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Analysis of Data Transmission Performance over a GSM Cellular Network[1]

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Abstract

Mobility in cellular networks requires to manage handovers, which occur as users move from one cell to another. Their effects, which are easily overcome for speech, may seriously affect data transmissions. In this paper we report about tests for evaluating the quality of transmission for data applications on a GSM cellular network. Static tests, consisting of file transfers on PSTN and on GSM networks with the MS located in a fixed place, have evidenced a substantial stability and reliability of the GSM radio link, while the throughput over the GSM link is smaller than that measured over PSTN of an amount depending on the packet size. Dynamic tests, consisting of file transfers on GSM with the MS moving along a selected path where transition borders between adjacent cells could be encountered, proved that the transition through the border region between adjacent cells appears to be quite critical and often causes the interruption of the transmission.

1. Introduction

Since the early seventies, the continuous evolution in computer and telecommunications technologies made the realisation of distributed computing and information systems a reality.

The advent of powerful portable notebook computers together with the availability of cellular communication networks pushes once more the development of complex applications, often referred to as “nomadic computing”, which have their distinctive features in the physical mobility of the end-users with respect to the information and computation resources and to the other users in the network. Such kinds of applications can be found in the areas of office automation, travelling salesmen support, systems maintenance support, environmental information systems, intelligent libraries, etc. [2,5].

However, the effective exploitment of such systems depends on the solution of several problems which rise from their complex structure and from the different, and often conflicting functional requirements, that the many intervening technologies put on the system’s architecture. For instance, real-time database systems, a technology which can prove very fruitful in nomadic computing and cellular communication systems, must balance the real-time deadlines with the time overheads incurred in concurrency control and transaction recovery mechanisms which assure the ACID (Atomicity, Consistency, Isolation, Durability) properties to application transactions [6]. Also, different choices within the same technology influence system modelling in such a way that extreme care has to be paid in extrapolating results obtained on a system to systems based on different choices.

As another example, the internal operation of a communication network should be transparent to application algorithms (this is the way the ISO-OSI framework manages distributed systems complexity). However, a cost model for a distributed algorithm on a cellular network heavily depends on the search strategy for locating the mobile units; therefore a linear model such as the one used in [3] cannot be applied to a GSM network (Global System for Mobile communication), where the network structure requires for a hierarchical search.

Several other causes add complexity to data transmissions on wireless and, even more, mobile networks. Some of them are interference due to nearby obstacles, cross-talk between adjacent channels, noise due to signal fluctuations and variable environmental conditions. They negatively affect all wireless communications. An additional contribution to complexity is given by the available limited bandwidth. As a result, wireless links are less performant than wireline ones in terms of throughput, quality and reliability. A study of the performance of cellular networks is presented in [1].

[1] work partially supported by CSISEI-CNR

Mobility often magnifies all of them and adds new problems. Among the latter, handover is the most relevant for cellular networks. Mobility management is the key aspect which really makes wireline and wireless communications different. A mobile user must be able of roaming in the area covered by a mobile network even during a conversation or a data transfer. The network support to such mobility consists of holding the connection, possibly in a way not noticeable to the user, but the used mechanism can be unsatisfactory from the end-user point of view for services based on data transmission. Under this respect handover plays a fundamental role. For this reason this paper mainly focuses on the end-to-end effects produced by this process on data transmission. A study of the effect of handover in cellular networks is presented in [4].

The paper is organised as follows. In section 2 the objective of the work is presented, in section 3 the experimental methodology and setup are described, section 4 shows the collection of data, in section 5 the results are commented, in section 6 conclusions are given and future steps are proposed.

2. Objective

To achieve a clearer understanding of some of the mentioned features of mobile communications, particularly the effects the handover procedure has on data transmission performance, a research has been started on end-to-end data transmissions. The activity is now being developed at Politecnico di Milano, in collaboration with Alcatel Italia and TIM (Telecom Italia Mobile).

The main objective is to explore, from the end-user point of view, the possibility of implementation of data transmission services to be used in industrial and business activities, like those existing in several medium and large companies.This means that any modification to the internal operation of the telecommunications system required to support transmissions is excluded. Possible transmission improvements are to be obtained through actions (processes, programmes, etc.) located in the user equipment.

To this end the transfer of data files has been performed in different environmental conditions between a mobile station and a fixed one. Tests between mobile stations, though important for some class of applications as those mentioned above, have been temporarily excluded.

3. Testing methodology

Static and dynamic tests were carried out to compare the performance of fixed transmissions with respect to mobile ones. They consisted of sets of file transfers from a Fixed Host (FH) to a Mobile Station (MS). For each file transfer (FT) a connection was established between FH and MS through a call made by MS. This caused different connections for different transfers of the same file to be possible, thus avoiding parameter trends to be biased by the quality of a connection. Transfer sessions are different for static and dynamic tests.

Static tests are of two types: file transfers on PSTN (Public

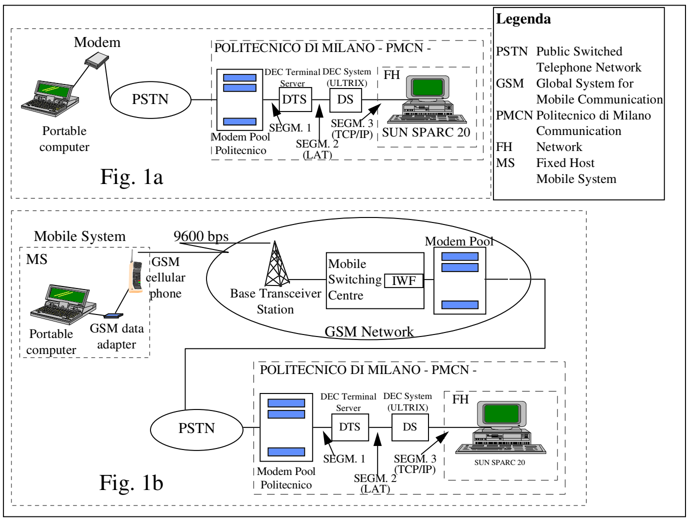

Fig. 1

Switched Telephone Network) with MS operating as a fixed station of the PSTN and file transfers on GSM with the MS held in a place. Dynamic tests consisted of file transfers on GSM with the MS moving along a selected path where transition borders between adjacent cells could be encountered and identified.

Specific support programmes have been developed to help collecting and analysing information on the transmission process. They have been used to help establishing the connection, generate preliminary raw trace files and extract and plot values of relevant parameters.

Figure 1 shows the general arrangement of the

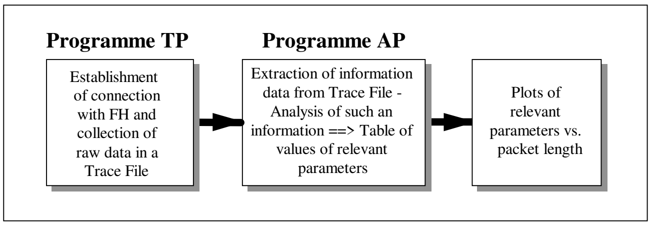

Fig. 2

equipment used during the execution of the work, when directly operating on PSTN (figure 1a) and on GSM (figure 1b). Figure 2 shows a simplified block diagram of the processing performed on data collected during the experiments.

The whole connection is always activated by MS dialling a destination number belonging to a modem in a pool which provides access to PMCN through a first DEC Terminal Server (DTS). In both cases the connection is made of two parts: the first part, connecting MS to a modem in the pool of Politecnico, is different for the two types of tests; the second part, connecting that modem to FH through PMCN (the private Communication Network of *Politecnico di Milano*), is common to both schemes.

For tests on PSTN, the first part is only made of the PSTN fixed network; for tests on GSM, it is made of the GSM and PSTN networks; in the GSM network, the following main functional entities can be noticed:

- a BTS (Base Transceiver Station), which comprises radio reception and transmission devices.

- a MSC (Mobile Switching Centre): one of its main functions is to interface GSM with externals networks through the IWF (InterWorking Function); in our case the external network was the Public Switched Telephone Network.

The second part can be considered as made up of three segments: the first one connects the modem of the pool to DTS (serial link RS232), the second one connects the DTS to a DEC System 5830 (DS) (Ethernet 10b2 link), which, in turn, is connected through the third segment to FH. Different protocols are used in the these segments, namely:

- LAT protocol in segment 2 (DEC proprietary for ISO-OSI lev.5-6), between DTS and DS. It establishes a local session to DS, running ULTRIX V4.3A system # 8;
- TCP-IP in segment 3, between DS and FH.

3.1. Equipment used

The configuration of the equipment used in tests is as follows:

MS is made of:

- an ACER 486DX at 33MHz notebook with 4 Mbytes of main memory, running MS-DOS, version 6.2 and Windows, version 3.1;
- a GSM data adapter SIEMENS PCMCIA 2.1 type 2 modem card;
- a cellular phone SIEMENS S3 plus.

The GSM data adapter links the cellular telephone to the notebook (see figure 1b); the cellular phone and the GSM data adapter together connect the notebook to the GSM network. An external modem (at 9600 b/s) has been used to connect to PSTN in static tests (figure 1a).

The FH is a SUN Spark 20/61, superspark processor at 60 MHz, with 64 Mbytes of main memory.

A connection monitoring procedure ("*monitor mode procedure*"[2]) can be activated via the insertion of a manufacturer provided code on the cellular phone. This procedure allows to access two screens on the cellular phone, whose content is different for standby and for call-in-progress conditions.

[2] Siemens Telecommunication internal document: "monitor mode".

When in standby, the first screen shows the following parameters:

CH The actual working channel (1-124)

RXLEV (RX Level) The power level (dBm) the Mobile phone receives from the Base Station (BS).

RXLEVAM (RX LEVel Access Minimum) The minimum received signal level at a MS for accessing a cell.

MS_TXPWR Value sent by BS to say how much power it needs. The used phone can't give more than 33 dBm.

NCC Network Colour Code.

BCC Base Station Colour Code: Frequency for each cell. It allows to know in which cell the user is operating.

C1 Cell Loss Criteria.
C1=(RXLEV-RXLEVAM) - (MS_TXPWR - Maximum Outgoing Power from Mobile)
If C1 is less than zero for more than 5 second, then the mobile phone will change cell (handover).

The second screen shows a list of six nearby cells and the following six related parameters, out of those described above:

CH, RXLEV, RXLEVAM, MS-TXPWR, BCC, NCC.

When a call is in progress the first screen shows, among others, the following parameters:

CH and RXLEV (see above).

TA Timing Advance: distance from BS (1 digit = 600 m, 6 digits = 3.600 m)

RXLF Received signal level full serving cell (110-RXLEV)

RXQF Received signal level quality full: tells how good is the speech (BER calculation); it varies from 0 (BER<0.2%) to 7 (BER> 12.8).

RXLS Received signal level quality sub: receiving quality on all received frames.

RXQS Received quality only on frames with data.

The second screen shows a list of six nearby cells and the following related parameters out of those described above:

CH, RXLEV, NCC, BCC.

The monitor mode procedure has been used in dynamic tests, when a data transfer between MS and FH was in progress, to identify the handover procedure due to cell border crossing.

3.2. Considered parameters

Single packet transfer throughput (EES, End-to-End Single packet transfer throughput), cumulative transfer throughput (EEC, End-to-End Cumulative transfer throughput), Bit Error Rate (BER), number of disconnections during a session (SDN, Session Disconnection Number), have been the considered performance parameters at an end-to-end level. Their values and trends vs. packet length have been evaluated. Kermit protocol (with CRC error correction algorithm set) has been used over the asynchronous transparent bearer service at 9600 bps offered by GSM.

The generic EES refers to a single packet and is defined as:

$$EES_i = \frac{PL_i}{\Delta t_i}$$

where PL_i is the packet length and Δt_i ("packet transfer time") is the elapsed time between the request of packet *i* and that of the following packet (*i*+1). A timestamp is recorded in a trace file every time a new line of incoming or outgoing data goes through the communication port; it allows to measure the time interval mentioned above; this includes the time needed:

a - for the packet request to reach FH from MS.
b - for the packet request to be processed and granted by FH.
c - for the packet to reach MS from FH.
d - for the packet to be processed and a new packet request to be generated by MS.

In figure 3 the four time intervals are shown with the same letters associated to the diagram in the upper part of the figure, where MS and FH are also indicated; in the lower part the generic composition of Δt_i is shown. While time intervals "a" and "b" are due to the connection path configuration, time intervals "c" and "d" depend on how FH and MS operate.

Thus the measured throughput (called "user throughput") is different from what is usually considered as "throughput" (system throughput): in the latter case, in fact, only the "c" component of the considered time interval (i.e. the time needed for packet to reach MS from FH) is generally taken into account. As a result, the values obtained for the user throughput are lower than those of the system throughput. Nevertheless, this is what the user sees as throughput in end-to-end transfers. Therefore it was decided to focus our attention on it in our experiments.

Similarly, the generic EEC refers to the set of packets transmitted since the beginning of the transfer up to the current packet, and it is defined as:

$$EEC_i = \frac{\sum_{n=1}^{i} PL_i}{\sum_{k=1}^{i} \Delta t_i}$$

where $\sum_{n=1}^{i} PL_i$ is the sum of the lengths of the packets since the transmission started until packet *i* (included) and $\sum_{k=1}^{i} \Delta t_i$ is the sum of the transfer times of these packets.

A comparison between a received and the corresponding transmitted file allows to identify possible differences due to transmission errors; the binary representation of the ASCII codes of the corrupted received characters and corresponding transmitted characters were compared to evaluate the number of wrong bits received and hence the value of "end-to-end" Bit Error Rate (BER) according to the following relation:

$$BER = \frac{WBR}{BT}$$

where WBR is the total number of wrong bits received and BT is the global number of bits transferred, evaluated as the number of characters transferred multiplied by 8 (8 bits per character).

A "NO CARRIER" message is recorded in the trace file each time a connection goes down, thus allowing to count the number of disconnections (a disconnection is also shown on the screen of the cellular phone).

3.3. Support programmes

In the following we give a concise description of two support programmes developed to help collecting and analysing information on the transmission process.

"Transmission" Programme (TP) -It allows:

- to automate the establishment of a connection between the MS and a modem of the remote pool of the Politecnico di Milano;

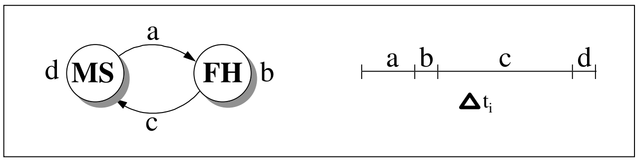

Fig. 3

- to log into the machines of the PMCN on the way to the FH (included);
- to issue commands to the remote FH in order to activate the kermit program on the FH and to realise a file transfer from FH to MS;
- to log out from the PMCN machines mentioned above;
- to trace the transmission operations presented above and the file transfer itself.

It has been written in RCL (Reflection Command Language), a Basic-like command language available in the used communication software (Reflection 2 for Windows ver. 5.0) as a text file of RCL commands (called also "script") that can run only from within this application; slightly different versions of this programme have been realised for static tests on PSTN and GSM and for dynamic tests on GSM; these versions include differences required by the different tests thus allowing for the maximum of automation in performing transmission operations. Once started, a command file ends without any intervention of the operator. This turned out to be particularly convenient in dynamic tests.

"Analysis" Programme (AP) - It allows to analyse a file transfer recorded in a single trace file; the outcome of this programme is a table which has as many rows as there are packets transferred and as many columns as there are parameters to consider; the trend of values of such parameters as the file transfer progresses, packet by packet, are thus recorded. An example of outcome of programme AP is shown in figure 4:

The meaning of the parameters is the following:

NF name of the transferred file.

For each packet:

#PACK is the progressive packet number.

INITT is the timestamp relative to the beginning of the considered packet transfer

ENDT is the timestamp relative to the end of the considered packet transfer

NF	#PACK	INITT	ENDT	DTP	DTPC	LP	LPC	TPTCAR	TPTBITS	TPTBPAC
BASE25	1	14:47:44.32	14:47:47.95	3630	3,63	1913	1913	527	4215,98	4215,98
	2	14:47:47.95	14:47:51.30	3350	6,98	1913	3826	548,14	4385,1	4568,36
	3	14:47:51.30	14:47:54.92	3620	10,6	1913	5739	541,42	4331,32	4227,62
	4	14:47:54.92	14:47:58.27	3350	13,95	1911	7650	548,39	4387,1	4563,58
	5	14:47:58.27	14:48:01.90	3630	17,58	1913	9563	543,97	4351,76	4215,98
	6	14:48:01.90	14:48:05.36	3460	21,04	1913	11476	545,44	4363,5	4423,12
	7	14:48:05.36	14:48:09.15	3790	24,83	1913	13389	539,23	4313,81	4037,99
	8	14:48:09.15	14:48:12.55	3400	28,23	1911	15300	541,98	4335,81	4496,47
	9	14:48:12.55	14:48:16.23	3680	31,91	1913	17213	539,42	4315,39	4158,7
	10	14:48:16.23	14:48:19.69	3460	35,37	1913	19126	540,74	4325,93	4423,12
	11	14:48:19.69	14:48:23.37	3680	39,05	1913	21039	538,77	4310,17	4158,7
	12	14:48:23.37	14:48:26.89	3520	42,57	1911	22950	539,11	4312,9	4343,18
	13	14:48:26.89	14:48:30.68	3790	46,36	1913	24863	536,3	4290,42	4037,99
	14	14:48:30.68	14:48:32.16	1480	47,84	137	25000	522,58	4180,6	740,54

Fig. 4

DTP is the assumed needed time ("transfer time") to transfer the considered packet and it corresponds to the elapsed time between the request of the current packet by MS and the request of the next packet.

DTPC is the cumulated transfer time, till the current packet.

LP is the packet length, without the header and the trailer added by kermit to realise the packet transfer.

LPC is the cumulated packet length, till the current packet.

TPTCAR is the end-to-end throughput measured as transferred characters.

TPTBITS is the end-to-end cumulated throughput, till the current packet, measured in bps. For the final packet of each transfer the value of this parameter is the average file transfer throughput.

TPTPAC is the end-to-end throughput of the current packet, measured in bps. It allows to identify, for example, which packets have been remarkably delayed.

Programme AP has been realised in C and it runs under DOS by calling "AP *trace-file-name"*.

3.4. Static tests

Static tests consist of file transfer sessions from FH to MS, a session being a set of transfers of a single fixed length text file, of 25.000 characters of information, with different packet sizes, from 64 to 2000 characters, at intervals of 100 characters, except the first one. The file is made of a text line repeated 500 times ("Questo Testo di prova di trasmissione dati GSM"). A successful transfer for each packet length have been realised, failed transfers have been recorded.

The external conditions under which the tests have been carried out are those of a good office environment: the field strength has always been good or fairly good, the distance of the transmitting/receiving BS from the MS has been less than 600 m, and the RXQF and RXQS quality parameters never exceeded a value of 3 (BER<1.6%).

Static tests are of two types: file transfers with MS operating as a fixed station of the PSTN, and file transfers on GSM with the MS holding in a place. They have been performed following the two connection schemes between FH and MS shown in figure 1.a and 1.b for tests on PSTN and GSM respectively:

3.5. Dynamic tests

Dynamic tests were carried out with MS located on a car moving along a closed path (figure 5) around a BTS and crossing three border lines between adjacent cells. The connection scheme is the same used for static tests on GSM (figure 1b).

Dynamic tests consisted of file transfer sessions from FH to MS, as for static tests. In this case, however, the packet sizes used grow in steps of 400 characters each, except the first one. This allows to complete a session in a reasonable time. The transmitted fixed length text file is of 2 Mbytes of information.

Static tests have evidenced that as the packet size grows from 64 to 2000 characters, the user throughput grows from about 500 bps to 4100 bps respectively.

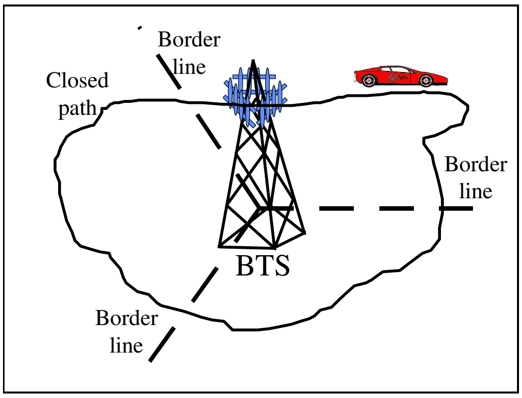

Fig. 5

The transfer of a 2 Mbytes file with the greatest packet size (2000 characters) results in

$$\frac{2.000.000 \times 8}{4100} s \approx 3902 s \approx 65 \text{ minutes}$$

required to be completed. Dynamic throughput, however, is likely to be lower than the static one due to additional delays introduced by factors as handover management and interferences. This leaves an average of more than 13 minutes to complete the path around the BTS. This time was quite adequate to operate even in the worst traffic conditions (the car speed varies from 0 to about 60 Km/h).

The transfer is performed as follows. After a connection is established and the file transfer begins, the car starts moving along the selected path; the aim is to complete five trips along the selected path, thus having 15 border crossings and activating 15 times the handover procedure at least. If transmission fails before this condition is reached the failure is recorded and the full transfer is repeated with the same parameters. Otherwise the transfer is interrupted and another file transfer is started with a new packet size.

A failed transfer is repeated no more than five times: a further failure causes the file transfer to be aborted. The file transfer is recorded as not feasible and a new test is ready to be started.

During a FT, the TA parameter (see “monitor mode” in section 3.1) is always 0, meaning that the receiving/transmitting BS is always at a distance less than 600 m, and the RXQS parameter seldom shows values of 4 or 5 (BER < 3.2% and < 6.4% respectively), thus witnessing for a usual good transmission quality.

Every change in the CH parameter (channel used), as observed on the phone screen when the monitor mode procedure is on, indicates a handover.

Different reasons cause handovers: a call in a congested cell may be handed over to a neighbour cell with an inferior traffic load (“traffic handover”) or may be assigned a different channel in the same cell due to intra-cell traffic reorganisation (intra-cell handover); inter-cell border crossing usually cause a call to be handed over to the entering cell (which must have enough resources to manage the incoming call) (“inter-cell handover”).

A map of coverage of radio channels of the BS considered and the output of the Monitor Mode Procedure allow to identify inter-cell handovers. The transferred portion of the file is recorded.

4. Data collection

Data collection occurs in two steps. In the first step a Trace File (TF) is produced for each File Transfer. In the second step a Result Table (RT) is produced for every Trace File. The first step is supported by TP while the second step is supported by AP.

A TF is a text file in which all data coming from or going to FH are recorded; escape sequences and control characters are included (XON/XOFF flow control is omitted).

The recording format is: “*timestamp, symbol, line of characters*”

The timestamp format is HH:MM:SS:CC, (hours, minutes, seconds, hundredths of a second); it indicates the time at which the immediately following recorded line has been received or transmitted. It is followed by a character, indicating the direction of the recorded data, which is the sign “> “ for data going from the MS to the FH and the sign “<“ for the reverse direction. Finally, the line of characters to which both timestamp and the direction sign refer is recorded.

All data related to the establishment of the connection with FH as well as to the proper file transfer are stored in the trace file: commands issued to the modem, connection retries when the line is busy, messages of established connection and relative speed, messages related to logging in the computers along the way from MS to FH among them; auxiliary information to better understand the structure of the file is also included.

A section of a trace file related to the beginning of the file transfer is shown in figure 6:

After kermit has been started, the server mode is activated; then in the first 8 lines some preliminary messages are exchanged between MS and FH to tune the applications running on them for transfer to be carried on. Following these operations, the file begins to be transferred using a predefined packet length (in the example the packet length is 64 characters) and recorded in the presented format.

The line repeatedly presented in the example is a packet with related header and trailer, clearly distinguishable in the trace file.

Each trace file is recorded by programme TP with different file names (traceaxx, where xx is the progressive number of the file transmission) for each different file transmission.

```
   C-Kermit>SERVER
   KERMIT READY TO SERVE...

   09:49:12.90>´. I`/ @-#Y3~,!M
   09:49:14.00<´0 Yz* @-#Y3~N! y/
   09:49:14.11>´- RBASE25.TXT0
   09:49:15.21<´0 Sy* @-#Y3~N! y(
   09:49:15.32>´. Y`/ @-#Y3~,!]
   09:49:16.36<´/!FBASE25.TXT,)-
   09:49:16.80>´%!Y,\I
   09:49:17.40<´K"A."U1""B8#119951215
17:23:05!"251%25000#=,
   09:49:17.62>´%"Y.5!
   09:49:18.28<´]#DQuesto Testo di prova di trasmissione
dati  GSM.#M#JQues!]H
   09:49:18.45>´%#Y/R9
   09:49:19.00<´]$Dto Testo di prova di trasmissione
dati  GSM.#M#JQuesto T ;U
   09:49:19.16>´%$Y+&1
   09:49:19.87<´]%Desto di prova di trasmissione dati
GSM.#M#JQuesto Testo,/4
   .........
```

Fig. 6

5. Results

Five static transfer sessions have been carried out on PSTN and GSM. The number of the observed disconnections on GSM has been small (3 disconnections over 105 transfers) and comparable with that found on PSTN. The number of failed transfers for causes different from disconnections has also been small, and will be analysed with major detail later on.

The analysis of successful transfers evidenced regular and stable transmissions, probably in virtue of the used GSM data transmission service. This situation is shown in figure 7, where the trend of DTP in function of #PACK for a typical transfer on GSM is reported.

Delays have been seldom observed during packet transmission (figure 8). Traffic handovers, intra-cell

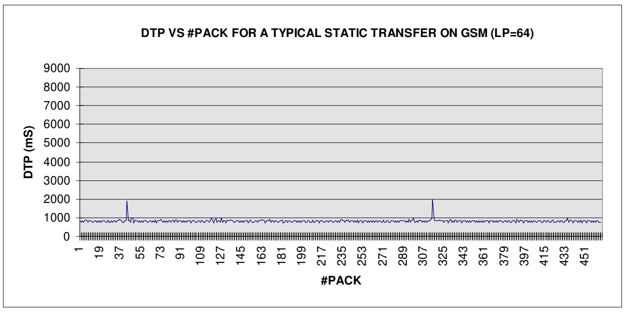

Fig. 7

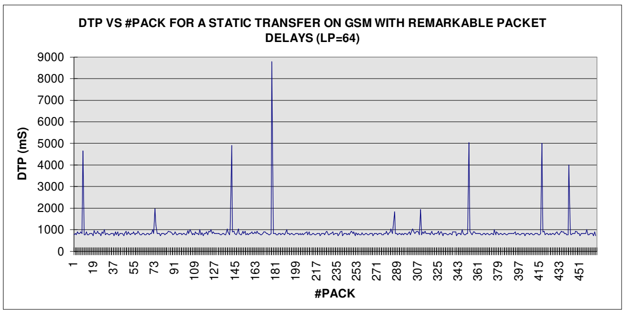

Fig. 8

handover as well as magnetic perturbation are possible causes of these peaks in DTP which seam to occur randomly. Further studies will inquire on this situation.

The analysis of transfers failed for reasons different from disconnection allowed to make a first guess on the network behaviour.

For some reason, perhaps because of heavy traffic, a packet is captured somewhere along the virtual path (VP) across the network and chopped in segments which are temporarily kept (stored) separate in some sort of a fragmented queue. These segments are then sent by the network one after the other to destination with long delays. When this occurs only the first segment of a packet is likely to be received within a Packet Request (PR) time-out. This segment is interpreted as a corrupted packet, and a Retransmission Request (RR) of the same packet is sent.

```
                    /*packet request*/
   16:24:16.11>´ DY # &Y%
        /*only the first part of the packet arrives*/
   16:24:16.82<´   ED$,\rova   di   trasmissione   dati
GSM.#M#JQuesto  Testo  di  prova  di  trasmissione  dati
GSM.#M#JQuesto Testo di prova di t
      /*a 10 seconds timeout expires and the packet is
                  requested again*/
   16:24:26.16>´ DY # &Y% ´ DY # &Y%
     /*21 seconds after the arrival of the first part of
             the packet,the second one arrives*/
   16:24:37.80<rasmissione  dati    GSM.#M#JQuesto  Testo
di prova di trasmissione dati   GSM.#M#JQuesto Testo di
prova  di  trasmissione  dati   GSM.#M#JQuesto  Testo  di
prova  di  trasmissione  dati   GSM.#M#JQuesto  Testo  di
prova  di  trasmissione  dati   GSM.#M#JQuesto  Testo  di
prova di trasmissione dati,9!
      /*the second part is interpreted as a wrog packet
     and new requests for the same packet are made*/
   16:24:46.42>´ DY  #  &Y%´ DY  #  &Y%´ DY  #  &Y%´ DY  #
&Y%´ DY # &Y%´ DY # &Y%´ DY # &Y%
´ DY # &Y%

   16:26:12.99<´   ED$,\rova   di   trasmissione   dati
GSM.#M#JQuesto  Testo  di  prova  di  trasmissione  dati
GSM.#M#JQuesto  Testo  di  prova  di  trasmissione  dati
GSM.#M#JQuesto  Testo  di  prova  di  trasmissione  dati
GSM.#M#JQuesto  Testo  di  prova  di  trasmissione  dati
GSM.#M#JQuesto  Testo  di  prova  di  trasmissione  dati
GSM.#M#JQuesto  Testo  di  prova  di  trasmissione  dati
GSM.#M#JQuesto Testo di prova di trasmissione dati,9!
´ ED$,\rova di trasmissione dati   GSM.#M#JQuesto Testo
di prova di trasmissione dati   GSM.#M#JQuesto Testo di
prova  di  trasmissione  dati   GSM.#M#JQuesto  Testo  di
prova  di  trasmissione  dati   GSM.#M#JQuesto  Testo  di
prova  di  trasmissione  dati   GSM.#M#JQuesto  Testo  di
prova  di  trasmissione  dati   GSM.#M#JQuesto  Testo  di
prova  di  trasmissione  dati   GSM.#M#JQuesto  Testo  di
prova di trasmissione dati,9!

       /*the packet is correctly sent but the transfer
  fails because the maximum number of retries has been
                        reached*/
   16:26:33.64>

   16:26:41.00<

   <Your 'COM2' connection has terminated>
```

Fig. 9

A new packet is thus queued along the VP with the remaining segments of the previous packet. When another segment arrives within a RR time-out, a further RR of the same packet is generated, thus making the packet queue along the VP longer. This queue is sent to destination by the network in a way that seems to be independent of the sequence of RRs. It may well be that, due to network delays, some previous packet requests did not receive any answer even if the corresponding packets were sent to the network. In this case a long queue is formed after the first segmented packet. The consequence is that a sequence of unanswered RRs is generated. If the number of such RRs is greater than a predefined threshold (in our case set to 10) the transmission is interrupted.

The two failed transfers observed are special cases of this mechanism. Figure 9 (FT with a 400 characters packet length, comments between "/*" and "*/") shows one of the two cases where the packet is fragmented in two segments. The first segment is received in the first time-out, and after two RRs the second segment is received. Then a series of unanswered RRs is sent and a double packet is received in the same time-out. After ten RRs the transmission is interrupted. From the results of the dynamic tests, explained in the following, it seems that this anomaly could depend on the time-out value.

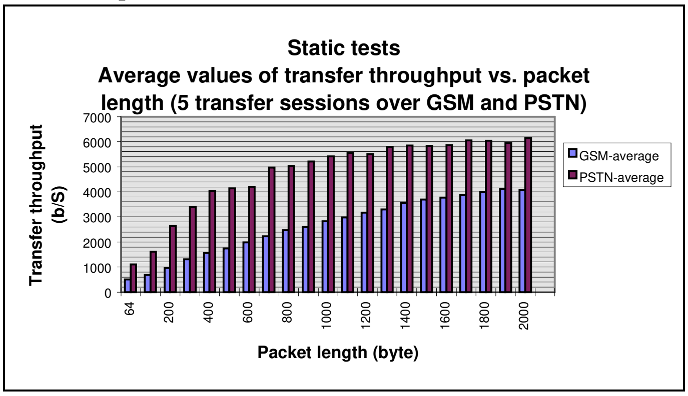

Fig. 10

The number of disconnections has been small as in the PSTN case and long packet delays have been seldom encountered; throughput increases with the packet size (figure 10, average values), while the number of disconnections do not increase significantly.

The throughput over GSM is smaller than that over PSTN of an amount depending on the packet size. The worst packet length is around 200 bytes, as it is shown in figure 11.

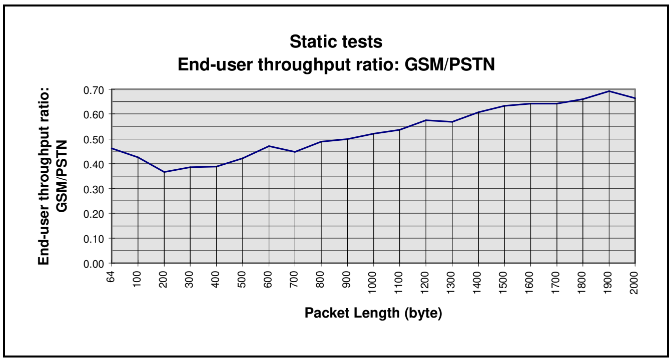

Fig. 11

All transferred files, even those interrupted by disconnections, where correctly received (consistent with the transmitted files), thus providing an end-to-end BER of 0. For the sake of completeness it is to be said that LAP-M error correction algorithm has been used between modems when on PSTN, and MNP5 compression and error correction algorithm has been used on GSM. The throughput observed in the static tests compares well with the data reported in [1].Four dynamic sessions have been carried out. For the first of them a time-out of 10 seconds was adopted, as for static sessions. For the other three sessions a longer time-out of 60 seconds was adopted. Analysis of stases (long delays of the order of several seconds) revealed that the transmission of a packet across an intercell handover is quite complex and in some cases resulted in corrupted packets being delivered to the receiving terminal. The transmission was interrupted after a predefined number of time-outs was reached. Two types of corruption have been observed: the former consisting of packet segments with missing header or trailer, the latter consisting of packets having right header and trailer, but shorter than expected.

In the first session file transfer was only possible with packet lengths of 64 and 400 characters. For longer packets stasis conditions occurred before 5 turns of the whole path were completed; transmission couldn't be resumed before the maximum number of time-outs was reached. All of these stases occurred after an intercell HV happened, a short time after the start of the file transfer. With a packet length of 800 characters a unique file transfer was successful out of 6. For all interruptions the failure mechanism seems to be the same as that found for static tests (see figure 9).

The adoption of a time-out of 60 seconds in the other three sessions allowed to complete file transfers with a packet length up to 2000 characters, which was the maximum value used. During these sessions several stases have been observed each time an intercell handover occurred. For all of them transmission was resumed with no RRs but for one case where two corrupted packets (shorter than the right one but with right header and trailer) have been received over 5 time-outs. The transmission was manually terminated after a 5 minutes wait.

In all the four sessions intra-cell handover (seldom encountered) caused no critical stasis. The number of disconnections occurred has been far greater than in static tests (16 out of 51 file transfers); they followed inter-cell handovers.

During dynamic file transfers delays have been observed; they were not always in correspondence of intra or inter-cell handovers (figure 12).

The so called "ping-pong" handover (repeated switches between channels relative to adjacent cells) was observed in the vicinity of cells borders especially when, for some reason, the car had to stop for a while (traffic queues or red traffic light) (figure 12). However they never gave rise to critical stases or disconnections. It is to be noticed that in all cases the received file contents were correct.

Throughput was found to be lower than for static file transfers with the same packet length. This is shown in figure 13.

6. Comments, conclusions and further work

The obtained results show that a significant reduction of performance is to be generally expected when using GSM. This is in accord with the results presented in [1], where only static tests have been carried out. This must be carefully taken into account by those who are required to design strategic services within a company, especially when mobile operations are necessary.

Preliminary considerations on the obtained results lead to think that the main reason of performance reduction in GSM static tests is to be due to GSM transmission support protocols, which are more sophisticated than those on PSTN since they are required to handle more complex situations. This effect, however, decreases when packet length increases. The situation becomes even worse when mobility is required, since interruptions caused by hand-overs introduce delays, further decreasing performance and they often cause the interruption of transmission.

These consequences are too severe to be accepted in strategic services of medium/large private enterprises.

The experiments performed, however, constitute a preliminary in-field study of the end-to-end effects of handover on data transmission performance on a GSM network.

Transmission parameters, such as packet length and timeout interval, should be carefully taken into account in order to increase transmission performance; the timeout interval, in particular, proved to be a critical parameter in assuring the success of dynamic transfers.

Other experiments should be carried on. Performance enhancements may be obtained working on window size and compression algorithm. More complex handovers, such as intra-MSC handover, should be studied to achieve a better understanding of their effects on data transmission; In fact they require a greater involvement of the network control operation on data transmission, which could cause further performance reduction.

Further steps have also been devised focusing on automating present manual procedures of the human end-user. Dynamic transmission parameters adjustment, such as timeout, packet length and window size, should be implemented in order to optimise performance; at session level, transmission interruption should be made transparent to the user , in order to free him from doing operations not directly involved with the services he uses.

These procedures are to be implemented within terminal equipment because it is very hard to change in a short time the operation of public telecommunications systems and networks which are led to apply modification, expansion or improvement of a service only when the market justifies it.

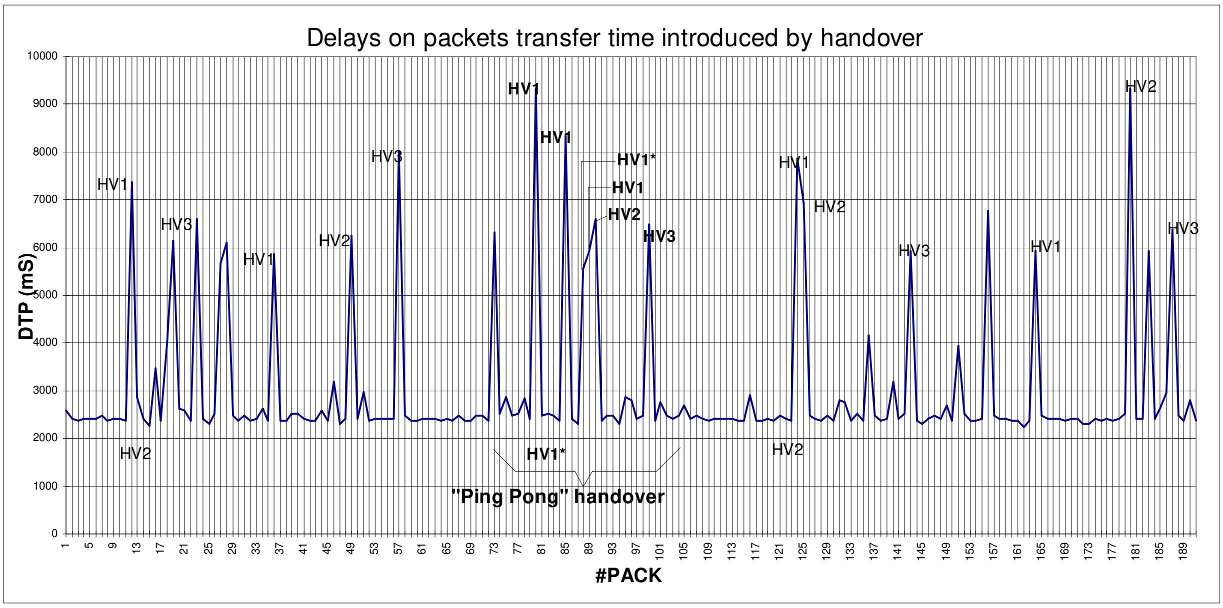

Fig. 12

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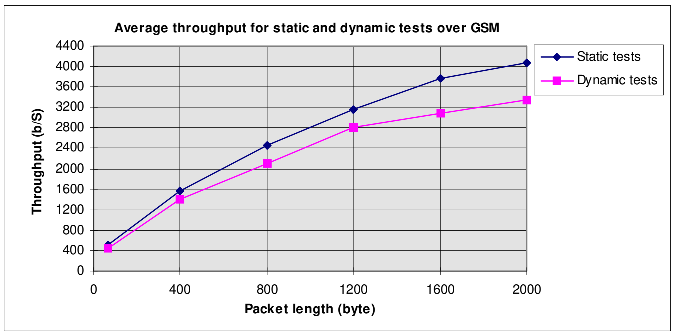

Fig. 13

information about cellular coverage and handover mechanism.

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