu_{h,GSM}$ for GSM calls and $1/\mu_{h,GPRS}$ for GPRS calls. The call durations are also exponentially distributed with mean values $1/\mu_{GSM}$ and $1/\mu_{GPRS}$ for GSM and GPRS calls, respectively.

To exactly model the user behavior in the seven cell cluster, we have to consider the handover flow of GSM and GPRS users from adjacent cells. At the boundary cells of the seven cell cluster, the intensity of the incoming handover flow cannot be specified in advance. This is due to the handover rate out of a cell depends on the number of active customers within the cell. On the other hand, the handover rate into the cell depends on the number of customers in the neighboring cells. Thus, the iterative procedure introduced in [2] is used to balance the incoming and outgoing handover rates, assuming that the incoming handover rate $\lambda_{h,GSM}^{(in)}(i)$ of GSM calls and $\lambda_{h,GPRS}^{(in)}(i)$ of GPRS calls at step i is equal to the outgoing handover rate $\lambda_{h,GSM}^{(out)}(i-1)$ and $\lambda_{h,GPRS}^{(out)}(i-1)$ computed at step i-1.

Since in the end-to-end path, the wireless link is typically the bottleneck, and given the anticipated traffic asymmetry, the simulator focuses on resource contention in the downlink (i.e., the path BSC → BTS → MS) of the radio interface. Because of the anticipated traffic asymmetry the amount of uplink traffic, e.g. induced by acknowledgments, is assumed to be negligible. In the study we focus on the radio interface. The functionality of the GPRS core network is not included. The arrival stream of packets is modeled at the IP layer. Let N be the number of physical channels available in the cell. We evaluate the performance of two types of radio resource sharing schemes, which specify how the cell capacity is shared by GSM and GPRS users:

- the *static scheme*; that is the cell capacity of N physical channels is split into N_{GPRS} channels reserved for GPRS data transfer and $N_{GSM} = N - N_{GPRS}$ channels reserved for GSM circuit-switched connections.
- the *dynamic scheme*; that is the N physical channels are shared by GSM and GPRS services, with priority for GSM calls; given n voice calls, the remaining N-n channels are fairly shared by all packets in transfer.

In both schemes, the PDCHs are fairly shared by all packets in transfer up to a maximum of 8 PDCHs per IP packet ("multislot mode") and a maximum of 8 packets per PDCH [6].

The software architecture of the simulator follows the network architecture of the GPRS Network [14]. To accurately model the communication over the radio interface, we include the functionality of a BSC and a BTS. IP packets that arrive at the BSC are logically organized in two distinct queues. The transfer queue can hold up to $Q = 8 \cdot n$ packets that are served according to a processor sharing service discipline, with n the number of physical channels that are potentially available for data transfer, i.e. $n = N_{GPRS}$ under the static scheme and n = N under the dynamic scheme. The processor sharing service discipline fairly shares the available channel capacity over the packets in the transfer queue. An arriving IP packet that cannot enter the transfer queue immediately is held in a first-come first-served (in case of one priority) access queue that can store up to K packets. The access queue models the BSC buffer in the GPRS network. Upon termination of a packet transfer, the IP packet at the head of the access queue is polled into the transfer queue, where it immediately shares in the assignment of available PDCHs. For this study, we fix the modulation and coding scheme to CS-2 [14]. It allows a data transfer rate of 13,4 kbit/sec on one PDCH. Figure 1 depicts the software architecture of the simulator.

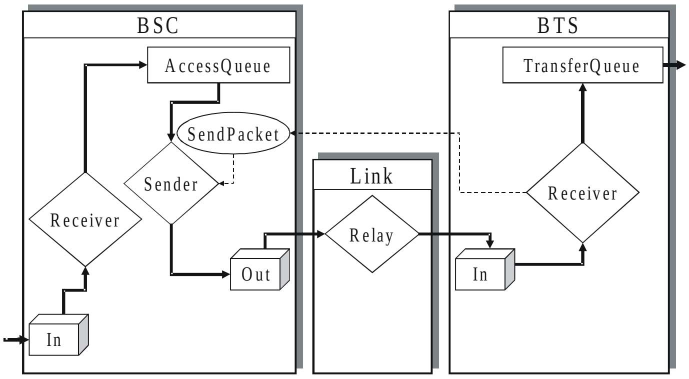

Figure 1. Software Architecture of GSM/GPRS Simulator

To model the different quality of service profiles GPRS provides, the simulator implemented a *Weighted Fair Queueing (WFQ)* strategy. The WFQ scheduling algorithm can easily be adopted to provide multiple data service classes by assigning each traffic source a weight determined by its class. The weight controls the amount of traffic a source may deliver relative to other active sources during some period of time. From the scheduling algorithm's point of view, a source is considered to be active if it has data queued at the BSC. For an active packet transfer with weight w_i the portion of the bandwidth $B_i(t)$ allocated at time t to this transfer should be

$$B_i(t) = \frac{w_i}{\sum_j w_j} \cdot B(t)$$

where the sum over all active packet transfers at time t. The overall bandwidth at time t is denoted by B(t) which is independent of t in the static channel allocation scheme.

The workload model used in the GPRS simulator is a *Markov-modulated Poisson Process (MMPP)* [7]. It is used to generate the IP traffic for each individual user in the system. The MMPP has been extensively used for modeling arrival processes, because it qualitatively models the time-varying arrival rate and captures some of the important correlations between the interarrival times. It is shown to be an accurate model for Internet traffic which usually shows self-similarity among different time scales. For our purpose the MMPP is parameterized by the two-state continuous-time Markov chain with infinitesimal generator matrix **Q** and rate matrix **Λ**:

$$\mathbf{Q} = \begin{pmatrix} -\alpha & \alpha \\ \beta & -\beta \end{pmatrix}, \qquad \mathbf{\Lambda} = \begin{pmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{pmatrix}$$

The two states represent bursty mode and non-bursty mode of the arrival process. The process resides in bursty mode for a mean time of $1/\alpha$ and in non-bursty mode for a mean time of $1/\beta$ respectively. Such an MMPP is characterized by the *average arrival rate* of packets, λ_{avg} and the *degree of burstiness,* B. The former is given by:

$$\lambda_{avg} = \frac{\beta \cdot \lambda_1 + \alpha \cdot \lambda_2}{\alpha + \beta}$$

The *degree of burstiness* is computed by the ratio between the bursty arrival rate and the average arrival rate, i.e., $B = \lambda_1/\lambda_{avg}$.

4 Simulation Results

Table 1 summarizes the parameter settings underlying the performance experiments. We group the parameters into three classes: network model, mobility model, and traffic model. The overall number of physical channels in a cell is set to N = 20 among which at least one channel is reserved for GPRS. The overall number of GPRS users that can be managed by a cell is set to M = 20. As base value, we assume that 5% of the arriving calls correspond to GPRS users and the remaining 95% are GSM calls. GSM call duration is set to 120 seconds and call dwell time to 60 seconds, so that users make 1-2 handovers on average. For GPRS sessions the average session duration is set to 5 minutes and the dwell time is 120 seconds. Thus, we assume longer "online times" and slower movement of GPRS users than for GSM users. The average arrival rate of data is set to 6 Kbit/sec per GPRS user corresponding to 0.73 IP packets per second of size 1 Kbyte.

Model Typ		Parameter	Base Value
Network Model		Number of physical channels, N	20
		Number of fixed PDCHs, N_{GPRS}	1, 2, 4
		Maximum number of GPRS users, M	20
		BSC buffer size, K	1000 IP-packets
		Transfer rate for one PDCH (CS-2), $\mu_{service}$	13.4 Kbit/sec
Mobility Model		GSM handover arrival rate, $\lambda_{h,GSM}$	0.3/sec
		GPRS handover arrival rate, $\lambda_{h,GPRS}$	0.075/sec
		Average GSM voice call duration, $1/\mu_{GSM}$	120 sec
		Average GSM voice call dwell time, $1/\mu_{h,GSM}$	60 sec
		Average GPRS session duration, $1/\mu_{GPRS}$	300 sec
		Average GPRS session dwell time, $1/\mu_{h,GPRS}$	120 sec
Traffic Model	Users	GSM/GPRS call arrival rate, $\lambda = \lambda_{GSM} + \lambda_{GPRS}$	1.0/sec
		Percentage of GSM users	95%
		Percentage of GPRS users	5%
		Percentages of customers with paket priority 1, 2, 3	10%, 30%, 60%
		Weights for packet priorities 1, 2, 3	4/7, 2/7, 1/7
	Packet Data	Average arrival rate of data, λ_{avg}	6 Kbit/sec
		Degree of burstiness, B	5
		Average duration of bursty phase, $1/\alpha$	2 sec
		Average duration of non-bursty phase, $1/\beta$	20 sec

Table 1. Base parameter setting of the simulation model

The simulation experiments consisted of two phases. First the incoming handover flow of GSM and GPRS users must be computed iteratively from the outgoing handover flow. This phase takes 4-6 short (6 seconds) and 3-4 longer (2 minutes) iterations to get an accurate balance between the handover flows. The second phase consists of the main simulation run. It takes a duration of about 30 minutes to achieve a confidence level of 95%. The curves presented show the confidence intervals as dashed lines and the mean values in solid lines. In all curves the arrival rate of GSM and GPRS users is varied to study the cell under increasing load conditions.

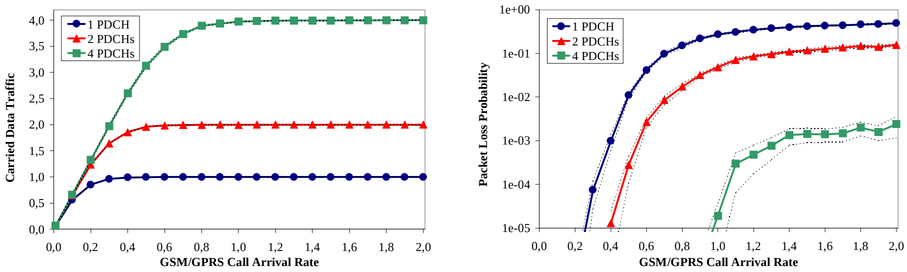

Figure 2. Carried data traffic and packet loss probability for static channel allocation

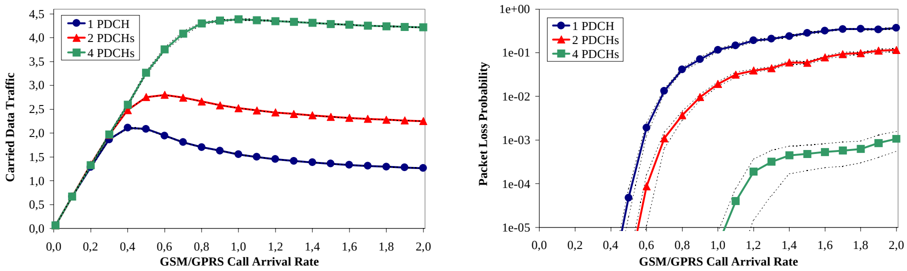

Figure 3. Carried data traffic and packet loss probability for dynamic channel allocation

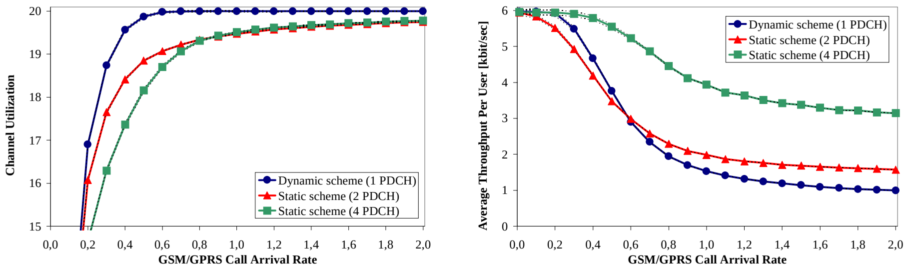

Figure 4. Channel utilization and throughput per user for static and dynamic channel allocation

Figure 2 presents curves for carried data traffic and packet loss probabilities due to buffer overflow in the BSC for the static channel allocation scheme and one packet priority. For GPRS 1, 2, and 4 PDCHs are reserved, respectively. The remaining channels can be used by GSM calls. With 4 PDCHs the system overloads at an arrival rate of 0.8 GSM/GPRS users per second. This corresponds to an average of 12 GPRS users in the cell (see Figure 7). In Figure 3 we present corresponding curves for the dynamic channel allocation scheme. For GPRS 1, 2, and 4 PDCHs are reserved, respectively but more PDCHs can be reserved "on demand". That means that additional PDCHs can be reserved if they are not used for GSM voice service. From Figure 3 we observe that for low traffic in the considered cell GPRS makes effectively use of the on demand PDCHs. For example if 1 PDCH is reserved GPRS utilizes up to 2 PDCHs at an arrival rate of 0.4 GSM/GPRS users per second. But with increasing load the overall performance of GPRS decreases because of concurrency among GPRS users, and more important, priority of GSM users over the radio interface. In comparison with the static channel allocation scheme we conclude that the combination of reserved PDCHs and on demand PDCH leads to a better utilization of the scarce radio frequencies. The only advantage of the static channel allocation scheme is that it can be realized more easily.

Figure 4 presents a comparison of overall channel utilization and average throughput per GPRS user for the static and dynamic channel allocation scheme. For the static scheme we reserved 2 and 4 PDCHs respectively and for the dynamic scheme only 1 PDCH. We observe a higher overall utilization of physical channels by the dynamic scheme. Comparing the dynamic with the static scheme for 2 PDCHs we detect a slightly higher throughput for low traffic load for dynamic channel allocation. This results from the high radio channel capacity available to GPRS users in this case. They can utilize up to 8 PDCHs for their transfer (in contrast to 2 PDCHs in the static scheme). When load increases, GSM calls allocate most of the physical channels. Thus, throughput for GPRS users decreases very fast. In the static scheme (4 PDCHs) the decrease in throughput is not so fast, because GSM calls do not effect the PDCHs.

In an additional experiment, we study the performance loss in the GSM voice service due to the introduction of GPRS. Figure 5 plots the carried voice traffic and voice blocking probability for different numbers of reserved PDCHs. The results are valid for both channel allocation schemes because of the priority of GSM voice service over GPRS. The presented curves indicate that the decrease in channel capacity and, thus, the increase of the blocking probability of the GSM voice service is negligible compared to the benefit of reserving additional PDCHs for GPRS users.

Figure 6 shows carried data traffic and packet loss probabilities for the dynamic channel allocation scheme and different packet priorities. For GPRS 1 PDCH is

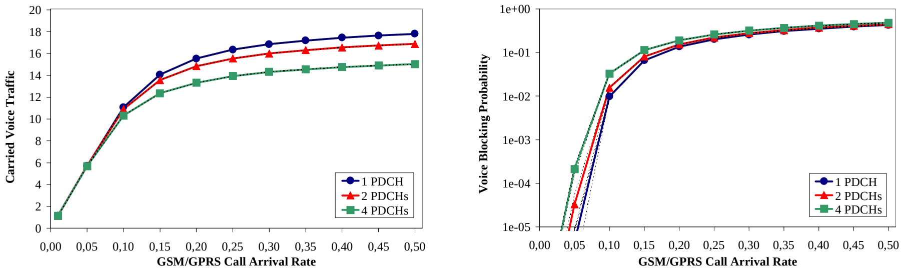

Figure 5. Impact of GPRS on GSM voice service: carried voice traffic and voice blocking probability

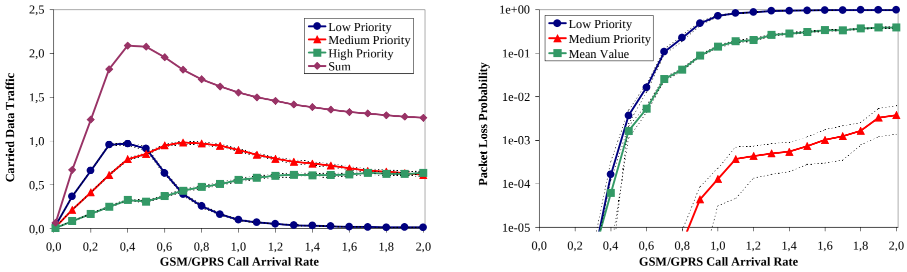

Figure 6. Carried data traffic and packet loss probability for different packet priorities

reserved. Weights for packets with priority 1 (high), 2 (medium), and 3 (low) and percentages of GPRS users utilizing these priorities are given in Table 1. We observe that for low traffic in the considered cell most channels are covered by packets of low priority. This is due to the high portion of low priority packets (60%) among all packets sharing the radio interface. With increasing load medium priority packets and at last high priority packets suppress packets of lower priority and therefore the utilization of PDCHs for low and medium priority packets decreases. For a call arrival rate of up to 2 calls per second the loss probability of high priority packets is still less than 10^{-5} and therefore the corresponding curve is omitted in Figure 6.

Figure 7 presents curves for average number of GPRS users in the cell and blocking probabilities of GPRS session requests due to reaching the limit of M active GPRS sessions. We observe that for 2% GPRS users the maximum number of 20 active GPRS sessions is not reached. Therefore, the blocking probability remains very low. For 10% GPRS users and increasing call arrival rate, the average number of sessions approaches its maximum. Thus, some GPRS users will be rejected. It is important to note that the curves of Figure 7 can be utilized for determining the average number of GPRS users in the cell for a given call arrival rate. In fact, together with the curves of Figure 2 and 3, we can provide estimates for the maximum number of GPRS users that can be managed by the cell without degradation of quality of service. For example, for 5% GPRS users and 1 PDCHs reserved, in the static allocation scheme a packet loss probability of 10^{-3} can be guarantied until the call arrival rate exceeds 0.4 calls per second, i.e., until there are on the average 6 active GPRS users in the cell. For the dynamic allocation scheme a packet loss probability of 10^{-3} can be guarantied until the call arrival rate exceeds 0.6 calls per second corresponding to 9 active GPRS users in the cell on average.

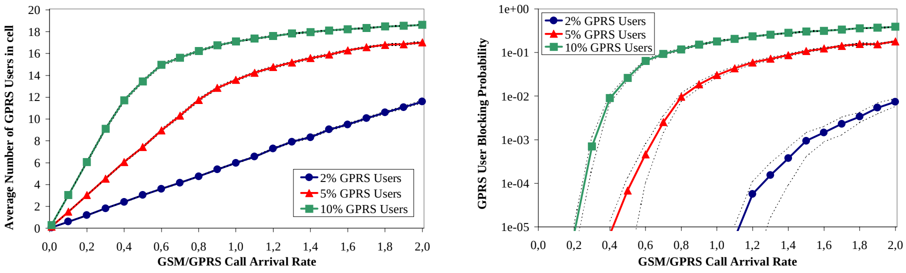

Figure 7. Average number of GPRS users in the cell and GPRS user blocking probability

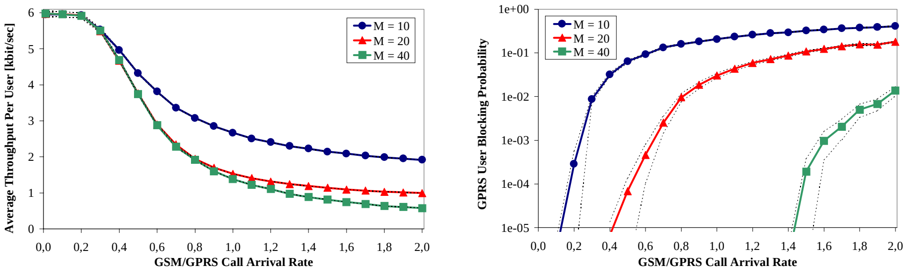

Figure 8. Average throughput per user and GPRS user blocking probability for different maximum numbers of GPRS users

Figure 8 investigates the impact of the maximum number of GPRS user per cell to the performance of GPRS for the dynamic channel allocation scheme with 1 PDCH reserved. Of course, the expected number of GPRS users should be less than the maximum number in order to avoid the rejection of new GPRS sessions. On the other hand, the maximum number of active GPRS sessions must be limited for guaranteeing quality of service for every active GPRS session even under high traffic. The tradeoff between increasing performance for allowing more active GPRS sessions and the increasing blocking probability for GPRS users is illustrated by the curves of Figure 8.

Conclusions

This paper presented a discrete-event simulator on the IP level for the General Packet Radio Service (GPRS). With the simulator, we provided a comprehensive performance study of the radio resource sharing by circuit switched GSM connections and packet switched GPRS sessions under a static and a dynamic channel allocation scheme. In the dynamic scheme we assumed a reserved number of physical channels permanently allocated to GPRS and the remaining channels to be on-demand channels that can be used by GSM voice service and GPRS packets. In the static scheme no on-demand channels exist. We investigated the impact of the number of packet data channels reserved for GPRS users on the performance of the cellular network. Furthermore, three different QoS profiles modeled by a weighted fair queueing scheme were considered.

Comparing both channel allocation schemes, we concluded that the dynamic scheme is preferable at all. The only advantage of the static scheme lies in its easy implementation. Next, we studied the impact of introducing GPRS on GSM voice service and observed that the decrease in channel capacity for GSM is negligible compared to the benefit of reserving additional packet data channels for GPRS. With the curves presented we provide estimates for the maximum number of GPRS users that can be managed by the cell without degradation of quality of service. Such results give valuable hints for network designers on how many packet data channels should be allocated for GPRS and how many GPRS session should be allowed for a given amount of traffic in order to guarantee appropriate quality of service.

Acknowledgements

The authors would like to thank Joachim Przybilke for implementing the GPRS simulation environment.

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