EUROPEAN RAILWAY TRAFFIC MANAGEMENT SYSTEM (ERTMS)
LEVEL 2: FROM GSM-R TO GPRS

* Rete Ferroviaria Italiana, Italy

Introduction
The article deals with a comparing study between GSM-R system, at present used in ERTMS level 2 as communication network between trainborne and trackside subsystems, and GPRS system. The study is based on both laboratory and field test campaign carried out on Milano-Bologna High Speed Line. The main aim of the tests has been to check the GPRS performance in the scenario where it would be used as transmission bearer for ETCS, when high QoS requirements in term of transfer delay and transmission reliability are needed. The main target of these activities is the evaluation of GSM-R limits applicability against GPRS (Global Packet Radio System) in terms of performance (bit/rate) and functionality (GPRS Attach request – PDP Context Activation – PDP Context Deactivation – GPRS Detach) in order to permit a migration towards a different technology. Five years commercial service’s experience of Italian High Speed lines has been taken into account to verify possible advantages, in terms of service availability and train punctuality, which could be achieved using GPRS technology.

Expected results are an improvement of service availability with a reduction of lost radio connections and a larger bandwidth to introduce new services like a remote diagnostic control. GPRS is only the first step to perform a migration to IP platform that would open developments and investments toward technology as LTE (Long Term Evolution).

Measurement architecture, Network and Test Set configuration
In order to define and to clarify the GPRS measurement aspects, the reference measurement architecture and the RFI’s GPRS measurement architecture are shown below.

Tests have been performed in the RFI’s Telecommunication Regional Operation Control Centre (ROCC) located in Milano and by two test trips on the new HS Line Milano-Bologna (ERTMS/ETCS Level 2).
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**Figure 2 - Measurement architecture – ROCC Milano and HSL Milano Bologna**

- **GSM-R / GPRS Network configuration:**
  - **ROCC - Milano:**
    - Technology: NokiaSiemens
    - Software releases:
      - NSS: SR12.0
      - BSS: BR7.0
        - N.2 BTS with interior antennas (one BTS – single Cell, single Carrier has been used during the tests);
        - Coding Scheme: CS2 – CS4
      - GSN (SGSN / GGSN / PCU): GR 5.0
  - **HSL Milano Bologna:**
    - Technology: NokiaSiemens
    - Software releases:
      - NSS: SR12.0
      - BSS: BR8.0
        - Coverage Level: -92dBm (95% each location interval of 100m)
        - Radio coverage redundancy
        - Coding Scheme: CS2 – CS4
      - GSN (SGSN / GGSN / PCU): GR 5.0

The GSM-R radio coverage leads to a good level inside the Coach. On the Milano-Bologna HSL the ERTMS/ETCS L2 Signaling System is implemented.
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- **Test Equipment:**
  - Trace Mobile Terminal: GPH Triorail S55-R, SW V: 26.2941+
  - Triotrace SW application
  - GPS Receiver
  - Ethereal Network Protocol Analyzer
  - Personal Computer
  - Tektronix K15-2 Protocol Tester
  - Application Server (Windows based) – (ftp Server)

- **Point of Control and Observation - PCO**
  - Gb Interface
  - Um Air Interface
  - I_GPRS Interface
  - I_fix, IP Interface

- **Measurement Method**
  - Network: Gb Interface
  End-to-end: Um, I_GPRS, I_fix, IP Interfaces

**Test cases**

The UIC Document “GPRS Measurements Specification” V.0.3 dated 9 December 2008 defines the following test cases:

- Data Transfer Delay;
- Data Transfer Error Ratio;
- GPRS Attach Delay;
- PDP Context Activation Delay;
- PDP Context Activation Error Ratio;
- PDP Context Loss Rate.

The first series of test has been carried out to measure the time needed to perform GPRS Attach/Detach, for the mobile on the network; in other terms, the time delay between the Attach Request Message sent out by the mobile terminal and the Attach Accept Message received back from the BSC.

Since the authentication feature is activated on the RFI network, also authentication messages are exchanged during this attach phase (ACRQ - Authentication and Ciphering Request message from the BSC to the mobile and AC Response answered by the mobile to the network).

We also measured the GPRS Detach Time, to have a full picture of the process.

The second series of tests has been performed in order to measure the time needed to set up a GPRS session, i.e. to activate the PDP context.

In other terms, the time delay between the Activate PDP Context Request Message sent out by the mobile and the Activate PDP Context Accept response from the network.

We have also measured the PDP Context deactivation time.

Tests were previously performed by the RFI experts also on the conventional line, even if in a smaller number of retries, to have a sample for comparing the results.
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- **GPRS Attach Delay**
  - Network:
  - End-to-end: U_{m} interface:
    → Value of elapsed time between messages: \textit{MM ATTACH COMP} and \textit{MM ATTACH REQ}

- **PDP Context Activation Delay**
  - Network:
  - End-to-end: U_{m} interface:
    → Value of elapsed time between messages: \textit{SM ACT. PDP CONTEXT ACC} and \textit{SM ACT. PDP CONTEXT REQ}

- **PDP Context Deactivation Delay**
  - Network:
  - End-to-end: U_{m} interface:
    → Value of elapsed time between messages: \textit{SM DEACT PDP CONTEXT ACC} and \textit{SM DEACT. PDP CONTEXT REQ}

- **GPRS Detach Delay**
  - Network:
  - End-to-end: U_{m} interface:
    → Value of elapsed time between messages: \textit{MM DETACH REQ} and \textit{MM DETACH ACC}

For the test trips on the HSL Milano Bologna, we decided to use as a test protocol the TCP IP, since it was simpler to prepare the tests in a short time (this way being used before by RFI). Therefore we decided to send a 128 bytes packet every 20 seconds, in downlink in the first trip, and in uplink in the second trip.

We used Triorail S55-R as mobile terminal, and a GPS Bluetooth receiver.

For the following test cases:
- Data Transfer Delay;
- Data Transfer Error Ratio;

a work bench with a computer connected to the Test MT via FTP server in the Lab has been equipped.
Test Results

GPRS Attach request – PDP Context Activation – PDP Context Deactivation – GPRS Detach:

Here below there are the results of the tests: 101 retries have been performed at Milan ROCC RFI.

Few days before this measurement campaign on the 4th of February 2009, similar tests were performed in the live network, on the Milano Bologna HSL.
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### High Speed Milan - Bologna - Dynamic Measure

**Figure 4 – High Speed line Milan-Bologna- Dynamic Measure**

**Packet Transfer Delay FTP**

Following the discussion on setting up the “live” tests in few weeks and the RFI experience, the Data Transfer Delay of a user data block has been evaluated using the File Transfer Protocol FTP.

Files transfer delay from a computer connected to the test MT, to a FTP Server directly connected to the GGSN Node (located in the NOCC Rome) has been tested in the ROCC of Milano.

The results induced the value of executing tests using this method in the HSL, in which occasion we could also see the GPRS system performance at 300 Km/h.

Preliminary tests were done in the ROCC. The FTP file transfer, using a 128 bytes data file has been performed by introducing a delay of 20 seconds and then 50 seconds time between two consecutive transfers. The results are the same, less than 400 ms for the transfer of the data file.

The same test has been executed during the test trips between Milano and Bologna (ERTMS/ETCS L2 HSL).

A 128 bytes file has been transferred using FTP 128 bytes file, with about 20 seconds gap between the consecutive transmissions. 114 FTP sessions has been tested. It was chosen to perform complete ftp sessions (GPRS Attach – PDP Context Activation – Get – PDP Context Deactivation – GPRS Detach), in order to test all process at 300 km/h, as meantime’s, and error’s rates.

The test has been carried out in the downlink direction, opening an ftp session and transferring a 128 bytes data file by means of FTP get command.
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Here below there is a sheet with the detailed test results, focused on the reported transmission delay. There were no lost packets, or errors in the GPRS processes.

Figure 5 – FTP time transfer distribution on High Speed line Milan-Bologna

Figure 6 – FTP time transfer Cumulative distribution on High Speed line Milan-Bologna
The point of observation for the results is the IGPRS interface. The results show the payload transfer time and the corresponding throughput. The capabilities of the Test MT allows to use 4 timeslots on the downlink connection.

The statistical Mode is 0.05 seconds; the meantime is 0.12 seconds. Two samples are longer than 3 seconds, which means that it was during a cell reselection.

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode [s]</td>
<td>0.05</td>
</tr>
<tr>
<td>Mean Value [s]</td>
<td>0.121</td>
</tr>
<tr>
<td>Minimum Value [s]</td>
<td>3.72</td>
</tr>
<tr>
<td>Maximum Value [s]</td>
<td>0.01</td>
</tr>
</tbody>
</table>

A second test has been executed during a test trip between Bologna and Milano (ERTMS/ETCS L2 HSL). A 128 bytes file has been transferred using FTP 128 bytes file, with about 20 seconds gap between a transmission and the next one. The test has been done in the uplink direction, opening an ftp session and transferring a 128 bytes data file by means of FTP put command. The results of the test is not indicative of the performance of the system as the test case seem not to be fit to evaluate the FTP data transfer delay in the uplink direction. The reason is that 128 byte data file is transmitted by means of a single data block (TCP/IP) and the measurements on the IGPRS interface are not indicative of the transfer data time and the corresponding throughput.

**Packet Transfer Delay - Internet Control Message Protocol (ICMP)**

The Data Transfer Delay of ICMP packets has been evaluated using Ping tool (measurement of the round trip time between ICMP “echo request” packets and the ICMP “echo response” replies). The round trip delay has been measured from a computer connected to the test MT, to the Application Server directly connected to the GGSN Node (located in the NOCC Rome) during a train trip from Bologna to Milano (HSL) reaching the maximum train speed of 300km/h. Here below there is the sheet with the detailed results of the tests. During the test few packets have been lost (ping request timeout): which is normal and depends on the cell selection / cell changing procedure of the Mobile Terminal. While the mobile was in the same cell no single ping packet was lost throughout the trip.
Figure 6– Round Trip Delay during a request of PING (ICMP) from Mobile Terminal to Server (Uplink) on High Speed line Milan-Bologna

The test has been done pinging the remote Application Server:

```
ping -t 10.1.28.41 (FTP Server)
```

<table>
<thead>
<tr>
<th>Ping statistics:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Packets sent:</td>
<td>2282;</td>
</tr>
<tr>
<td>Packets received:</td>
<td>2232</td>
</tr>
<tr>
<td>Packets lost:</td>
<td>50 (2%)</td>
</tr>
</tbody>
</table>

Approximate round trip times in milli-seconds:
Minimum = 446ms
Maximum = 4225ms
Average = 1086ms

It has to be pointed out that the round trip time depends on the network topology. Figure 2 shows the measurement architecture: the Application Server (target host) is directly connected to the GGSN Node located in Rome, the reference BSC/PCU is located in Bologna and directly connected to the SGSN Node in Milan.

**Packet Transfer Delay – UDP**

The last session of test has been done in the ROCC (Milan) where it has been evaluated the transfer delay from a computer connected to the test MT, to a UDP Server directly connected to the GGSN Node in the ROCC of Milan. We used the application “Wire Shark” on server and client and we had two antenna GPS for synchronization.

During the first test 100 packets (30 Byte) have been transferred using UDP protocol, with about 1,5 seconds gap between the consecutive transmissions.

<table>
<thead>
<tr>
<th>Mode [ms]</th>
<th>100-125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Value [ms]</td>
<td>121,93</td>
</tr>
<tr>
<td>Minimum Value [ms]</td>
<td>96,938</td>
</tr>
<tr>
<td>Maximum Value [ms]</td>
<td>410,28</td>
</tr>
</tbody>
</table>

Packet statistics:

<table>
<thead>
<tr>
<th>Packets sent:</th>
<th>100;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packets received:</td>
<td>100;</td>
</tr>
<tr>
<td>Packets lost:</td>
<td>0;</td>
</tr>
<tr>
<td>MTU Server:</td>
<td>400 Byte;</td>
</tr>
</tbody>
</table>
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Figure 7 – UDP time transfer delay during a transmission (packets 30 byte) from Server (downlink) to Mobile Terminal - ROCC RFI Milan

During the second test 100 packets (300 Byte) have been transferred using UDP protocol, with about 1.5 seconds gap between the consecutive transmissions.

Packet statistics:

- Packets sent: 100;
- Packets received: 100;
- Packets lost: 0;
- MTU Server: 576 Byte;
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Figure 8 – UDP time transfer delay during a transmission (packets 300 byte) from Server (downlink) to Mobile Terminal - ROCC RFI Milan
Conclusions

The following table resumes the results of Italian tests comparing GPRS and GSM-R QoS parameters.

<table>
<thead>
<tr>
<th>GPRS QoS parameters</th>
<th>GPRS Test Results</th>
<th>GPRS Key-Features</th>
<th>GSM-R Test Results</th>
<th>GSM-R QoS parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service Access Delay</td>
<td>3.2s (95%)</td>
<td>✓</td>
<td>4.5s (95%)</td>
<td>Call Setup Time from Mobile Terminal</td>
</tr>
<tr>
<td>Service access accuracy</td>
<td>0</td>
<td>✓</td>
<td>0.2</td>
<td>Call Setup error ratio (&lt;1%)</td>
</tr>
<tr>
<td>Service integrity delay</td>
<td>0.200s 95% (UDP)</td>
<td>✓</td>
<td>0.383s (95%)</td>
<td>Max Transfer Delay RBC-EVC</td>
</tr>
<tr>
<td>Service integrity accuracy</td>
<td>0.01</td>
<td>=</td>
<td>0.01</td>
<td>Packets lost ratio</td>
</tr>
<tr>
<td>Service retainability delay</td>
<td>0</td>
<td>=</td>
<td>0</td>
<td>Radio connection's lost ratio</td>
</tr>
</tbody>
</table>

Table 1 – Comparative Table GPRS v GSMR

From comparative analysis follows:

- GPRS Service Access Delays is better than GSM-R
- End to End Transfer Delay shows encouraging performances.
- UDP protocol has less protection but offer better performance
- Mobility management (cell reselection) has a significant effect on RTD (around 3s up to 10s) but with a limited number of events
- Improvements can be made (Network Assisted Cell Change, Network Controlled Cell Reselection, engineering rules …)

ETCS needs to be opened towards IP & Packet Switch, with a EURORADIO independent from Technology, in order to be a future proof system, needed for the European Market, but also largely abroad. As stated in the report, we believe that GPRS is feasible for ETCS, with the condition to start the work on solving the challenges by all parts - Authorities, Railways, GSM-R and Signaling Suppliers - as it was done for CS (Circuit Switch) some years ago – political support and funding are needed. Expected results are an improvement of service availability with a reduction of lost radio connections and a larger bandwidth to introduce new services like a remote diagnostic control. GPRS is only the first step to start the migration toward IP platform that open news development and investments toward technology as LTE (Long Term Evolution).
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**Acronyms**

- BSC Base Station Controller
- BSS Base Station Subsystem
- BTS Base Transceiver Station
- CS Coding Scheme
- DL Down Link
- ERTMS (European Railway Train Management System)
- ETCS (European Train Control System)
- GGSN Gateway GPRS Support Node
- GMSC Gateway MSC
- GPRS General Packet Radio Service
- GSM Global System for Mobile communications
- HLR Home Location Register
- IP Internet Protocol
- LAN Local Area Network
- LLC Logical Link Control
- MAC Medium Access Control
- MS Mobile Station
- MSC Mobile Switching Center
- MSC/VLR MSC/Visitor Location Register
- NSS Network Switching Sub System
- PCU Packet Control Unit
- PDN Packet Data Network
- PDP Packet Data Protocol
- PDU Packet Data Unit
- PLMN Public Land Mobile Network
- QoS Quality of Service
- SGSN Serving GPRS Support Node
- TBF Temporary Block Flow
- TCP Transmission Control Protocol
- TDMA Time Division Multiple Access
- TS Time Slot
- UDP User Datagram Protocol
- UL Up Link