A Performance Evaluation of Internet Access via the General Packet Radio Service of GSM

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Abstract: The General Packet Radio Service (GPRS) is currently being standardized by the European Telecommunications Standard Institute (ETSI) to extend the services provided by the Global System for Mobile Communications (GSM). GPRS is dedicated to support packet-oriented traffic, e.g. Internet traffic. Packet oriented transmission is by nature better suited to convey bursty traffic, as it is generated by Internet applications. Applications contributing most to the data volume in the Internet are WWW, FTP and e-mail.

This paper presents a simulator, which was developed to assess the performance of GPRS when used as access means to the Internet. The focus is on the evaluation of the interaction between the protocols applied in the Internet and for GPRS. Only by considering both parts the assessment of the overall performance, which will be recognized by the end-user, is possible. This paper presents the simulation environment and discusses the simulation results regarding the end-to-end performance of TCP/IP based applications. It is shown that GPRS is a suitable wireless access to Internet applications.

I. INTRODUCTION

Although the main objective of GSM is to support mobile telephony services, mobile data communication is getting steadily a larger portion of the overall service portfolio. In today's GSM networks data communication is supported by circuit switched data bearer services with different data rates ranging up to 9.6 kbit/s.

The increasing demand for mobile data communication and the recent developments of mobile data applications resulted in a need for new and more sophisticated data services for GSM. Consequently, the European Telecommunications Standard Institute (ETSI) started to standardize two additional data bearer services. Firstly, the High Speed Circuit Switched Data (HSCSD) service, which allows to allocate and to combine up to 6 data channels resulting in a maximum data rate of approximately 64 kbit/s. Secondly, the General Packet Radio Service (GPRS), which will provide a packet switched transmission within GSM, is under development. It is primarily intended to support applications, which generate bursty traffic, where packet switched transmission is obviously a more efficient transportation means. The application of the packet oriented transmission scheme on the air-link, results in a better utilization of the scarce radio resources for typical Internet applications like e.g. World Wide Web (WWW).

Since Internet applications are identified as one major traffic source for the future GPRS, this paper focuses on the performance evaluation of GPRS used as access means to the Internet. As GPRS is still under development, no implementation is currently available; therefore, simulations are one appropriate way to get an insight into the performance of GPRS.

II. GENERAL PACKET RADIO SERVICE

A. GPRS Objectives

The performance of Internet applications in a cellular environment is typically characterized by the low available bandwidth, long connection set-up times and an inefficient use of the rare airlink capacity. The standardization of GPRS focused therefore strongly on the development of a service, which overcomes these drawbacks of a mobile Internet access. The improvements are gained from the provision of a packet-oriented data service for GSM, which (see [10])

- allows reduced connection set-up times,
- supports existing packet-oriented protocols like X.25 and IP and
- provides an optimized usage of radio resources.

GPRS is standardized to optimally support a wide range of applications ranging from very frequent transmissions of small data volumes to infrequent transmissions of medium to large data volumes.

B. Network Architecture

To introduce GPRS in the existing GSM infrastructure, additional network elements are added to the GSM architecture. This structure is depicted in Figure 1.

Since the existing GSM network provides only circuit-switched services, two new network nodes are defined to give support for packet switching: the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN). The SGSN is responsible for the communication between the mobile station (MS) and the GPRS network. It serves the mobile station and maintains the mobility context. The GGSN provides the interface to external packet data networks like X.25 or the Internet, but also to GPRS networks of other operators. It routes incoming packets to the appropriate SGSN for a particular mobile station. For the communication between the GPRS Support nodes within one Public Land
Mobile Network (PLMN), the IP-based Intra-PLMN Backbone network is used.

The GSM Base Station Subsystem (BSS) is used as a shared resource of both circuit-switched and packet switched network elements to ensure backward compatibility and keep the required investments for the introduction of GPRS at a sustainable level.

C. GPRS Protocols

The proposed protocol stack for GPRS is shown in Figure 2. Three protocols are controlling the link between MS and SGSN:

- Subnetwork Dependent Convergence Protocol (SNDCP)
- Logical Link Control (LLC) Protocol
- Radio Link Control/Medium Access Control (RLC/MAC) Protocol

SNDCP provides convergence functionality to map different protocols onto the single link supported by LLC. This comprises multiplexing of packets from different protocols, header compression (e.g. TCP/IP) and data compression (e.g. V42.bis), and segmentation of packets larger than the maximum LLC packet data size.

The LLC Protocol establishes a logical link between MS and SGSN. The LLC operates either in an unacknowledged mode, not taking care of packet losses, or in an acknowledged mode, which applies retransmissions and flow control to ensure a correct delivery of data.

The LLC packets (≤ 1600 bytes) are passed to the RLC layer, where they are segmented into smaller RLC blocks. The size of these depends on the applied coding scheme. RLC is always operated in an acknowledged mode with a sliding window flow control mechanism and a selective ARQ mode providing a reliable link between MS and SGSN. Additionally, a new medium access control scheme, tailored to the demands of the packet oriented data transmission, is introduced. The RLC/MAC layer will ensure the concurrent access to radio resources in a more flexible way compared to the unmodified TDMA structure. The flexibility is achieved by the introduction of a logical Packet Data Traffic Channel (PDTC) which is multiplexed onto a physical data channel. It is planned that up to eight of these PDTCHs share one timeslot (TS) in the TDMA frame, i.e. eight MS might share a single timeslot.

The physical layer is adapted to the needs of GPRS. Four different channel coding schemes are defined allowing a trade off between error correction capability and throughput. Interleaving is done across one RLC block, which consists of 4 bursts, resulting in a significant reduction of the interleaving delay compared to the circuit switched case.

GPRS complies with the standard Time Division Multiple Access (TDMA) scheme of GSM, i.e. the burst structure of GPRS is compatible to standard GSM. Nevertheless, there are many extensions made to better adapt to the needs of a packet-oriented transmission, e.g. up- and down-link resources are used independently. A GPRS terminal is also allowed to operate in a multi-slot mode to improve the flexibility and to cover a wider range of Quality of Service requirements.

A special multiframe structure has been defined for GPRS, which is divided into blocks comprising 4 consecutive TSs for the transmission of a single RLC block. Resource assignments to a particular terminal are always based on these four consecutive TSs. The allocation of these Radio Blocks (RB) to a terminal is determined by the BSS. This implies that uplink resources are also controlled by the BSS and the MS is notified about reserved uplink resources by means of Uplink State Flags (USF) on the downlink.

III. SIMULATOR STRUCTURE

The developed GPRS system simulator presented in this section is based on the paradigm of event oriented simulation (see for example [3]) for an introduction to this simulation principle). The simulator was implemented using the simulation tool BONeS\(^1\) which supports a block oriented hierarchical system modeling approach [2].

In contrast to previously developed simulation systems, see for example [7],[8], which primarily aimed at performance investigations of lower layer protocols and system aspects of GPRS (such as protocols between MS and BSS), our approach focuses on the investigation of the end-to-end communication from an application, user and operator perspective. Thus, the simulator has to model the whole GPRS node chain including the Internet. Figure 3 shows the top-level of the simulator comprising the GPRS nodes and communication links in between. The single blocks Terminal and Mobile Station

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1 Block-Oriented Network Simulator
represent in fact multiple instances, i.e. multiple users, applications and mobiles. From this level the BONeS blocks are hierarchically decomposed into blocks representing the internal node structure, i.e., the protocol stacks and their (simplified) simulation models respectively.

For example, the block Mobile Station triggered by IP packets from the Terminal Equipment block and by signals arriving from the logical channels via the radio link includes blocks representing the GPRS protocols SNDCP, LLC and MAC/RLC. Consequently the block Terminal Equipment comprises the transport, application and user model related protocol stack. In the next levels of decomposition, the models for the protocols and communication channels are implemented. Regarding the level of abstraction and simplification in these models, we made the following assumptions:

Application and user behavior: The simulator supports models for WWW, FTP and SMTP. Currently, one user can only use one application. However, different users may use different applications enabling the specification of a huge range of traffic mixes. Stochastic On/Off Sources are used for the user and application behavior as illustrated by Figure 4 for the WWW traffic model. See [1] for a general introduction to the different commonly used traffic models in telecommunication network simulation and analysis. The idle time between two document fetches is assumed to be exponentially distributed, the number of WWW objects per document is obtained from a geometrical distribution. Type and size of the different WWW objects is determined by the peer entity of the Terminal’s traffic model implementation located in the Server block. Here the size of a WWW object is sampled from a Pareto distribution. The parameters for the different distributions were obtained from measurements.

TCP: The TCP version Tahoe is used with the restriction that in our implementation the RTT measurement is based on explicit ACK messages only.

IP: The Internet is modeled by a self-similar delay model, which additionally takes into account different routes and packet losses. See [6] for a comprehensive introduction to self-similar processes. In our simulator the self similar process is obtained by sampling the number of customers in a M/G/Inf queue (with Pareto distributed service time).

SNDCP: TCP/IP header compression is included in our implementation. V42.bis data compression is currently not supported.
The GPRS Attach procedure is not implemented and hence the mobile starts in stand-by mode. Our current implementation supports the acknowledged and unacknowledged LLC mode.

**RLC/MAC:** All four proposed coding schemes are supported. The 52-multiframe structure and the defined logical channels for GPRS are used. The random access procedure is implemented in detail including a model for the capture effect. Round Robin scheduling is assumed for resource assignment on the BSS side. The sliding window mechanism for RLC is supported.

**Radio Link:** The error model is based on pre-simulated Block Error Rates (BLER) with the first and second moment of the C/I as user parameter (see Figure 5). This enables the mapping of a given C/I to BLER for the currently transmitted block. For channel model and assumptions of the radio link related pre-simulations see [4],[5].

Furthermore, the simulations are based on the assumption that all MSs use the same channel coding scheme and experience the same mean C/I. The main characteristics of the GPRS coding schemes are summarized in Table 2.

### Table 2: GPRS coding schemes

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Code Rate</th>
<th>Payload [bit]</th>
<th>Data Rate [kbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS1</td>
<td>1/2</td>
<td>181</td>
<td>9.05</td>
</tr>
<tr>
<td>CS2</td>
<td>≈ 2/3</td>
<td>268</td>
<td>13.4</td>
</tr>
<tr>
<td>CS3</td>
<td>≈ 3/4</td>
<td>312</td>
<td>15.6</td>
</tr>
<tr>
<td>CS 4</td>
<td>1</td>
<td>428</td>
<td>21.4</td>
</tr>
</tbody>
</table>

Figure 6 shows the downlink system throughput on application level for the range of considered mean C/Is and the four coding schemes.

### Figure 6: System throughput downlink at application level for varied mean C/I

The simulation results show, as expected, a strong dependency between the throughput and the underlying channel conditions. It is evident that the most robust coding scheme CS1 provides the best performance for low C/Is and only for these. Already for a mean C/I for 6 dB, CS2 performs in terms of the system throughput as well as CS1. Between 10 and 17 dB, CS3 is superior, while CS4 provides the best results under very good conditions (more than 17 dB). This leads to the conclusion that the use of all four coding schemes is justified, because all have their range where one performs best. But one can expect that the probability of very good channel conditions is rather small, especially when power control is used for GPRS. Therefore, CS4 seems to be not so important.

Additionally, it is apparent that the performance of CS1 is very limited for medium and good channel quality. That means the balance between error correction capability and ARQ is not kept. CS2 and CS3 show a much better behavior in this range. They improve the throughput compared to CS1 by 30 to 50%. CS4 (no error correction at all) performs very poor for low C/Is and is only useful for high C/Is, but then it is very powerful.

**IV. SIMULATION RESULTS**

The developed simulator was intensively utilized to investigate the behavior for WWW over GPRS. For the results presented in this paper the following parameters were used.

### Table 1: Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of WWW Processes</td>
<td>30</td>
</tr>
<tr>
<td>TCP maximum segment size</td>
<td>1460 Byte</td>
</tr>
<tr>
<td>Mean Internet Packet Loss Rate</td>
<td>2 %</td>
</tr>
<tr>
<td>Mean Internet Delay</td>
<td>100 ms</td>
</tr>
<tr>
<td>TCP/IP Header Compression</td>
<td>Off</td>
</tr>
<tr>
<td>LLC Mode</td>
<td>ACK</td>
</tr>
<tr>
<td>Number of GPRS TSs</td>
<td>8</td>
</tr>
<tr>
<td>Global Multislot Class Uplink</td>
<td>1 TS</td>
</tr>
<tr>
<td>Global Multislot Class Downlink</td>
<td>4 TS</td>
</tr>
<tr>
<td>C/I Mean</td>
<td>3-18 dB</td>
</tr>
<tr>
<td>C/I Variance</td>
<td>3 dB</td>
</tr>
<tr>
<td>PRACH Blocks</td>
<td>0, 6</td>
</tr>
<tr>
<td>Channel Coding</td>
<td>CS 1 - CS4</td>
</tr>
<tr>
<td>Simulation Duration</td>
<td>30 min</td>
</tr>
</tbody>
</table>

All TSs of one GSM frequency are used for GPRS. The mobile terminals can operate in multislot mode for the downlink with 4 TSs used simultaneously, whereas only one TS is used for the uplink. This reflects the highly asymmetric traffic pattern of WWW.
From a user point of view, it is of higher importance, which mean throughput he can expect while he is active. Figure 7 gives the mean throughput (file size divided by the delay) for a WWW-object transmitted on the downlink. Besides the facts shown already by Figure 6, the results point out that for a medium channel quality (e.g., 12 dB) CS2 and CS3 outperform CS1 already by a factor of 2 to 3 in terms of packet throughput, by far more than the gain for the system throughput. Under very good conditions CS3 and CS4 provide a 4 times better packet-throughput than CS1 and 1.5-times better than CS2.

Figure 8 shows the measured throughputs for all individual WWW objects for the simulation with 30 users and CS2.

Each requested WWW-page consists of one or several WWW objects (text, pictures,...) with different sizes. The shown results represent the packet size of these objects divided by the delay from the server to the client. For display purposes the results are restricted to object sizes smaller than 10 kbyte, although the used distribution generated also larger objects.

One can observe that the throughput varies in a wide range up to a maximum of 45 kbit/s. Lower values for very small packets result from the relatively higher overhead of the underlying protocols. In general, the majority of objects reach the client with a throughput of more than 10 kbit/s. The picture shows that for this traffic scenario, the multiplexing capabilities of GPRS are well used. With circuit switched data services and the considered radio resources only 8 users can be supported.

V. CONCLUSIONS

This paper presents for the first time simulation results for WWW traffic over GPRS under consideration of all involved protocol layers. The developed simulation environment allows the assessment of the TCP/IP performance for different parameter settings for GPRS. The influence of parameters and their interdependence can be investigated.

The results have shown that GPRS is a highly suitable bearer service for TCP/IP traffic. It copes with the bursty nature of Internet traffic and allows a better utilization of the scarce radio resources than circuit switched connections. It improves the performance for a single user and allows the support of a larger number of parallel connections.

The simulations have shown that all proposed CSs work as expected, although the application of CS4 makes only sense for very good radio conditions.

REFERENCES

[10] Digital cellular telecommunications system (Phase 2+); General Packet Radio Service (GPRS); Service description; Stage 1 (GSM 02.60 version 5.1.0)