GSM-R Network Dimensioning, Design & Optimization

• Giorgio Ronchi, NOKIA
GSM-R Network Planning & Optimization

Agenda

• Network Dimensioning – Traffic Model
• Network Design
• Tunnel Coverage
• Planning for High-Speed Lines
• Tuning, Acceptance & Optimization.
• References.
GSM-R Dimensioning

- GSM-R Applications: ETCS tracks /VGCS.
- Subscribers: workers of the railway transportation company.
- Smaller traffic, however some connections (i.e. ETCS) need to be permanent.
- Limited number of frequencies available.
- Traffic is concentrated in certain areas i.e. in railway platforms and shunting platforms.
GSM-R Applications

- personnel at stations
- driver
- train
- trackside workers
- railroad engine depot
- Shunting Teams
- Train Controller
- Radio Block System
- Voice-Traffic
- Data-Traffic

Train Controller

Radio Block System

Shunting Teams
Traffic types

Data/Voice:
- Point-to-point voice ➔ standard calculation (MOC, MMC, MTC).
- Data circuit switched traffic (DCSS traffic) ➔ (Goes to RBC).
- VGCS/VBCS voice ➔ ASCI uses network resource differently.
- GPRS ➔ Toward GGSN/SGSN.

Signalling:
- USSD (registration / deregistration for functional number).
- SMS.

The following penetration factors must also be identified:
- VMS (typical 0-15%).
- IN (typical 80-100% due to FN & part. LDA).
<table>
<thead>
<tr>
<th>Users involved in call</th>
<th>Call Type</th>
<th># users</th>
<th># calls, per user, BH</th>
<th># calls, total, BH</th>
<th>Call duration, mean time</th>
<th>BH traffic [Erl]</th>
<th>MOC %</th>
<th>MTC %</th>
<th>MTM %</th>
<th>Calls with fixed dispatcher %</th>
<th>Calls with mobile dispatcher %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver - Traffic controller</td>
<td>Voice</td>
<td>0.5</td>
<td>0</td>
<td>120</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Driver - Driver</td>
<td>Voice</td>
<td>0.01</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Driver - Train Guard</td>
<td>Voice</td>
<td>0.2</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Driver - Station Controller</td>
<td>Voice</td>
<td>0.2</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>15</td>
<td>15</td>
<td>70</td>
<td>30</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Train Guard - Traffic Controller</td>
<td>Voice</td>
<td>0.2</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Train Guard - Station Controller</td>
<td>Voice</td>
<td>0.3</td>
<td>0</td>
<td>200</td>
<td>0</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>70</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Other calls between train functions</td>
<td>Voice</td>
<td>0.01</td>
<td>0</td>
<td>120</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>REC in stations</td>
<td>Voice</td>
<td>0.001</td>
<td>0</td>
<td>120</td>
<td>0</td>
<td>15</td>
<td>15</td>
<td>70</td>
<td>30</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>REC along tracks</td>
<td>Voice</td>
<td>0.0001</td>
<td>0</td>
<td>120</td>
<td>0</td>
<td>15</td>
<td>15</td>
<td>70</td>
<td>30</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Maintenance teams</td>
<td>Voice</td>
<td>3</td>
<td>0</td>
<td>180</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>80</td>
<td>20</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Shunting teams in small - medium size stations</td>
<td>Voice</td>
<td>1</td>
<td>0</td>
<td>3,600</td>
<td>0</td>
<td>15</td>
<td>15</td>
<td>70</td>
<td>30</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Shunting teams in big stations</td>
<td>Voice</td>
<td>0.5</td>
<td>0</td>
<td>3,600</td>
<td>0</td>
<td>50</td>
<td>50</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other GSM-R internal calls</td>
<td>Voice</td>
<td>1</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>15</td>
<td>15</td>
<td>70</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other GSM-R internal calls</td>
<td>Data</td>
<td>0.15</td>
<td>0</td>
<td>300</td>
<td>0</td>
<td>30</td>
<td>30</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ERTMS</td>
<td>Data</td>
<td>1</td>
<td>0</td>
<td>3,600</td>
<td>0</td>
<td>100 towards RBC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other GSM-R external calls</td>
<td>Voice</td>
<td>1</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>25</td>
<td>25</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
GSM-R Network Planning & Optimization

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Coverage Planning

Rules for a coverage and cost efficient planning

• Precise requirements defined at the start of the project (redundancy, signal levels, traffic, ETCS)
• Use standardized equipment as much as possible
• Minimum total amount of BTS is not necessarily the most cost efficient
• Careful frequency allocation
• Innovative and creative design

Maximum use of friendly sites
# Network Design Approach

<table>
<thead>
<tr>
<th>Type of service</th>
<th>Coverage approach</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice &amp; standard GSM services</td>
<td>Simple coverage, with safety margins</td>
<td></td>
</tr>
<tr>
<td>GPRS &amp; data services</td>
<td>Simple coverage, with safety margins</td>
<td>Interference control Frequency plan</td>
</tr>
<tr>
<td>ETCS L1, ASCI, other specific GSM-R services</td>
<td>Simple coverage, with safety margins</td>
<td>Traffic control data as input</td>
</tr>
<tr>
<td>ETCS L2</td>
<td>Double coverage</td>
<td>High system reliability</td>
</tr>
</tbody>
</table>

**Tunnel coverage!**
GSM-R Network Design: the Railway environment

- It is different from standard GSM networks environments and Nominal Network Design is based on a few basic requirements:

  **Model Tuning**
  - A standard GSM propagation model is not suitable for GSM-R environment since it considers propagation beyond roof top heights.
  - You need a GSM-R specific propagation model that considers the propagation along the “rail corridor”.
  - Basically don’t care about what happens far from the railway tracks.

  **Terrain database**
  - A detailed description of railway line vector is a key-factor. Consider in deep detail cuttings, viaducts, tunnels.
  - Height modification can help to better describe propagation.
  - Clutter modification (“Rail Clutter”) allows to better evaluate and display coverage levels.
GSM-R Network Design: Nominal Plan

- Traffic model
- Link budgets
- Coverage levels
- Nominal Plan
- Site configuration
- Frequency plan
- Neighboring plan
- Project databases (NSS, BSS)
- Group Call Areas plan
- Project database (IN)
- Train traffic control data

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Sites to be placed along the railway tracks to use friendly sites.

- Reduce overall number of HO, by combining cells.
- Antennae: 30° beam width to better control interference and better fit the 2D coverage requirements.
- Frequency plan: AFP tools are not suitable for GSM-R applications, better to perform frequency plan MANUALLY.
- Coverage redundancy (opt): better with alternate site location. Single layer or double layer.
Coverage Planning - Single Coverage

Single layer no overlap

Single layer high overlap
Coverage Planning – Double Coverage

Double Layer co-located

Double Layer interleaved
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Tunnel coverage

Most of railway lines have a great number of tunnels, some or them are very long.

EIRENE does not have specific requirements for tunnels, but Railway Operators often require higher safety levels inside tunnels (i.e. Redundancy, in-train coverage, other MNO coverage).

- Tunnel coverage strategy depends on:

<table>
<thead>
<tr>
<th>Coverage levels:</th>
<th>Out train or in train</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel type:</td>
<td>Single or double, size and shape, ...</td>
</tr>
<tr>
<td>Equipments:</td>
<td>BTS or Repeaters (off-air, F.O., other third-party).</td>
</tr>
<tr>
<td>Radiating system:</td>
<td>Antennas or leaky feeders.</td>
</tr>
</tbody>
</table>
## Tunnel coverage strategies

<table>
<thead>
<tr>
<th>Equipment</th>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTS</td>
<td>✓ High power</td>
<td>✓ Installation, especially inside tunnels</td>
</tr>
<tr>
<td></td>
<td>✓ No new O&amp;M system</td>
<td></td>
</tr>
<tr>
<td>Repeater, other Third-Party</td>
<td>✓ Easier Installation</td>
<td>✓ New O&amp;M required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Time delay on signal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Noise</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radiating system</th>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>✓ Easier Installation and maintenance</td>
<td>✓ Wide dynamic range</td>
</tr>
<tr>
<td></td>
<td>✓ Safety</td>
<td>✓ Fading</td>
</tr>
<tr>
<td></td>
<td></td>
<td>✓ Frequency band</td>
</tr>
<tr>
<td>Leaky cable</td>
<td>✓ Thin dynamic range</td>
<td>✓ Installation and maintenance</td>
</tr>
<tr>
<td></td>
<td>✓ Application field</td>
<td>✓ Reliability</td>
</tr>
<tr>
<td></td>
<td>✓ Wide freq. band</td>
<td></td>
</tr>
</tbody>
</table>
Phased array antenna system

Phased array antenna system is used in tunnels to improve the coverage and decrease the «fast fading» effect.

The system is composed by a pair of antennas and a variable phase shifter.
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Network Design for ETCS L2

- Coverage level: -92 dBm, 95%, redundant.
- Tuned propagation models:
  - For GSM-R urban area
  - For GSM-R open-area.
- Typical inter-site distance: 4 km (open area, 900 MHz).
- Urban area could be out-of-scope for ETCS L2.
- Track environment has great influence on Network Design
  - Environment
  - Presence of bridges and viaducts.
  - Presence of tunnels.
Traffic Model for HSL

- Traffic model is an important input:
  - Each train requires 1 TCH FR for ETCS L2.
  - 2 TCH FR are needed in RBC HO areas.
  - Worst case: based on Block Length (bl).

\[
Train_{track} = \frac{n \times L_{track}}{bl}
\]

- Normal case: based on speed profile and rate.

\[
Train_{track} = \frac{n \times L_{track}}{Speed_{track} \times T_{train}}
\]
Handover Planning for HSL

• Minimum site distance for TIR requirements!
  • Error-free-period (< 20 s, 95%)

<table>
<thead>
<tr>
<th>Speed [km/h]</th>
<th>Site distance [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>666.7</td>
</tr>
<tr>
<td>160</td>
<td>888.9</td>
</tr>
<tr>
<td>200</td>
<td>1111.1</td>
</tr>
<tr>
<td>300</td>
<td>1666.7</td>
</tr>
</tbody>
</table>

• Overlapping area for HO execution.

  \[ h_{\text{min}} = v_{\text{max}} \times t_{\text{ho}} = 250 \text{ km/h} \times 8 \text{ s} = 555 \text{ m} \]
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## GSM-R Network KPI

### Special KPIs specified for railway networks spec. O-2475

<table>
<thead>
<tr>
<th>KPI</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage ETCS</td>
<td>-95 dBm @ 95% probability over area &amp; time</td>
</tr>
<tr>
<td>HO success rate</td>
<td>&gt; 99.5%</td>
</tr>
<tr>
<td>Call setup success rate</td>
<td>&gt; 99%</td>
</tr>
<tr>
<td>HO execution time</td>
<td>&lt; 500 ms (95%)</td>
</tr>
<tr>
<td>Data connection establishment delay</td>
<td>&lt; 8.5 sec (95%), &lt;10 sec (100%)</td>
</tr>
<tr>
<td>Data connection loss rate</td>
<td>&lt; 0.01/ hour connection time</td>
</tr>
<tr>
<td>Data transmission interference rate</td>
<td>&lt; 0.8 sec (95%), &lt;1 sec (99%)</td>
</tr>
<tr>
<td>Transmission interference period</td>
<td>&gt; 20 sec (95%), &gt;7 sec (99%)</td>
</tr>
<tr>
<td>Error free period</td>
<td></td>
</tr>
</tbody>
</table>

Require high amount of testing time and automatic test tools
Tuning and optimization process

Drive Test: Is the starting point of GSM-R optimization

Target: Is the railway track; track should be optimized for maximum speed

It is most important a detailed track database (tunnels, stations, ...) with Km points, than GPS data.

- Preliminary spectrum clearance assessment
- Coverage and continuous call tests
- Frequency plan optimization
- Handover test and tuning
- Test of specific ETCS L2 parameters
- Track is ready for trial operation of signaling systems
- Track is ready for commercial operations
Drive test equipments

**Traditional drive test solution**

Portable equipments – for single drive test, post-processing and tuning

**Unattended data collection system**

For traffic generation, load-stress and statistical KPI collection

**Fixed installation in Train**

A combination of previous options
Optimization process

• Tuning and optimazition is a critical phase during the realization of a GSM-R network.
• A big amount of drive-test is needed to collect all the necessary informations.
• Step 0 is the preliminar assessment of the environment, for the detection of external interferences.
• Step 1 is the coverage optimization with adjustements of antenna azimuts and tilts.
• Step 2 is the optimization of network performances with the setting of optimized database parameters for each cell.
• At the end of Step 2 network is fully ready for commercial operations.
Coverage optimization

• During coverage assessment phase, some coverage problem COULD be detected and MUST be solved before proceeding.

• Possible coverage problems are:
  1. Lack of coverage (holes, fast-field-drop).
  2. Far cell camping.

• Possible solutions are:
  1. Check site installation, correct azimut.
  2. Add mechanical or electrical downtilt.
Performances optimization

• The most critical performances are related to ETCS services (CSD calls).
• Typical problems are the violations of $T_{TI}$ or $T_{REC}$.
• Possible causes are of 2 types:
  1. For both parameters: HO break time too long or interference.
  2. For $T_{REC}$ violation, HO procedures: distance between HO too short or ping-pong/intracell HO.
HO optimization in live network

Overshooting

Distance between HO not controlled according to requirements. TIR violations.

Ping-pong HO reduces time between consecutive HO. TIR violations.

Back-HO
About me ...

• Giorgio Ronchi, PMP
• Working in Italtel (Siemens Group) from Dec-1998, then Siemens, Nokia-Siemens and Nokia.
• Working on RFI/GSM-R Project from National Rollout tender phase, in 2002.
• Supporting GSM-R projects in Europe and worldwide: Denmark, Norway, Sweden, Poland, Romania, Greece, Saudi Arabia, China and more …
ETCS: Level 1

As long as the signal is red, I must wait and not pass the balise.
ETCS: Level 1

As there is an in-fill loop, I have now received authority to pass the signal already - before passing the balise. So I can accelerate as soon as the signal changes to green!
ETCS: Level 2

My movement authority and track data come directly via GSM-R. Now, my display is always up-to-date and I don't need trackside signals!
ETCS: Level 3

My train integrity checking is now done on-board so train detection equipment is no longer needed. Train control is now based on moving block!

Balise (fixed message)

Speed Profile & Breaking Point