GSM-R Traffic Model for Radio-based Train Operation  
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Summary

The article presents the GSR-R traffic model for FFB railway operation (FFB is the German abbreviation for FunkFahrBetrieb, a radio-based train operation system for regional railway lines). The traffic model is derived from the general communication principles of FFB and from the experiences of the first-time application of the Siemens SIMIS FFB system at the Brackwede-Dissen/Bad Rothenfelde line. The GSM-R radio network infrastructure assumed for traffic calculations is based on EIRENE and the experiences of Siemens radio network planning. The paper outlines the particular FFB communication requirements and its implications for the traffic model.

1 Introduction

Operators of regional railway lines are coming under increasing cost pressure, forcing them to exploit all cost-saving potential. With regard to operations management, radio-based train operation (FFB) represents a cost-effective operating system. This system is based largely on the exchange of data between an FFB control centre, on-board units and route elements via a radio network in line with the GSM-R standard. The first global system of this type was presented at EXPO 2000 on the Brackwede - Dissen/Bad Rothenfelde line [1].

In general, the number of communication links involved in radio-based train operation is dependent on the number of route elements on the length of a line (for example, points or level-crossing protection systems) as well as the number of vehicles in concurrent use on the line. The dynamism of the communication is characterised primarily by the line speed. The traffic model described below helps to determine the traffic load typical with radio-based train operation for each radio base station, i.e. for each radio cell in the GSM-R network. This includes technical interrelationships and assumptions, based on GSM specifications, on initial experiences with the SIMIS FFB system on the Brackwede - Dissen/Bad Rothenfelde line and on Siemens planning principles for GSM-R radio networks in Sweden, Holland, Spain and Switzerland (SIMIS® fail-safe microcomputer system from Siemens).
Communication Requirements for Radio-based Train Operation

Radio-based train operation essentially involves the communication links defined in between the FFB control centre, the on-board units and the route elements. Voice communication between an operator and a vehicle driver or others (e.g. maintenance personnel) is not one of the primary communication requirements of FFB and is therefore not taken into consideration in this traffic model.

Every FFB vehicle is fitted with two mobile radio communication systems (MS) for transmitting data. Each route element contains one mobile radio communication system. Alternatively, a route element can also be connected via an ISDN base connection (ISDN - Integrated Services Digital Network). As the FFB centre is connected via an ISDN primary multiplex connection (maximum transmission rate: 2 Mbit/s) to the network control centre – the Mobile Switching Center (MSC) - a maximum of 30 MTC connections can be set up or executed simultaneously by an FFB control centre in the basic configuration (MTC - Mobile Terminated Call). The data service BS 25 (Bearer Service) is used for all connections.

The following is an example of a typical communication scenario in radio-based train operation. A vehicle in railway station A is intended to travel to a destination platform in station B. The FFB on-board unit first sends a route request by radio to the FFB control centre, which generally responds with a route allocation. The allocated route consists of a sequence of route sections from the start.
platform to the destination platform. The on-board computer obtains all data necessary for the run, such as the positions of all level-crossing protection systems and points, required point positions and the speed profile, from the digital on-board route map. In the course of the run, the vehicle sets all points, closes the level crossings within a precise time and, at specific locations, transmits position indications to the FFB control centre. A GSM-R link from the vehicle to the corresponding communication partner is set up during each action and is disconnected again after the communication. Depending on the vehicle speed and the density of the route elements, a sequence of rapidly varying radio connections occurs with various destinations. These connections must in some cases overlap in terms of time.

Various different GSM-R call types are used depending on the destination of the call. For position indications, for example, this is type MOC (Mobile Originated Call). For calls to route elements, either an MMC (Mobile to Mobile Call) or a combined call (consisting of an MOC from the vehicle to a gateway in the control centre and one or more MTCs from the gateway to route elements) is used [2].

In Table 1, the communication links for radio-based train operation are listed in order according to calling party, called party, call type and requirement. The GSM-R call set-up times for the FFB pilot line in Brackwede and typical call durations in radio-based train operation for the various call types (including call set-up times) are listed in Table 2.

The comparatively high call duration occurs due to the use of cryptographically protected calls in line with the EUROradio protocol. The call set-up time in the GSM-R network can be shortened to up to 2 s by means of a fast call set-up. The call duration can thus be shortened to 21 s for the MMC and to 15 s for the MOC and the MTC.

Shunting operations in the FFB operating mode are not critical for the traffic volume. The typical communications procedure in this case includes an MOC to request the shunting operation, two to three MTCs to transfer the route elements into shunting mode and approximately two MOCs to control the shunting operation.

3 Base Data of the GSM-R

The number of possible communication links via a GSM-R network per cell are defined below. As a blocking of up to 1% due to the air interface is assumed, no more than 1% of all call set-up attempts of a mobile or fixed-network telephone may be rejected by the radio network. This may therefore lead to a shortage of resources in the signalling channels (SDCCH - Stand Alone Dedicated Control Channel), and as a result, call set-up attempts would be rejected due to the absence of a signalling possibility despite available radio network resources. This is compensated by flexible allocation of the SDCCH according to traffic volume. A blocking on the ISDN primary multiplex interface between the route computer and MSC is not to be expected as sufficient transmission capacity can be provided for.
The GSM-R network is a cellular-structure radio system with 19 frequencies for the traffic from the radio base stations to the mobile radio communications systems (down link) and 19 frequencies for the traffic from the mobile radio communications systems to the radio base stations (up link). To achieve the optimum signal-to-noise ratio with the radio interface, that is, to achieve the essential conditions for high transmission quality, the frequency pairs are reused. In GSM-R networks, a frequency pair is normally reused in every fourth consecutive cell (reuse factor = 3:1). For each frequency, there are up to seven traffic channels (TCH), whereas when two frequencies are used, there are up to 15 TCHs.

Due to the cellular structure of the mobile radio communications network, each call is transferred to the adjacent cell at the edge of a radio cell. The overlap area (handover area) required for this is defined by the maximum expected speed of the trains and consequently of the mobile radio communications systems, as well as the total time required for handover (HO). For example, with a line speed of 80 km/h and a total time for the handover of 7 s, the handover area would be 160 m long. The radio cell is usually elliptic to enable an optimum emission along the track. The distance is indicated on the main axis of the ellipse with the cell diameter. It typically is about 5 km but can fluctuate between 3.5 and 11 km, depending on the topography of the line.

4 Traffic Table

The following data applies to trains with a maximum speed of 80 km/h. With higher speeds (for example 120 km/h), the number of simultaneously required data channels per cell increases. However, when the line speed increases, the density of the route elements is usually reduced (for example, the number of level-crossing protection systems is reduced) and so is the communication load. With 39 system-controlled level crossings, 4 points and 11 key release instruments on 26 kilometres of track and with a line speed of 80 km/h, the pilot line Brackwede – Dissen/Bad Rothenfelde is in the upper requirement area.

To allow correct GSM-R network dimensioning the typical GSM-R traffic per radio cell in the case of radio-based train operation is shown below. For simplification purposes, a cell size of 5 km including handover area is assumed. If different cell sizes exist, the traffic data should be multiplied by the correction factor “cell size divided by five”.

In total, a maximum of 14 TCHs is required per radio cell for radio-based train operation. This is reduced in the following grades:

- 14 TCHs with three route elements per km (12 TCHs for multiplex transmission)
- 12 TCHs with two route elements per km (11 TCHs when using fast call set-up)
- 10 TCHs with one route element per km

Higher route element densities are controlled in the SIMIS FFB system by means of the following optimisations, which lead to a reduction of the communication load and the required TCHs [2]:

\[\text{Traffic Table}\]

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1. Physical grouping of route elements with local cabling (for example, connection of a level-crossing protection system with adjacent points or key release instruments).

2. Logical grouping of route elements with multiplex transmission via a gateway in the FFB control centre. For example, if two upstream route elements are called directly (via MMC) by two on-board mobile radio communications systems simultaneously, four traffic channels (TCH) are required. With multiplex transmission via a gateway in the FFB control centre, one on-board mobile radio communication system on the vehicle is sufficient using a mobile originated call (MOC) and two mobile terminated calls (MTC), i.e. three THCs. In this example, the ratio of the number of traffic channels required without and with multiplex transmission is exactly four to three. This ratio (A) with n route elements is generally calculated according to the following formula:

\[ A = \frac{2n}{n+1} \]

3. Use of ISDN base interfaces between route elements and the FFB control centre.

5 Conclusion

Two transceivers per cell (radio base station) are necessary for the use of FFB to enable data transmission in line with the GSM-R standard. With multiplex transmission between the vehicle and the FFB control centre, the required communication resources can be reduced by approximately 25% (or more). High traffic concentrations as a result of high route element density can be lessened by forming physical groups and connecting the route elements to the FFB control centre via ISDN base connections. It is also possible to use the FFB operating procedure in mixed networks (public GSM and GSM-R) with identical on-board equipment when the potential for reducing the communication load is fully utilised.

As the high demand on links for FFB radio-based train operation is to a large extent caused by the use of the circuit switched EUROradio system required for compatibility reasons, the use of packet-oriented data transmission (GPRS - General Packet Radio Services) provides a solution. However, this is on condition that packet-oriented data transmission is also included in the safety layer of the EUROradio system.

References


<table>
<thead>
<tr>
<th>Calling party</th>
<th>Called party</th>
<th>Call type</th>
<th>Requirement</th>
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<tbody>
<tr>
<td>On-board</td>
<td>FFB control</td>
<td>MOC</td>
<td>BS 25</td>
</tr>
<tr>
<td>computer</td>
<td>centre</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Route element</td>
<td>MMC, MOC+MTC</td>
<td></td>
<td></td>
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<tr>
<td>FFB control</td>
<td>On-board</td>
<td>MTC</td>
<td>Connection to the MSC via an ISDN primary multiplex</td>
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<tr>
<td>centre</td>
<td>computer</td>
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Table 1: Call types in radio-based train operation

<table>
<thead>
<tr>
<th>Action</th>
<th>Call type</th>
<th>Duration [s]</th>
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<tbody>
<tr>
<td>GSM-R call set-up</td>
<td>MOC and MTC</td>
<td>approx. 6</td>
</tr>
<tr>
<td>GSM-R call set-up</td>
<td>MMC</td>
<td>approx. 10</td>
</tr>
<tr>
<td>Call</td>
<td>MMC</td>
<td>approx. 25</td>
</tr>
<tr>
<td>Call</td>
<td>MOC</td>
<td>approx. 19</td>
</tr>
<tr>
<td>Call</td>
<td>MTC</td>
<td>approx. 19</td>
</tr>
</tbody>
</table>

Table 2: Connection times in radio-based train operation

Authors
