Analysis of the General Packet Radio Service (GPRS) of GSM as Access to the Internet

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Abstract: The General Packet Radio Service (GPRS) of the Global System for Mobile Communications (GSM) is designed for packet switched data transmission and is a mean of mobile access to packet data networks, e.g. the Internet. Packet switched transmission is inherently better suited for bursty traffic as it is generated by typical Internet applications - primarily WWW, FTP and e-mail.
A simulator is presented showing the performance of GPRS for accessing TCP/IP based applications in the Internet. Performance will be evaluated from the point of end-user perception as well as from a network operator's perspective. The results will demonstrate that GPRS is well suited for accessing Internet services in GSM.

I. INTRODUCTION

Within our information society the Internet has become an important backbone for communication as well as for distribution and access of information. The enormous growth of Internet usage has partly been enabled by the increasing number of new services offered by Internet service providers and new user friendly applications. Additionally novel access technologies provide a more flexible Internet access for a wider range of users. Owing to these advances the Internet has reached acceptance in a wide part of the population. There is also a clear trend going towards mobile Internet access, going hand in hand with new services tailored to the demands of people on the move.

The mobile networks in use nowadays have been designed for speech services. Data transmissions in these networks are still regarded as too slow and often too expensive for many applications. The services which are accepted nowadays can be characterized by their low bandwidth requirements.

The GSM system is one of the most successful digital mobile telecommunication systems. At present it offers data transmissions of up to 9.6 kbit/s. In the near future two enhanced data services, which are being standardized at the European Telecommunications Standards Institute (ETSI), will be included in the GSM system. The high speed circuit switched data service (HSCSD) will allow to allocate and combine up to 6 data channels leading to a maximum data rate of approximately 64 kbit/s. Secondly, the general packet radio service (GPRS) exploits the advantages of packet switched data transmission in GSM. One of the advantages of packet switching is a more efficient utilization of scarce radio resources on the air link. The benefits of statistical multiplexing can be especially exploited when the transmitted data has bursty traffic characteristics. Typical Internet applications like e.g. World Wide Web (WWW) show such traffic behavior. Since Internet applications will be one major traffic source for future GPRS this paper focuses on identifying the performance characteristics of GPRS as access to Internet services. As GPRS is still under development no implementation is currently available. Therefore simulations are used to derive insight into GPRS performance for Internet traffic. In this paper simulation results will be presented showing the throughput performance of GPRS on system level for different numbers of mobile users. An evaluation will be provided by a network operator's view, as well as the end-user perception for WWW browsing.

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

- 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.

Since GPRS is packet oriented it enables volume based charging in contrast to GSM like charging of on-line time. This will open the door too a variety of new Internet applications, where you can stay constantly on-line while you pay only for the occasional data transfer.

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.

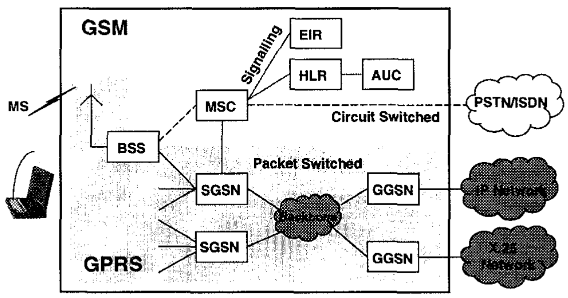

Figure 1: GPRS Architecture

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 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.

B. 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 (≤ 1520 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 BSS. 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 (PDTCH) which is multiplexed onto a physical data channel, the Packet Data Channel (PDCH), which corresponds to one timeslot (TS) in the GSM TDMA frame. Up to eight of these PDTCHs share one PDCH.

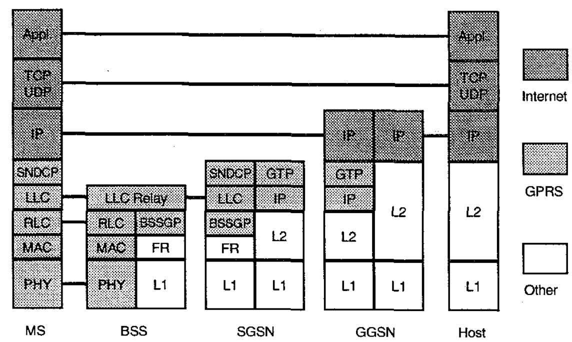

Figure 2: GPRS Protocol Structure

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 down to approx. 18 ms 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 downlink resources are used independently. A GPRS terminal is also allowed to operate in a multislot 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 the same TS in four consecutive TDMA frames 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 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.

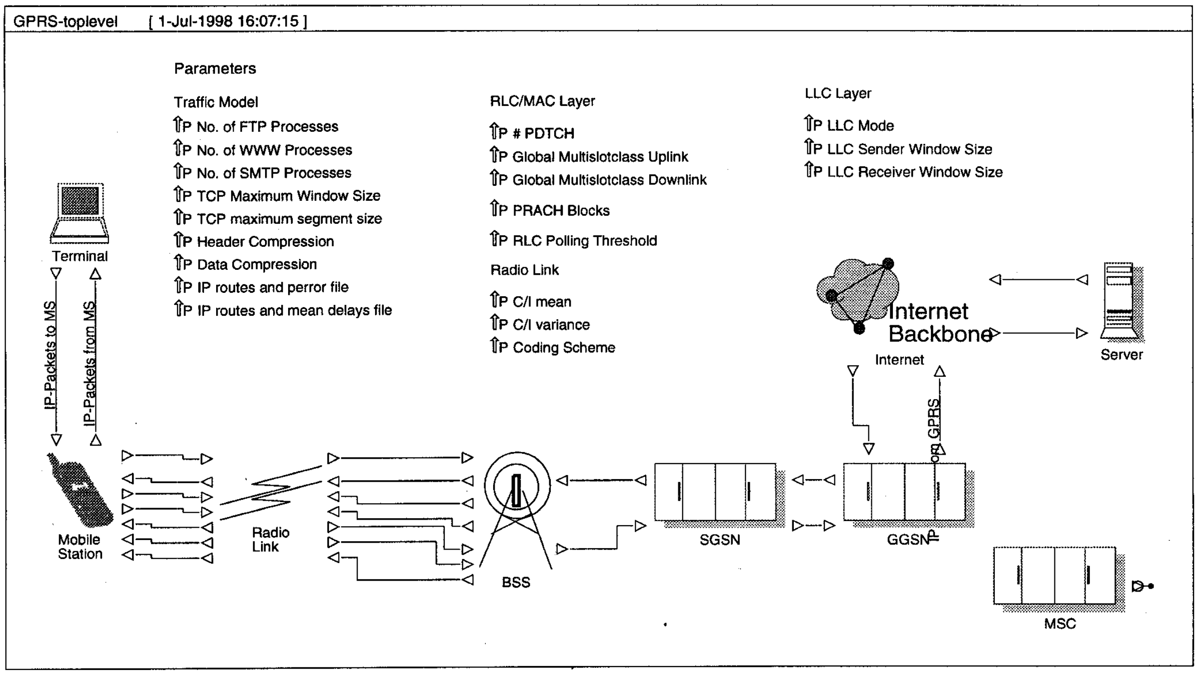

Figure 3: Toplevel of the simulation environment

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 [8],[9], 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 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. 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 [7] 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. V.42bis data compression is currently not supported.

LLC: The GPRS Attach procedure is not implemented and hence the mobile starts in stand-by mode.

[1] Block-Oriented Network Simulator

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. 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],[6].

IV. SIMULATION RESULTS

For the presented results the behavior of WWW over GPRS has been investigated and the parameters in Table 1 were used.

Table 1: Simulation Parameters

No. of WWW Users	1 – 40
TCP maximum segment size	536 Byte
Mean Internet Packet Loss Rate	2 %
Mean Internet Delay	100 ms
Number of PDCH	1 – 8
Global Multislot Class Uplink	1 TS
Global Multislot Class Downlink	1, 2, 4 TS
C/I Mean	12 dB
C/I Variance	5 dB
PRACH Blocks	0; 6
Channel Coding	CS 2
Simulation Duration	30 min

The number of PDCHs specifies how many of the 8 TSs in a TDMA frame are reserved for GPRS traffic by the network operator for one GSM frequency. The mobile terminals can operate in multislot mode which allows to use several TSs in parallel. In uplink only one TS is used whereas in downlink 1, 2 and 4 TSs are analyzed. This reflects the highly asymmetric traffic pattern of WWW. Furthermore, the simulations are based on the assumption that all MSs use channel coding scheme 2 with a net data rate of 13.4 kbit/s per TS [11]. A performance analysis of all four GPRS coding schemes at different C/I values is given in [4]. All throughput measures in this section are given for the application layer, that means that all protocol overheads due to headers, error recovery and flow control (e.g. TCP slow start) are included. The throughput is defined here as the packet size of a WWW object divided by its transmission delay. This normalized measure is used in order to gain comparable results for different object sizes. When the mean throughput is given it signifies the mean value of the throughput of all individual WWW-objects of all users. Since the majority of WWW traffic is on the downlink only downlink throughput is analyzed here.

In Figure 4 the end-user performance for downlink is depicted in terms of mean throughput for WWW traffic of all users. All terminals have a multislot capability of 1 TS for uplink and 2 TSs for downlink direction. The different graphs signify different numbers of PDCHs provided by

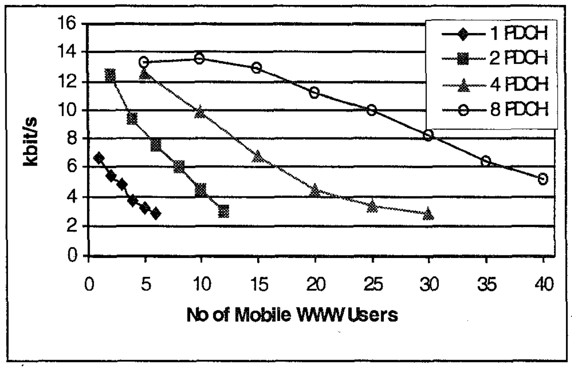

Figure 4: Mean throughput downlink per WWW-object

the system. Consequently when only a single PDCH is available a terminal can use at maximum 1 TS. For one PDCH the maximum achievable mean throughput is around 6.7 kbit/s. When more PDCHs are available and all MSs use their 2 TSs the maximum mean throughput doubles to approximately 13.5 kbit/s. This value is reached for low load, i.e. few numbers of users. For increasing load the throughput perceived by the end-user decreases. As soon as the number of active users multiplied by the number of TSs they use is larger than the number PDCHs the system starts to multiplex. The multiplexing gain is significantly higher for more PDCHs, especially for high load. E.g. when 25 users try to access 2 TSs of 8 PDCHs their mean throughput is roughly three times higher than when only half the resources are available with 4 PDCHs. The reduced probability of the

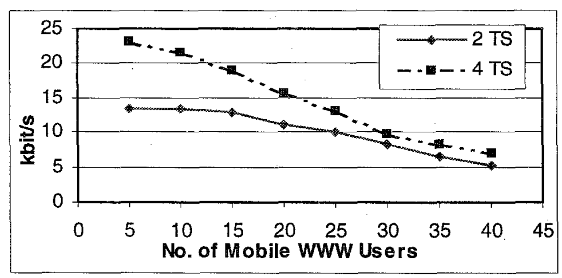

Figure 5: Mean throughput downlink (8 PDCH)

resources being blocked by other users leads to the higher multiplexing gain.

In Figure 5 again the performance of mobile terminals is demonstrated, this time comparing two classes of MSs, i.e. those using 2 TS and those using 4 TS. Terminals can have multislot capabilities of up to 8 TS. Note that more users can be supported than PDCHs are available. This is in contrast to circuit switched networks, where at maximum 2 users using 4 TS in parallel or 4 users using 2 TSs could be supported.

The relationship of system and user performance is displayed in Figure 6 for 15 users and Figure 7 for 10 users. The system capacity at application level with 4 PDCHs is at approximately 34 kbit/s. In instants when this limit reached all users share the resources available and their performance degrades. The maximum observed throughput for an individual terminal with 2 TSs is

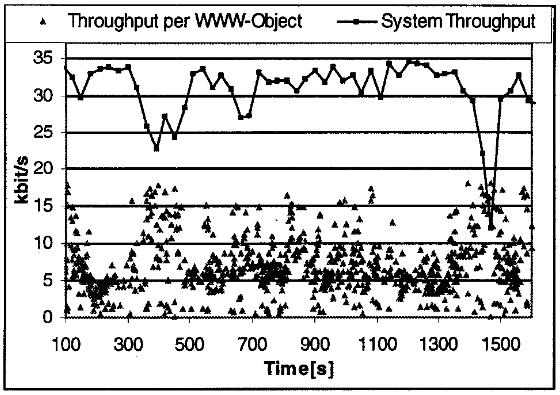

Figure 6: 15 users with 2 TS and 4 PDCH

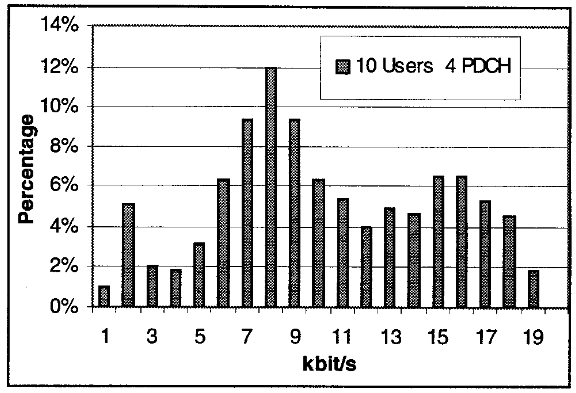

Figure 8: Histogram of WWW object throughput

approximately 18 kbit/s. As soon as the system throughput is below the capacity the performance of all users rises. This can be seen e.g. in Figure 6 at simulation times 400 s and 1400 s. The throughput of WWW objects is higher but still keeping a large variance. This is due to effects of underlying protocols, e.g. retransmission in TCP, LLC or RLC. In Figure 7 the performance is presented when the system operates below its capacity. Even then WWW objects with very low throughput occur. This is mainly owing to TCP retransmission with large timeout periods occurring due to the assumed mean Internet packet loss of 2%.

A throughput histogram of the traffic for 10 users using 2 TSs in downlink and 4 PDCHs is depicted in Figure 8. The graph shows the high variance of transmission rates a user perceives during a WWW session. Nevertheless 60 % of the packets are received with rates between 8-19 kbit/s on application level.

V. CONCLUSIONS

A simulation environment has been presented which allows performance analysis of Internet applications for different parameter settings for GPRS. The impact of specific parameters as well as their interdependence has been investigated.

The results have shown that GPRS is a highly suitable bearer service for TCP/IP traffic. It allows a better utilization of the scarce radio resources than circuit switched connections and supports a larger number of parallel connections. It has been demonstrated how an operator can scale a GPRS system by increasing the number of PDCHs. He can thus balance between GSM voice capacity and GPRS data capacity in his network.

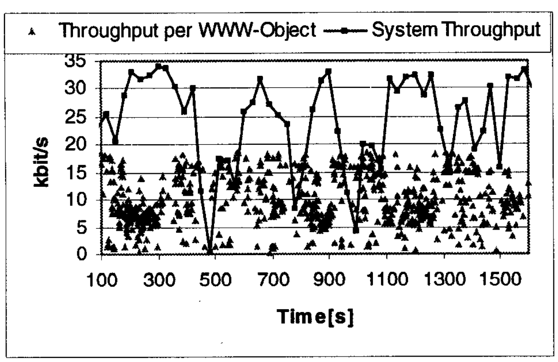

Figure 7: 10 users with 2 TS and 4 PDCH

Additionally, the end-user perception has been analyzed for mobile terminals with different capabilities. GPRS is particularly well suited for bursty traffic, as it is found for most Internet applications.

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