Measured Performance of GSM HSCSD and GPRS

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***Abstract* – In this paper we present results of measurements on the performance of GSM HSCSD and GPRS data transmission. We used a measurement tool that we have developed to study the performance of various wireless links as perceived by nomadic applications using the TCP protocol. The results show that in stationary connections the throughput and response time were stable and, in general, close to the theoretical values. However, the throughput and response time varied a lot when connections were used in motion. One of the reasons is that TCP was not capable to adapt itself properly to the variability of QoS of HSCSD and GPRS, and therefore, it did a lot of unnecessary retransmissions causing performance slowdown. The performance of HSCSD was better than the performance of GPRS. Reliability was adequate in stationary connections, but in moving connections there were unwanted disconnections or long pauses in data transfer.**

I. INTRODUCTION

The basic GSM data services [1] have been in the market for about 6 years. However, they have not reached wide scale usage. Some of the basic reasons are low throughput and dependability of GSM data transmission. ETSI [2] has planned a technology path to higher throughput and more dependable services. High Speed Circuit Switched Data (HSCSD) [3, 4] and 14400 bps channel coding (144CC) [5] were the first steps in the path. General Packet Radio Services (GPRS) [6] is entering the market, and Universal Mobile Telecommunications Services (UMTS) [7] will succeed them within next 2-3 years.

HSCSD offers higher transfer rates by combining two or more time slots. It implements a flexible time slot allocation scheme. The allocation of time slots depends on the following factors: end user's subscription, air capacity, and network load. HSCSD uses an Automatic Link Adaptation scheme (ALA) for the best channel coding at each occasion. GPRS enhances GSM data services to a packet switched data transmission. GPRS has also a flexible time slot allocation scheme and ALA. In the first phase, GPRS uses CS-1 (9.05 kbps line rate) and CS-2 (13.4 kbps line rate) channel codings [15].

We made this study to understand the performance of HSCSD and GPRS from the viewpoint of nomadic applications. In the study we used a performance measurement tool (Wireless Link Tester – WLT) [11] that we have developed to study the performance of various wireless links. WLT implements a client – server model and uses TCP as its transport protocol. With WLT we can measure the throughput, round-trip time, and reliability of a wireless link. We made the measurements on HSCSD using the public GSM network and on GPRS using the public GPRS network in Helsinki surroundings operated by Sonera.

Our major results are the following:

1. Generally, in stationary connections the performance was stable meaning that the variation in both the throughput and round-trip time was small and there were only few disconnections [11].
2. In moving connections, the variation in both the throughput and the round-trip time was high, and there were several disconnections or long pauses in data transfer. Disconnections happened on the average every 11th-12th minute. In addition, there were cases where the round-trip time was exceptionally long and the throughput was very low.
3. The measurements indicated that TCP was not capable to adapt itself properly to the variability of QoS of HSCSD and GPRS. Therefore, TCP did unnecessary retransmissions causing significant performance slowdown.

The rest of the paper is organized as follows: Section 2 discusses HSCSD and GPRS. Section 3 describes our measurements including WLT, measurement setup, and traffic loads. We then present the results of the measurements in Section 4. Finally we summarize the study in Section 5.

II. HSCSD AND GPRS

HSCSD consists of two separate technologies: multislot capability and modified channel coding scheme. The former provides the usage of several parallel time slots per user thus increasing the user data rate respectively. The first phase of HSCSD specifications allows the usage of 4+4 time slots, but in practice, the mobile equipment manufacturers implement more limited versions of that. At the beginning of HSCSD services, the maximum number of time slots is mostly limited

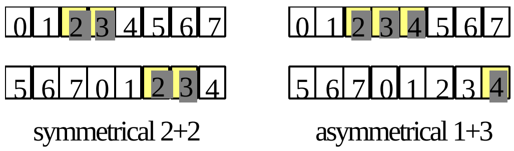

Fig. 1. Example of symmetric and asymmetric HSCSD multi slot-scheme

to 1+3 and 2+2 (Fig. 1). The specifications define asymmetric traffic in such a way, that the amount of time slots in uplink direction cannot exceed the number of time slots in downlink direction.

The 144CC scheme provides a 14.4 kbps line rate instead of the original 9.6 kbps line rate. In order to achieve higher line rates there is a more efficient puncturing method used, which on the other hand decreases the radio interface error correction performance. This means, that 144CC cannot be used, when there are a lot of noise and interference affecting the quality of the radio signal.

The specifications define upgrading and downgrading of air interface resources. It means that the amount of parallel time slots can vary between one and the maximum defined value. Up- and downgrading may occur when the signal level, interference level or capacity varies during a connection. The system can also use ALA, which means that the data rate can be 14.4 kbps or 9.6 kbps for an individual time slot depending on the radio path conditions. Both up- and downgrading of the resources and ALA can happen during a data transfer. Even though, the specifications allow the up- and downgrading and ALA, the combinations might be limited depending on the network and mobile terminal capabilities.

In the first phase, the maximum data rate of HSCSD is limited to 64.0 kbps due to the A-interface [4]. Depending on the connection type and the infrastructure capabilities of the network, the maximum user rate can be 38.4 kbps using ISDN V.110 protocol, and 57.6 kbps using ISDN V.120 protocol.

GPRS maintains the GSM Base Station Subsystem (BSS) access technologies with some modifications to the allocation of air interface resources. In contrary to HSCSD, time slots are allocated for a terminal when needed and up to eight terminals may share one time slot. GPRS uses a flexible time slot allocation scheme with up to 8+8 time slots. GPRS has four channel coding schemes (CS-1 9.05 kbps, CS-2 13.4 kbps, CS-3 15.6 kbps, and CS-4 21.4 kbps below the RLC level). In practice CS-1 provides about 8.0 kbps data rate and CS-2 about 12.0 kbps data rate [16]. Different coding has different performance and error resiliency characteristics. Most important new components to support packet switched data transmission in the Network Subsystem are: the Serving GPRS Support Node (SGSN), the Gateway GPRS Support Node (GGSN), and the Border Gateway (BG) [12, 13].

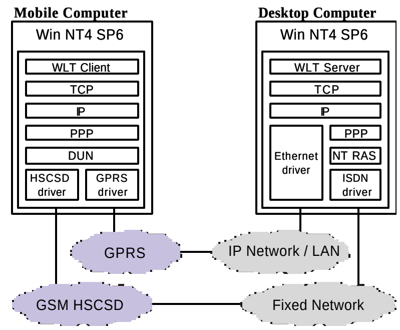

Fig. 2. Configuration of the measurement tool

III. MEASUREMENTS

In this section, we describe our measurement tool, measurement setup, and traffic workloads used in the study.

A. Measurement Tool

WLT is designed to measure the throughput and round-trip time of a wireless link. WLT also collects TCP segment counters and link disconnections.

No data compressions (Van Jacobson [8], V.42bis [9], etc.) are used, so the actual throughput – not improved by data compressions – is measured.

The Dialup Networking (DUN) and Remote Access Service (RAS) of Windows NT4SP6a are used to establish the data link connection between the mobile computer and the desktop computer. The configuration of the measurement tool is shown in Fig. 2.

B. Measurement Setup

For HSCSD measurements we used 1+3 time slot allocation with 144CC and ALA in the air interface and V.110 protocol in the ISDN interface between MSC IWU and the desktop computer. Fig. 3 shows the HSCSD test configuration. For GPRS measurements we used 1+2 time slot allocation with CS-2 because that was the best the mobile terminal was able to support. During live GPRS tests the ALA functionality was disabled in the GPRS network. The requested reliability class was “Unacknowledged GTP and LLC; Acknowledged RLC, Protected data”. Fig. 4 shows the GPRS test configuration.

We have used following TCP parameters: MSS of 536 bytes and the receiver window of 16 kilobytes. No other TCP options (SACK, timestamps, etc.) were enabled.

C. Traffic Workloads

We measured two types of workloads: bulk data transfers and request – reply transfers. Bulk data transfer simulates for

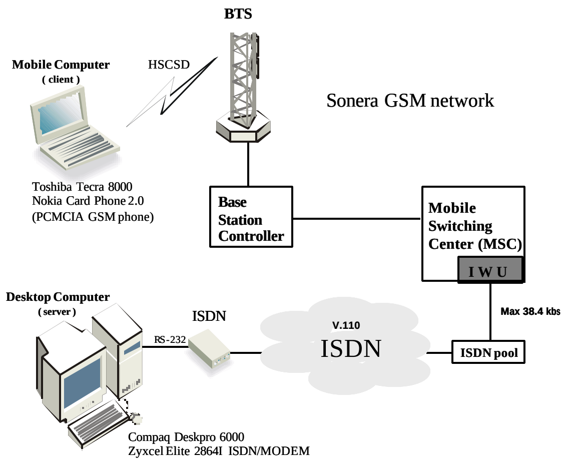

Fig. 3. HSCSD test configuration

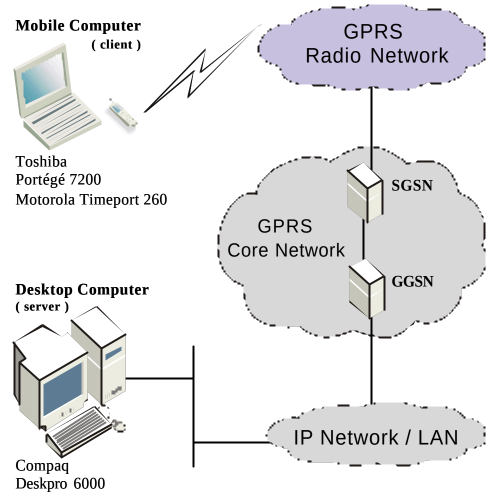

Fig. 4. A model of GPRS used in test

example FTP transfers or a retrieval of large image. The bulk transfer sequences consisted of 40 repetitions of 150000 bytes data transfers.

The request – reply transfers simulate HTTP transactions. The test sequences are described in Table 1. The sizes for request – reply measurements are based on a real HTTP trace collected from one Sonera's Internet service access point and its transparent proxy. The HTTP trace was collected during one week and contains almost two billion requests. The selection criteria for the message sizes of the measurements were the frequencies of message sizes categorized by appropriate ranges. We intentionally rejected browser's cache hits and huge downloads. This scales minimum reply sizes up and maximum reply sizes down than those of typical Web browsing; however, the overall response time of Web browsing can be estimated from our results.

IV. Results of Measurements

In this section, we present the results of the measurements.

A. *HSCSD Bulk Data Transfers*

Stationary connections had generally a stable throughput [11]. Measured throughput for moving connections is illustrated in Fig. 5.

The uplink throughput was the following: maximum 23.3 kbps, minimum 4.1 kbps, and average 9.6 kbps. We experienced some variation in the throughput and few significant peaks. The cause for variation was mostly ALA. The peaks can be explained by our network configuration; the tested network allocated 2+2 time slots instead of 1+3, if there was no capacity to provide three downlink time slots. About 18% of uplink test sequences had significant amount of TCP retransmissions – in some cases even all segments were resent.

The downlink throughput was the following: maximum 27.9 kbps, minimum 13.4 kbps, and average 22.7 kbps. There was less variation in downlink than in uplink throughput. We also experienced less TCP retransmissions; 5% of test sequences had over 1/3 of all segments resent.

B. *HSCSD Request – Reply Transfers*

Response times for each request – reply test sequences are illustrated in Fig. 6. The performance was good; though, the variation increased considerably when the request – reply data size increased. Small transactions (280/499) had the following round-trip times: the average 1.0 sec, the minimum 0.8 sec, and the maximum 7.2 sec. The average round-trip time for medium size transactions (348/4758) was 2.7 sec, the minimum was 2.1 sec, and the maximum was 13.3 sec, whereas for large size transactions (539/5070) the average round-trip time was 3.1 sec, the minimum was 2.3 sec, and the maximum was 26.8 sec. Although there were variations, they were less than half of those of GPRS. Over 60% of the test sequences had only a few TCP retransmissions. But there were some large size (539/5070) test sequences where over 1/3 of segments was resent.

C. *GPRS Bulk Data Transfers*

Uplink bulk data transfers in GPRS (Fig. 7) were more problematic than downlink, which was similar to HSCSD. Almost all uplink data transfers have retransmitted segments, in some cases the amount of retransmissions have exceeded the size of transferred user data. Only a small part of

TABLE 1
TEST SEQUENCES IN REQUEST - REPLY TRANSFERS

Number of Tests	Average Request Message (bytes)	Average Reply Message (bytes)
19*120	280	499
19*120	348	4758
19*120	539	5070

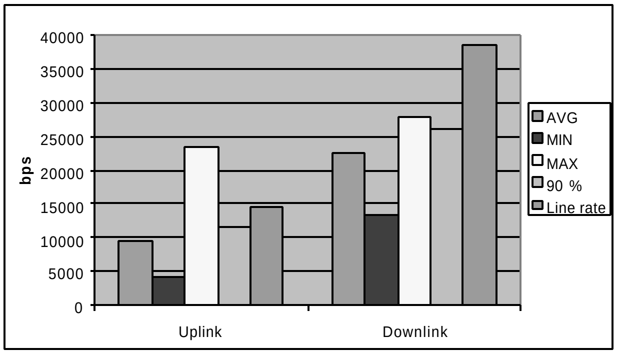

Fig. 5. Throughput of HSCSD (38*150000 bytes transfers)

retransmissions was recovering lost segments, the larger part of retransmissions was unnecessary. We could observe this by studying the receiver-side TCP traces and comparing the number of segments sent and received. The maximum throughput in the uplink direction was 7 kbps, which is significantly less than the data rate of 12 kbps, even with TCP/IP header overhead included. Some transfers took a very long time to complete. The lowest throughput was only 1.8 kbps, which is more than six times less than the data rate. The average uplink throughput in GPRS of 3.8 kbps was less than a half of HSCSD.

In the downlink direction, only a few transfers have had retransmissions and throughput was good (results cannot be directly compared to HSCSD, since GPRS tests have had two timeslots allocated versus three for HSCSD). Downlink tests were stable; 90% of tests have had throughput close to the maximum of 20 kbps, which still is 17% lower than the data rate of 24 kbps. However, the lowest throughput of 2.6 kbps was almost ten times less than the data rate.

D. GPRS Request – Reply Transfers

On the average, all transactions showed satisfactory performance over GPRS (Fig. 8). However, the maximum response time was extremely high, in the order of several minutes. For small transactions (260/499), we noticed only a few retransmissions, but the minimum response time of 1.5 seconds was almost twice as large as for HSCSD. For medium (348/4758) and large (539/5070) transactions, the minimum response time was approximately 30 % larger than for HSCSD and 90 % of transactions took approximately twice longer to complete over GPRS than over HSCSD. Approximately 10% of segments were retransmitted.

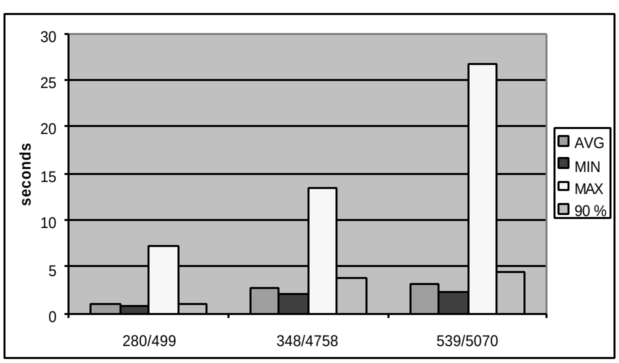

Fig. 6. Response times of HSCSD request – reply transfers

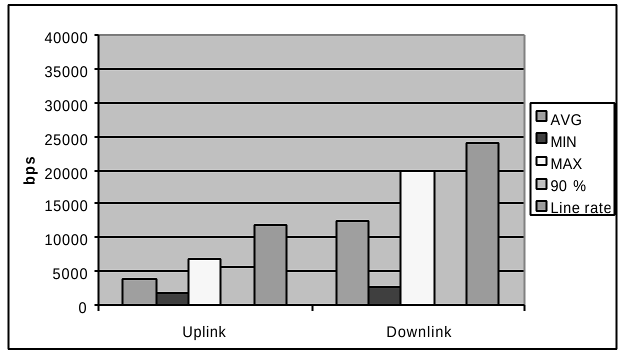

Fig. 7. Throughput of GPRS (40*150000 bytes transfers)

E. Reliability

In general, in the case of HSCSD the reliability of stationary connections was adequate for nomadic end users. However, in moving connections there were disconnections caused by handover failures, air interface failures, and remote equipment failures. On the average, there was a disconnection every 11th - 12th minute. In the case of GPRS, in moving connections there were several cases, where transfer was paused for exceptionally long time. One of the reasons was that GPRS is still in earlier phase, and thus, there were software faults causing performance slow down.

V. SUMMARY

In general, in good radio signal quality environment, both HSCSD and GPRS provided significantly better throughput

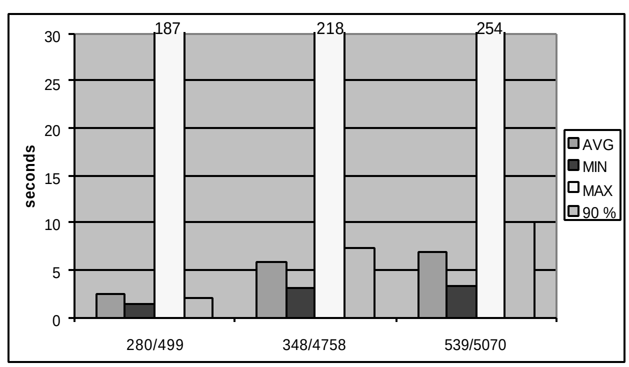

Fig. 8. Response times of GPRS request – reply transfers

and response time than the basic GSM data service. The throughput and round-trip time in stationary connections were stable. However, in moving connections they may change a lot; for example, the throughput changed between 23.2 kbps and 2.4 kbps and response time changed between 2.3 sec and 26.8 sec. One of the reasons to the high variance was the behavior of TCP. TCP could not cope properly with the characteristics of HSCSD and GPRS data transmission, thus causing performance slow down by doing a lot of unnecessary retransmissions. The problems with TCP are discussed, for example, in [10]. IETF has started to address these problems [14].

HSCSD provided better performance than GPRS does. GPRS had higher variance in performance than HSCSD. The high variance needs to be addressed when developing nomadic applications over GPRS.

The reliability in stationary connections is adequate. But the reliability in moving connections – a disconnection every 11th-12th minute (HSCSD) or long pauses in data transfer (GPRS) – may create problems, for example, in long web browsing sessions or in long file transfers. Therefore, the reliability of moving connections may create problems, if a distributed application cannot cope properly disconnections or long pauses.

Future studies will include performance measurements using simulated UMTS.

References

[1] Michel Mouly, Marie-Bernadette Pautet, “The GSM System for Mobile Communications”, 1992.

[2] European Telecommunications Standards Institute, WWW.ETSI.ORG, checked 19.2.2001.

[3] GSM Technical Specification, “GSM 02.34, High Speed Circuit Switched Data (HSCSD), Stage 1”, Version 5.2.0. ETSI, July 1997.

[4] GSM Technical Specification, “GSM 03.34, High Speed Circuit Switched Data (HSCSD), Stage 2+”, Version 5.2.0. ETSI, May 1999.

[5] GSM Technical Specification, “GSM 10.14 version 1.0.1, Digital cellular telecommunications system (Phase 2+), System Overview for 14.4 kbit/s Work Item”, ETSI, 1997.

[6] GSM Technical Specification, “GSM 02.60 version 6.1.0, GPRS Service Description, Stage 1”, ETSI 1998.

[7] WWW.3GPP.ORG, checked 19.2.2001.

[8] Van Jacobson, “Compressing TCP/IP Headers for Low-Speed Serial Links”, RFC 1144, 1990.

[9] ITU-T, “Recommendation V.42bis: Data Compression Procedures for Data Circuit Terminating Equipment (DCE) Using Error Correction Procedures”, ITU-R, January 1990.

[10] Reiner Ludwig, and Randy H. Katz, “The Eifel Algorithm: Making TCP Robust Against Spurious Retransmissions”, *Computer Communication Review*, Vol 30, Number 1, January 2000.

[11] H. Laamanen, J. Penttinen, and J. Laukkanen, ”Measured Performance of GSM High Speed Circuit Switched Data Link”, *BAS2000*, 5th Computer Networks Symposium, June 2000.

[12] GSM Technical Specification, “GSM 03.60 version 7.4.0, Digital cellular telecommunications system (Phase 2+), General Packet Radio Service (GPRS) Service Description – Stage 2”, ETSI, 2000.

[13] Jian Cai, David Goodman, “General Packet Radio Service in GSM”, *IEEE Communications Magazine*, October 1997.

[14] G. Montenegro, et al, “Long Thin Networks”, RFC 2757, January 2000.

[15] GSM Technical Specification, “GSM 03.64 version 7.1.0, Digital cellular telecommunications system (Phase 2+), Overall description of the GPRS radio interface, Stage 2”, ETSI 1999

[16] M. Mayer, “TCP Performance over GPRS”, *IEEE Wireless Communications and Networking Conference 1999*, New Orleans, LA, September 21-24, 1999