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Report C-1995-41

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Abstract. Recent developments in mobile computing have created new possibilities for mobile offices. Integration of wireline and wireless networking lays a new foundation for services available in traditional fixed computer networks almost everywhere. However, integration of a wireless wide area network (WWAN) and a fixed data network raises several technical questions including dependability and performance. An experiment was carried out at Digital Equipment Corporation Oy (Finland). The goals of this experiment were to examine the dependability and the performance of GSM data communications in everyday working circumstances and to explore users' opinions about GSM data communications. Employees had wireless data access to Digital's fixed data network. The participants of the experiment used the same applications out of the office as they normally used at the office. The participants' opinions were obtained using questionnaires. The performance was measured with software tools in two different environments. Three basic operations were measured: connection establishment, exchange of request-reply messages, and bulk data transfer.

The results of the experiment demonstrate that the participants were satisfied with GSM data communications, regardless of the unreliability and the occasional unavailability. The results indicate that the technology of the GSM data service is mature enough to be used in specific, well-defined services of computer networks. However, the reliability and the availability of the GSM data service are not satisfactory for today's client-server applications. A disconnection of the GSM connection is common in everyday working circumstances. The response time in an interactive operation is sufficient to end-users when the amount of data is small. The maximum sustainable transfer rate is about 900 octets per seconds. The transfer rate of the uplink is normally less and more unsteady than the transfer rate of the downlink.

Key Words: wireless data, mobility, mobile workstations, mobile office, GSM, TCP/IP

CR Classification: C.2.1, C.4

1. Introduction

It is often predicted that mobile computing will be the revolution of 90's in the same way as personal computers were of the 80's. The key factor in this revolution is wireless networking. Integration of wireline and wireless networking creates new possibilities to use services available in computer networks. However, integration of a wireless wide area network (WWAN) and a fixed data network raises both technical and economical questions. Discussions [Badr1, Bakr1, Cace1, Form1, Kojo1, Wats1, Yava1] presenting challenges of the integration are still few.

Global System for Mobile communications (GSM) is a Pan-European digital cellular telephone network [Rahn1, Moul1]. Today, the GSM network creates a platform for wireless wide-area data communication by offering a variety of data services: both bearer services and teleservices. GSM specifies two asynchronous bearer services: transparent and non-transparent. The non-transparent mode is implemented using the Radio Link Protocol (RLP), and therefore, it is more reliable than the transparent mode. The maximum line rate is 9600 bps. GSM specifies interworking with several wireline networks including Public Switched Telephone Network (PSTN), Integrated Services Digital Network (ISDN), and Packet Switched Public Data Network (PSPDN). GSM makes the wireless access to fixed data networks possible almost everywhere in Western Europe and also in some countries outside Europe.

We carried out an experimental study in order to understand issues of the integration, including dependability and performance. Through understanding these issues we can decide what kind of legacy applications can be used in the integrated network and we can better design and implement new applications. The study started at Digital Equipment Corporation Oy (Finland) in November 1994 and ended in March 1995.

In the study we used Digital's existing software and hardware platforms and applications. Digital Equipment Corporation has a world-wide data network, called Easynet, consisting of more than 85.000 systems. Most of the services provided of Easynet can be reached anywhere in the network. Our test group consisted of 10 persons from five different organizational units. They present four different working profiles: consultant, employee in duty, service van, and traveling salesperson. The participants used same applications 'on the road' as they used at the office.

In this paper we describe the study and discuss the results. We collected information using two different methods. We measured the performance of the system using software tools and we used questionnaires to gather the participants' experiences about reliability, availability, and performance. We do not try to present a complete and comprehensive analysis of all important issues. Instead, we offer the reader aspects about dependability and performance that we regard important for the design and implementation of integration.

The rest of the paper is organized as follows. In Section 2 we discuss the objectives of the study. In Section 3 we describe environments and configurations including hardware, software, working profiles, and the GSM network. In Section 4 we discuss the measurements. In Section 5 we present the results of our study. In Section 6 we present the conclusions and the summary.

2. Objectives of the Study

At the time of this study access to Easynet was through wireline connections, except a few wireless LAN configurations and test sites. This limited the access only to places, where there is a wireline connection. We believe that a location-independent access to services in Easynet will improve productivity.

We think the main technical challenges of integration are the following: dependability, performance, security, and management. Our main objectives of this case study were the technical requirements and boundaries of the integration. Our emphasis was on dependability and performance.

Dependability is the trustworthiness of a computer system such that reliance can justifiably be placed on the service it delivers [Lapr1]. It is a general concept including reliability, availability, security, and safety. Different attributes can be emphasized depending on applications. In this study the main attributes are reliability and availability. Wireless data transmission is more unreliable than wireline data transmission. The bit error rate of the GSM data transmission is between 10^{-3} and 10^{-8} [Etsi1] while a bit error rate is 10^{-9} in a copper wire and 10^{-11} in a fiber optic wire. The link stability varies depending on the movement and the location of the mobile node in a cell. We define availability as the fraction of time the system is available for 'useful' work [Jalo1]. The coverage area of a GSM network affect availability of services of the fixed data network. Digital's applications — at the time of this study — were built based on an assumption that a platform, especially a communication system, is reliable and available. Our objective was to study whether GSM data services offer reliability and availability for Digital's applications that satisfy end-users.

Measurements of performance have been carried out in [Alan1], but the actual response time, the actual throughput and the connection establishment time in various environments — micro cell and macro cell — were not well known. Our objective was to measure the performance in two different environments using a performance measurement tool. The first environment represents ideal air link conditions in which the RF (Radio Frequency) quality is excellent. The second environment represents arbitrary air link conditions. Our objective was also to obtain end-users' opinions about the performance 'on the road' in various working environments.

3. Environment of the Study

We carried out this study in an everyday working environment of Digital Equipment Corporation Oy. The only change we did was that we added the software and the hardware which were required to connect the GSM data services to Easynet.

3.1 Hardware

The hardware configuration is shown in Figure 3.1. Our intention is not to describe the whole hardware configuration but only those equipment and options, that are relevant to the study. The end-user equipment consisted of a laptop PC, a GSM phone, and a GSM data adapter card.

Laptop PCs have variant configurations. The processor is either Intel 386 or 486 based, 25 - 33 MHz model. The amount of the main memory is from 4 to 12 megabytes. The average operation time with a battery is 2-3 hours. The weights of the PCs are between 2 and 3 kilograms.

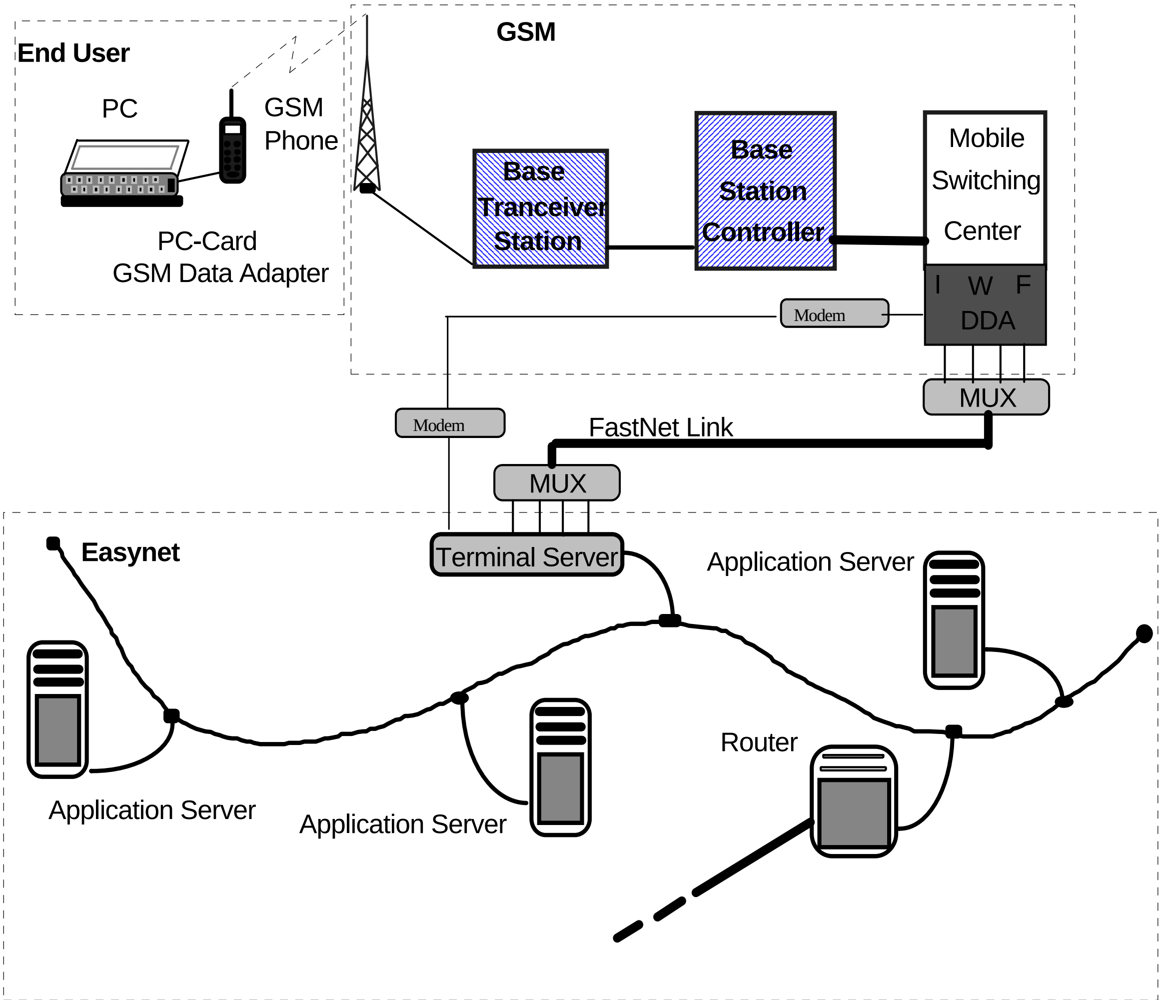

Figure 3.1: Hardware Configuration of Study

The GSM phone (Nokia 2110) is a handheld model. The maximum connection time is with a standard battery 70 minutes and with a heavy duty battery 180 minutes. The maximum transmission power is 2 W that is always used in data transmission. The GSM data adapter card, DTP-2 Cellular Data Card, is designed and manufactured by Nokia Mobile Phones. It is a PC Card (PCMCIA) version 2 type 2 equipment. The adapter supports the asynchronous, non-transparent, 2400 - 9600 bps bearer service.

The GSM network is built and operated by Telecom Finland. The Mobile Switching Center (MSC) DX200 — designed and manufactured by Nokia Telecommunications — we used in this study is configured with a Direct Data Access (DDA) controller. DDA enables a direct, digital path to Easynet. Another possibility is to use modems which require digital - analog - digital conversions. We used the modem connection as a backup link.

Equipment of the Easynet infrastructure consisted of communication servers — e.g. terminal servers, routers, bridges, and repeaters — and application servers, which are either VAX or Alpha-based computers and workstations. The transmission path from the Direct Data Access controller to the terminal server — FastNet offered by Telecom Finland — consists of four asynchronous 9600 bps links. The actual access point to Easynet is a DECServer 900 terminal server. The local area network is Ethernet.

3.2 Software

Our intention is not to list all software but only programs that are relevant to the study. The operating environment of the laptop PCs was MS-DOS version 6.2 and Microsoft Windows version 3.1. The communication software was either an implementation of the TCP/IP protocol suite — RoamAbout MIP version 2 or Trumpet versions 1.0, 2.0 — or a VT300 terminal emulation software. In case of TCP/IP the data link protocol was Serial Line IP (SLIP) [Romk1].

We categorized two types of Digital applications. The user interface of the first type is a character-oriented terminal; we call those applications as terminal access applications. The second type is the client - server application. The applications used in this study are listed in Table 3.1.

Table 3.1: Applications and their Functions

Application	Type	Function
ALL-IN-1	terminal access	Office automation platform: mail, document management, text processing, calendar, etc.
NICE	terminal access	Call dispatching
Notes	client-server	Conferencing
Teamlinks	client-server	Mail and document handling
Teleworks	client-server	Remote conferencing
TIMA	terminal access	Problem and solution database
VTX	client-server	Information board
ISC	terminal access	Spare parts management

3.3 Working Profiles

We selected employees, whose working profiles were different so that we were able to gather information from various aspects of Digital’s working practices.

The **consultant** designs systems, advises customers, and supports sales persons in their work. He or she needs access to product information, price information, and knowledge databases. The consultant uses office applications, such as electronic mail (ALL-IN-1, Teamlinks), videotex information board (VTX), and conferences (Notes).

The **employee in duty** - Multivendor Customer Services and Logistics - is responsible for managing emergency customer calls and for delivering spare parts. He or she works 24 hours per day in various places like at the office, at a customer, or at home. He or she needs access to databases, for example the dispatching database (NICE), the problem and solution database (TIMA), and the spare-parts database (ISC).

'Service Van' is a concept where a customer service engineer works all the time on the road. The engineer drives from one customer to another customer. He or she does not work at the office. He or she needs access to dispatching, problem and solution, and logistics databases. The customer service engineer uses also electronic mail and Videotex information board.

The **traveling salesperson** works both at the office and at customers. He or she accesses product information (VTX), price information (ALL-IN-1), and stock information databases, and uses electronic mail and Videotex information board.

3.4 Working Environment

We distinguished three working environments: stationary micro cell, stationary macro cell, and mobile environment. In the first case, stationary micro cell, the GSM coverage is implemented by using micro cells with in-building antennas. This is an example of the working environment where the quality of the radio signal is the best possible. The headquarters of Digital Equipment Corporation Oy (Finland) offer this environment. The second case, stationary macro cell, contains two different environments: indoor coverage and outdoor coverage achieved by macro cells with outdoor antennas. In these working environments the quality of the radio signal varies from good to very poor. Good examples of the indoor coverage are offices of customers, homes, hotels, and public buildings. In the third case, mobile, the working environment is usually a car where the quality of the radio signal changes rapidly as a function of movement and location.

4. Measurements

In this section we describe methods and tools, which we used to collect data. At first, we present the software tools and the workloads of the measurements. Next, we describe the questionnaires, which we used to gather the participants' experiences and opinions.

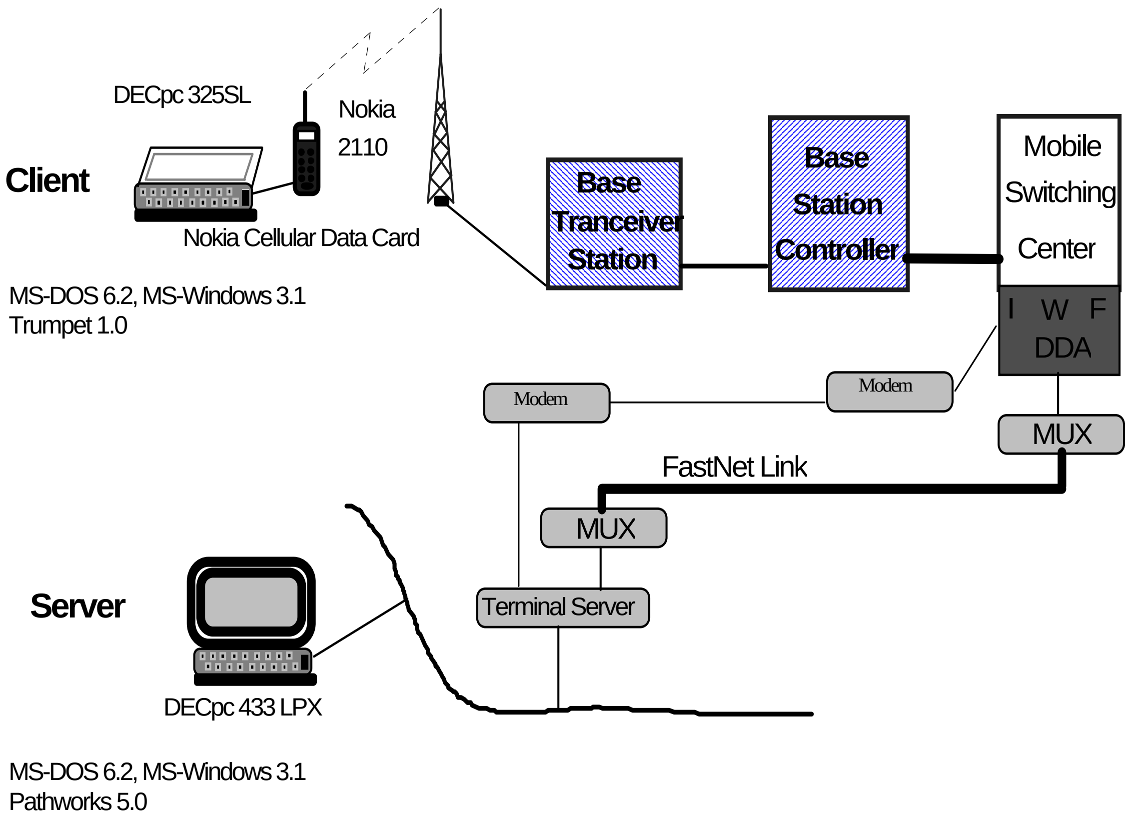

Figure 4.1: Hardware and Software Configurations of the Performance Measurements

4.1 Performance Measurements

We measured the actual performance of the GSM transmission path — connection establishment, response time, and throughput — with software tools. We had two tools: one to measure connection establishment time and another one to measure response time and throughput. The data processing configuration of our software tool was similar to traditional client-server environments; the only difference was that the transmission path contained a wireless link. The hardware and software configurations of the performance measurements are in Figure 4.1. It is obvious that the processing power of the computers affects the results as does the implementations of the TCP/IP protocol suite.

In the connection establishment tests we measured the time between the call activation and the establishment of the connection. The starting point of the timing was the AT Hayes dial command 'ATDT' to Cellular Data Card and the finishing point was a 'CONNECT' message received by the measurement tool. Each trial was followed by at least an one minute pause. We carried out over 500 trials and summarized the following parameters: the success rate, the minimum connection establishment time, the maximum - successful - connection establishment time, the median and the 95th percentile [Jain1] of connection establishment times.

The tool to measure the response time and the throughput was designed and developed to measure performance as end-users see it; it used the TCP/IP protocol suite as the communication platform.

Table 4.1: Message Sizes of Request-Reply Tests

Test Number	Request Message (octets)	Response Message (octets)	Simulates
1	3	50	DCL [terminal emulation]
2	5	515	ALL-IN-1 [terminal emulation]
3	43	2144	VTX [client - server]
4	85	2680	TIMA interaction [terminal emulation]
5	2136	112	Sending of mail [client - server]
6	612	612	TeleVenue [client - server]
7	427	3116	WWW [client - server]

We did the response time tests using artificial transactions, where the client sent a message — typically a short one — to the server, which in turn replied with another message — typically a large one. We also had a transaction where the request was a large message and the reply was a short message to see the difference between the down-link and the up-link in GSM data transmission. The time between the beginning of transmission of the request message and the end of receiving of the reply message was measured. The message sizes of the request-reply measurements (Table 4.1) were selected to be close to the message exchanges of real applications (see Table 3.1). In the applications ALL-IN-1, VTX, and TIMA the request is usually short and the reply contains a full screen of information including also screen control commands. The size of the reply message in the World Wide Web (WWW) type transaction does not contain images.

In the response time measurements each test sequence consisted of 100 artificial transactions. Each test sequence was repeated until 20 successful results were obtained. We performed the above test set in two different environments: stationary micro cell and stationary macro cell (indoor). We summarized for each working environment the following parameters: the minimum response time, the maximum (successful) response time, the median, and the 95^{th} percentile of response times.

We performed the throughput measurements by transferring bulk data, ASCII text, from the client to the server and vice versa. The measurement tool measured the arrival rate of incoming bytes. Data compression was not used, so the actual throughput — not improved by data compression — was measured. The test sequences of the throughput measurements consisted of nine 100 KB, of five 500 KB, and of two 1000 KB bulk data transmissions. We performed the above test set in a micro cell environment and in a macro cell environment. We summarized for each working environment the following parameters: the message error rate, the effective transfer rate, and the maximum sustainable transfer rate.

4.2 Questionnaires

We made questionnaires to collect data about the participants' experiences in the every day working environment. We had two different kinds of questionnaire. The first questionnaire was a PC application. The participants answered the questions after each session. Six sets of questions were asked: working environment, performance, reliability, ease of use, application requirements, and benefits of wireless access. The performance set contained questions about the overall system performance and about the network performance. The questions in the reliability set were the following: the number of failed connection establishments, the reason for the failure in the connection establishment, the number of disconnections during a session, the reason for the disconnections, and withdrawal. The second questionnaire was given to the participant after the test period. The participants were asked their overall conclusions about the performance and the reliability.

4.3 Evaluation of Dependability

In the evaluation of dependability we considered the GSM data service as a layer 1 — physical layer — service. Our factors of reliability were the following: the failure rate of the connection establishment, the error rate of data transmission, and the disconnections of sessions. The topology of the GSM network — specifying the quality of the radio signal in each geographical region — is the major factor that affects availability of the GSM data services. The signal quality is continuously changing, especially in movement. We had no tools to examine it in this study. Availability was measured as a function of the success rate of user sessions (whether the end-user was able to carry out what he or she wanted to do).

The failure rate of the connection establishment was evaluated both from the performance measurements and from the participants' statistics. The error rate of data transmission was computed from statistics of the TCP (Pathworks) counters, collected in the performance measurements. We were not able to get error statistics of the RLP protocol. Therefore, the bit error rate could not be calculated. We used the error rate of the TCP segments. We evaluated the disconnectedness of sessions from the participants' statistics. We measured the disconnectedness as a function of a session. To measure it as a function of time would have been a more precise method. Unfortunately, we did not have any tools to reliably measure the disconnectedness as a function of time.

About 550 test sequences including 36.000 transactions, transfer of 28 MB information, and over 500 connection trials were carried out. All this required about 80 hours air time. The participants had about 350 sessions during the test period. The average length of a session was about 20 minutes. In 25% of the sessions the end-users spent less than 10 minutes and in 35% of the sessions the length was between 10 and 20 minutes. The longest session was 160 minutes. The total air time used by the participants was about 130 hours.

5. Results of the Study

As stated in the Objectives of Study, we are interested in the technical requirements and boundaries of the wireless access. Our emphasis was on dependability and performance. In this section we describe results of the study.

5.1 Dependability

This study comprised many hardware and software components, which were either prototype or first production versions. As such, they included many errors that decreased overall reliability. We were not able to distinguish all those failures from failures caused by the GSM data transmission itself. The coverage area of the GSM network was rapidly expanding during the time of this study. Some of the results of the availability measurements reflect the status of that time, and they may change in a succeeding measurement.

5.1.1 Connection Establishment

Our study shows two different reliability levels in the connection establishment. In the performance measurements — that were carried out in controlled, good conditions — we counted less than 4% unsuccessful connection establishments in case of the DDA link and less than 15% when modems were involved. This result is similar to [Alan1].

On the other hand an analysis of the participants' statistics indicates that the failure probability is about 27% in every day working circumstances. The main reason was 'No Carrier' (59%). It means that an RLP link cannot be established. In majority of these cases the strength of the radio signal shown by a phone was 3 or above (maximum 5). This indicates that a good field strength shown by a phone — the end-user's only indicator of the quality of a radio signal — does not guarantee a successful connection establishment. The phone shows, as a matter of fact, the signal strength it receives; it does not indicate either the signal strength that a base transceiver station receives from the phone or the actual quality of the radio signal. The reason was 'Busy' in 8% of the unsuccessful connection establishments. There were 31% unidentified cases, where the participants were not able to specify the reason for the failure. These cases include phone, GSM data adapter card, and DDA failures.

5.1.2 Disconnectedness of GSM Connection

The analysis of the participants' statistics shows that a disconnection of the GSM connection is common in everyday working circumstances. In 41% of the end-users' sessions the GSM connection broke down. The distribution of the number of disconnections during a session is Table 5.1.

Table 5.1: The distribution of the number of disconnections

Number of Disconnections	1	2	3	> 3
Distribution	19%	16%	3%	3%

The reasons for disconnections shown by the survey — as end-users see them — are low battery 2%, poor quality of the radio signal 37%, and unknown 61%. The high number of unknown reasons includes both software and hardware failures that the end-users were not able to identify. We were capable to trace some reasons for those failures. The phone itself was one source of disconnections: it crashed — started to perform a self-test sequence — in several cases, or it lost the connection to the network and could not reconnect without a total 'power down and up' cycle.

5.1.3 Error Rate of Transmission

The TCP statistics collected from the performance measurements shows that the average message error rate of the down-link direction was 0.14% and of the up-link direction was 0.47%. One reason for the asymmetry is the difference in transmission powers between the handheld phone and the Base Transceiver Station (BTS). The highest rate of the segment format error — a mismatch of the cyclic redundancy code (CRC) of a received segment — was 0.73%. The GSM specification [Etsi 1] requires the bit error rate to be less than 10^{-8}. This mismatch requires more measurements and analysis about possible reasons.

5.1.4 Availability

Availability — the fraction of time the system is available for 'useful' work [Jalo1] —depends on two factors: the coverage area of the GSM network and the quality of the radio signal. The analysis of the participants' statistics indicates that in 17% of sessions an end-user gave up without finishing the task she or he was trying to perform. The main reason was the poor quality of the radio signal. As operators are continuously developing their GSM networks by expanding the coverage area and by building smaller cells where required, the availability is expected to increase in the future.

5.2 Performance

In the performance of the GSM data service we are interested in the connection establishment times, in the typical round-trip times, and in the throughput. In addition to the measured performance, we also examined end-users' opinions about the performance.

5.2.1 Dial-Up Connection Establishment

Figure 5.1 shows the maximums, the 95th percentiles, the medians, and the minimums of measured dial-up connection establishment times. The figure is based on over 500 tests — 245 through the DDA and 310 through the modems (see Figure 3.1) — successful connection establishment. The measurements were carried out in the macro cell environment.

Through the DDA link a successful connection establishment typically takes 6.4 seconds. The minimum is 5.4 seconds. The maximum connection establishment time is 21.4 seconds and the 95th percentile (20.4 seconds) is close to the maximum. The distribution of the observed connection establishment times indicates that an establishment takes either less than 9 seconds or more than 18 seconds. There are only very few cases where the connection establishment time is between 9 and 18 seconds. To understand this phenomena requires more experiments to be carried out.

The modem handshaking increases the connection establishment time. Through the modem link the median is 24.4 seconds. The minimum time is 17.0 seconds. As the median and the 95th percentile (27.5 seconds) are close to each other, the dispersion of the connection establishment times is small. The maximum connection establishment time is 33.6 seconds. We had the same modems (V.32bis, V.42bis) with the same setup at both ends. If either the modem or the setup is changed, the modem handshaking time may change.

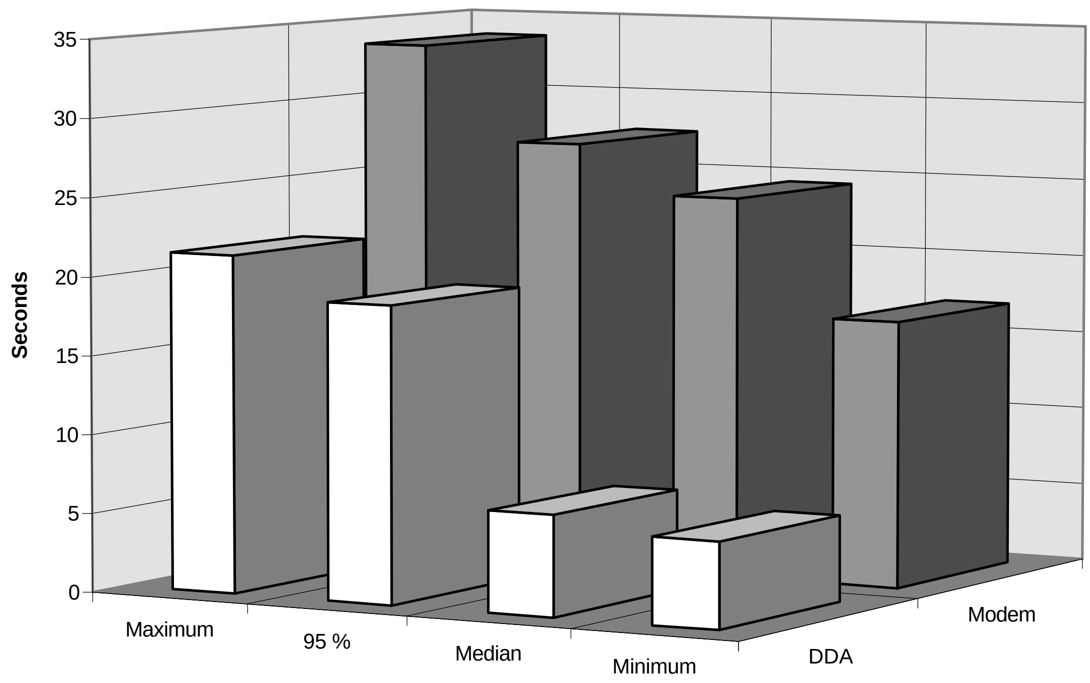

Figure 5.1 Summary of Connection Establishment Times in the Macro Cell Environment

5.2.2 Exchange of Request-Reply Messages

In the performance measurements of request-reply messages we are interested in

- typical round-trip times,
- the fraction of operations that take an exceptionally long time,
- the behavior of exchange of messages of various sizes, and
- the behavior of exchange of messages in various circumstances.

The medians of the round-trip times are presented in Table 5.2. Each median is calculated from 2000 request-reply message exchanges. The minimum of the medians is 0.8 seconds, and all the medians are less than 5 seconds. A typical round-trip time of a World-Wide Web -type of application

(427 / 3116) is several seconds and it does not include delays of the wide area network and the WWW server itself. Analysis of the participants' statistics indicates that end-users were satisfied with the performance (see Figure 5.11). This result suggests that end-users could even use World-Wide Web browsers — without embedded images — over GSM links. The response time can be improved by optimizing World-Wide Web for this kind of connection [Lilj1].

Table 5.2: Medians of Round-Trip Times

Test Number	Message Sizes (octets)	Round-Trip Times (seconds)	Simulates
1	5/50	0.8	DCL interaction [terminal emulation]
2	5/515	1.3	ALL-IN-1 [terminal emulation]
3	43/2144	3.2	VTX [client - server]
4	85/2680	3.8	TIMA interaction [terminal emulation]
5	2136/112	2.7	Sending of mail [client - server]
6	612/612	2.8	TeleVenue [client - server]
7	427/3116	4.6	WWW [client - server]

The distributions of the round-trip times for the micro-cell environment and for the macro-cell environment are summarized in Figures 5.2 and 5.3. Each test series in the figures is based on 20 successful sequences of 100 request-reply message exchanges. The figures show the minimums, the medians, the 95th percentiles, and the maximums of round-trip times. The following conclusions can be drawn. Firstly, the minimum and the 95th percentile of the round-trip times are very close to the median. This indicates that the behavior is generally stable. Secondly, the difference in the round-trip times between very good (Figure 5.2) and moderate (Figure 5.3) circumstances is small. Generally, end-users do not notice any difference in the performance. Thirdly, only few round-trip times — from 1% up to 5% — are exceptionally long, but then they may be up to 12 times longer than the median. In the macro cell environment these long round-trip times occur more often. A possible reason is that problems in the GSM air interface may cumulate along the whole transmission path causing retransmissions at the transport level (TCP timers expire).

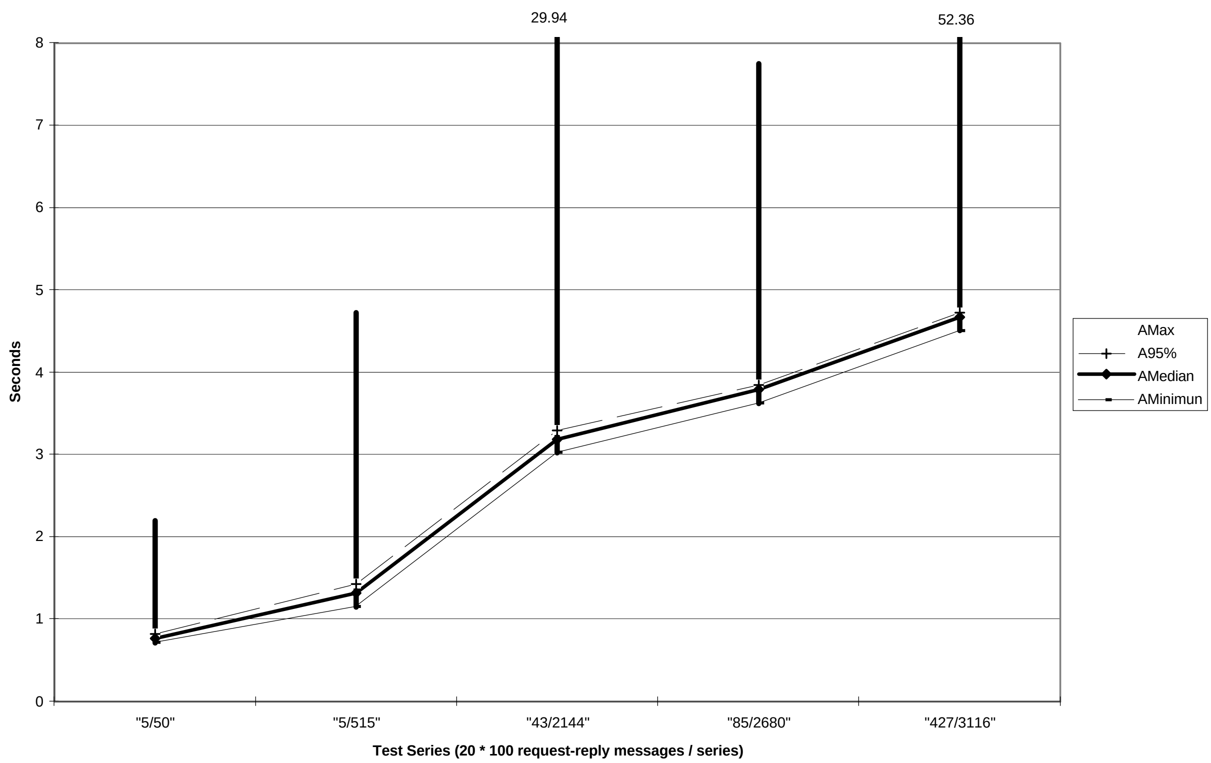

Figure 5.2: Summary of Round-trip Times in the Micro-Cell Environment

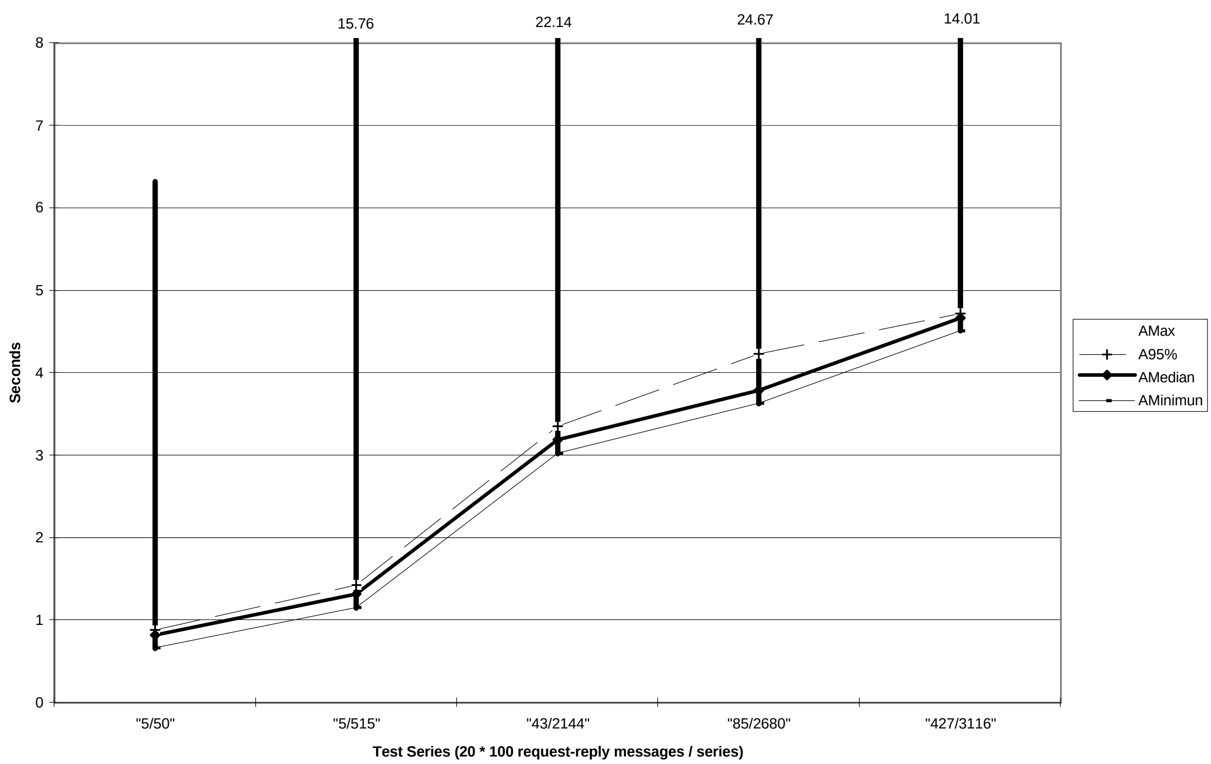

Figure 5.3: Summary of Round-trip Times in the Macro-Cell Environment

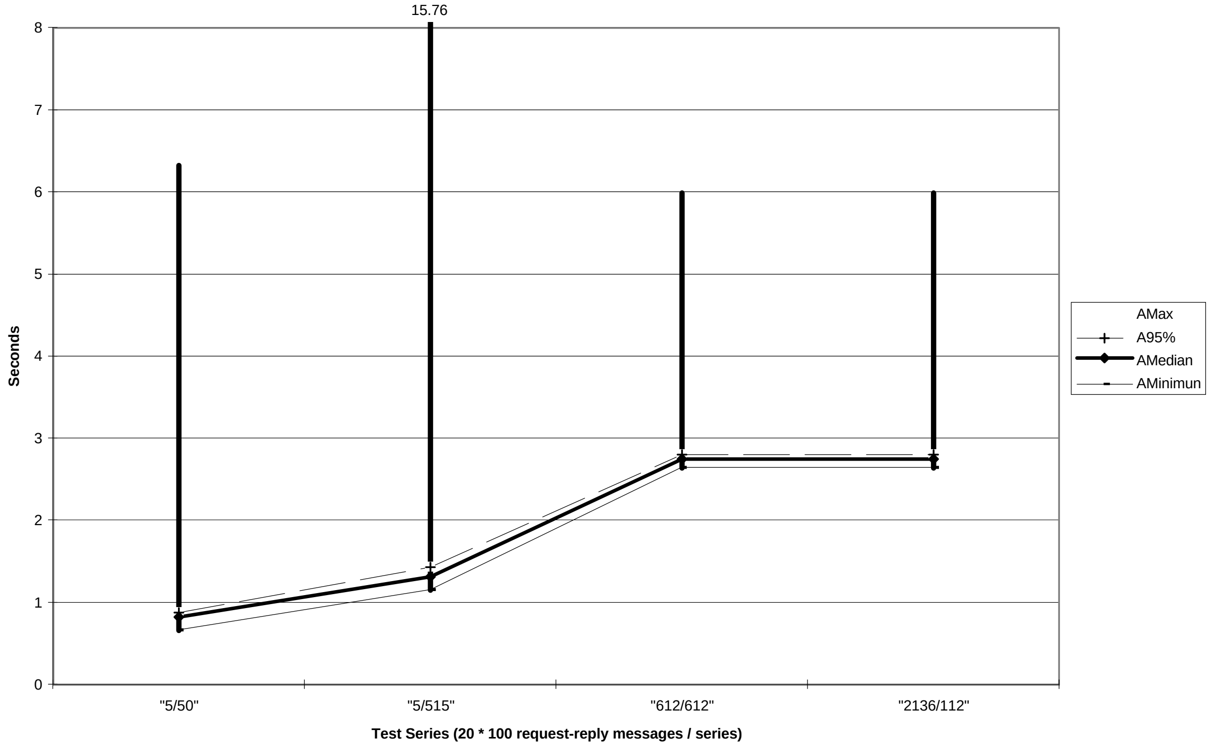

Figure 5.4: Example of an Effect of the Segmentation on Round-trip Times

Figure 5.4 shows the relation between the round-trip time and the number of TCP segments required in the message exchange. In our measurements the maximum segment size (MSS) was 536 bytes. The difference in the round-trip times between the cases of "5/50" and "5/515" is 0.5 seconds. The noticeable increment (1.5 seconds) occurs when either the request or the reply or both require transmission of more than one TCP segment. This is illustrated in the cases of "5/515" , "612/612", and "2136/112".

We measured the exchange of request-reply messages through the modem link (see Figure 3.1), as well. The results are shown in Figures 5.5 and 5.7. The most important difference in the results between the DDA link and the modem link is the behavior of the round-trip times in the cases of "85/2680" and "427/3116". A comparison between Figures 5.5 and 5.6 shows clearly the difference. The 95^{th} percentiles in case of the DDA link are very close to the median whereas in case of the modem link they are close to the maximums. Figure 5.7 shows a closer look at a test sequence. It indicates that the reason most probably is 'a misbehavior' of the TCP timer. The timer expires on every second request-reply message exchange. The most important result is that even a minor change in the configuration may improve or corrupt the performance significantly.

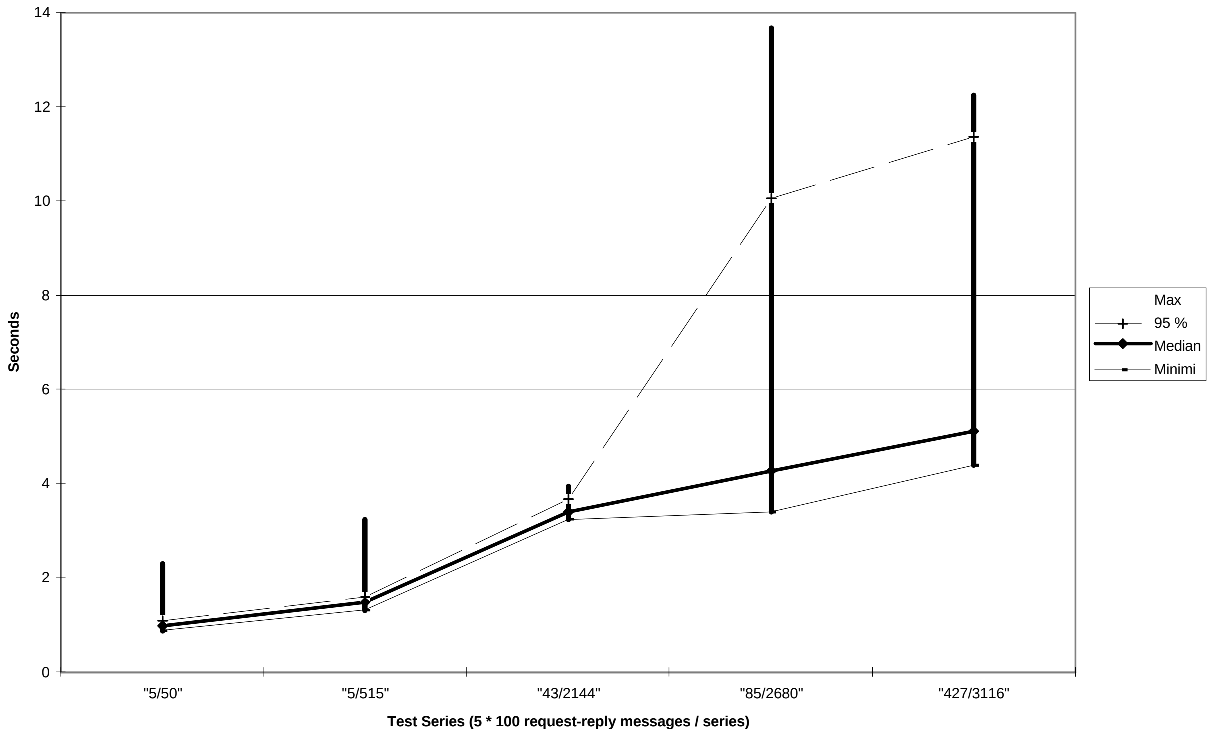

Figure 5.5: Summary of Round-trip Times in the Micro Cell Environment using Modem Link

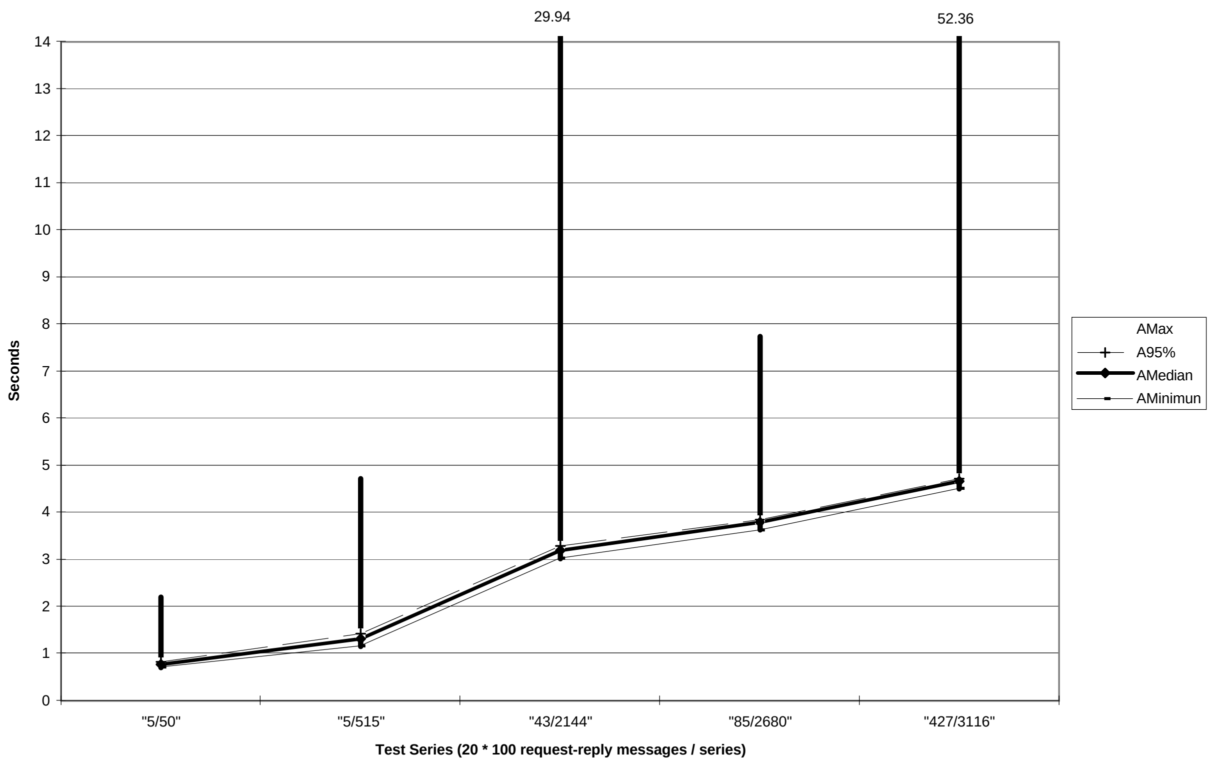

Figure 5.6: Summary of round-trip Times in the Micro Cell Environment using DDA Link

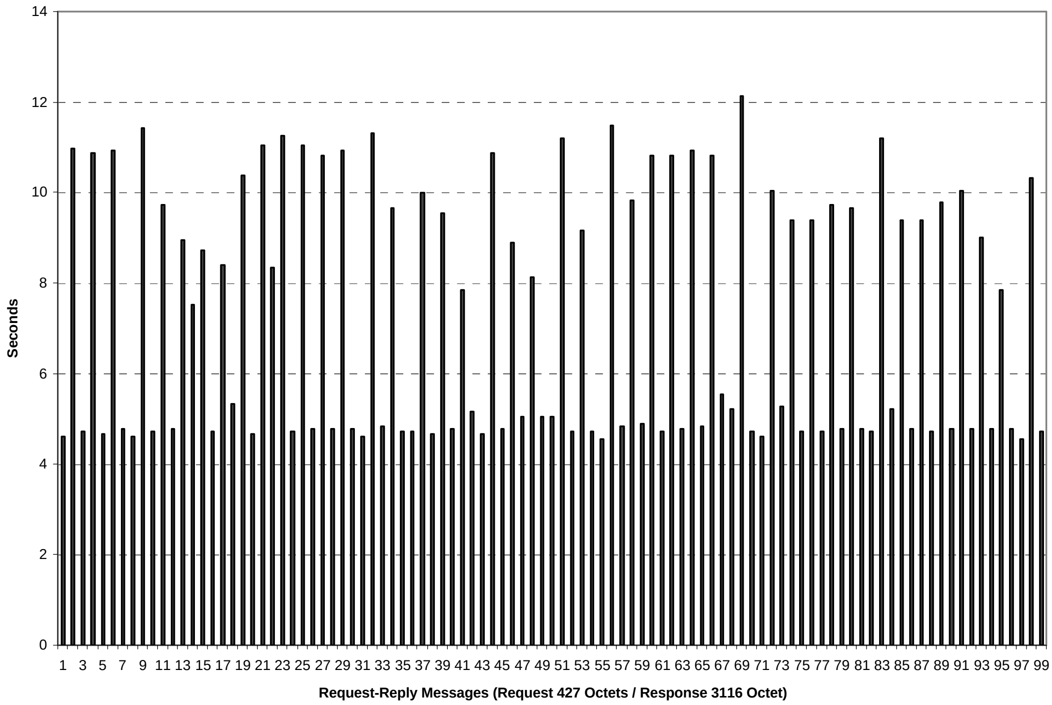

Figure 5.7: Example of Request-Reply Message Exchange in the Micro Cell Environment using Modem Link

5.2.3 Bulk Data Transfer

In the performance measurements of the bulk data transfer we are interested in the maximum sustainable transfer rate in good conditions, the effective transfer rate in different operating environments, and the difference in the transfer rate between transfer directions — from the client to the server and vice versa.

Figure 5.8 illustrates the behavior of the bulk transfer in the micro cell environment. The maximum sustainable transfer rate is 897 octets per second. The effective transfer rate is about 870 octets per second. A minor asymmetry becomes clearly visible even in the micro cell environment. The transfer rate to the client, the GSM down-link, is more stable than to the server, the GSM up-link. The asymmetry can be seen more clearly in Figure 5.9, that shows transfer rates at the macro cell environment. The transfer rate to the down-link is stable, about 890 octets per seconds, whereas the rate to the up-link is noticeably lower and varies between 560 and 820 octets per seconds. The effective transfer rate from the client to the server is about 690 octets per second. The difference between Figures 5.8 and 5.9 implies the effective transfer rate to be sensitive to the quality of the wireless link. The poor quality of the wireless link causes transmission errors which in turn leads to retransmissions and therefore to the lower throughput.

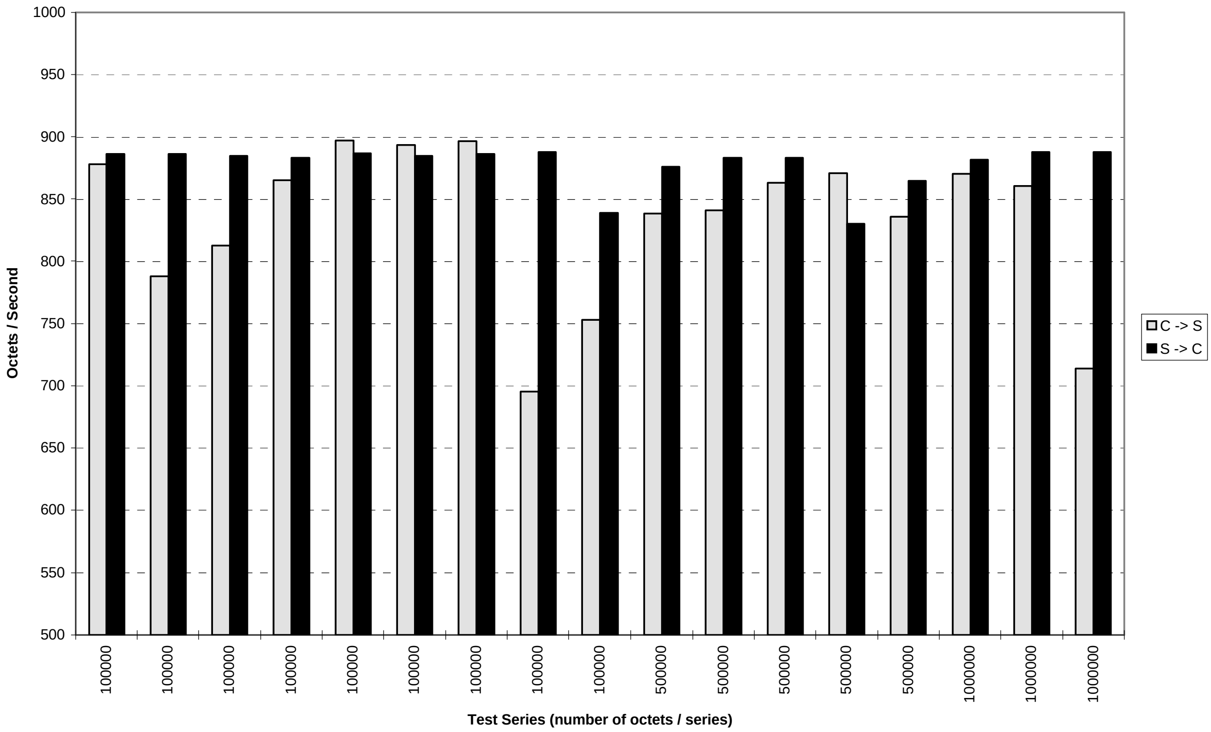

Figure 5.8: Summary of Throughput of Bulk Data Transfer at the Micro Cell Environment

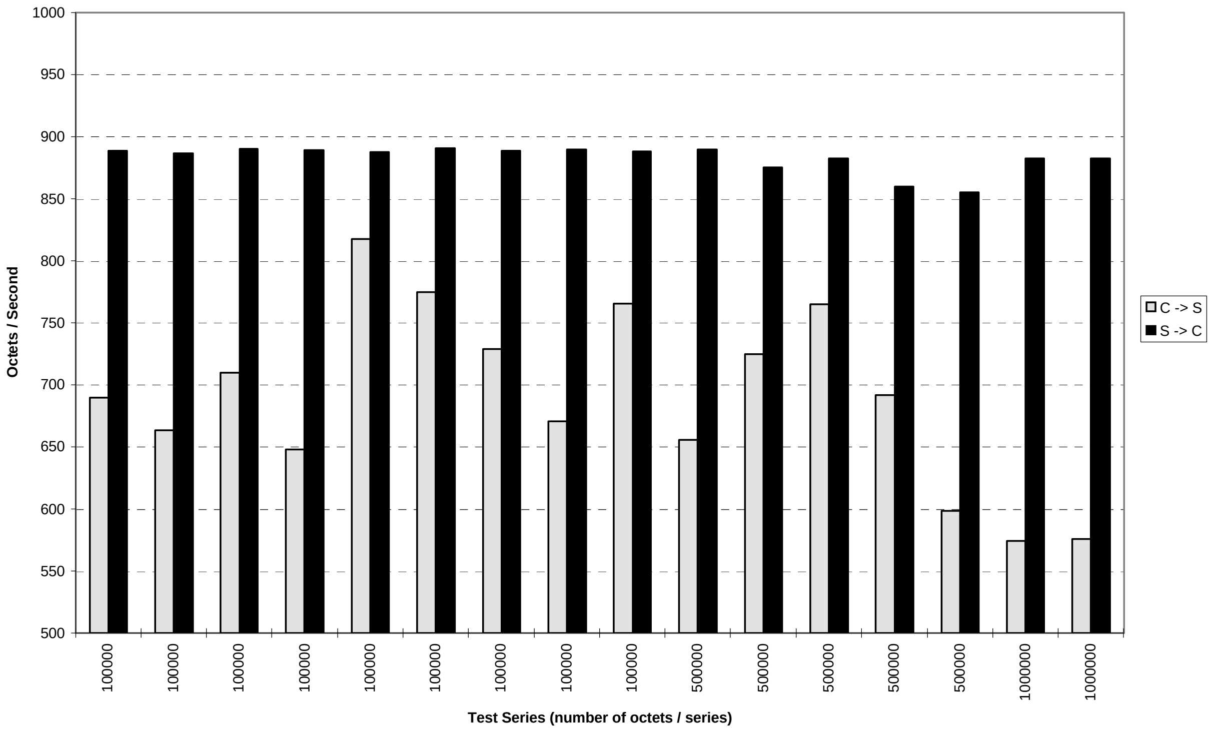

Figure 5.9: Summary of Throughput of Bulk Data Transfer in the Macro Cell Environment

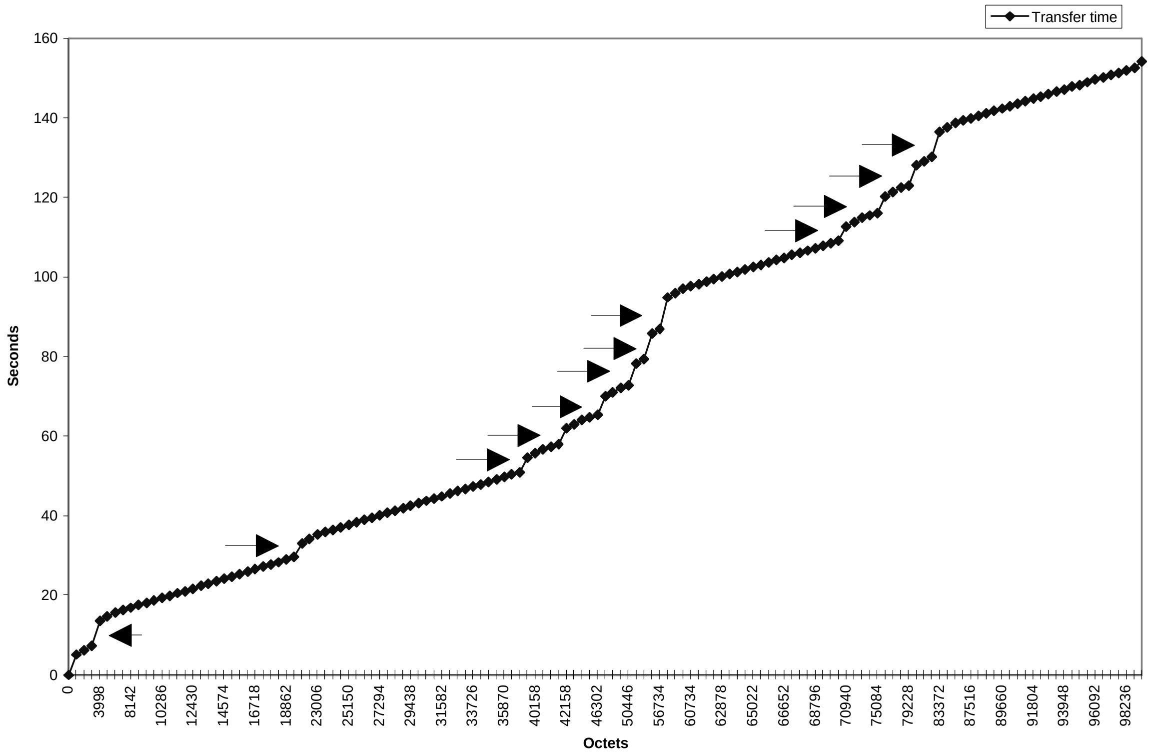

Figure 5.10: Example of Test Sequence of Bulk Data Transfer (Client -> Server) in the Macro Cell Environment

Figure 5.10 illustrates the behavior of the bulk data transfer when the client transmits 100.000 octets to the server. The effects of the radio link problems are clearly visible. The transfer stagnates for the period of poor quality of the radio signal — arrows in Figure 5.10 — to be continued later at a full rate.

The maximum sustainable transfer rate can be estimated [Alan1]. In the GSM environment the estimation is 890 octets per second. The measured bulk data transfer rates imply that a transmission of a 0.5 MB file takes from 10 up to 15 minutes to be finished in good radio signal conditions.

5.2.4 Performance Results Based on Survey

Figure 5.11 shows the results of participants‘ opinions about the system and network performance as a distribution of the satisfaction level. The performance is each participant's subjective opinion and participant's previous experiences have biased his or her opinion. Therefore, these results relate to the context of this experiment and the results should not be generalized. The participants compared the system and network performance with the performance of their home system (slow speed, dial-up modem) — not with the performance of their office system (10Mb Ethernet). Most of the participants considered both the system and network performance to be either good or satisfactory for their needs.

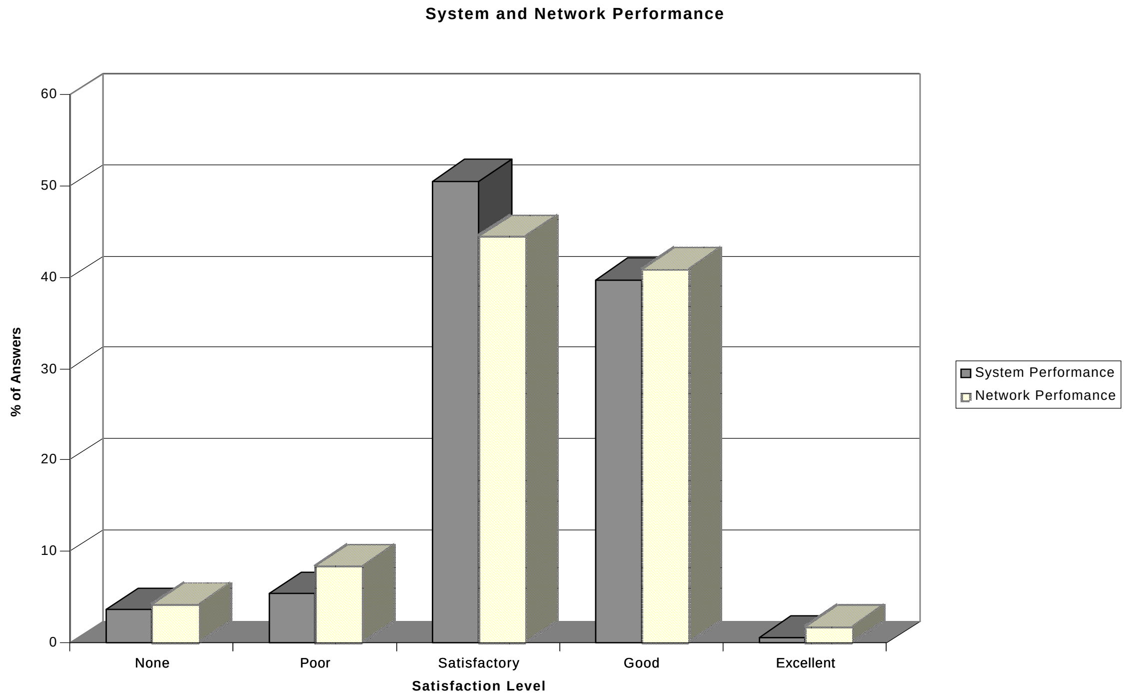

Figure 5.11: Summary of End-Users' Satisfaction to System and Network Performance

6. Conclusions and Summary

In this section we discuss conclusions of this study. We do not present a complete and comprehensive list of the conclusions. Instead, we give the reader conclusions that we regard to be important for the design and implementation of integration.

This case study supports the following conclusions:

- The technology of the GSM data services is mature enough to be used in specific, well-defined services of computer networks.
- The trustworthiness of the GSM data services is not sufficient for today's client-server applications.
- Other access methods (for example, wireline dial-up modem) are required to improve availability of the network services.
- The response time in an interactive operation with a modest amount of data exchange is adequate for end-users.
- Only files of a modest size should be transferred over the GSM air interface.
- A digital interworking (e.g., DDA, ISDN, etc.) between a GSM network and a corporate data network offers better performance and is more reliable than the modem interworking.
- Even a minor change in the configuration of the transmission path may significantly decrease or increase the performance.

The GSM data services form a good solution to extend services available in the corporate data network to the mobile computing environment. The dependability of the GSM data transmission is lower than the dependability of data transmission in fixed networks. Today's software solutions, both at the data communication level and at the application level, do not provide adequate support for working in the integrated environment. Possible solutions to these problems are presented in [Kojo1, Bakr1, Badr1, Cace1, Form1, Yava1, Wats1]. A main idea is a mediator residing between the wireless and fixed networks. A support for disconnected mode operations increases the availability seen by end users in case of the unavailability of the GSM data service.

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