GSM-R Procurement & Implementation Guide

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Foreword

The development of a specific set of railway telecommunications functions and applications for the digital age has been the founding principle of UIC's involvement in the GSM-R project from its very inception.

UIC gathered support for its adoption within the rail system through a Memorandum of Understanding (MoU) between Members, which has now been endorsed by 34 European countries.

In terms of physical migration, GSM-R projects have been implemented in 17 countries in Europe, five of which have already made a full transition to GSM-R digital networks in the entire networks, or in the main parts.

Outside of Europe, GSM-R is fast becoming the system of choice for railway telecommunication network solutions, with commercial projects already in progress in 6 countries

This procurement guideline thus represents the distillation of the extensive experience which has been built up by UIC and its Members through their interaction with the supply industry and their partners, in the tendering process for GSM-R and in the actual performance of commercial projects in the field.

UIC's intention, in preparing the guideline, is to offer the readers the benefit of this rich experience and thus allow them to gain an appreciation of the issues they will need to take account of in setting out to procure GSM-R projects.

Like any guideline, it must be read and interpreted in a practical way and placed in the specific context and business environment in which it will be utilised

I wish to express my great appreciation to all those who have contributed to this publication in one way or another and to applaud the continuous generosity of UIC Members who show a willingness and richness of spirit to share their learning experience in the desire that others will benefit.

Such confraternity underlines the mission of UIC and expresses its values in the truest and most explicit sense of the word.

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March 2009

GSM-R
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List of abbreviations

3GPP	3rd Generation Partnership Program
ARFCN	Absolute Radio Frequency Channel Number
ASCI	Advanced Speech Call Items
AuC	Authentication Centre
BER	Bit Error Rate
BRI	Basic Rate Interface
BSC	Base Station Controller
BSS	Base Station Sub-System
BTS	Base Transceiver Station
C/A	Carrier to Adjacent (ratio)
C/I	Carrier to Interference (ratio)
CENELEC	European Committee for Electro-technical Standardization
CEPT	Conference of European Postal and Telecomms administrations
CUG	Closed User Group
DCN	Data Communication Network
DSD	Driver Safety Device
DSS1	Digital Subscriber Signaling 1
E-FRS	EIRENE Functional Requirements Specification
eLDA	enhanced Location Dependent Addressing
E-SRS	EIRENE System Requirements Specification
ECMA	European Computer Manufacturers' Association
EIR	Equipment Identity Register
EIRENE	European Integrated Railway Enhanced Network
EIRP	Effective Isotropic Radiated Power

eLDA	enhanced Location Dependent Addressing
EMC	Electromagnetic Compatibility
eMLPP	enhanced Multi-Level Precedence and Pre-emption
ENAN	EIRENE Network Access Number
ENF	European Numbering Forum
EPT	EIRENE Project Team
ERA	European Railway Agency
ERC	European Radio communications Committee
eREC	enhanced Railway Emergency Call
ERIG	European Radio Implementation Group
ERO	European Radio Office
ETCS	European Train Control System
ETNS	European Telecommunications Numbering Space
ETSI	European Telecommunications Standards Institute
EUG	EIRENE User Group
EVC	European Vital Computer
FA	Functional Addressing
FFFIS	Form Fit Functional Interface Specification
FFN	Follow-me Function Node
FRS	Functional Requirements Specification
GCR	Group Call Register
GIS	Geographical Information System
GMSC	Gateway MSC
GPRS	General Packet Radio Service

GPS	Global Positioning System
GSC	Group Switching Centre
GSM	Global System for Mobile communications
HLR	Home Location Register
HMI	Human-Machine Interface
IC	International Code
IFN	International Functional Number
IMSI	International Mobile Subscriber Identity
IN	Intelligent Node
IP	Intelligent Protocol
ISDN	Integrated Services Digital Network
ISO	International Standards Organization
ITT	Invitation To Tender
ITU	International Telecommunications Union
IWF	Interworking Function
LDA	Location Dependent Addressing
MAP	Mobile Application Part
MCC	Mobile Country Code
ME	Mobile Equipment
MMI	Man-Machine Interface
MNC	Mobile Network Code
MORANE	MObile radio for RAilway Networks in Europe
MoU	Memorandum of Understanding
MS	Mobile Station

MSC	Mobile (services) Switching Centre
MSISDN	Mobile Station ISDN Number
MT2	Mobile Terminal 2
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
MUX	MUltipleXer
NFN	National Functional Number
NMF	Network Management Forum
NSS	Network Sub-System
OMC	Operation and Maintenance Centre
OMC-S	Operation and Maintenance Centre - Switch
OPH	OPerational Handset
OSI	Open System Interface
OTA	Over The Air
PAMR	Public Access Mobile Radio
PBX	Private Branch eXchange
PLMN	Public Land Mobile Network
PMR	Private Mobile Radio
PRI	Private Rate Interface
PSDN	Public Switched Data Network
PSTN	Public Switched Telephone Network
PTT	Push-To-Talk
RAM	Reliability, Availability and Maintainability
RBC	Radio Block Centre

RxQual	Received Signal Quality
SIM	Subscriber Identity Module
SLA	Service Level Agreement
SMPP	Short Message Peer to Peer
SMS	Short Message Service
SMS-C	Short Message Service Centre
SRS	System Requirements Specification
SS7	Signaling System number 7
SSRS	Sub-System Requirements Specification
TC-RT	Technical Committee - Railway Telecommunications
TMN	Telecommunications Managed Network
TRX	Transceiver
TSI	Technical Specification for Interoperability
UIC	Union Internationale des Chemins de Fer
UIN	User Identifier Number
UN	User Number
USSD	Unstructured Supplementary Service Data
UUS1	User-to-User Signaling type 1
VBS	Voice Broadcast Service
VGCS	Voice Group Call Service
VLR	Visitor Location Register
VMS	Voice Mail System
VPN	Virtual Private Network

1 Procurement guide overview

1.1 Legal Disclaimer

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1.2 General

1.2.1 The original Procurement Guide was developed together with Detica Limited for UIC Project ERTMS/GSM-R.

1.2.2 The purpose of this latest guide produced together with Systra is to provide guidance on the use of the EIRENE System Requirements Specification and the EIRENE Functional Requirements Specification to assist national railways with the *procurement and implementation* of a GSM-R radio system that meets the EIRENE Specifications. As such this document is a continuation of the 2007 Procurement Guide providing additional information in the areas of design and implementation based on experience of the first GSM-R projects.

1.3 Procurement and Implementation Guide aims and objectives

1.3.1 The EIRENE System Requirements and Functional Requirements Specifications allow for some flexibility in the allowed procurement approaches and implementation options for an EIRENE-compliant integrated radio communications system. In order to ensure interoperability between national GSM-R networks, it is necessary to provide some guidance on the development of national specifications. This procurement and implementation guide is intended to provide help with the interpretation of the EIRENE Specifications in order to:

- provide a framework for interoperability;
- ensure common interpretation of requirements in the context of how EIRENE-compliant systems may be implemented;
- provide guidance in areas where there is flexibility in the implementation options.

1.3.2 The remainder of this section outlines the aspects that are covered by the Procurement and Implementation Guide in order to meet these requirements.

1.3.3 The realization of a GSM-R network is complex and requires much planning. It is not intended that every topic related to GSM-R implementation is covered here in this version of the document. *Future versions of the document will build upon the information provided here by adding new sections, error corrections or more in depth explanations in order to form a more comprehensive handbook for GSM-R implementers.*

1.4 Document scope

1.4.1 In order to provide practical assistance to the implementation of an EIRENE-compliant radio network, this guide:

- provides an overview of GSM-R and gives a single point of reference for all of the relevant documentation;
- describes the various design options available and how these implementations can be made to result in an interoperable EIRENE-compliant system;
- provides guidance on the use of the EIRENE System Requirements Specification and Functional Requirements Specification and explains how this information may be used to develop a national strategy;
- provides guidance on issues, which have an effect on implementation and interoperability, but are not comprehensively covered in the EIRENE Specifications.

1.5 System lifecycle overview

1.5.1 This sub-section provides a summary of the main activities that are likely to be undertaken as part of the full lifecycle of a GSM-R radio system. It also indicates which of these phases are covered by this guide.

1.5.2 The full system lifecycle can be divided into five distinct phases as follows:

1 **System planning and specification**. This is the preliminary phase of system procurement, mainly dealing with the feasibility and viability of the new system. This phase therefore includes activities such as:

– system feasibility study;

– development of project remit;

– requirements capture;

– business case development;

– system specification;

– procurement strategy definition;

– planning of implementation and migration.

2 **Tendering.** Once the business case has been accepted and the user requirements defined, the next step is to procure the system. This includes taking the following steps:

– ITT development;

– tendering, which may include a requirement for issuing OJEC notices;

– evaluation of tenders and short-listing of potential suppliers;

– negotiations with potential suppliers;

– final selection of supplier(s);

– contract award.

3 **Implementation**. Once the contracts have been awarded, the system needs to be implemented. This phase will typically include the following elements:

– development of an operational system;

– installation, testing and commissioning of the system;

– migration from current system(s).

4 **Operation and maintenance**. Once implementation of the system has been completed, the system enters a 'steady state' situation, in which the system will be operated and maintained. This phase will typically involve the following activities:

– operation and maintenance of the system;

– introduction of minor changes to the system;

– introduction of major changes to the system and intermediate upgrades to allow the system to meet changing demands.

5 **Decommissioning**. At the end of the life of the system, the current system will be replaced by a new system. Once the new system has become operational (i.e. the system lifecycle has entered stage 4), the old system will be decommissioned.

1.5.3 The core function of the procurement and implementation guide is to give assistance with the planning of the system, the system specification the procurement, system design and implementation. There are, however, a number of aspects of the GSM-R system lifecycle that this document does not cover. It is assumed, for example, that individual railways will have their own procedures for the process of tendering. It is therefore outside the scope of this guide to provide assistance with tendering aspects.

The various guidelines outlined in this document may not be suitable for every situation nor are they a replacement for a dedicated strategy tailored for the individual needs of a railway. A migration strategy, for example, has to take into account all the relevant railway operating procedures if dual-mode working is to be considered.

This document highlights the main areas for consideration only.

Contents of this document

1.5.4 The following list provides a summary of the contents of this document, stating the issues that will be dealt with in each of the sections:

- **Introduction:** A brief history of how GSM-R came into existence and how the EIRENE specifications are maintained.
- **Overview of GSM-R:** Provides an overview of the integrated radio system, detailing what is covered in the EIRENE specifications and what must be added in order to provide the required end-to-end functionality. In addition, this section considers the definition of railway communications requirements with particular reference to interoperability. It also gives a brief overview of the organizational structure of the GSM-R Project.
- **System infrastructure provision:** This section deals with technical aspects of procurement and implementation of the GSM-R system with particular reference to the implications of using a private, public or hybrid GSM network.
- **International interoperability considerations:** This section details some of the functional options allowed by the EIRENE specifications (such as flexibility in call routing, the numbering plan and location dependant addressing) and considers their implications for international interoperability between GSM-R networks.
- **System planning and specification:** Provides an overview of the system planning and specification process. It details aspects requiring special attention in this initial stage of the system procurement cycle.
- **Requirements capture and business case development**: These two activities form an important part of the preliminary phase in the system lifecycle. This section provides general guidelines on how to perform these activities.
- **Procurement strategy:** Provides guidance on the overall procurement strategy. It considers and discusses the merits of different procurement and contracting strategies.
- **System design:** This section highlights the main aspects relating to the design of the various sub-systems.
- **Performance of the GSM-R network**: Provides guidance on the specification of the performance requirements and how they can be verified.
- **Implementation:** This section covers the main aspects of the implementation of the network once the system has been designed. This includes the major activities up until acceptance of the network.
- **Annex A - Documentation overview:** This appendix provides an overview of GSM-R documentation, indicating the status of the documents.
- **Annex B - Examples of available terminal equipment and accessories:** This appendix provides a list of terminal equipment and accessories that are available at the time of writing this report.

- **Annex C - Examples of available network equipment and accessories:** This section will be completed in a future version of this document.
- **Annex D - Voice and data service functionality when crossing borders between GSM-R networks**
- **Annex E – Example set of radio planning guidelines:** A sample document provided by Swiss railways defining the various parameters for the radio planning of the Swiss GSM-R network.

2 Introduction

2.1 What is GSM-R?

2.1.1 GSM-R stands for Global System for Mobile Communication for Railways and is based on the commercial system GSM. GSM is the most advanced and frequently used mobile telecommunication system in the world. GSM is standardized by ETSI, the European Telecom Standards Institute and well supported by the GSM Association Group, the association of the GSM suppliers.

2.1.2 GSM-R is based on GSM. To integrate the specific requirements of railways in mobile communication some additional features had to be described, standardized and developed. These features are called ASCI features. ASCI stand for Advanced Speech Call Items. These features are:

- fast call set-up for railway emergency calls;
- priority and pre-emption;
- group-calls;
- voice broadcast calls;
- railway emergency calls;
- functional numbering;
- location dependent addressing.

2.1.3 All these features, which were developed together with ETSI, are incorporated into the GSM standards and are now also partly developed by GSM suppliers and available for public operators in some public networks.

2.1.4 GSM-R is the future system used by the railways for their mobile communication needs. In a first step it will be used to replace the existing analogue train radio systems, as they become obsolete, in the near future. The next step will then be the use of GSM-R as a bearer service for ETCS level 2 and higher. Other applications that are already used in analogue radio systems will then be migrated to GSM-R.

2.1.5 The target is, to replace most of the existing analogue radio systems with GSM-R and to convert the relevant applications into GSM-R. It is the aim of the railways to allow the development of cost-effective products and to reduce costs for maintenance.

2.1.6 GSM-R consists of network infrastructure components and mobile equipment.

2.2 Why GSM-R?

2.2.1 During the course of their work in the period 1985 to 1989, the UIC Radio Frequency Group concluded that efforts would have to be undertaken to negotiate, with the European Frequency Committee (CEPT), for the allocation of a certain spectrum of the GSM-band to the railways, due to the permanent increasing needs to secure frequencies to underpin future railway needs. This request was supported by a pre-study on the usability of either GSM or TETRA for the future railway mobile communications. Some studies were undertaken to assess possible frequency needs (Studies to define a traffic model for three representative areas, London, Paris and Munich, were carried out) and in parallel the advantages and disadvantages of the two potential systems (GSM or TETRA) were discussed.

2.2.2 Finally a decision was taken to adopt GSM, which was, at that time, the only system in commercial operation with products available. This was a very important consideration as one of the main objectives was, to use a system, which was already proven and where off-the-shelf products were available, with the minimum of modifications.

2.2.3 However, even at that time it was clear, that GSM could not fulfil all the requirements necessary for an efficient railway service. Therefore it was necessary to identify and specify the above mentioned ASCI features.

2.2.4 The request for frequencies resulted in a recommendation from CEPT, to provide a spectrum of 4 MHz out of the GSM-band and to allocate this for railway use only.

2.2.5 This recommendation was later modified into a decision, which required the national frequency authorities to free this spectrum, which was already used (mainly by military services), by 2005 at the latest.

2.3 The birth of GSM-R

2.3.1 Following the decision to adopt GSM, the UIC launched a project in 1992, together with the EC and the railways, called EIRENE (European Integrated Radio Enhanced Network). The aim of this project was, to specify the functional and technical requirements for mobile networks which would both fulfill the needs of railways and ensure interoperability across borders. That involved the description of mandatory requirements for operational communication services, in and between networks of neighboring railways, with the goal to allow, in the future, uninterrupted train-services, when crossing borders.

2.3.2 Two leading working-groups were established within this project, a functional group and a project team.

2.3.3 The functional group had the task to prepare a Functional Requirement Specification (FRS), which would mainly describe the mandatory features necessary for interoperability. In addition, a description of some optional features was envisaged to also take account of national requirements.

2.3.4 The project team had the task to develop the System Requirement Specification (SRS), based on the functional requirements. This document also set out to define the technical specialties related to railway operation and the specification of the additional ASCI features.

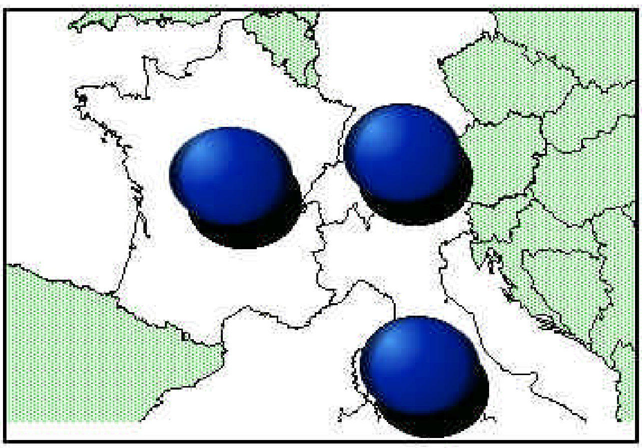
2.3.5 As these ASCI features were based on the GSM standardization it was necessary to work together with specialized ETSI working groups to find the right definitions for these features and to incorporate them into the standards.

2.3.6 A first draft of these EIRENE specifications was finalized by 1995.

2.3.7 To validate, that these specifications could be transferred into technical implementations, a further project was launched in 1995 with the involvement of the UIC, three major railways, the EC and a limited number of GSM suppliers, who were willing to support GSM-R.

2.3.8 This project was named MORANE (Mobile oriented Radio Network), supported by the railways in France, Italy and Germany and established in Paris. Three pilot-lines were planned and implemented:

– Florence – Arezzo;
– Stuttgart – Mannheim;
– Paris suburban area.



2.3.9 With the help of the manufacturers, three small networks were set up and the relevant components for networks and mobile equipment provided. The three systems were independent and not interconnected. Nevertheless, it was possible to prove, during the lifetime of this project, that all the mandatory functions could be implemented and tested. One issue that remained was the testing of inter-working and thus interoperability.

2.3.10 In 1997, the UIC prepared a ***Memorandum of Understanding*** (MoU), committing the railways, who signed this MoU, to no longer investing in analogue radio systems, and only investing in the implementation of GSM-R. It also included the major statements, that early implementers would help the other railways starting an implementation, through the exchange of knowledge and experience.

2.3.11 This MoU was signed at that time by 32 railways all over Europe. As of to-day, the number of signatories has increased to 37, including railways outside of Europe.

2.3.12 In addition to the declaration of willingness set out in the MoU, the UIC also instigated an ***Agreement of Implementation*** (AoI), where the signing railways committed themselves to start their implementation of the national GSM-R system in 2003 at the latest. This AoI was signed by 17 railways.

Note: The MoU and AoI text and the signatories can be found on the UIC ERTMS/GSM-R Web Site

2.3.13 The two Projects EIRENE and MORANE were finally concluded at the end of 2000 with the delivery of the FRS and SRS versions 4 and 12, respectively, the delivery of the MORANE FFFIS and FFFS documents and a final report incorporating the result of the measurement campaigns from all three trial sites.

2.4 EIRENE Specifications

2.4.1 The UIC project EIRENE developed a set of specifications for the European railways that form part of the specification for technical interoperability as required by the EC Directive for interoperability of the Trans-European high speed rail system (see below).

2.4.2 The EIRENE Specifications define a radio system satisfying the mobile communications requirements of the European railways. They encompass ground-to-train voice and data communications, together with the ground-based mobile communications needs of track-side workers, station and depot staff and railway administrative and managerial personnel. The application of the specifications will ensure interoperability for trains and staff crossing national and other borders between systems. It also intends to provide manufacturing economies of scale wherever practical.

2.4.3 The EIRENE Specifications consist of:

- **EIRENE Functional Requirements Specification (E-FRS)**: defines a set of high-level functional requirements for the GSM-R railway radio system. This specification facilitates international interoperability between national railways by ensuring that core railway functionality is provided.
- **EIRENE System Requirements Specification (E-SRS)**: defines the set of technical requirements and constraints in order to ensure international interoperability between national railways. It includes the architecture of the target on-board and track-side systems with references to the detailed specifications defining standardised interfaces. The E-SRS contains much of the information and specifications key to achieving international interoperability.
- **MORANE Specifications:** This is a set of detailed technical specifications consisting of the following documents:
  - **MORANE Sub System Requirements Specification (SSRS)**: Specifies all the functions which have to be implemented on the GSM equipment in order to fulfil all requirements identified in the E-FRS and E-SRS;
  - **MORANE Form Fit Functional Specifications (FFFS)**: details the implementation of functions required from the various network components to meet the technical system requirements defined in the higher-level system specifications;
  - **MORANE Functional Interface Specifications (FIS)**: defines the interfaces between network components required to meet the system requirements defined in the higher-level system specifications.

2.4.4 The specifications also make reference to European Standards as well as GSM Technical Specifications and 3GPP Specifications. Technical advice on the contents of these specifications can be obtained from the following bodies:

- UIC (http://www.uic.asso.fr);
- **UIC ERTMS/GSM-R (http://ertms.uic.asso.fr – GSM-R section)***

  (Former http://gsm-r.uic.asso.fr is still active, being forwarded to the actual link)
- ERA(http://www.era.europa.eu/Pages/default.aspx)
- ETSI (http://www.etsi.org);
- 3GPP (http://www.3gpp.org);
- ERO Website (http://www.ero.dk/)
- CEPT (http://www.cept.org);
- GSM Association (http://www.gsmworld.com)
- GSM-R Industry Group (www.gsm-rail.com)

* The EIRENE FRS 7 and SRS 15, the MORANE documents, the former GSM-R Procurement Guide, The UIC ERTMS/GSM-R Projects description and other information’s are placed I n this area. .

2.5 Areas covered by the EIRENE Specifications

2.5.1 This section gives an outline overview of the aspects of the integrated radio communications system covered by the EIRENE Specifications by taking each section of the E-SRS and summarizing its content and purpose.

2.5.2 It should be noted that the EIRENE and MORANE Specifications are designed to provide the minimum set of requirements necessary to ensure international interoperability between GSM-R networks. Therefore, some additional requirements capture and specification may be necessary to integrate the GSM-R network into the national operational railway at both a systems and procedural level.

2.5.3 A national GSM-R specification would then be produced and used as the basis for the tender documentation necessary to support the procurement of each railway's national network. Railways must to ensure that the mandatory requirements of the EIRENE and MORANE specifications are fully taken into account when developing their national GSM-R specifications.

2.5.4 The areas covered by each section in the E-SRS can be summarized as follows:

- **network services**: this provides an overview of the network services that must be supported by the mobile radio system. The services are grouped as:
  - **GSM Phase 2 tele-services** concerning bearer and supplementary services;
  - **GSM Phase 2+ services** encompassing a number of services at the system level (including the railway driven features such as voice group calls, broadcast calls and priority and pre-emption). Rail specific services are mandated, although other advanced features are optional. Individual operators may choose whether they wish to offer these services based on their individual requirements and objectives. Phase 2+ is currently evolving with new standards being added as required;
  - **railway-specific services** not part of the GSM functionality specified by ETSI; such as functional addressing and railway emergency calls;
- **network planning**: this section draws together specifications and information related to the planning of an GSM-R network, and provides guidance on target performance levels for GSM coverage, hand-over and cell selection, call set-up time requirement and broadcast and group call areas;
- **mobile equipment specification**: within EIRENE, three types of mobile radio are identified and their requirements are covered by four separate sections of the system specifications as follows:
  - **core specification:** this provides an overview of the basic services, facilities and features that an EIRENE-compliant radio must possess to ensure interoperability;
  - **cab radio specification:** this section considers in detail the specific requirements placed on the cab radio. It identifies the system requirements for the radio and the HMI and how the functionality is to be provided;

  - **general purpose radio:** this section defines the functions and physical properties required from an EIRENE-compliant general purpose radio;
  - **operational radio:** this section defines the functions and physical properties required from an EIRENE-compliant operational radio (based on the general purpose radio but with the addition of functions to support railway operations);
- **numbering plan & call routing**: the following issues are amongst those addressed:
  - numbering plan requirements;
  - numbering plan constraints;
  - structure of Functional Numbers;
  - EIRENE numbering plan;
- **subscriber management**: this is a particular aspect of system management dealing with the requirements for provision of subscription details and other user information stored in the network. In particular, requirements for call priorities, encryption and authentication, broadcasts and Closed User Groups are detailed;
- **modes of operation**: the alternative modes to the standard mode of operation for GSM-R systems are outlined as follows:
  - **railway emergency calls:** this section describes the handling of high priority voice calls for railway operational emergencies;
  - **shunting mode**: this will be specified in later versions of the E-SRS. Shunting mode is the term used to describe the application that will regulate and control user access to facilities and features in the mobile while it is being used for shunting communications;
  - **direct mode**: this section states that the implementation of direct mode communication is optional, however in the cases where it is implemented mandatory requirements are stated. Direct mode allows mobile radio users to communicate over short distances without using the mobile network infrastructure. This mode is intended to provide short range fall-back communications between drivers and track-side personnel in the event of the failure of the mobile telephony services normally available.

2.6 Areas not covered by EIRENE Specifications

2.6.1 It should be noted that there are a number of components, essential for the functioning of an integrated radio communication system (although not directly affecting international interoperability), which are not covered in the EIRENE Specifications. These include:

- **fixed network elements**: the complete integrated communications system not only consists of the mobile network, it will also require an extensive fixed network consisting of links, switches and terminal equipment. This part of the network will require specification, with particular respect to RAM, network interconnections and capacity. It should be noted that in many cases this infrastructure already exists;
- **network services**: the EIRENE Specifications detail which services need to be supported by the mobile part of the network in order to achieve international interoperability. In addition, to provide end-to-end functionality, the fixed network must also support a specified set of services. The inter-working between the fixed and mobile side of the network must be considered carefully;
- **signaling systems**: it is assumed that the mobile network components support Signaling System Number 7 (SS7) as specified by the ITU-T. This provides signaling within each Network Sub-System (NSS) and between other NSSs, making specific use of the mobile application part (MAP) of the SS7 standard. The EIRENE Specifications do not detail any requirements for signaling systems to be used within the fixed network. It is up to the railway to specify the signaling system, taking into account the network services requirements, the network services supported by the different signaling systems and the inter-working between signaling systems used in different parts of the network;
- **network implementation**: although the EIRENE Specifications define requirements for the mobile network, they do not deal with the way in which the network (including the fixed network) is to be implemented. This will affect not only the procurement strategy to be followed by each individual railway, but also the provision of required functionality;
- **numbering plan and call routing implementation**: the EIRENE Specifications detail the numbering plan and call routing principles but do not detail the way in which it may be realized by an individual railway in terms of how number space is to be obtained, how Functional Number translation takes place, etc; (the International Call Routing Table (Routing Data Sets) is now under ENIR supervision
- **controller equipment**: although the E-FRS mentions controller equipment specifications, it does not pose any mandatory requirements. Instead, it leaves the details of the specification of such equipment, the interface between the equipment and the GSM-R network to the railway operator;
- **system management**: a major part of any communications network is the specification of the system management functionality required. This requires specification of fault, configuration, accounting, performance and security management, as well as the definition of the system management platforms. One particular area of concern is how much the GSM Operation and Maintenance Centers (OMC's) should be integrated with the overall GSM-R OMC;
- **Reliability, Availability, Maintainability (RAM) requirements**: this aspect relates to the design and dimensioning of the communications network, as well as to the on-going operations of the network. This must be considered in conjunction with network design and system management;

- **type approvals**: to allow equipment to be connected to the network, various type approvals are required. In addition, as the communications system may be considered safety related, there could be a requirement for each railway to perform safety approvals;
- **text messaging**: there may be a requirement for individual railways to transmit text messages between users of the network. As the requirements for and contents of such messages will vary per railway and per application used, each railway will be obliged to specify this as part of the individual national requirements. The GSM Short Message Service has been mandated as the mechanism for GSM-R text messaging and all Cab Radio equipment must be capable of receiving such messages.
- **roaming on to a national public GSM network**: as part of a disaster recovery strategy for a particular GSM-R network it may be decided that mobiles be able to roam on to a public GSM network in case of a loss of service. Alternatively, a GSM-R network implementer may decide to only equip some railway lines with GSM-R leaving the remaining lines to be covered by one or more public operators. It should be noted that the features available to mobiles which are roaming on to a public network are limited.

2.6.2 It is up to the individual railway to define its requirements for these aspects of the communications system and to include them in the system specification that is part of the tender documentation.

2.7 The UIC ERTMS/GSM-R Project

2.7.1 The EIRENE Memorandum of Understanding (MoU) was been signed by 32 railways and operating companies (April 1998). The signing of the EIRENE MoU demonstrated the importance attached to the development of interoperable train communication by the individual railways in the UIC.

2.7.2 The signatories of this MoU have agreed that in the development and introduction of new radio communications systems for railway operations they will ensure that full interoperability (as defined by the mandatory requirements of the EIRENE Specifications) is supported within the systems of their individual railways.

2.7.3 To complement the work carried out in EIRENE and MORANE the UIC started a new project, called ERTMS/GSM-R to take account that ERTMS is a system, formed by three elements:

- GSM-R as a radio telecommunication system and bearer system for ETCS
- ETCS as the future European train control system
- The future Traffic Management Layer, which was conceived during the EU project OptiRails and has since been developed into a working system in the Europtirails project.

2.7.4 The new ERTMS/GSM-R project combined experiences from the trial-sites and knowledge from early implementing railways. This common development has continued up to to-day. Within this project there are three permanent working groups and a number of Ad Hoc groups integrated. These groups are:

- ERIG (European Radio Implementation Group)
- GSM-R Pre Qualification Group (Pre Q)
- Functional Group (FG)
- Operators Group (OG)

2.7.5 These groups met regularly to address system requirements, functional requirements and implementation issues respectively. The groups have now been replaced by the UIC European Radio Implementation Group (ERIG), which was founded during the latter stages of Project EIRENE and has now taken over responsibility for the maintenance of the EIRENE Specifications and the co-ordination of implementation activities.

2.8 UIC European Radio Implementation Group (ERIG)

2.8.1 In order to meet the changing needs of GSM-R development as it moved from specification to implementation, ERIG was established at the beginning of 1999 to take responsibility for overseeing the standardization elements necessary to ensure the interoperability of national GSM-R implementations. The group comprises of representatives from MoU signatory railways with an interest in implementing GSM-R networks.

2.8.2 The main responsibilities of **ERIG** are as follows:

- supporting railways in their procurement of GSM-R systems, which includes setting codes of practice for network planning and supporting in setting up frequency planning agreements;
- further development of issues essential to interoperability (eg billing and tariffing, roaming agreements and network management);
- development of type approval agreements for GSM-R equipment and ongoing type approval management;
- liaising with the GSM MoU Association regarding issues such as ciphering algorithms.
- Assessing the CR’s (starting 2009)

2.9 GSM-R Pre-Qualification Group

The GSM-R Pre-Qualification Group is the first instance of discussing the Implementation Reports, which are the official way to report a malfunction, a gap or a new functionality concerning EIRENE. The group comprises together experts from CER, EIM, ERA, UIC and the ERIG groups Chairmen's. This group was created within the new CR Process, organized together with ERA. The kick off meeting was in January 2009.

2.10 Functional Group (FG)

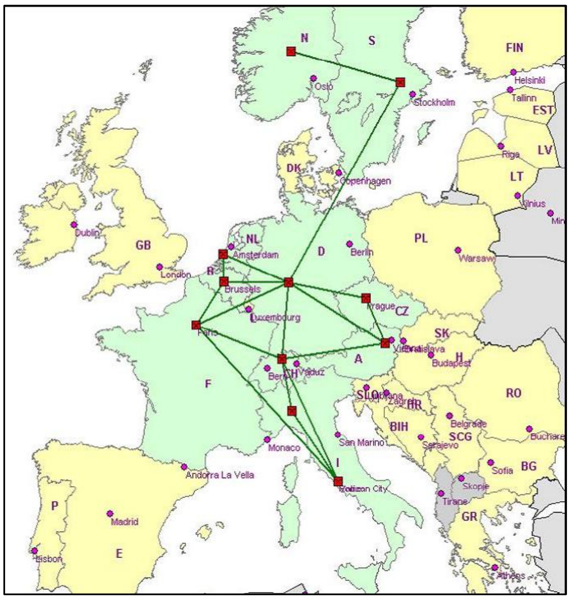
2.10.1 The main task of this expert group is to maintain the FRS, to check incoming implementation reports concerning impact to functional requirements and to raise change requests related to the FRS. The FG is also responsible for creating a new version of the FRS. The FG works with OG and the GSM-R industry Group (IG) to find the right solutions and requirements. The FG takes responsibility for the migration of functional requirements towards new and future technologies to ensure consistent railway operation.

2.11 Operators' Group (OG)

2.11.1 The main task of this expert group is to maintain the SRS, to define technical solutions for functional requirements, to liaise with ETSI, the standardization Body for GSM related to railway requirements, to create change requests, based on implementation reports, to liaise with the TIG (technical part of the Industry Group) to find solutions and to ask for technical improvement. The OG is also responsible for creating a new version of the SRS and upgrading of former MORANE documents.

2.11.2 When it is necessary to work on specific subjects, in a more detailed way, the OG forms Ad Hoc Groups with experts from the GSM-R industry and from the railways. These groups prepare the ground for a deeper analysis of specific subjects, which cannot be developed, in detail, in the permanent working groups.

2.11.3 By the end of 2007 five countries were migrated to GSM-R, or first step migrated, Italy, Germany, Netherlands, Norway and Sweden, which means more than 47. 000 km of railways migrated to GSM-R. (Arround 145.000 are planned to be covered with GSM-R in Europe).



2.11.4 End 2008 10 direct links were operational between Railways MSC's. 17 European countries were implementing EIRENE.

2.11.5 This leads to a new context, with several administrations with GSM-R networks in operation, which asked for a new approach in order to have a European harmonized network: the need to work on international interconnections, roaming agreements, roaming rules.

2.12 NMG & ENIR

NMG (Network Management Group): This group takes care for the proper interworking between the owners/operators of the different operational GSM-R network. The main objective is to have control of all prerequisites needed to fulfil the full set of Eirene functionalities for roaming users:

- Roaming and interconnection design documents
- Roaming and interconnection agreements
- Operation and Maintenance agreements (incl. Incident management, Change management, updates of routing tables, etc)
- Requirements to the interconnection network (capacity, availability, planning)
- Information database (contacts, technical documentation, etc.)

The NMG has normally three regular meetings yearly, however information exchange between the participants is not restricted to these meetings and can take place whenever needed.

ENIR (European Networks Integration for Railways Group): looking after all preparations necessary for technical migration of stand alone GSM-R networks to a European wide overlay network. This working group was founded as a centralized body to prevent unexpected and unwanted interconnections load, circular routing, mismatch of routing. Another result is having agreed guidelines and decisions for the planning and realization process (network architecture, interconnection availability, interconnection load, etc.)

2.12.1 In parallel to this railway oriented working groups the GSM-R suppliers have formed a separated group, called IG (GSM-R Industry Groups) which works on two aspects:

- a marketing part, looking for common approaches to promote GSM-R worldwide, called MIG (Marketing IG)
- a technical part, which forms the interface to the railway groups FG and OG, called TIG (Technical Industry Group)

2.12.2 To protect the specific railway features of GSM and to improve the development of the GSM standard, UIC has created, together with ETSI, an interface group that has the status of a technical committee in ETSI. Based on liaison-statements with the different committees in ETSI this group is in a position to improve the standards and to protect them against commercial encroachment from public suppliers.

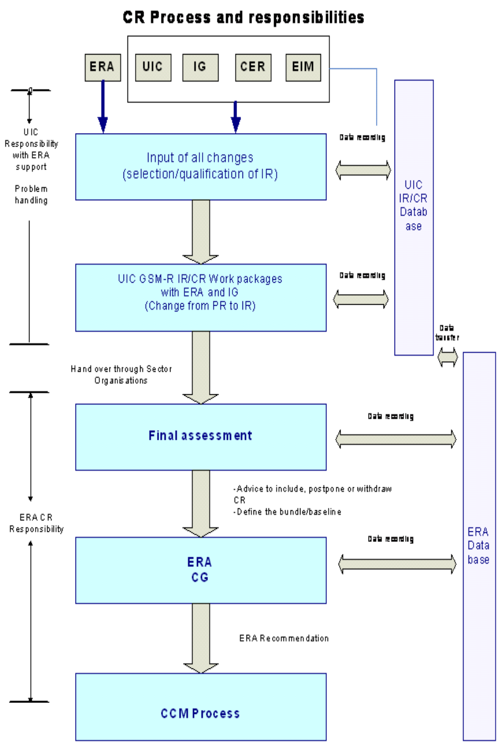
2.12.3 The ETSI Technical Committee Railway Telecommunications TC-RT (formerly Project Railway Telecommunications (EP-RT)) is responsible for the ETSI standardization of railway telecommunication aspects. TC-RT will develop and maintain ETSI standards (as necessary) for application of GSM-R to railways as required by the European Directive on High Speed Train Interoperability and by other forthcoming European Directives for railways (including the European Directive on Conventional Lines Interoperability).

2.13 European Railway Agency

2.13.1 The European Railway Agency (ERA) was set up to help create an integrated railway area within the European Union by reinforcing safety and interoperability. Its main task is to develop economically viable common technical standards and approaches to safety, working closely with railway sector stakeholders, national authorities and other concerned parties, as well as with the European institutions.

2.13.2 The Agency also acts as the system authority for the European Rail Traffic Management System (ERTMS) project, which has been set up to create unique signaling standards throughout Europe.

2.13.3 Modifications and updates to the GSM-R specifications are handled via change requests. Once a change request to the EIRENE FRS or SRS is approved by the Functional, Operators' and Technical Industry Groups it is submitted to ERA for assessment and ultimately approval.



3 Overview of GSM-R

3.1 Railway Telecommunications – The European Choice

3.1.1.1 According to the European Council Directive 91/449/EEG of 29 July 1991 concerning the development of Railways in the European Community a new telecommunications network must:

(a) be open and non-proprietary, i.e. standardized;

(b) be nationally interoperable ;

(c) allow for international train traffic;

(d) allow for open competition between train operators;

(e) support new, standardized train control systems (ETCS);

(f) be future-proof ;

(g) be able to support safety voice communication and other railway functionality;

(h) be able to support the business needs of track owners and train operators (telemetry, freight tracking etc.);

(i) allow for competition between telecom suppliers.

3.1.1.2 **1995:** UIC (International Railway Union) selects GSM as the most suitable platform for railways and specification work is started.

3.1.1.3 **1997:** 32 railway companies from 24 European countries sign EIRENE Memorandum of Understanding on 19 June 1997.

3.1.1.4 **2000:** EIRENE Agreement on Implementation on 9 June 2000 (begin GSM-R deployment 2003 at the latest).

3.1.1.5 The Council Directive 96/48/EC of 23 July 1996 for **High Speed Lines HSL** defines the following six sub-systems:

a. Control and Command (i.e. ERTMS, GSM-R and ETCS);
b. Infrastructure;
c. Energy;
d. Rolling Stock;
e. Operation;
f. Maintenance.

3.1.2 Each consisting of a number of Interoperability Constituents; and described in Technical Specifications for Interoperability TSI

3.1.3 The Council Directive 2001/16/EC of 19 March 2001 for Conventional Rail CR – analogue with High Speed Directive

- The TSIs for Control and Command – both for HSL and CR - contain a rather complex structure of generic requirements on **GSM-R** and ETCS; they contain references (indices) to underlying, detailed technical specifications. The indices referring to GSM-R are:
  - Index 32, EIRENE (UIC) Functional Requirements Specification FRS
  - Index 33, EIRENE (UIC) System Requirements Specification SRS
  - Index 34, MORANE (UIC) FFFIS for Euroradio
  - Index 48, Test Specifications for Mobile Equipment GSM-R
  - Index 61, GSM-R Version Management
- EIRENE specifications contains references to many further even more detailed specifications :
  - MORANE (UIC) for FA, LDA, etc etc
  - 3GPP (ETSI)
  - Others

GSM-R Definition

3.1.4 GSM-R is the railway radio digital system, based on ETSI GSM, and it is standardized. In Europe, GSM-R is designated as being the Train Radio and ETCS bearer solution.

A GSM-R network will be named in this document an EIRENE network, since the GSM-R specifications are named EIRENE, and a GSM-R Network is an EIRENE-compliant network.

3.1.5 An EIRENE-compliant integrated radio communications system for railway applications consists of the following main elements:

- mobile network and associated equipment;
- fixed network and associated equipment;
- mobile and fixed terminal equipment;
- interfaces to railway equipment (e.g. signaling system) and other equipment;
- system management equipment.

3.1.6 Each national GSM-R network may be based on one or more mobile GSM networks, interconnected either directly or indirectly via fixed networks. These physical networks need to be connected together such that they form a single logical network. In addition, National GSM-R networks will be interconnected to provide a consistent service across a number of countries (roaming services).

3.1.7 Figure 2-1 shows how the system elements relate to each other for the case of interoperation between two separate national GSM-R networks (Country A and Country B). The dotted arrows in the diagram represent logical links between the system elements, although not all of these links will be present for some of the possible EIRENE-compliant system implementation options.

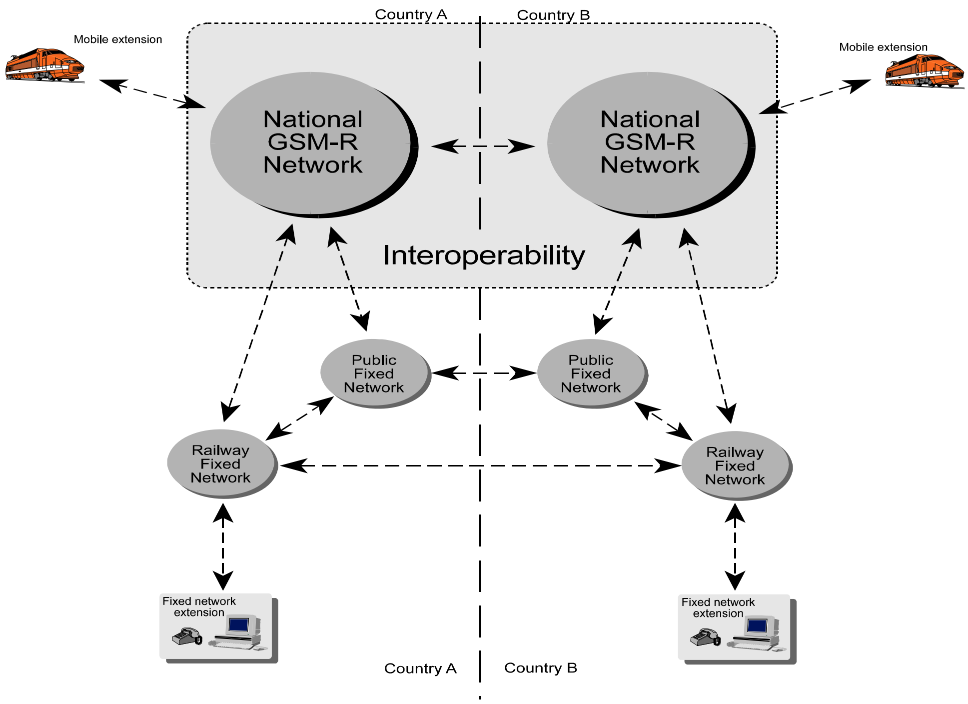


Figure 2-1: National Networks and their logical interconnections

3.2 Mobile network

3.2.1 Overview

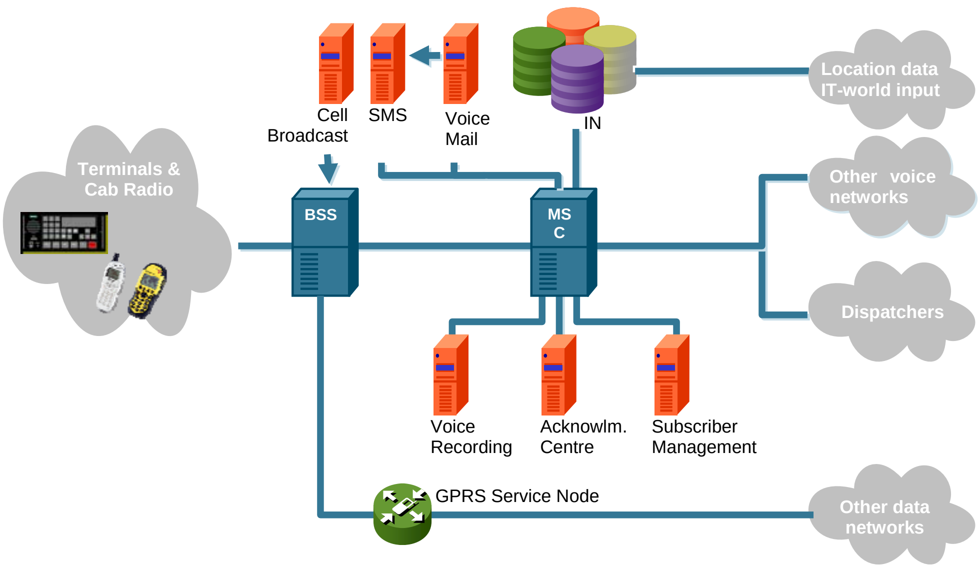
3.2.1.1 The GSM-R network is GSM based and comprises the following elements:

– **Base Station Sub-System (BSS)** of Base Station Controllers (BSCs) controlling Base Transceiver Stations (BTSs) each containing a number of transceivers (TRXs).

- **Network Sub-System (NSS)** interfacing to the BSS via the GSM 'A' interface. The NSS contains Mobile service Switching Centers (MSCs) with primary responsibility for call control. The MSC is supported by a Home Location Register (HLR) holding subscriber details on a permanent basis, and a Visitor Location Register (VLR) containing temporary details of subscribers active within the MSC area.
- **Fixed Terminal Sub-system** comprises the dispatcher terminals used by the controllers. If required, this may also contain equipment interfacing with the NSS in order to provide additional routing information based on external location information.
- **Mobile Equipment (ME)** interfacing to the BSS via the air interface.
- **Subscriber Identity Modules (SIMs)** containing information specific to single subscribers. A standardized interface links mobile equipment to SIM cards. A SIM and ME combined are termed a Mobile Station (MS). Functionally, however, the SIM card remains part of the network infrastructure, typically associated with the NSS for technical and procurement purposes.
- **Operation and Maintenance Centre (OMC)** responsible for fault monitoring and maintenance of the mobile network.
- **Management Centre** responsible for network configuration, network performance monitoring, management of subscribers to the mobile network, etc. This is typically combined with the OMC to form a Network Operations Centre (NOC).
- **Fixed transmission links** these are required to connect together the components of the mobile network (e.g. BSC to BTS links, NSS to Billing Platform links, etc). These are generally considered part of the fixed network. Interconnection links to other networks (GSM-R, public) also belong to this group.

3.2.1.2 The standard GSM system architecture is shown in figure 2-2:

Figure 2-2: Overview of GSM architecture



3.2.2 Base Station Sub-system

3.2.2.1 The BSS comprises the radio specific equipments for GSM.

3.2.2.2 **Base transceiver stations (BTS)** located at radio sites along the track provides the continuous GSM-R coverage.

3.2.2.3 Each BTS is connected to one **base station controller** (BSC) which is responsible for controlling a number of BTS in a region or along a railway line. The BSC provides the "intelligence" of the BSS and is interfaced to the Network Sub-system via a transcoder unit which modifies the bit rate between the BSC and MSC.

3.2.3 Network Sub-system

3.2.3.1 The NSS includes the main switching functions for the network, and the databases necessary to assure the mobility management.

3.2.3.2 The NSS of a GSM-R network consists of the following components:

3.2.3.3 **Mobile Switching Centre (MSC)** – The MSC is the central component of the NSS. It performs the call processing and switching functions of the system. In particular, it provides the functionality needed to handle a mobile subscriber, such as network registration, authentication, location updating, handovers, and call routing to roaming subscribers. It also provides the connection to other networks (such as the PSTN, Railways internal networks, neighboring GSM-R networks).

3.2.3.4 **Gateway-MSC (GMSC)** – The GMSC serves as an interface to other networks (PSTN, PLMN, or other GSM-R) and is capable of routing calls between across networks. The GMSC is often implemented on the same machine as the MSC.

3.2.3.5 **Home Location Register (HLR)** - The HLR is a database that holds permanent subscriber's data (such as services information), along with the current location of the mobile.

3.2.3.6 **Visitor Location Register (VLR)** – The VLR is a database that holds subscriber's information pertaining to Mobile Stations that are currently located in the VLR serving area. The VLR obtains this information from the HLR.

3.2.3.7 **The Authentication Centre (AuC)** – The AuC ensures that only authorized users have access to the network. The AuC provides parameters needed for authentication and encryption functions to help verify the user's identity.

3.2.3.8 **Interworking Function (IWF)** – The IWF provides an interface to various networks for data communications. It provides the required rate adaptation, radio link protocol, and modems to allow end-to-end connection between a mobile subscriber and a remote device for data communications.

3.2.3.9 **Short Message Service Centre (SMS-C)** – The SMS-C is responsible for the saving and forwarding of point-to-point short messages. It is also used for Over The Air (OTA) update of SIM cards.

3.2.3.10 **Group Call Register (GCR)** – The GCR contains attributes of voice group and broadcast call configurations for the related MSC area.

3.2.3.11 **Follow-me Function Node (FFN)** – The FFN is a database containing the mapping between Functional Numbers and MSISDN.

3.2.3.12 **Intelligent Network (IN)** – An IN platform may be used to implement some of the GSM-R features, such as Functional Numbering (FFN function) or Location Dependant Addressing /enhanced Location Dependent Addressing (LDA/eLDA).

3.2.3.13 **Call Recording System** – GSM-R operators may want to record some or all voice calls taking place on their networks by implementing a call recording system within the NSS. This function is not mandated by EIRENE.

3.2.3.14 **Equipment Identity Register (EIR)** - The EIR is a database that is used to prevent unapproved, stolen, or faulty Mobile Station equipment from accessing the network. This function is not mandated by EIRENE.

3.2.3.15 **Voice Mail System (VMS)** – The VMS provides the ability to leave Voice Mail messages to Mobile Subscribers. This function is not mandated by EIRENE.

3.2.3.16 **Operation and Maintenance Centre - Switch (OMC-S)** – The OMC-S is the element manager for the NSS. It provides the fault management, performance management, and configuration management functions.

3.2.4 Fixed Terminal (Dispatcher) Sub-system

3.2.4.1 This consists primarily of the consoles used by controllers to communicate with other GSM-R users, notably train drivers.

3.2.4.2 Although the EIRENE FRS mentions controller equipment specifications, it does not pose many mandatory requirements. Instead, it leaves the details of the specification of such equipment, and the interface between the equipment and the GSM-R network to the railway operator.

3.2.4.3 Extra functionality may be provided for these terminals by the addition of equipment interfacing with the NSS. The support for enhanced Location Dependent Addressing (eLDA) may be provided by routing calls based on train location information provided by a ground-based system such as a train describer. In such cases, a location database may be required which takes a feed from the train describer and correlates this information with train running numbers. This would allow for calls from drivers to be routed to the most appropriate controller with a higher degree of accuracy.

3.2.4.4 As stated in the eLDA specification [1] this ground-based approach is outside the EIRENE specifications as it does not directly affect interoperability and is therefore a matter for individual railways.

3.2.4.5 In addition to eLDA, other advanced functions can be implemented on dispatchers systems. Below are some examples:

- Text Messaging
- Role Management
- Dynamic train lists
- Phone books
- ...

3.2.4.6 The basic architecture of the FTS includes a switch (such as a PBX or GSC) and the dispatchers' terminals. The switch is connected to the GSM-R network via the MSC. This architecture performs the basic call management function.

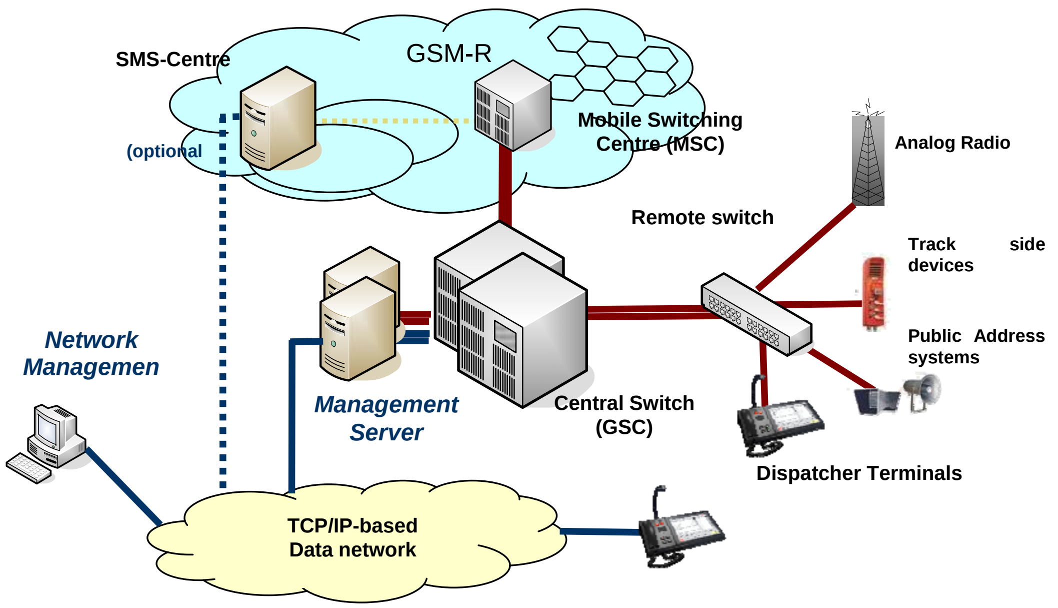
3.2.4.7 The interface between the switch and the MSC is composed of multiple E1 links carrying a variant of the ISDN PRI protocol.

3.2.4.8 To provide the more advanced functions, additional components and interfaces can be added. These are described in more detail in the section 9 System Design.

3.2.4.9 Various accessories are available for the dispatcher terminals: wireless headsets, keypads, keyboards, PTT handsets, microphones, touch screens etc. as shown in the examples below.

Example of fixed terminals

3.2.4.10 An example of such Dispatcher Network architecture is shown in Figure below.



Example of fixed terminal sub-system architecture

3.2.5 Mobile Equipment

3.2.5.1 The main items are the mobile terminals, which are located in the drivers' cabs (cab radios). This equipment is either stand-alone and provides only driver-to-ground communications, or as in most cases, the cab radio will be connected to a number of other on-board systems (for example, the public address system). In addition to the cab radio, there will be provision of portable GSM handsets which may be issued to various other users, both on the train and track-side.

3.2.5.2 Five distinct mobile radio types are required, based on the type of role they will perform and the environment in which they will operate. These are as follows:

- Cab radio – for use by the driver of a train and/or by other on-train systems;
- ETCS Data Only Radio – for use by the ETCS train control application;
- General purpose radio – for general use by railway personnel;
- Operational radio – for use by railway personnel involved in train operations such as shunting and trackside maintenance.
- Shunting radio – a variant of the operational radio with specific shunting features.

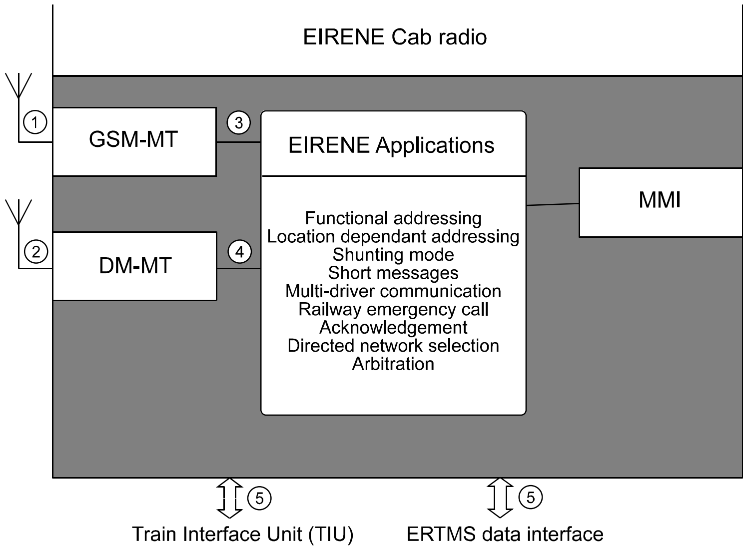
Cab Radios

3.2.5.3 The Cab Radio is the on board part of the GSM-R; being the “exposed” part to interoperability issues, since it is GSM-R component who “travels” between more EIRENE networks.

3.2.5.4 The cab radios can be GSM-R cab radios or dual mode cab radios, when GSM-R and analogue radio is provided in the same unit, in order to allow using the same machine in areas covered and not covered with GSM-R.

3.2.5.5 The figure below shows the logical architecture of an EIRENE Cab radio. The architecture comprises the following elements: (I)

- **GSM Mobile Termination (GSM-MT):** comprising GSM mobile equipment and SIM;
- **Direct Mode Mobile Termination (DM-MT):** for direct mode communications;
- **EIRENE Cab radio applications:** standardized features outside GSM;
- **Man Machine Interface (MMI).**



Logical Cab radio architecture and interfaces

3.2.5.6 The architecture comprises a number of interfaces between the different EIRENE-MS elements. These are:

1) **GSM-MT air interface:** mandatory for interoperability and conformant to GSM specifications. (M)

2) **DM-MT air interface:** Direct Mode is optional. However, where implemented, the requirements concerning this interface are mandatory for interoperability. (O)

3) **GSM-MT - EIRENE Applications interface:** specified to allow the option for separate procurement of GSM-MT and EIRENE Application equipment for the Cab radio. The MORANE FFFIS [MORANE FFFIS MTI] specifies two types of interface based on V.24 and TDMA.

   [Note: this interface is not required where a Cab radio is implemented as an integrated unit.]

4) **DM-MT - EIRENE Applications interface:** specified to allow the option for separate procurement of DM-MT and EIRENE Application equipment for Cab radio. (O)

5) Interfaces may be provided to a Train Interface Unit and an ERTMS data interface. More requirements are given on these interfaces, where implemented, in EIRENE SRS 15, subsections 5.10 and 5.15.

Examples of cab radio equipment are shown below:

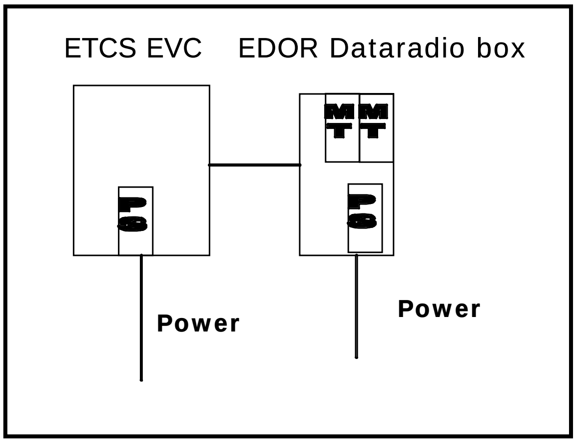
Typical cab radio equipment

EDOR

3.2.5.7 EDOR stands for *ETCS Data Only Radio* and is a data radio box that is dedicated to providing the communications for the ETCS train control application. The EDOR provides a limited set of functions and services and is exempt from many of the requirements of the other types of EIRENE mobile equipment (for example requirements relating to voice call services and the user interface).

3.2.5.8 The typical configuration of the EDOR showing Power Supplies (PS) and Mobile Terminals (MT) is shown in figure B.3.6:

Configuration of the EDOR



Handhelds

3.2.5.9 The following GSM-R handheld radios are specified

– **Operational radio** – this is a radio built to a rugged design suitable for use in the railway environment by operational railway personnel (for example persons involved in train operations and trackside maintenance). The operational radio shall provide a single red button for the purposes of making railway emergency calls, shall be able to register/deregister functional numbers and shall be capable of making/receiving group calls and broadcast calls.

Typical operational radios

- **Shunting radio** – this is a variant of the operational radio with specific shunting features. It shall provide all of the features required on the operational radio plus a number of specific shunting features such as the ability to send/receive shunting emergency calls and the link assurance signal.

– **General purpose radio –** the general purpose radio is basically a standard GSM mobile which has been adapted to operate on GSM-R networks. It is intended for use by non-operational staff (for example on-train catering staff). It offers less functionality than the operational radio (emergency call support is optional with no dedicated button and the design is less rugged). The general purpose radio is therefore a lower cost item than the Shunting Radio and the operational radio.

Typical general purpose radios

3.2.5.10 Railways need to consider the use of International Mobile Equipment Identities (IMEIs) to be able to identify and prevent the use of stolen equipment and equipment which should not be allowed in their network for technical reasons. Mobile equipment identities are managed via black, white and grey lists in the Equipment Identity Register (EIR) and the IMEI database (formerly the Central Equipment Identity Register CEIR). The IMEI database is based in Dublin, Ireland and provides a central resource to store all blocked mobile phones..

3.2.5.11 There are a number of guidelines that need to be adhered to if the IMEI is to be successfully implemented allowing the use of EIR and CEIR equipment. Failure to do so will make it impossible to implement EIR and CEIR equipment effectively. This information is available from http://www.3gpp.org/.

3.3 Fixed network

3.3.1 Overview

3.3.1.1 The fixed network implementation depends on the requirements of the individual railway and consists of private railway-specific fixed networks, public fixed networks or a combination of the two.

3.3.1.2 Whichever type of implementation is chosen, the fixed network will consist of at least the following elements:

– **network switches**: these are required to route the calls through the network to the correct called party;

– **fixed transmission links**;

- **network termination points**: these are the locations at which terminal equipment can be connected to the fixed network, where fixed networks may be interconnected and where railway-specific supporting systems can be connected to the fixed network;
- **management centre**: required for the configuration of the network, performance monitoring, fault management, management of subscribers, etc.

3.3.1.3 The fixed network may provide connections between the GSM network and fixed railway locations (control centers, stations, etc). Furthermore, it may provide interfaces to signaling systems and other railway-specific equipment to support the functionality of the integrated radio communications system.

3.3.1.4 The individual railway is free to define the fixed network and the technology on which this is based. In some cases, the fixed network may be privately owned by the railway. Alternatively, it may be provided by a third party network operator, in which case the fixed network could be a Virtual Private Network (VPN) and the physical network infrastructure will be shared with other users. It should be noted that although there is freedom in the choice of fixed network implementation, the fixed network must provide compatible interfaces and support specified services to ensure the required end-to-end functionality.

3.3.2 GSM-R network Interfaces with Fixed Network

3.3.2.1 Fixed Links are required to connect together the components of the GSM-R network across sites, and to connect the GSM-R network to external networks.

3.3.2.2 The interface to the Fixed Network can be a 2Mb/s interface or a Data Communications Network (DCN) for the following GSM-R components:

- A-bis interface between the BSCs and groups of BTSs;
- A interface between the TCU and the MSC;
- Interfaces between NSS components that are located on different sites such as inter-MSCs links, MSC to HLR or IN links;
- MSC to RBC for ETCS;
- MSC to Dispatchers' System switch;
- Dispatcher System switch to Dispatchers terminals MUXes in remote locations;
- Links to external networks (for e.g. PSTN, PLMNs, other GSM-R, Railway private telecommunication network).

3.3.2.3 Collocated network elements do not use Fixed links. They are connected through a Distribution Frame on site.

3.3.2.4 At interfaces where a 64kb/s connection is sufficient (such as links carrying SS7 signaling), a V.35 interface may be implemented. These links are sometimes used instead of 2Mb/s links to connect the MSC to the HLR, IN, or SMS-C.

3.3.2.5 DCN links are also carried over the Fixed Networks. These links include the management traffic between all the GSM-R equipment and the Network Operations Centre, or the operational traffic such as between external train location databases and the IN system.

3.3.2.6 A traffic study needs to be carried out to specify the required bandwidth on the Fixed Network to carry the GSM-R DCN traffic.

3.3.2.7 The DCN interfaces are usually 100Mb/s but can be higher. They are connected to the Fixed Network through a network router.

3.3.2.8 All critical E1 or SS7 links must be dimensioned with an N+1 redundancy. In addition, a high level of path diversity must be included in the design of the interface of the GSM-R elements to the Fixed Network to ensure the highest possible availability.

3.3.2.9 In Disaster Recovery scenarios, the Fixed Network is used to switch connections from the failed equipment (for example the MSC) to the standby equipment. This can be achieved by using pre-programmed scripts on the transmission equipment.

3.4 Network management

3.4.1 In order to operate a communications network, additional equipment is required for the purposes of network management. Equipment may be dedicated to a particular part of the network, or the entire network may be managed by a single network management system. This depends on the way in which the network is procured and implemented.

3.4.2 The basic functionality offered should take the form of distributed network management; to include fault, configuration, accounting, performance and security management functions.

3.5 Interfaces to ETCS

3.5.1 GSM-R is used as a radio telecommunication and bearer system for ETCS level 2 or higher.

3.5.2 There are a number of interfaces between GSM-R and ETCS. These are as follows:

- The fixed network interfaces between the RBCs and the MSC(s).
- The interface between the ETCS EVC and the EDOR (ETCS Data Only Radio).
- The interface between the ETCS EVC and the EIRENE Cab Radio for transferring the Train Number.

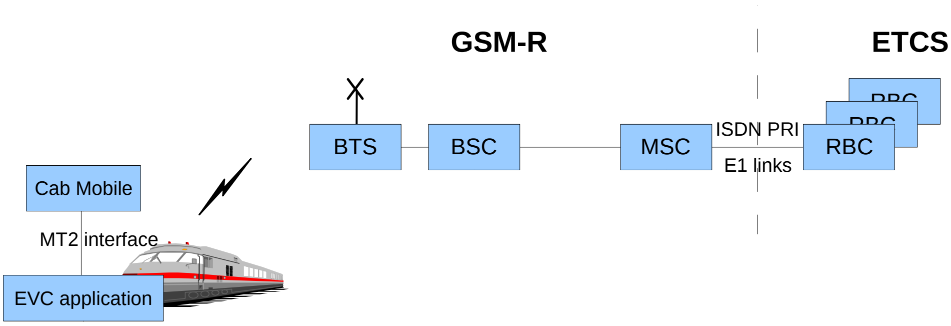
3.5.3 The first two of these interfaces are defined in detail in the FFFIS for EURORADIO.

3.5.4 The data transmitted over GSM-R is transmitted as circuit switched data using data rates specified in EIRENE. The calls are routed through the IWF function of the NSS for rate adaptation.

3.5.5 The figure below shows the interfaces between the GSM-R network and ETCS.

3.5.6 The interface between the MSC and the RBCs are redundant E1 links carrying the ISDN PRI protocol.

3.5.7 The interface between the Cab Mobile and the EVC is a standard MT2 interface.



ETCS Interfaces

3.6 The Applications - Mandatory Features

Fast Call Set Up

3.6.1 This feature is required to support the EIRENE FRS requirement for railway emergency calls to be set-up in less than 2 seconds in 95% of cases.

3.6.2 Achievement of fast call setup times requires information in the setup message to be compressed. Due to this compression, a maximum of 12 digits may be sent as mobile originator-to-dispatcher information.

3.6.3 It is important to understand the in the transmission chain for the call set-up, an important role goes to the fixed network, which could delay the call set-up; a 250 ms time for this factor is considered for the fixed network.

Location Dependent Addressing

3.6.4 EIRENE aims to offer a system of communication between driver and controller that allows the driver to contact the appropriate controller by the press of a single button or entering a common short dialing code. The driver must also be able to contact others (e.g. the power controller and the secondary controller) in a similar manner.

3.6.5 As the train progresses along its journey, it will pass through a number of different controlling areas. It is time consuming and dangerous, particularly as far as emergency calls are concerned, if the driver needs to manually determine where the train is located and then type this information into the handset before being able to make the call. Instead, an automatic updating process is required, which routes the driver's call to the correct controller at any given time. In order to be able to route the call correctly through the network, GSM-R requires train location information.

3.6.6 The called party number depends on that party's function and:

- location of train (railway area);
- track number that the train is running on;
- direction of the train running through the railway area.

3.6.7 Another parameter which may influence the routing procedure is the time of day and/or date.

3.6.8 The call always has to be routed according to the information available when the call is initiated. The location dependent routing has to be done even if no additional information is available or necessary (eg tracks without balises or railway areas not matched to radio cells).

Functional Addressing, Numbering Scheme

3.6.9 Possible options for implementing a Functional Addressing service include:

- using Intelligent Network (IN) facilities;
- within the GSM network's HLR using the 'follow-me' supplementary service;
- implementation of a dedicated switch with associated databases.

3.6.10 For each of these options, the registration and de-registration aspects need to be considered carefully. In particular, this needs to be done with a view to ensuring that roaming equipment from other railways is fully interoperable with the GSM-R network implementation.

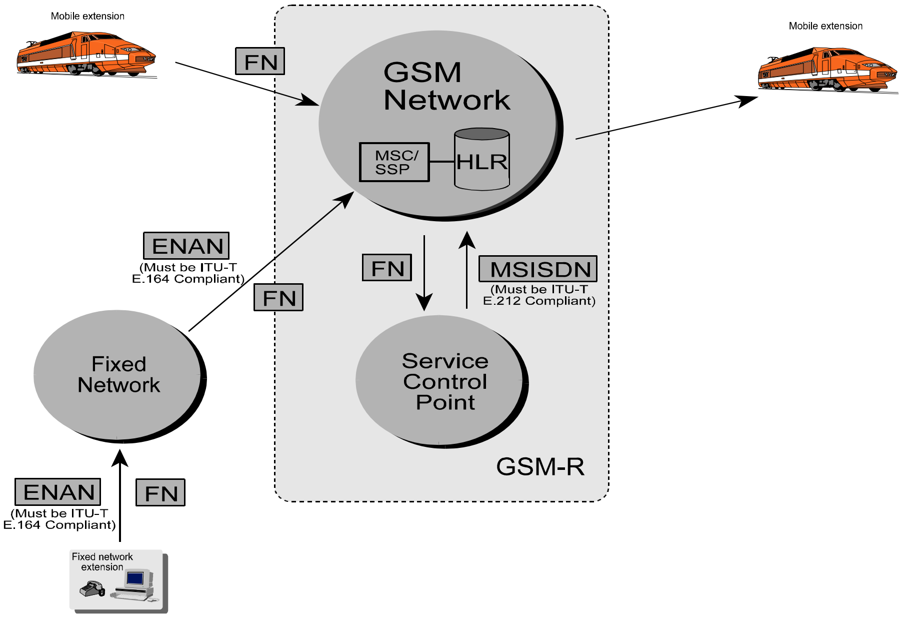
3.6.11 The most commonly used of these options is the Intelligent network implementation. The remainder of this section will therefore focus on this option.

3.6.12 In IN-based solutions, call routing is considered separately from the service provision. In these situations, Service Switching Points (SSP) are used to detect whether a calling party wishes to use IN functionality. If this is detected, then the information provided by the calling party is transferred to the Service Control Point (SCP) which will act upon the information provided.

3.6.13 If the IN solution is used within the GSM-R network, then the calling party can dial the Functional Number, which is 'trapped' by the SSP and passed on to the SCP. The SCP then performs the translation of the Functional Number into the appropriate MSISDN number and passes this information back to the SSP. The SSP will then set up the call as requested.

3.6.14 The key to IN solutions is the ability of the SSP to detect whether a calling party wishes to use IN functionality or not. In public fixed networks this is normally achieved by using specific dialing codes. If the IN solution were to be used in a private network environment, then the initial digits dialed could be used to act as a trigger1 for the SSP.

3.6.15 Within GSM-R networks, the IN solution will rely on the combination of the mobile subscriber profile and the number dialed. When a mobile user, who is registered to use IN services, dials a Functional Number, the GSM SSP will 'trap' this number based on the subscriber profile and pass the information to the SCP, after which the associated MSISDN number is passed back to the SSP. This is shown in figure B.4.13.



IN implementation

[1] Triggers are call-related conditions that cause a switch to interrupt its own processing of the call and launch a query to an SCP.

3.6.16 It is not possible to use the same approach if a calling party wishes to establish a link using a Functional Number from a fixed terminal. For calls from fixed extensions, the calling party would establish contact via the fixed network by dialling the appropriate GSM-R Network Access Number (ENAN), which forms the 'trigger' for using IN services.

3.6.17 Once the connection is established, the Functional Number is passed via the fixed network and the MSC/SSP to the Service Control Point, where it will be translated into the MSISDN number of the appropriate mobile equipment. Using this number, the call will then be set up via the GSM network to the correct mobile extension. Alternatively, the Subscriber Number could be called using the National Destination Code plus the MSISDN number.

3.6.18 Note: It is possible that the General purpose and Operational radios may have a number of variants to meet railway requirements.

Group & Broadcast Calls

3.6.19 Group calls and broadcast calls are used widely in GSM-R, for example, railway emergency calls use the group call service and so do most shunting communications. Broadcast calls are used to provide information to a certain group of users, for example when controllers wish to give information to all drivers in the area.

3.6.20 The group or broadcast call area used will have the effect of determining which mobiles can participate in the call (i.e. those currently within the area defined). The area over which the call takes place is determined by one, or a combination, of the following:

- the location of the call initiator (if mobile-originated);
- the identity of the group being called (e.g. all users, all trains, etc);
- a prefix to the group identity specifying the call area (if fixed network-initiated).

3.6.21 Group or broadcast calls initiated in a given location are broadcast over an associated area based on the location of the call originator, and also to any fixed network numbers associated with the originating location.

3.6.22 Group calls in GSM-R are based on the GSM ASCI Voice Group Call Service (VGCS) whereas broadcast calls are based on the GSM ASCI Voice Broadcast Service (VBS). However, it should be noted that these specifications contain implementation options. The options required for GSM-R interoperability are as stated in [MORANE ASCI OPTIONS]

3.6.23 Group calls in GSM-R are based on a single channel solution. DTMF signals are required for muting and un-muting control and for termination of the calls from fixed line dispatchers. Further detail is provided in the EIRENE Specifications.

eMLPP

3.6.24 eMLPP stands for enhanced Multi-Level Precedence and Pre-emption and is a mandatory feature in GSM-R. As the name suggests, the service has two parts - precedence and pre-emption. Precedence involves assigning a priority level to a call in combination with fast call set-up. Pre-emption involves the seizing of resources, which are in use by a call of a lower precedence, by a higher level precedence call in the absence of idle resources. Pre-emption can also involve the disconnection of an on-going call of lower precedence to accept an incoming call of higher precedence.

3.6.25 The following table summarizes how the eMLPP levels are used in GSM-R:

UIC Priority	eMLPP priority designation	Pre-emption (of)
Railway emergency	0	Control-command (safety) and below
Control-command (safety)	1	Public emergency, group calls between drivers in the same area and below
Public emergency and group calls between drivers in the same area	2	Railway operation. Control-command information and below
Railway operation (eg calls from or for drivers and controllers) and Control-command information	3	Railway information and all other calls
Railway information and all other calls	4	-

Emergency Calls

3.6.26 A Railway Emergency Call (REC) is a group call for informing drivers, controllers and other concerned personnel of a level of danger requiring all Railway movements in a pre-defined area to stop. Two types of Railway emergency calls are defined:

- Train emergency calls (for Railway emergencies whilst not involved in Shunting operations);
- Shunting emergency calls (for Railway emergencies whilst involved in Shunting operations).

3.6.27 Railway emergency calls do not cover public emergencies (i.e. 112 and 999 calls), which are handled by GSM-R at a lower eMLPP priority (please see the previous section on eMLPP for further details).

3.6.28 A Railway emergency call may be defined in three distinct phases. These are as follows: (I)

- Stage 1: Warning (where an alarm tone is sounded for 5 seconds)
- Stage 2: Information (where speech from the originator to the recipients is possible, followed by the possibility for the other participants to take the uplink and provide information)
- Stage 3: Terminate Railway emergency call.

Cell reselection

3.6.29 In GSM-R the mobiles operate in two modes: these are called idle mode and dedicated mode (the latter being when the mobile is involved in a circuit switched communication). When in idle mode, the mobile monitors the network in order to check whether it is being paged. It also measures the BCCH carrier in neighboring cells and decides whether it should camp on that cell instead. The process of changing cells in idle mode is called cell reselection. This can be contrasted with the mobile's behavior in dedicated mode (i.e. during a call) where the process of changing cell is called a handover.

3.6.30 Cell reselection can have a negative impact on applications that require a certain configuration and availability of resources to work properly. For example, in cases where the mobile is involved in GPRS (General Packet Radio Service) communications.

3.6.31 In the case of GPRS, during cell reselection the mobile aborts its operation on the old cell (e.g. when the user leaves the radio range of an area), reselects a new cell and attempts to set up a packet data transfer which may fail because the new cell may not have sufficient capacity to support another mobile. If this is the case, the mobile must now wait and try to set up the transfer again or will have to reselect to another cell capable of accommodating its request for a packet data transfer. In worst case scenarios, this process can be lengthy, therefore the issue needs to be avoided by careful network planning/dimensioning, capacity modeling and subscriber management.

Bulk registration

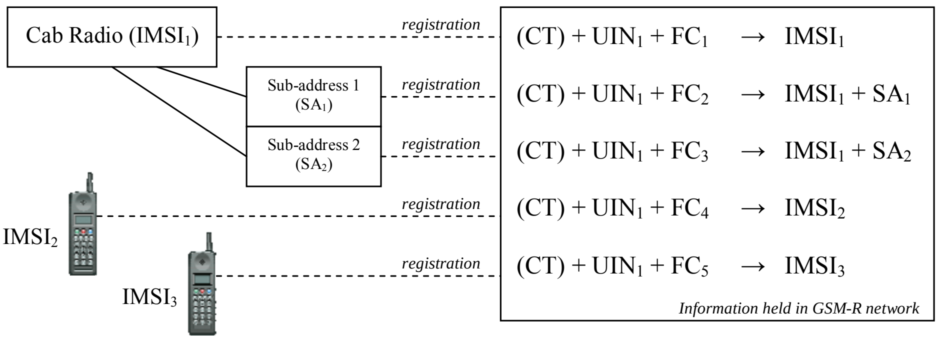
3.6.32 The EIRENE FRS states:

11.3.2.3 It shall be possible to register ten functions on the same functional number within 30 seconds from a single mobile. (M)

3.6.33 The cab radio needs to be able to register functional numbers rapidly to its sub addresses (other terminals or applications directly connected to the cab radio). All of the required information for this process (with the exception of the new UIN - which would have to be input manually) could be stored within the application of the cab radio and could be readily transmitted to the network for the bulk (global) registration of these functions.

3.6.34 For the registration of other mobiles, the registering mobile must send to the GSM-R network a complete list of the functional numbers to be registered along with the IMSIs of the mobiles it wishes to associate with these functions. In order to accomplish the registration within 30 seconds, this information may have to be pre-programmed into the mobile application, which may not be practical. This depends on how the registration time is to be measured, which is not stated in the requirement.

3.6.35 The following figure provides an example of the information that will be stored in the network after mobile equipment registrations have been successfully completed:



ETCS (QoS)

3.6.36 One of the major applications for GSM-R is ETCS. GSM-R is the only bearer for ETCS.

3.6.37 In order to fulfill ETCS needs, a more stringent set of requirements described in EIRENE needs to be applied to the GSM-R network. The Quality of Service requirements are described in Subset 093. The test cases and the test conditions for measuring Subset 093 fulfillment are described in the UIC document O-2475, v 3.0 (Subset 093 – GSM-R for ETCS QoS Requirements)

3.6.38 For the transmission of information between OBU and RBC, the EuroRadio protocol uses the bearer services of a GSM-R network. The service provider makes these data bearer services available at defined interfaces.

3.6.39 The data bearer services are described as data access and transfer in the GSM network from Terminal Equipment (TE) on the mobile side (i.e. OBU) to a network gateway interworking with Public Switched Telephonic Network (PSTN) or Integrated Services Digital Network (ISDN) on the fixed side (i.e. RBC).

3.6.40 The following features and attributes of the required bearer service shall be provided:

(a) Data transfer in circuit switched mode;

(b) Data transfer allowing multiple rate data streams which are rate-adapted [GSM04.21] and [ITU-T V.110];

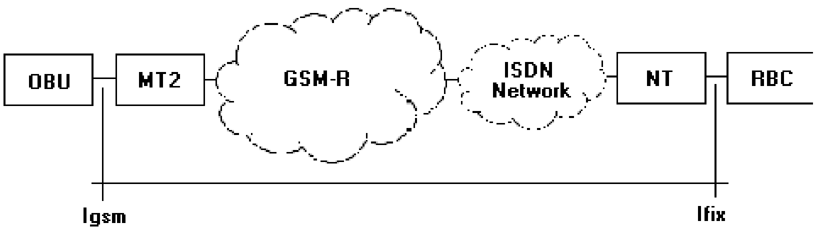
(c) Unrestricted Digital Information (UDI) – only supported through ISDN interworking (no analogue modem in the transmission path);

(d) Radio channel in full rate;

(e) Transfer of data only (no alternate speech/data);

(f) Transfer in asynchronous transparent mode.

3.6.41 As an end-to-end bearer service is used, a restriction of requirements on the service quality placed on the air interface is not sufficient.



3.6.42 The network shall be able to support transparent train-to-trackside and trackside-to-train data communications at speeds up to 500 km/h e.g. in tunnels, cuttings, on elevated structures, at gradients, on bridges and stations.

3.6.43 The parameters are valid for one end-to-end connection for one train running under all operational conditions.

3.7 The Applications - Optional features

eLDA

3.7.1 eLDA is short for enhanced Location Dependent Addressing. This is an optional feature that improves the accuracy of GSM-R Location Dependent Addressing by making use of data from systems external to GSM-R (for example GPS, balises and trackside train detection systems).

3.7.2 Please note that eLDA is not applicable to emergency calls, group and broadcast calls, GPRS calls or SMS message transfer.

3.7.3 eLDA is specified in the eLDA FRS and IRS and is intended for use in situations where it is recognized that the accuracy of cell dependent addressing is not sufficient.

3.7.4 Key requirements of eLDA are as follows:

- eLDA call setup shall not require any additional manual action, in comparison with LDA call setup.
- eLDA call setup times shall meet the call setup timing requirements for point to point calls as specified in the EIRENE specification (i.e. [EIRENE FRS])
- The eLDA system shall be specified in such a way that it will be possible to transmit train location data over the air interface with a granularity equivalent to a distance of 1 meter or better

Shunting

3.7.5 The EIRENE FRS and SRS describe the requirements for shunting, Although shunting as a GSM-R application is optional, some shunting features are mandatory in all cab radios. The shunting requirements have been written as a compromise between the different existing shunting procedures adopted by national railways, but with the view to integrate additional common features to make shunting safer and more viable. These features include the link assurance signal, protected group calls and shunting emergency calls.

3.7.6 During 2007, an ad-hoc working group has been tasked to improve further the shunting requirements in conjunction with a group of expert users. This has resulted in a number of changes to the specifications to add more desired functionality whilst preserving and enhancing the flexibility of the solution.

3.7.7 The main proposed changes to the specification are as follows:

- Addition of a new section for the Operational Shunting Radio (OPS). The principle behind this is that the OPS will be based on the standard Operational Handheld Radio (OPH) with the addition of a number of extra features to support shunting.
- Improved specification for the OPS user interface.
- Removal of the need for members to register to functional numbers.
- Increased flexibility in the realization of the link assurance signal functionality and the use of the push-to-talk (PTT) button. A number of parameters relating to these functions will be set according to national preferences by maintenance personnel, thus allowing a single piece of equipment to support diverse operational concepts in different countries.
- Addition of point-to-point calls as well as group calls for shunting.
- Updated requirements on climatic conditions.

3.7.8 It is anticipated that these changes will shortly be finalized with GSM-R Industry and will then be introduced via EIM and CER into the ERA Change Control process and incorporated into the next releases of the EIRENE FRS and SRS.

Direct Mode

3.7.9 The EIRENE specifications define an option for the provision of direct point-to-point communications between personnel for instances where the services normally provided by the GSM network become unavailable. This system is known as direct mode.

3.7.10 The operational requirement for direct mode is to:

– provide short range fall-back communications between train drivers and trackside personnel in the event of failure of all railway and/or public GSM services normally available;

– provide short range communications for railway personnel operating in remote areas where no GSM facilities are available.

3.7.11 For further details of direct mode, please refer to the EIRENE FRS and SRS sections 15.

GPRS

3.7.12 GPRS stands for the General Packet Radio Service and the implementation of GPRS is an option in the GSM-R specifications.

3.7.13 GPRS is a data service that uses radio resources only when data is actually sent. The channel utilization for some applications is therefore significantly more efficient, leading to a more economic use of the available bandwidth.

3.7.14 GPRS enhances GSM data services significantly by providing end-to-end packet switched data connections. GPRS is particularly advantageous for traffic where short bursts of data communications activity are interspersed with relatively long periods of inactivity.

3.7.15 Communications between mobile applications and the network are managed as sessions, although there is no permanent end-to-end connection. Once a session has been established, users can be continuously on-line without using network resources when data is not being sent. Data packets can be transmitted rapidly when communication is required. In this way, a given amount of radio bandwidth can be shared between multiple users simultaneously.

3.7.16 GPRS will be implemented by adding new packet data nodes and upgrading existing nodes to provide a routing path for packet data between the wireless terminal and a gateway node, which inter-operates with external data packet networks. GPRS allows point-to-multipoint (PTM) services, which is not possible in circuit switched networks.

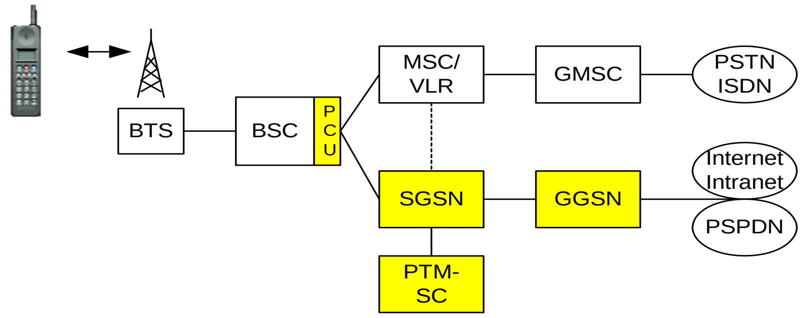
3.7.17 The following additional infrastructure elements are required to support the packet radio services.

– **Serving GPRS Support Node (SGSN)** - a location register function storing subscription information and location information for each subscriber registered in that node. It interfaces to the BSS via the Gb interface and to the MSC/VLR via the Gs interface and to the HLR via the Gr interface.

– **Gateway GPRS Support Node (GGSN)** - a location register function storing subscription information and routing information (needed to tunnel packet data traffic destined for a GPRS MS to the SGSN where the MS is registered) for each subscriber for which the GGSN has at least one PDP context active. It interfaces to the SGSN via the Gn interface, to the HLR via the Gx interface, to external packet data networks via the Gi interface and to other GSM/GPRS networks via the Gp interface.

– **Point-to-Multipoint Service Centre (PTM-SC)** - Handles Point-to-Multipoint traffic between GPRS and the Home Location Register (HLR) of the network.

3.7.18 Implementation of GPRS will require few changes to the existing GSM nodes. Transmission between BTS and BSC will remain the same for GSM networks after the addition of GPRS. However, the BSC will require a Packet Control Unit (PCU), to control the packet channels. The following figure shows the network architecture of a GSM-GPRS network. New and enhanced nodes are highlighted in yellow.



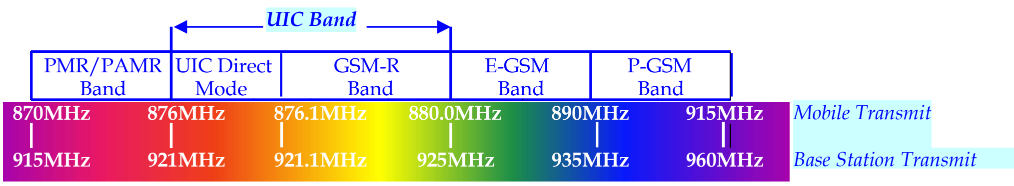
GPRS in a GSM-R architecture

Typical GPRS terminals

3.8 Future features

GPRS for ETCS

3.8.1 The frequency band allocated for Railway use for GSM-R is limited to 4MHz. This means that 19 frequencies are available in most countries, providing a limited number of circuit switched traffic channels for voice or data transmission.



GSM-R spectrum and surrounding frequency band

3.8.2 Some railways have identified that sufficient GSM-R capacity is unlikely to be available to support ETCS level 2/3 (in addition to the other data and voice applications) in densely trafficked areas2 because each ETCS onboard unit engaged in a data call (and each voice and non-ETCS data call) will occupy an entire traffic channel.

3.8.3 Depending on network configuration, GPRS can support seven subscribers interspersing their data on each available packet data traffic channel (c.f. circuit switched data where only one user can be supported on each traffic channel). This represents a significant potential saving of radio resources.

3.8.4 GPRS also has the potential to provide faster data transmission, improve the handling of RBC-RBC handovers and could provide more efficient solutions for key management.

3.8.5 At present, the ETCS train control application only operates over a circuit switched GSM-R bearer.

3.8.6 UIC has provided in 2006 the GPRS for ETCS White Paper, followed by a CR. The CR was and is still pending; waiting for clear proves about the robustness of GPRS when bearing the ETCS data.

3.8.7 In 2008, a feasibility study was launched by EEIG/UNISIG/UIC to prove that GPRS is suitable for ETCS. The WG has first compared GPRS against Circuit Switched in the Subset 093 context, based we have produced a common agreed set of Test Cases. The test are focused on the GPRS main parameters – GAPR Activation/Deactivation Delay, PDP Context Activation/Deactivation, First Packet, and on Delay Distribution.

3.8.8 A Test Campaign was held end 2008 in Belgium, with the support of the B-Holding and NSN experts. The tests showed that the transmission is fast, and the minimum gain in frequency usage is 300%- e.g. at least three mobiles can use in parallel (in ETCS mode application only) one single time slot.

3.8.9 Beginning 2009 we have performed a first test campaign in Italy, with the support of RFI and NSN experts, in their Lab, in Milano, and another live test campaign will be held on Milano-Bologna HSL. The target is to finalize the feasibility study, and to promote the GPRS for ETCS CR, as an option, in 2009/2010.

3.8.10 EDGE

3.8.11 Further improvements to GPRS (principally to the speed of data transmission) could be realized by enhancing the network and mobiles with Enhanced Data for GPRS Evolution (EDGE). The following figure illustrates the raw data rates that can be achieved with the available coding schemes (the figures are in kbps).

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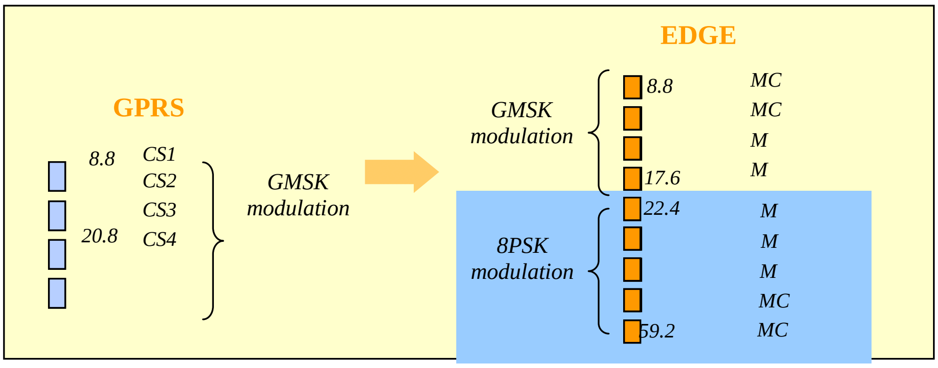
[2] For the purposes of illustration, the limits of capacity are likely to be reached in a cell with 22 traffic channels when more than 15 ETCS onboard units are engaged in data calls (assuming that 7 traffic channels will be sufficient to support all other voice and non safety related calls).



High performance coding schemes brought in by EDGE modulation

3.8.12 EDGE is not a replacement for GPRS; it is an improvement in the bearer and would improve the data rate. Furthermore, EDGE will continue to use the same TDMA frame structure, logical channel and 200 kHz carrier bandwidth, but with new modulation techniques so there should be no implications on GPRS ready applications as a result of changing from a GPRS bearer to a GPRS bearer enhanced by EDGE.

On Board Applications

3.8.13 On-board train equipment is becoming more and more reliant on radio communications. Additionally, passenger and crew needs for radio services are also increasing.

3.8.14 Services such as on-board internet access for passengers are now possible using a range of technologies including satellite, Wi-Max and WiFi.

3.8.15 It is unlikely that GSM-R can be used to satisfy high-bandwidth applications, particularly those that are revenue generating.

3.8.16 In countries where spectrum has been reserved for GSM-R there is generally a condition that the GSM-R services are only to be used for railway operations and not for commercial applications.

3.8.17 Additionally, GSM-R has limited bandwidth. Whilst the throughput offered by GSM-R and its supporting technologies is sufficient for voice and train control applications, high-speed internet access cannot reliably be offered to passengers using GSM-R.

3.8.18 Low bandwidth applications however, such as live seat reservation, train condition monitoring, crew desk, etc. , could use GSM-R as a bearer.

eREC

3.8.19 Current analogue systems used for train-ground communication are often based on the selection of an appropriate channel for each area or line. Thus, in an area where there is for example a conventional line parallel to or crossing under/over a high speed line, a call related to one line can have no impact on the other line because the channels used can be different.

3.8.20 With emergency calls in GSM-R, there is no similar distinction between track lines and appropriate use of channels. Therefore, when a REC is initiated in such area, the trains on the other line(s) can also receive the REC.

3.8.21 The consequence of this can be to stop trains unnecessarily on lines that are not affected by the emergency. This can be a big drawback in terms of the costs of delays, particularly when a high-speed train is stopped to due to a conventional train.

3.8.22 eREC stands for enhanced Railway Emergency Calls and its purpose is to provide a solution to this problem by enabling Railway Emergency calls to be set up only to the subscribers/lines that are directly affected.

3.9 Encryption and authentication algorithms

3.9.1 Examples of GSM cryptographic algorithms are:

- A3 and A8 authentication algorithms (commonly combined as A3/A8 of which COMP 128 is an example);
- A5/3 encryption algorithm.

3.9.2 Of interest to railways proposing to implement private GSM networks is securing the use of voice privacy (encryption) algorithms and authentication algorithms for SIM cards. The following points should be noted regarding algorithms:

- The ETSI GSM specifications only refer to the algorithms in general terms (i.e. they do not specify them in detail).
- The use of standardized voice privacy algorithms is mandatory for a GSM-R network.
- Each railway is free to implement its own authentication algorithms providing that there is no resulting loss in cross-border interoperability.
- Encryption for voice group calls is not required.

3.9.3 Examples of the A3 and A8 algorithms are freely available (see 3GPP TS 55.205 "Specification of the GSM-MILENAGE Algorithms”). Download, implementation and use of the example algorithm set is subject to the terms indicated in the document only and is available at no cost.

3.9.4 National railways will be able to secure the use of the A5/3 algorithm, which is owned by ETSI by ordering it through TC-RT (contact details are provided on the GSM-R Website (http://gsm-r.uic.asso.fr/). It should be noted that other algorithms are available for use by railways.

4 System infrastructure provision

4.1 Introduction

4.1.1 One of the aspects to be considered when procuring a communications network is the way in which the network is to be implemented. Although the EIRENE Specifications provide a set of requirements for the communications system, they do not give guidance on procurement of the network infrastructure. This section is provided to give a summary of the infrastructure procurement options that are available.

4.1.2 As railways have to comply with the EC Interoperability Directive it is important to consider whether any particular implementation could lead to difficulties in achieving interoperability with other GSM-R networks.

4.1.3 It should be noted that, although this section discusses the implementation options for national GSM-R networks (ie the mobile network part of the overall integrated radio communications network), similar considerations need to be given to the fixed network. This is, however, the responsibility of the individual railway and falls outside the scope of this guide.

4.2 Implementation aspects overview

4.2.1 The options available for the implementation of an EIRENE-compliant network may be considered from two viewpoints:

- the aspects relating to the implementation of GSM-R on a national basis in order to provide a suitable national communications infrastructure;
- the aspects relating to the implementation of GSM-R on an international basis to ensure interoperability with other national GSM-R networks.

4.2.2 This section is concerned with the provision of a suitable national communications infrastructure. Aspects relating to international interoperability will be addressed in section 4.

4.2.3 Section 5 of this guide will then consider additional aspects that have an impact on system planning and specifications and need to be considered whatever implementation is chosen by the individual railway.

4.3 Overview of national implementation options

4.3.1 One of the main factors that will influence the national implementation of GSM-R is the nature of the GSM network to be used. Three main options are available:

- Public GSM network;
- Private GSM network;
- Hybrid GSM network, in which a private and a public GSM network are integrated in order to potentially provide a more cost-effective implementation.

4.3.2 Similar implementations need to be considered for the fixed part of the communications network, leading to a large number of possible combinations for the implementation of the full communications network.

4.3.3 It should be noted that it is outside the scope of this guide to consider each of the full network implementations in detail. Instead, this guide will consider the options for the mobile network (ie the GSM network and air interface) and look at the issues associated with each of the available implementations.

4.4 National implementation using a public GSM network

4.4.1 Using a public GSM network means that the mobile side of the network will be out-sourced to a public network operator. In this case, the railway will have limited control over the way the network is implemented and operated, as the railway will probably form only a small part of the network operator's overall customer base. The network operator may also have conflicting commercial considerations.

4.4.2 It should be noted that some railways are partners in public GSM networks and may therefore find greater advantages than other railways in the choice of this implementation option.

4.4.3 In order to implement a GSM-R network using a public GSM network, the following issues must be addressed, with particular reference to each of the prospective network operators:

- the current areas of coverage provided by the network operator and how this compares with the designated coverage area required for the implementation of GSM-R;
- the level of coverage recommended by the EIRENE Specifications and required by the national railway and how this compares to the level of coverage provided by the network operator;
- the mechanism for the public network operator to provide any additional coverage required by the railway and organizational aspects such as the access to sites for installation;
- the provision of special GSM solutions for tunnels and cuttings, the ability of the network operator to either provide these solutions, sub-contract for their provision or to work with an independent contractor;
- the level of required GSM supplementary services that are provided by the network operator such as USSD, VGCS, VBS, UUS1 and eMLPP. Some public GSM network operators may not provide some or all of the additional services required to meet the EIRENE Specifications;
- compliance with the relevant standards, which include the EIRENE Specifications and the MORANE FFFIS for EURORADIO.

- the standards and methods that will be used to assess the service provided by the network operator and the system of penalties that will be enforced if the network operator does not perform to the required level;
- the extent to which the public GSM network operator will be willing to support all of the railway applications. Some network operators may have concerns over the provision of safety related voice communications or the use of radio for low cost signaling.

4.4.4 Each of these aspects needs to be addressed in the technical specification of the network and the railway needs to consider in which way any deficiencies could be resolved.

4.5 National implementation using a private GSM network

4.5.1 With this option, the railway operator is given a more or less complete degree of freedom and the network could be effectively designed to meet all of the functional and system requirements, albeit at a certain cost. There are, however, specific aspects that need to be addressed when considering the implementation of a private network.

4.5.2 One of the main considerations when deciding on the implementation of a private GSM network is to ensure that the network conforms to the existing GSM regulations. The GSM MoU and ETSI administer these regulations and further details about these standards and how they relate to other EIRENE related standards and regulations are given in section 2.7 of this document.

4.5.3 The availability of frequencies will also need to be considered, given that there is a requirement in the EIRENE Specifications to conform to the correct operational frequency bands. The particular aspects related to the allocation of frequencies are further discussed in section 5.3.

4.5.4 The other major consideration when implementing a private GSM network is to ensure that the proposed network implementation will lead to a fully functional GSM-R system within acceptable budget constraints and that ongoing revenue costs (such as the provision of maintenance and service) will meet the targets set out in the Business Case.

4.5.5 Before implementation, a detailed study may need to be conducted in order to establish the cost of providing private GSM coverage over the designated area. This will require survey data of the rail network and the surrounding area in order to determine where base stations need to be implemented and the number of installations that will be required. In addition, this will highlight any aspects of planning permissions required for the base station implementations.

4.5.6 As with the public network implementation, methods may need to be introduced to assess network performance after implementation, albeit that in this implementation the railway will have more direct control over the levels of performance and the ways in which these can be maintained.

4.5.7 When implementing a private GSM network, the railway has to identify the best sites and characteristics of the base stations. This involves a prediction of radio coverage using dedicated coverage tools to determine the optimum base station parameters (eg location, type, antenna, mast height, etc). In designing the network, the railway should take into account:

- transmission power and receiver levels of the mobiles on the trains;
- location of base stations on railway property;
- provision of telecommunications and power;
- site constraints (e.g. mast heights, environmental restrictions);
- resilience requirements;
- planning permission requirements.

4.5.8 In addition, the railway operator will need to procure the additional equipment of the GSM network (BSCs, MSCs and management systems). Finally, the railway must decide on the way in which the network elements are interconnected.

4.6 National implementation using a hybrid GSM network

4.6.1 A hybrid implementation will usually take one of the following forms:

- the private provision of GSM coverage to operate alongside an existing public GSM network. In this situation, the railway operator will fund, install and interconnect the additional network elements required to meet the railway mobile network requirements. This will lead to areas of private coverage, which will operate alongside the coverage areas provided by the public network. In this situation, there will be interoperability aspects to be addressed for the national use of the system;
- the funding of GSM network infrastructure enhancements by the railway in order to make the provision of required coverage economically viable for the network operator. In this situation, the GSM network operator will own the completed network, but the railway will finance the network enhancements required for the installation of an EIRENE-compliant system. The final result of an implementation of this type will therefore be no different from the case of a public GSM network, although there are additional implementation considerations.

4.6.2 The issues related to this type of network implementation are:

- equipment compatibility considerations with the existing public GSM network;
- that there may be difficulties in providing additional network services (in particular the Phase 2+ supplementary services) if these services are not already supported by the public network;
- any business benefits that the public network receives from the private enhancements should be addressed (for example, in terms of adjustments to the costs incurred by the railway for the services provided by the network operator);

– the cost of implementing the enhancements and the benefits that this will provide to the GSM-R network over and above the service that can already be provided using the existing public network should be considered;
– with whom the responsibility for the maintenance of equipment lies;
– the introduction of methods to monitor network performance after implementation, to determine the performance responsibilities of the network operator and to establish and enforce a system of penalties if the required level of service is not provided.

4.6.3 In this situation, the railway operator must assess what the GSM network operator already provides, what he is willing to provide in addition and whether this will be feasible on a commercial basis. Furthermore, the railway operator must consider the willingness of the GSM network operator to accept the required enhancements to the network and the associated cost implications.

4.6.4 The railway needs to consider whether the public GSM network operator will be willing to support all of the railway applications. Some network operators may have concerns over the provision of safety related voice communications or the use of radio for low cost signaling.

4.6.5 Enhancements to an existing GSM network must be considered in terms of how busy the individual routes are and the perceived benefits of implementing them. For example, it may make the most sense to implement a private GSM-R network covering the busiest railway routes and make use of public GSM coverage in the other areas. Alternatively, one may choose to finance enhancements to a public network on the busier sections of the rail system and rely on the existing level of coverage for the remainder of the network. It should be noted that the problem with this approach is that, in general, the public GSM coverage in low traffic areas is low, so the cost of this implementation may not be significantly less than for an entirely private network.

5 International numbering and call routing considerations

5.1 Overview

5.1.1 Although individual railways will not be responsible for the installation of an international network, they are still obliged to achieve international interoperability. This section deals with the options available to accomplish this interoperability, with particular reference to functional considerations such as the numbering plan.

5.1.2 The considerations for international implementation concern the conservation of interoperability requirements of the GSM-R network across national boundaries. In order for interoperability to be achieved, there are several issues requiring consideration:

- the provision of a consistent numbering plan and how this relates to the numbering systems used in other GSM-R networks;
- the call routing mechanism that is used in the network and how this may be interfaced to another GSM-R network;
- the movement of trains across international boundaries and the procedures that are available for addressing the on-board equipment by Functional Number alone (ie without the need for knowledge of the origin of the train);
- the system for call logging and performance monitoring that has been used in the network and how this will operate for international services;
- the compatibility of mobile equipment from network to network and the provision of supplementary services for the Phase 2 and Phase 2+ implementation;
- the additional data and signaling systems integrated with each national GSM-R implementation and how these will operate for international services.

5.2 EIRENE call routing & numbering plan

5.2.1 Introduction

5.2.1.1 One of the main aims of the EIRENE Specifications is to ensure interoperability between railway communications networks of the future. Interoperability is a key feature of communications networks, not only because it will allow trains to roam seamlessly between countries, but also because it will allow co-existence of GSM-R and other networks.

5.2.1.2 A prerequisite of interoperability in communications networks is the agreement on a common standard numbering plan and associated call routing. In public networks, the numbering plan is defined internationally in the ITU-T E.164 recommendation (note that for land mobile networks, compliance with ITU-T recommendations E.212, E.213 and E.214 is also required). These recommendations mandate the structure for ISDN numbers in order to ensure international interoperability for fixed and mobile communications networks throughout the world.

5.2.1.3 The EIRENE numbering plan is designed to include numbers that identify trains and individuals by function as well as by equipment. Part of the numbering plan is concerned with functional numbering whereby the running numbers of services are used to construct Functional Numbers, which are in turn used to access the on-board mobile equipment for the duration of the service. There is therefore a need to map Functional Numbers defined in EIRENE to Subscriber Numbers in a flexible and future-proof manner which will allow railways to develop and enhance their operations throughout the entire lifetime of the network.

5.2.1.4 Although the E-SRS specifies the structure of the numbering plan to be used and the over-the-air protocol, it does not specify the mechanism whereby Functional Numbers are to be mapped onto the appropriate Subscriber Numbers. In addition, the E-SRS specifies the way in which calls based on Functional Numbers can be routed through the network, but does not consider any particular network implementation to achieve this.

5.2.1.5 An associated aspect is the implementation of location dependent routing. The E-SRS requires location dependent addressing based on cell routing as a minimum (E-SRS 10.10), although a more accurate method of location determination for call routing is advised. The method of implementation depends on the national railway requirements.

5.2.1.6 It is up to each individual railway to define an implementation of the EIRENE numbering plan and the network implementation that supports functional addressing and location dependent call routing. The aim of this section is to provide an overview of the main implementation options, detailing the particular aspects associated with each of the options.

5.2.2 Numbering plan principles

5.2.2.1 Train controllers, station staff, etc will normally want to call a train by its running number rather than by the actual Subscriber Number associated with the mobile in the locomotive. This is because the locomotive of a certain regular service may change from day to day, whereas the running number is uniquely identified, at least within a single railway domain. On the other hand, maintenance personnel in depots will only know a locomotive by its engine number and will prefer to set up a call to a mobile or device within the locomotive by this number. In each of these situations, it is necessary to be able to call a mobile on the train without knowing its Subscriber Number.

5.2.2.2 To allow for these requirements, the following numbering plans form part of each GSM-R network:

- **EIRENE numbering plan**: Provides a range of number types to meet railway addressing requirements; for instance, a certain Functional Number identifies the driver of a certain train rather than the number of the phone of the cab radio installed in the locomotive. For example, if the locomotive is changed during the journey, the Functional Number based on the Train Running Number will stay the same. GSM-R network users shall therefore be able to originate and receive calls using Functional Numbers. This need to comply with the requirements specified by EIRENE for the structure of Functional Numbers, whilst taking into account the railway private numbering plan and the national numbering plan.
- **Public numbering plan**: This is the numbering plan used by the public network operator to route calls through the network and which consists of the actual telephone numbers (e.g. MSISDN numbers) of the called party terminal equipment.

5.2.2.3 There may exist an overlap between the EIRENE and Public numbering plans, since for certain Call Types, the User Number (EIRENE numbering plan) may be equal to a Subscriber Number (Public numbering plan).

5.2.2.4 The establishment of the relation between a Functional Number and the Subscriber Number is performed by the user through the Registration Procedure and is removed by the user through the De-registration Procedure. This has to be performed every time the association requires an update. The association between the Functional Number and Subscriber Number is held in appropriate routing databases. When a call is set up, a translation from the Functional Number to the Subscriber Number is performed. Functional Numbers should be de-registered as soon as they are no longer required so that they are made available for subsequent users.

5.2.2.5 The structure for the Functional numbering plan to be used within GSM-R networks is detailed in section 9 of the E-SRS.

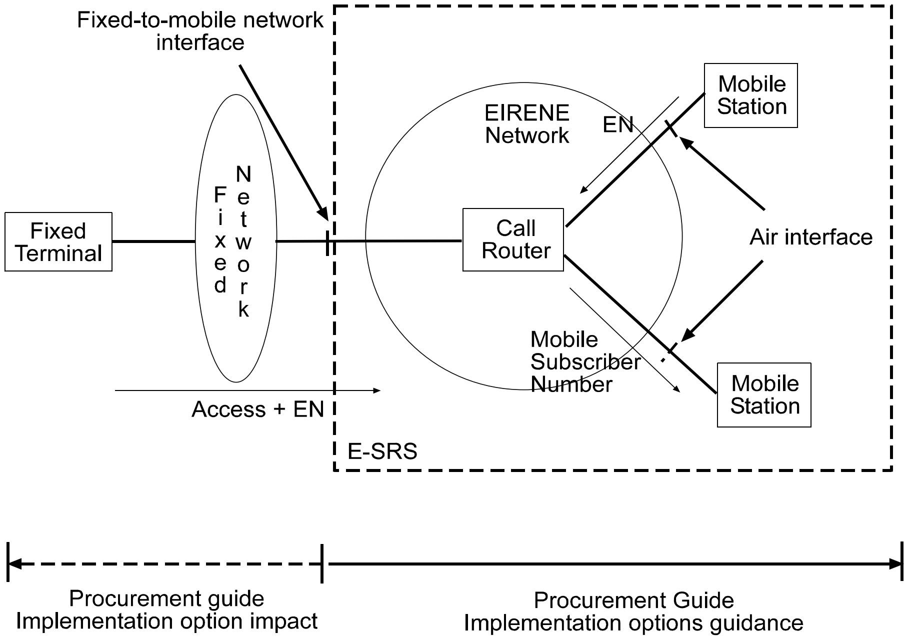
5.2.2.6 The EIRENE numbering plan also defines a set of short codes to be used within GSM-R networks. These short codes are not restricted to call set-up to mobile users only. Instead, their prime function is to ease the use of GSM-R for drivers by reducing the number of digits to be dialed when calling the local controller or to place an emergency call.

5.2.2.7 It will be the responsibility of the railway to define in addition to the numbering plan specified in the E-SRS:

- a suitable Numbering plan for fixed network extensions if required;
- how the Functional Numbers used within the GSM-R network can be accessed if a call is to be set up from a fixed network extension.

5.2.2.8 This guide will discuss the possible options for implementing the functionality required to translate[3] the Functional Number into the associated Subscriber number and the impact each of these options has on the fixed-to-mobile interface.

5.2.2.9 The relationship between the aspects considered in the E-SRS, this guide and those that are to be defined by the national railway are shown in the figure below. This diagram shows the different components of the integrated radio communications network, the different interfaces, the call set-up information to be passed from the calling party to the network and the location of the 'Call Router' which translates the Functional Number into the Subscriber Number. In addition, the diagram shows that the E-SRS covers the functional requirements (including the EIRENE Numbering plan) within the GSM-R network, whereas the procurement and implementation guide details the implementation aspects and the impact these may have on the functionality required in the fixed network implementation



Scope of Guide

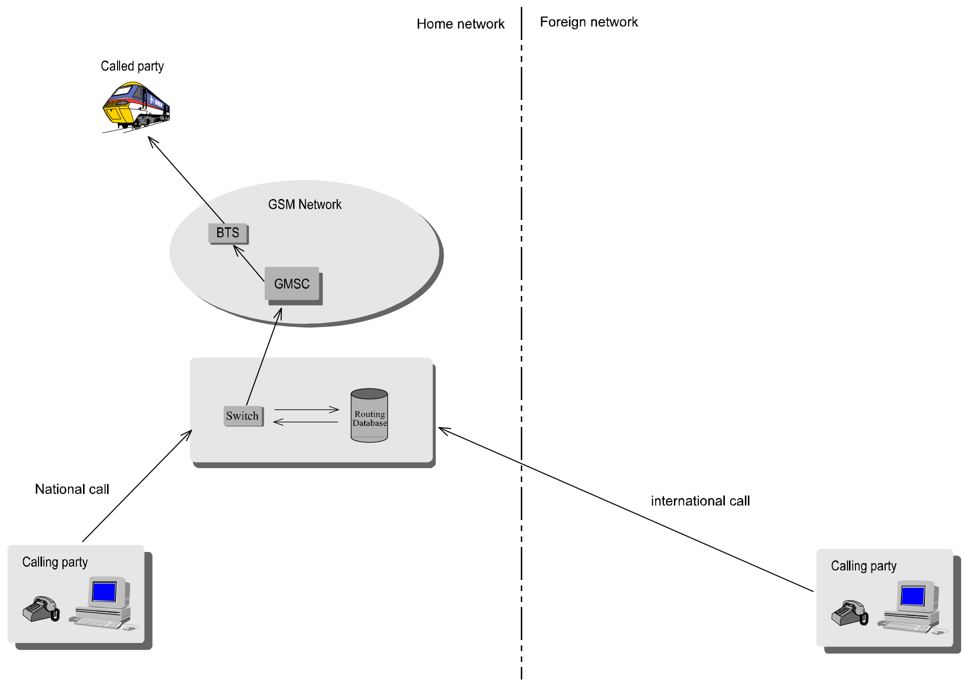
[3] Number translation is the mapping of one 'name', the Functional Number into another, the MSISDN number. The mapping of a Freephone number into a public telephone number may serve as another example.

5.2.2.10 Sub-section 5.2.4 considers in more detail the main options available for using functional addressing in GSM-R networks and the associated mechanisms for translating Functional Numbers into Subscriber Numbers. Specific aspects related to the allocation of numbers for different GSM-R network implementations are considered in more detail in sub-section 6.8.

5.2.3 Call routing principles

5.2.3.1 In order to provide international communications, national GSM-R networks will need to be interconnected to allow calls to be routed between users in different networks. The specific aspects related to interconnecting GSM-R networks are addressed in sub-section 6.2of this guide.

5.2.3.2 When a train is operating in its home network, all Functional Numbers (eg Engine Number and Running Number) associated with the train will be stored in the home network. All users who want to call the train by a Functional Number will need to address the call via the train's home network. For users in the same country this will require only a national call, for users in other countries an international call will be required. The Functional Number will be translated by the home network and routed to the mobile. This type of call routing is shown in the figure below.



Call routing to train operating in home network

5.2.3.3 When a train moves from its home network to a foreign railway network, calls set up using Functional Numbers stored within its home network will be translated to the relevant mobile Subscriber Number and routed to the train through GSM procedures for mobiles roaming on foreign GSM networks. For users in other countries, including the foreign country in which the train is currently operating, an international call set-up will be required. The Functional Number will be translated by the home network and routed to the mobile. This type of call routing is shown in figure 4-3.

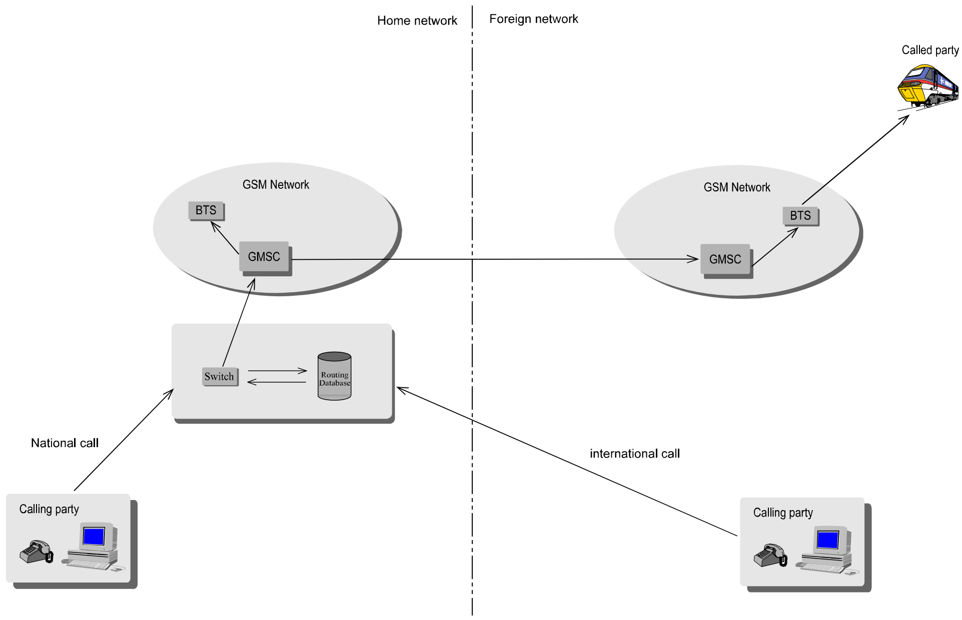


Figure 4-3: Call routing to trains operating in foreign network (scenario 1)

5.2.3.4 Generally, controllers will need to address an international train, operating in their area of control, by a national running number. This avoids the need for the controller to know the originating country of the train. This requires a transfer of Functional Number information associated with the train running number, when a train crosses a boundary. Other Functional Numbers (e.g. those based on Engine or Coach numbers) should remain with the train's home network. The controller should therefore only be required to set up an international call when there is a requirement to call a train operating in another GSM-R network (the situation as described in paragraph 4.2.3.2).

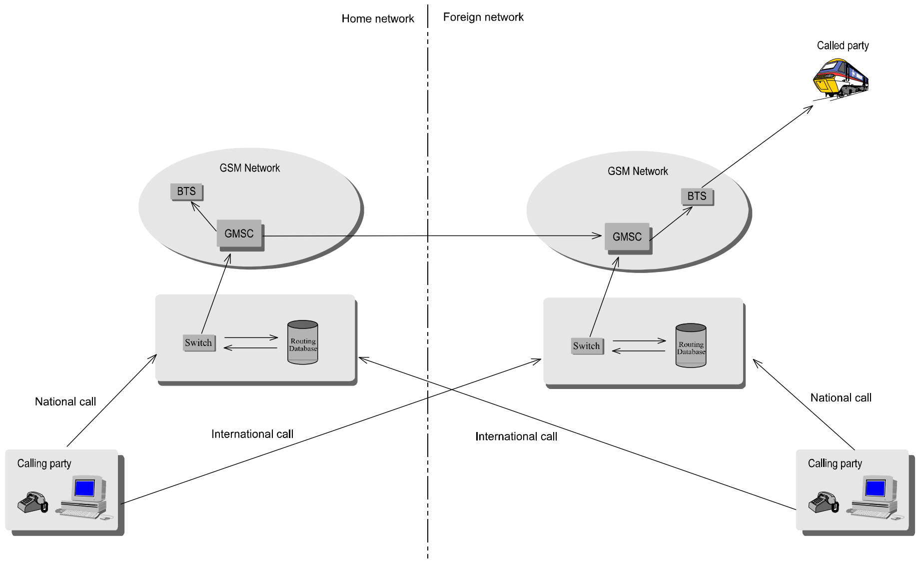


Figure 4-4: Call routing to trains operating in foreign networks (scenario 2)

5.2.4 Number translation implementation options

5.2.4.1 The EIRENE Specifications do not mandate the way in which functional addressing and the associated translation of Functional Numbers into Subscriber Numbers should be implemented within the GSM-R network, only the messages which should be used over the air interface and between networks, to control the functional addressing service.

5.2.4.2 Possible options for implementing a Functional Numbering service include:

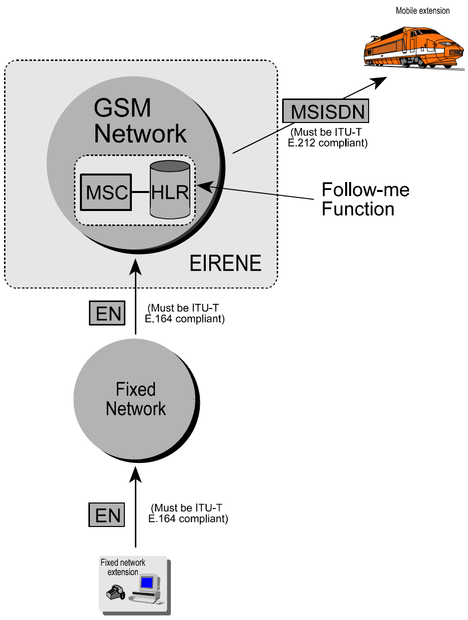
- using Intelligent Network (IN) facilities;
- within the GSM network's HLR using the 'follow-me' supplementary service;
- implementation of a dedicated switch with associated databases.

For each of these options, the registration and de-registration aspects need to be considered carefully. In particular, this needs to be done with a view to ensuring that roaming equipment from other railways is fully interoperable with the GSM-R network implementation.

5.2.4.3 This section discusses the options outlined above to implement a GSM-R network with a view to achieving international interoperability.

HLR implementation

5.2.4.4 With the HLR-based solution, the GSM ‘follow-me’ supplementary service is used to provide the required translation of Functional Number to MSISDN number within the HLR. Although this has the advantage of not requiring additional network elements, there is a danger of making less efficient use of the numbering space as it may not be possible to gain access to the required blocks of numbers to match the required Functional Numbers from the national telecommunications regulator.



HLR implementation

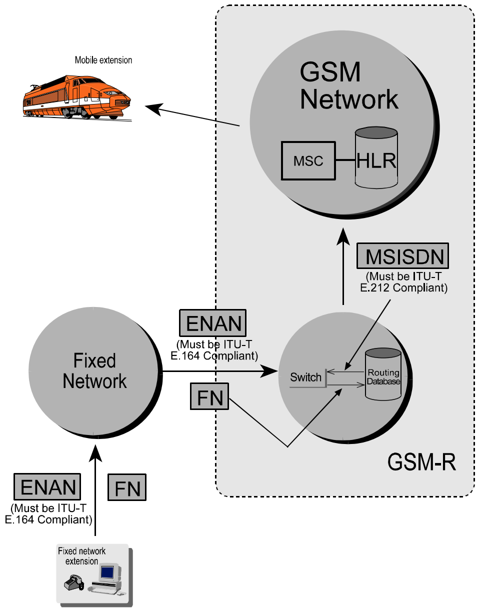
5.2.4.5 In the HLR implementation, shown in the figure above, the EN is dialed directly by the calling party and the call is routed through the network to the GSM MSC. The GSM Call Forwarding Unconditional Supplementary Service is then used to translate the dialed EN into the MSISDN number of the relevant mobile equipment and the call is set up.

5.2.4.6 The key to success of this approach is either to ensure that all of the ENs used are ITU-T E.164 compliant (ie they must be valid mobile telephone numbers) and available (ie they must not be already taken by other subscribers) or the ENs can be interpreted by the GMSC to allow the call forwarding to be invoked.

Dedicated switch implementation

5.2.4.7 With this implementation, the railway does not use any number translation functionality provided by the GSM network. Calls are routed via a dedicated switch, which performs all necessary number translations. Essentially, this is an "external" Intelligent Node, although the switch does not form an integral part of the GSM network.

5.2.4.8 The calling party (whether mobile or fixed terminal) must first gain access to the switch before passing the Functional Number information, in order to allow calls using Functional Numbers to be made. Once the Functional Number is passed to the switch, it will search its routing databases and translates the Functional Number into the proper MSISDN number. The switch will then attempt to complete call set-up to the mobile. This process is shown in the figure below.



Dedicated switch implementation

5.2.4.9 Based on the network procurement option chosen by the railway, access to the dedicated switch could be obtained by dialing a specific number, the ENAN. If a completely private network implementation is used, then the railway will have more freedom in defining the way in which the dedicated switch is accessed.

5.2.4.10 When the railway decides to implement this option, it will be required to specify all aspects of the required functionality for the switch and its databases. In addition, as the switch does not form an integral part of the GSM network, the specification must also include the way in which the switch is connected to the GMSC.

Calls initiated by a mobile user

5.2.4.11 It should be noted that in the case of the implementations discussed in this section, the emphasis has been on the called party being a mobile user. Similar consideration will have to be given to the call routing mechanisms required for calls where the called party is located at a fixed network extension. The railway will have to specify, as part of their technical specification, how calls are to be routed to fixed network extensions. This will largely depend on aspects such as:

- the type of fixed network implementation (private, public, VPN, etc);
- whether functional addressing is extended to cover the fixed network;
- location where number translation is to take place (eg within the GSM network, the fixed network);
- the functionality provided within the network for translation of numbers (IN solution, standard Supplementary Services provided in the fixed network, dedicated switch, etc).

Interconnection aspects

5.2.4.12 Although aspects related to the interconnection of national GSM-R networks will be considered in more detail in section 6 of this guide, the table below summarizes some of the aspects that require consideration. It considers the interoperability issues that will be raised in four possible scenarios of a train moving from a home GSM-R network with either an IN or HLR implementation to a foreign GSM-R network with either an IN or HLR implementation.

5.2.4.13 The situation where an GSM-R network has to be connected to another GSM-R network that uses a dedicated switch/database for translation of Functional Numbers and call routing, should be considered separately. In general, the particular interconnection aspects that require attention are the method of interconnection and the protocol for exchange of data.

		Traveling to a Foreign Network with an:	
		IN implementation	**HLR implementation**
Home Network:	**IN implementation**	Protocol for the exchange of data.	. Method of interconnection. Protocol for the exchange of data.
	HLR implementation	Method of interconnection. Protocol for the exchange of data.	Method of interconnection. Protocol for the exchange of data

Interconnection aspects

6 System planning and specification

6.1 Introduction

6.1.1 This preliminary phase deals with the feasibility and viability of the new system. It therefore includes the following activities:

- **A system feasibility study**, to perform an initial assessment of the proposed system. The aim is to determine whether the system can meet its business requirements and whether there is a sound financial case for developing it. The study consists of defining the reasons for the introduction of the new system, establishing implementation options and the assessment of their implications.
- **A requirements capture**, leading to a clear definition of user requirements, both functional and non-functional. This will determine requirements relevant to the size of the network, coverage levels, interconnections, migration, terminal design, call model etc.
- **A business case development**, which will lead to the formal acceptance of the system procurement and will secure the funding for the project.
- **Development of a system specification**, which will look at the system requirements and address issues such as interfacing the network to other networks and systems (e.g. location systems, signaling systems, train control systems and other telecommunications networks). It will also consider operational requirements, provision of services and facilities, system design, equipment requirements, management systems, implementation requirements, safety aspects, RAM requirements and EMC.
- **Development of a procurement strategy**, which will detail how the network is to be procured and will deal with issues such as implementation options (private versus public network) and service provision (privately operated or outsourced).
- **Development of a migration plan**, which will include aspects such as the rollout plans and plans for the transfer from the old system to the new system.

6.1.2 The basis for the mobile part of the integrated radio system specification is provided by the E-SRS and the E-FRS. However, the E-FRS provides top-level user requirements and constraints and the E-SRS provides technical standards and constraints required for international interoperability. Therefore, neither document alone could serve as a technical system specification for the entire integrated radio system as part of an ITT.

6.1.3 Due to the nature of the E-FRS and E-SRS, there are several options for implementing an EIRENE-compliant radio system. The previous section of this document has pointed out where the specifications allow for flexibility in design and how this can be used in the development of the national system specification.

6.1.4 In addition, the EIRENE Specifications do not comprehensively cover certain aspects of implementation and design such as network architecture coverage, frequency allocation or performance monitoring. These additional aspects of system design form an important part of the technical specification, but their needs are mainly driven by operational and business requirements. Since these will differ between individual railways, the railways must be responsible for the specification of their own system designs.

6.1.5 This section discusses several of the particular aspects to be considered by the individual railway when specifying the radio system, but which are not fully addressed in the EIRENE Specifications:

– network interconnections;
– European Train Control System (ETCS) requirements;
– licensing and frequency allocation;
– radio coverage;
– type and safety approvals;
– RAM requirements;
– network management;
– international roaming.

6.1.6 For a more comprehensive list and description of the aspects not addressed by the EIRENE Specifications, please refer to sub-section 2.5 of this document.

6.1.7 It should be stressed that it is not the aim of this procurement and implementation guide to detail the way in which the feasibility study, requirements capture and business case need to be performed. The way in which these are carried out is entirely driven by the procedures each railway has for these aspects of system planning. However, general guidelines are provided at the end of this section.

6.2 GSM-R network interconnection

6.2.1 Introduction

6.2.1.1 The GSM-R network is unlikely be stand-alone. It may be connected to a number of other voice and data networks (e.g. PSTN, PSDN, railway fixed network). This section discusses the technical issues related to the interconnection of GSM-R networks operated by different railways, in order to provide roaming services and to facilitate calls from/to fixed or mobile numbers in an other GSM-R network. It covers the following areas:

– **physical interconnection:** the actual interfacing of equipment;
– **logical interconnection:** the information to be transported over the interface;
– **procedural interconnection:** the procedural interface requirements.

6.2.1.2 Interconnection of networks is required to exchange the required signalling messages, voice and data traffic. The method of interconnection will define whether it is possible to hand over calls without interruption to support roaming mobiles.

6.2.2 Physical interface

6.2.2.1 The physical interface describes the link between the GSM-R networks of different railways. This link is connected to the break out/break in points of the network, which are considered to be the GSM-R Gateway Switches.

6.2.2.2 The link between the Gateway Switches of different GSM-R networks may be either via the private pan-European Railway network or via one or more public networks. Three main inter-GSM-R network interfaces can be considered, regardless of implementation:

- **Private link**. In this situation, the GSM-R networks and interconnections form a private network. This situation potentially gives the railways the highest degree of flexibility in interface definition and use of numbering plans. However, achieving the full potential advantages from this approach (whilst ensuring international interoperability) will require a high degree of co-ordination between the national railways. Furthermore, the adoption of bespoke solutions in this implementation may lead to problems.
- **Public leased line**. In this situation, the GSM-R networks are connected as a Virtual Private Network. However, as the leased line is part of one or more public networks, care should be taken that information specific to GSM-R is passed transparently. If so, this situation potentially gives the railways the same terms of flexibility as the private link. Furthermore, as the GSM-R networks are connected to public networks, the network interfaces and associated 'low level' protocols (see below) need to be agreed with the public network operators.
- **Public switched link**. In this situation, the networks are connected via public networks without any specific arrangements. This interconnection gives the lowest level of flexibility as the protocols and any information passed during call set-up have to comply with the public network requirements. The EIRENE numbering plan will most likely not supported.

6.2.2.3 In general, in the situation of using GSM-R network interconnections via the public network, the interface between the GSM-R networks and public networks requires standard interfaces and signaling protocols for call set-up.

6.2.2.4 The interface needs to support the standard voice and data bearer services specified in the EIRENE System Specification.

6.2.3 Logical interface

6.2.3.1 The logical interface deals with the protocols to be used over the physical interconnection and the information to be conveyed.

Protocols

6.2.3.2 Depending on the approach, the interconnection of the GSM-R networks could be completely private, or partly via public networks. To provide full functionality, two types of protocol need to be considered:

- **Call set-up protocols**. These are the low-level protocols that are used by networks to establish calls. The protocols referred to are DSS1, SS7, etc. As long as EIRENE does not require any specific functionality from these protocols, then there are no specific requirements to be set. However, the E-SRS refers to UUS1, sub-addressing, etc, which may have an impact on the call set-up for international roaming trains. The degree to which the different network and protocols support these features during call set-up need to be considered.
- **Information exchange protocols**. These protocols relate to the exchange of information between applications after the link between the Gateway Switches has been established and are considered to be 'high level', i.e. are passed on the voice or data channel, rather than conveyed via the signaling channel.

Functional Number registration and de-registration

6.2.3.3 The information related to a train's ***Functional Number*** registration is held in the routing databases of the IN and to some extent in the Gateway Switch in the GSM-R network in which the train is currently operating. However, when a train crosses a network border, the Gateway Switch of the network entered needs to be informed of the on-train users. This registration and de-registration can take place via manual actions of the on-train users, or the information can be passed from the 'old' Gateway Switch to the 'new' Gateway Switch, in which case registration and de-registration is done automatically.

6.2.3.4 The question is, at what point the user should de-register from the 'old' Gateway Switch and whether there should be a consistency check. Furthermore, what time interval is available for the user to register at the 'new' Gateway Switch and what would happen if a user fails to re-register? These are issues that need to be addressed in the procedures to be followed, which are discussed in the following section.

6.2.3.5 If the re-registration takes place automatically, the boundary crossing of the train needs to be registered and the information exchange between the two Gateway Switches needs to be initiated. This can either be a manual activity of one of the controllers at either end of the boundary, or via the position information system detecting the train passing over the boundary. Whatever approach is taken, the two Gateway Switches have to establish a link, after which the routing database information can be exchanged.

Hand-over of calls

6.2.3.6 During boundary crossings, calls between train drivers and signalers may still be ongoing. It is expected that there will be a degree of overlap between the GSM-R networks and the call can therefore be continued for some time after crossing the boundary.

6.2.3.7 Deleted.

6.2.3.8 This issue should also be considered for other on-train users (e.g. catering staff), although hand-over requirements for these users will be less strict than those required for train drivers. In practice, this facility may be implemented between two national networks if both parties are in agreement that it is required.

Position information

6.2.3.9 It is not envisaged that any position information is to be exchanged between GSM-R networks when a train crosses a boundary for the purpose of (location dependent) call routing. It is, however, assumed that each railway will have an appropriate train position information system at boundaries of their network to allow sufficient detection of trains entering and leaving the railway network.

6.2.3.10 It should be noted that this aspect also needs to be considered as part of the roll-out of the GSM-R network as trains may enter and leave areas covered by the GSM-R network on a national basis.

Functional Number transfer

6.2.3.11 The inter-network transfer of ***Functional Number***s takes place in two situations of call set-up:

- **Call routing without roaming**. This situation arises when the calling party as subscriber to one railway network wants to contact a called party registered in another railway network. In this situation, the calling party will dial an International Functional Number, which is translated by the Gateway Switch into a National Functional Number with an appropriate prefix to get the call routed to the destination network. The way in which this is achieved depends on the way in which the numbering plan is implemented and how Functional Numbers are used in call set-ups. The protocol and format for the exchange of data between the Gateway Switches of different GSM-R networks should be as defined in the EIRENE Specifications.
- **Call routing with roaming**. This situation arises when a calling party of one railway network wants to contact a called party belonging to the same railway network, but currently positioned outside its own railway network boundary. In this situation, a National Functional Number is dialed and the translation into the MSISDN number of the mobile takes place before the international link is established. Therefore, this situation does not require the transfer of any Functional Number information.

6.2.4 Procedural interface

6.2.4.1 These interfaces cover the procedures related to trains crossing boundaries. These procedures describe the way in which, for example, hand-over between controllers takes place or how re-registration is performed.

6.2.4.2 The procedures need to be established on a bilateral basis and fall outside the scope of this document.

6.3 Licensing and frequency allocation

6.3.1 Frequency allocations

6.3.1.1 To establish a new pan-European radio system, the UIC identified at an early stage a common frequency band as a key element to ensure economies of scale and international operation.

6.3.1.2 The UIC has, on a European level, negotiated with the Frequency Management Working Group of the ERC for a block of frequencies for GSM-R. This resulted in Recommendation T/R 25-09 E, in which the CEPT (now ERO) recommends designating the band 876-880 MHz (up-link) paired with 921-925 MHz (down-link) for GSM-R systems, as follows:

1. *that in CEPT countries the international requirements without excluding national requirements of railways for non-public digital radio communications system in the 900 MHz band should be covered by selecting appropriate sub-bands from the designated band 876-880 MHz (mobile station transmit) paired with 921-925 MHz (base station transmit) with a duplex separation of 45 MHz.*

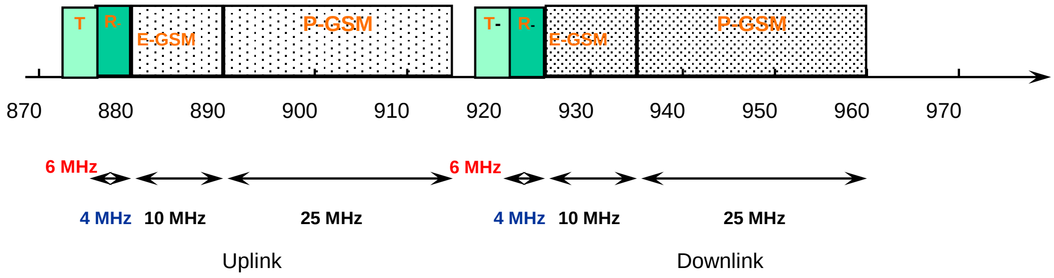
2. *that close liaison between CEPT and UIC should be established in order to provide by the year 2005 the designated frequencies for international use.*

6.3.1.3 It should be noted that the recommendation also states that '*after the introduction of the radio system most of the frequencies presently used would be liberated by the railways*'.

6.3.1.4 The recommendation of introducing frequencies for railways in the 900 MHz band leads to the classification of frequency allocation for GSM 900 as detailed in the table below [GSM TS 05.05].

	Uplink	**Downlink**
Primary GSM	890 – 915 MHz	935 – 960 MHz
Extended GSM	880 – 915 MHz	925 – 960 MHz
Railways GSM	876 – 915 MHz	921 – 960 MHz

GSM frequency allocations



6.3.1.5 EIRENE-compliant radios are expected to be able to operate in the Railways GSM band as stated in section 4.2 of the E-SRS.

6.3.1.6 Although the European Radio Implementation Group manages the international aspects of frequency allocation, it is the responsibility of each railway to go to its individual frequency administration and negotiate the exact frequency requirements. This is of particular interest in those situations where a railway decides to implement either a private network or a hybrid solution.

6.3.1.7 When implementing a private or hybrid network, the railway must ensure that a frequency band is allocated in the UIC frequency range.

6.3.1.8 Although a specific frequency band has been allocated for use by railways in Europe, on a country-by-country basis, this band may currently be in use by other organizations and not be available at the time the railway seeks to implement an EIRENE-compliant network. This will have an effect on the ease of implementation and interoperability, which will vary according to the individual circumstances encountered at the time of implementation. This aspect also needs to be considered when implementing a network using public GSM network providers (see section 3.3).

6.3.1.9 Additional frequencies may also be necessary to cater for high traffic requirements (voice and data). Again this will have an effect on the ease of implementation and interoperability, which will vary according to the individual circumstances encountered at the time of implementation.

6.3.2 Licensing

6.3.2.1 Originally, railways included all aspects of railway operations within a single organization. However, more and more railways find themselves split into various organizations responsible for railway operations. This trend makes it less clear whether an EIRENE-compliant communications system can be considered as a true private network, or whether the railways are providing services to third parties.

6.3.2.2 It is important for a railway to investigate how the national Administration considers the GSM-R network and its users and whether this has any implications for obtaining licenses to operate the network and to provide services.

6.3.2.3 It should be noted that even in the situation where the GSM-R network is provided by a public network operator, the complete integrated radio system may still be considered as run by the railway and therefore needing a license. This is due to the fact that the complete network also consists of fixed network elements and an associated management system which are most likely procured and operated by the railway.

6.4 Radio coverage

6.4.1 A fundamental part of the design of a radio network is the radio coverage requirement. For railways, this is mainly driven by the safety and performance requirements of train operations.

6.4.2 It is up to individual railways to determine their requirements for coverage levels. The E-SRS does, however, provide guidelines for the level of coverage required. These guidelines are as follows:

6.4.3 The following minimum values shall apply: (M)

- coverage probability of 95% based on a coverage level of 38.5 dBµV/m (-98 dBm) for voice and non-safety critical data;
- coverage probability of 95% based on a coverage level of 41.5 dBµV/m (-95 dBm) on lines with ETCS levels 2/3 for speeds lower than or equal to 220km/h.

Note 1: The specified coverage probability means that with a probability value of at least 95% in each location interval (length: 100m) the measured coverage level shall be greater than or equal to the figures stated above. The coverage levels specified above consider a maximum loss of 3 dB between antenna and receiver and an additional margin of 3 dB for other factors such as ageing.

Note 2: The values for ETCS levels 2/3 concerning coverage and speed-limitations are to be validated and, if necessary, reviewed after the first operational implementation of ETCS.

6.4.4 In order to understand the meaning of these guidelines, it should be appreciated that due to various conditions, the signal strength at any particular point on the network will vary as a function of time. This aspect and the availability of the network need to be factored into any coverage level calculations.

6.4.5 Finally, it is not sufficient to provide coverage requirements as outlined above. In addition, the railway must guarantee that coverage levels are actually maintained at the right level over time. This requires performance measures and an associated performance monitoring strategy to be defined. This is particularly important when procuring services from a public network operator as this will form a major part of the Service Level Agreement.

6.4.6 In Border Crossing case, the requirements and pre conditions can be found in the FFFIS for Border Crossing, available on the UIC/GSM-R Web Site.

6.5 Type & Safety approvals

6.5.1 General

6.5.1.1 EIRENE type approval issues primarily concern mobiles since it is the mobiles on trains that will roam between different railway networks. Various forms of type approval can be identified for GSM-R:

- **EIRENE functional approval**: to ensure that GSM-R equipment provides functionality in accordance with the EIRENE standards;
- **EIRENE safety approval**: to ensure that GSM-R will operate and be used safely on the railway;
- **Railway environmental type approval**: to ensure that equipment used on the railway is fit for purpose and meets the various statutory health and safety requirements.

6.5.1.2 Type approvals are well established and show a large amount of harmonization across Europe. The situation with respect to safety approvals is different.

6.5.1.3 Safety involves careful consideration of both the functionality of GSM-R and the operational procedures, which control the use of the system. The fundamental difficulty with carrying out GSM-R safety approvals work at a European level is that operational procedures are not harmonized amongst national railways. Safety approvals will need to be carried out nationally based on national requirements. No European safety approval is planned beyond the functions provided for interoperability and specifications for reliability and availability levels.

6.5.2 Type approvals

6.5.2.1 The procedures for GSM type approval are well established. Type approval specifications are drawn up and maintained by ETSI and are adopted by national regulators throughout Europe using approved test-houses.

6.5.2.2 Railway environmental specifications are becoming increasingly harmonized across Europe through the work of CENELEC. However, many national requirements remain.

6.5.2.3 The Interoperability Directive requires a conformity assessment process consisting of procedures chosen from modules defined in Directive 93/465/EEC. This Directive lays down the general framework of the modular system. Based on this general framework, it is the specific Directive, and in this case the relevant TSI, that determines the conformity assessment procedures that the supplier must apply.

6.5.2.4 The GSM-R type approval regime, which will form part of the conformity assessment process, will need to consist of several layers, defined as follows:

- **Core GSM type approval**: This covers testing of features available in public networks against a set of harmonized standards covering the GSM specifications GSM TS 11.10, GSM TS 11.21 and the associated Common Technical Regulations (CTRs);
- **Enhanced GSM type approval**: This covers additional GSM features, which have been introduced as part of the development of the GSM-R radio system such as ASCI and R-Band. Tests are carried out against a set of harmonized standards covering the relevant GSM specifications GSM TS 11.01 and the associated CTRs.
- **Railway specific type approval**: This covers features specific to the GSM-R radio system, which include functional and location dependent addressing and specific environmental requirements. Tests are carried out against harmonized CENELEC standards, which are currently being drafted. These standards are partly based on the EIRENE Functional Requirements Specification and the EIRENE System Requirements Specification.
- **Other type approval**: In addition to the type approval elements described above, there may be additional requirements, which are the result of other applicable Directives such as the Low Voltage and the EMC Directives. Specific type approval is required according to the harmonized standards defined in these Directives.

6.5.2.5 Based on the conformity assessment process modules defined in Directive 93/465/EEC, combined with the type approval regime outlined above, the following strategies need to be considered:

1. **Full type approval**: This relates either to the type examination as defined in module B[4] of the Directive or to the unit verification of the design and production of each product controlled by a notified body as defined in module G. If module B is chosen, then this needs to be followed by one of the modules specifically covering the production phase;

[4] A short explanation of the modules defined in Directive 93/465/EEC is given in appendix D of this document.

2 **Self certification**: The manufacturer ensures and declares that the product satisfies the directives that apply to it without the intervention of a notified body. This is based on module A of the Directive;

3 **Hybrid solution**: The manufacturer is responsible for all tests according to a certified quality system covering design, manufacturing, testing and production. This total quality system must be based on EN ISO 9001 and must be approved by a notified body, which performs the audit role.

6.5.2.6 Both strategies 1 and 3 require intervention from the notified body. The difference is in the involvement of the Notified Body in testing of the equipment. Strategy 1 requires the notified body to take an active role in the conformity assessment process, whereas strategy 3 only requires the Notified Body to approve and audit the quality process, with the manufacturer having the responsibility for testing. Strategy 2, on the other hand, does not require the intervention of a notified body. This may not be ideal for type approving an GSM-R radio system.

6.5.2.7 Notified Bodies play an important role since they are designated to carry out the conformity assessment procedures as set out in the Directives to ascertain that a product conforms to the essential requirements of the applicable Directives. These actions are carried out under the authority and control of the national authorities of the Member States.

6.5.2.8 The Directives lay down the minimum criteria to be fulfilled by Notified Bodies. Key elements in this are:

- availability of personnel and equipment;
- independence and impartiality of the body, its management and staff in carrying out the conformity assessment procedures in relation to those directly or indirectly concerned with the product (eg designer, manufacturer, supplier, installer);
- technical competence (training, knowledge and ability to carry out test examinations, draw up certificates, etc) and professional integrity of personnel;
- maintenance of professional secrecy;
- subscription to civil liability insurance unless that liability is covered by the state under national law.

6.5.2.9 Bodies may be accredited to carry out tasks under one or more of the conformity assessment modules defined in Council Directive 93/465/EEC.

6.5.2.10 A body wishing to offer 'one stop testing and certification' under a directive will need to be notified for the modules indicated in the Directive that cover both design and production phase.

6.5.3 Safety approvals

6.5.3.1 Safety approvals for train communications systems are carried out on a national level. However, two articles of Council Directive 96/48/EC need to be considered by the national railway operator with respect to obtaining safety approvals for EIRENE-compliant systems:

- **Article 20** requires that each Member State notifies the Commission and other Member States of the bodies responsible for *"assessing the conformity or suitability for use of an interoperability constituent"* in compliance with the Directive;
- **Article 9** suggests that an GSM-R system which meets the safety approval requirements of the notified body of one Member State may, by implication, be considered to possess safety approval for operation in all other Member States. Practical enforcement of this principle is, however, likely to prove difficult. Co-ordinating effort will be required at European level to resolve differences in safety approval procedures and in the functionality and use of EIRENE-compliant systems.

6.5.3.2 However, several of the railways of the Member States, as well as the UIC Safety Committee have stated that the GSM-R system itself does not possess any safety requirements. The basis of this assertion is as follows:

- telecommunications services are used to support safety-related railway applications. However, safety is assured by means of applications external to the telecommunications bearer, or by means of operational procedures. Telecommunications are simply used as a non-safety-related bearer service;
- in order to ensure adequate safety of those applications which use telecommunications services, the telecommunications systems themselves have certain dependability requirements (in terms of reliability, availability and maintainability) but no specific safety requirements as such;
- the GSM-R system is no exception to this rule. It has no specific safety requirements and need not therefore be associated with a specific safety integrity level (SIL);
- certification will however be required for certain GSM-R system elements. For example:
  - compliance with ETSI norms, assurance of transmission and frequency aspects, health and safety of individual persons, etc;
  - certification of railway-specific elements such as EMC, interoperable functions, ability to be used in a railway environment and supplementary national functions. Certification requirements are likely to be identified either by European Norms (CENELEC, CEN) or by UIC rules (UIC leaflet 751-4 etc).

6.5.3.3 In order to interpret the assertion that no safety requirements are to be placed upon GSM-R, it is important for each railway to identify exactly which applications are being referred to. In particular:

- there are many applications *external* to GSM-R (eg ETCS) which will make use of GSM-R as a bearer service;

- there are also several applications internal to GSM-R (eg railway emergency calls, driver-controller calls, DSD messages) which are provided by the GSM-R telecommunications service and which use a GSM network as a radio bearer.

6.5.3.4 Demonstrating that an EIRENE-compliant system is safe for railway operation therefore depends to a large extent on:

- the functionality and performance provided by the system, and the integrity with which it is provided;
- the manner in which the system will be used, and the operational procedures to be employed to support its use;
- the other applications that will use the system and the level of integrity which they will assume.

6.5.3.5 At a European level, there are a number of standards available or under development which may be relevant to the safety of railway communications:

- IEC 61508, *Functional Safety: Safety Related Systems;*
- EN 50126, *Railway Applications: Dependability for Guided Transport Systems;*
- EN 50128, *Railway Applications: Software for railway control and protection systems;*
- ENV 50129, *Railway Applications: Safety-related Electronic Railway Control and Protection Systems;*
- EN 50159-1, *Railway Applications Part 1: Requirements for Safety-Related Communication in Closed Transmission Systems;*
- EN 50159-2, *Railway Applications Part 2: Requirements for Safety-Related Communication in Open Transmission Systems.*

6.5.3.6 The first four standards are aimed at the development, maintenance and operation of systems. Each embodies the Safety Lifecycle concept, defining the key stages of safety assurance and the processes and procedures to be adopted at each stage according to the required safety integrity. The last two standards apply to communications systems, which involve the transfer of safety-related data. Since GSM-R simply provides a bearer for data messaging, these standards do not appear to apply to GSM-R directly. They would however apply to any application, which employs GSM-R for the transmission of safety-related data.

6.5.3.7 Some railways/bodies have their own safety standards and procedures in addition to the European and international standards. By definition, these additional standards/procedures must be consistent with the relevant European and International safety standards.

6.5.3.8 When procuring an EIRENE-compliant system the railway needs to gain approval from the notified body for its country as required by Article 20 of the EC Directive on Interoperability. This body should state whether any additional requirements over and above those advocated by existing safety standards need to be imposed.

6.6 RAM requirements

6.6.1 General

6.6.1.1 The RAM (Reliability/Availability/Maintainability) requirements placed on the radio system will depend largely on the application(s) being run over the radio system. The requirements fall into two categories, operational requirements and safety requirements, while the applications can be split into two general classes, driver to controller communications and train control applications.

6.6.1.2 In order to assess the RAM requirements placed on a given application, the impact on train running of an application failure due to a radio system problem needs to be quantified. For example, in a driver to controller communication application, the loss of radio communication may not physically stop the train from running. However, it will have an impact in terms of safety, as the driver and controller will not be able to communicate in the event of an accident or emergency, which may lead to train running being suspended.

6.6.1.3 In comparison, for a train control application such as full in-cab signaling, the loss of the radio bearer will lead to a loss of signaling information, and may in some cases result in the train being forced to stop. It should be noted, however, that the signalling system is assumed to be fail-safe and there will be no safety implications of losing communications.

6.6.1.4 The impact of any system failure will also depend on the location and extent of the failure. For example, the effect of the loss of radio coverage on a small stretch of a lightly used, isolated section of line will be small compared to the loss of radio coverage at a major junction or over many kilometers of busy, intersecting lines.

6.6.1.5 Therefore, the availability requirements of the communications network, as well as being specified for the application being used, may also need to be specified by line or by geographical area.

6.6.1.6 Once the effects of failures of the application due to each identified failure mode have been identified, the potential end user is then in a position to set the availability requirements for the network.

6.6.1.7 This is achieved by deciding what levels of availability are acceptable for each of the failure modes. As each of the failure modes can affect different lengths of track and therefore can have significant differences in their impact on train running, the availability requirements may be different for each of the different failure modes.

6.6.1.8 This therefore indicates that a single availability figure for a system may not be appropriate. Typically, a system's availability is expressed as its ability to provide full functionality and, conversely, it is deemed to be unavailable if any of its components becomes unavailable, leading to a loss of functionality. This implies that the loss of coverage over a small length of track has the same impact, and hence is equally undesirable, as the loss of coverage over a large length of track. Therefore in some instances there will be a need to specify system availability in terms of the system's different failure modes.

6.6.1.9 Care should also be taken in setting availability levels for a given system. Whilst an overall availability can be quoted either for a whole system or for its differing failure modes, the impact of this on system design will depend on the size of the system. For example, if two systems have the same overall availability, but one covers twice the area of the other and therefore has twice the number of components, these components will need to be twice as reliable to meet the same system-wide availability target.

6.6.1.10 The availability of the radio system should also be computed in conjunction with the availability of the rest of the railway infrastructure. There is no point in designing and paying for a radio system, which provides availability some orders of magnitude higher than the availability of other system elements.

6.6.1.11 For example, a failure of the in-cab radio will, from the point of view of the train driver, be the same as a failure of the whole radio network. If the failure of cab radios is the dominant failure mode, then improving the reliability of the GSM network by an order of magnitude will not improve the overall reliability of the railway. Similarly, in the example of train control, if other parts of the train control system have a low availability, e.g. the infrastructure providing train location information, then the overall availability of the train control system will be low, regardless of the availability of the GSM network.

6.6.1.12 Therefore, the availability requirements of the radio system should be set with the size and physical extent of the system in mind and with respect to the availability of the rest of the railway infrastructure.

6.6.1.13 Also, certain parts of the network may need enhanced availability, thus requiring extra resilience in those areas. The enhanced availability will need to be determined for each of the failure modes and, if it is required at a sufficiently high level (e.g. the network-wide failure mode), the enhanced requirements may effectively become the requirements for the whole system.

6.6.1.14 Finally, availability of a system is closely related to the maintainability of the system. The maintainability of the system, which is a function of the system design, will be related to the fault management and maintenance strategy employed, as availability is directly related to the speed with which failures in the system can be detected, located and functionality restored. These aspects need to be considered carefully by the railway when specifying performance parameters.

6.6.2 Methodology

6.6.2.1 A methodology for producing availability requirements for a communications network depending on the application(s) being run over the radio system and the needs of the end users of the system includes the following main steps:

- determine the application(s) running over the GSM network;
- determine the failure modes of the GSM network;
- determine the failure modes of the application, based on the failure modes of the GSM network;
- determine the operational and safety requirements of the train operator based on the failure modes of the application;
- determine the impact on train running of the various GSM failure modes, based on the above requirements;
- determine the level of impact deemed acceptable by the train operator and use this to set the requirements on the GSM network's availability.

6.6.2.2 Once the requirements have been set according to the steps outlined above, it is then possible to carry out a cost-benefit analysis by comparing the available network architectures and to consider what steps need to be taken to increase network resilience to support the required performance levels. The cost of any proposed solution should then be compared to the cost savings arising from the increased resilience.

6.6.2.3 When specifying the RAM requirements, the railway should bear in mind that in some instances separate availability requirements will need to be specified for the various system failure modes and not just for the system as a whole. It also demonstrates that the requirements will vary on an installation-by-installation basis.

6.6.2.4 The railway should keep in mind that, when specifying the end-to-end performance parameters, a similar methodology needs to be followed for the fixed network. The results then need to be combined with those obtained for the mobile network to derive the optimum end-to-end solution.

6.6.3 Availability and reliability issues

6.6.3.1 End-to-end performances of voice and data services are the main points of interest for railway users. In order to determine the performance requirements for a communications network, the following availability issues need to be taken into account for both private and public network implementations:

- networks have many different failure modes which may have different impacts on train running, leading to a degraded service or a complete failure of the application;

- the same failure mode may have different impacts on train running, depending on the location of the failure, the level and type of traffic using the line and even where the trains are at the time of failure;
- the availability of a system will vary with the size of the system and the number of elements in the system or, conversely, to achieve the same level of availability from two systems, where one has double the number of components of the other, these components will need to be twice as reliable;
- the availability of the system needs to be set in the context of the availability of the rest of the railway infrastructure contributing to the application in question.

6.6.3.2 As national railway authorities specify and install GSM-R systems, they will need to base their reliability and availability requirements around the requirements of the applications running over the system. The particular demands of any application will therefore depend on the national railway authority implementing the application and the type of traffic using the application.

6.6.3.3 Reliability requirements are often expressed in terms of the Mean Time Between Failures (MTBF) of specific equipment components (ie the average period for which an item of equipment will continue to operate before failure).

6.6.3.4 Availability is generally specified as a combination of the MTBF and Mean Time To Repair (MTTR) of a given equipment item. It is a measure of the percentage of time for which an item of equipment is in operation.

6.6.3.5 For information and only as an example, here below we are presenting as a return of experience in the case of an operational network - the availability figures for 2008, kindly offered by ProRail:

Overall network availability:	**99, 97%**
Dispatcher systems availability:	**99, 91%**
GSM-R for ETCS network availability:	**99,999%**
Note: excl. planned work	
Average non-availability per incident:	**1.2 hr**

6.6.4 Performance monitoring

6.6.4.1 In the case of a public GSM network, RAM requirements and the associated levels of service required from the network operator(s) will need to be carefully considered and set out in the Service Level Agreement (SLA) between the network operator(s) and the railway. In order to be able to assess the actual quality of service provided by the network, methods should be devised to monitor, on an ongoing basis, quantities such as:

- call set-up times;
- coverage reliability and signal strength;
- hand-over times;
- hand-over interruption;
- byte error rates;
- end-to-end transmission delays;
- number of calls dropped.

6.6.4.2 The railway should consider the aspect of performance monitoring and the way in which this can be achieved. In most cases, the method by which this on-going monitoring can be achieved will be subject to discussion between the railway and the network operator(s).

6.6.5 Maintainability

6.6.5.1 The *maintainability* of an object, system or service is a measure of how easy it is to repair a fault within the system. It is also a measure of how easy it is to perform routine and preventative maintenance, which enhances the object, system or service's reliability. Maintainability is therefore closely related to the system and component design and should as such be considered in conjunction with these aspects of system specification and procurement.

6.6.5.2 The ease with which an object, system or service is repaired is usually expressed as its Mean Time To Repair (MTTR), although the acronym MTTR is also sometimes used as Mean Time To Replace. This is particularly the case in modern systems, where individual sub-systems can be replaced upon failure, thus effecting a repair on the overall system.

6.6.5.3 Note that the definition of MTTR includes not only the ease with which the object, system or service can be repaired, but also the speed with which the fault is detected and identified and the speed with which the relevant maintainer is notified and can attend to the problem. Maintainability therefore includes the aspects of fault detection, fault identification and the notification and attendance of the relevant maintenance personnel.

6.6.5.4 Maintainability will also include preventative and routine maintenance, especially the ability of an object, system or service to maintain full functionality while undergoing maintenance.

6.6.5.5 Maintainability of the communications system is not covered by the EIRENE Specifications. It is the responsibility of the railway to define its requirements, which are most likely driven by its business and operational needs.

6.6.5.6 As part of the maintainability specifications to be included in the ITT, the railway should consider the following particular aspects:

- specification of fault management functionality required;
- definition of a maintenance strategy, which should include both preventative and corrective maintenance;
- definition of responsibilities and clear lines of reporting.

6.6.5.7 Fault management is a set of functions which enables the detection, identification, localization and, where possible, isolation and correction of abnormal operation of the communications system. It provides facilities for the performance of maintenance phases from ITU-T Recommendation M.20:

- **alarm surveillance**: provides the capability to monitor the quality of service provided through network elements. When an event indicates a measured degradation of service or equipment performance, surveillance features either inform the system manager or invoke other operations which minimize and correct the faults, thus allowing proactive maintenance capabilities.
- **fault localization**: where the initial failure information provided by the system is insufficient for fault localization, it has to be augmented with information obtained by additional failure localization routines. The routines can employ internal or external test systems and could be controlled by the system management platform(s).
- **fault correction**: fault correction normally requires change or repair of equipment. One or more fault corrections can be performed in the course of a maintenance visit. It is desirable that strategies be developed to accomplish fault correction satisfying overall maintenance objectives within a minimum number of visits, using the concept of logistic delay.
- **verification testing**: after the fault has been corrected, checks must be carried out to assure that the equipment is working correctly. The diagnostics testing can either be carried out locally or remotely. Two principal methods are available:
  - analysis is carried out by equipment and results reported to the management platform;
  - analysis is carried out by the management platform.
- **trouble administration**: records should be kept, detailing current trouble status, additional information, actions that have been executed, are being executed or will be executed, which troubles have been resolved, etc. Accurate record keeping will allow organization of maintenance and optimization of the maintenance policy.

6.6.5.8 To allow this, fault management must include functions to:

- generate, maintain and examine error logs;
- accept and act upon error detection notifications;
- trace and identify faults;

- carry out sequences of diagnostics tests;
- correct faults.

6.6.5.9 The maintenance strategy should build on the fault management functionality provided. It should cover aspects such as:

- preventative and corrective maintenance activities;
- maintenance support (e.g. sub-contracting maintenance aspects);
- spares holding, supply lead times, etc;
- logistics, including response times and accessibility of sites;
- resource requirements.

6.6.5.10 When defining the maintenance strategy, the railway should also take into account the performance and availability requirements placed on the system, as these will be a main driver for most of the aspects to be considered.

6.6.5.11 Finally, the railway should ensure that clear lines of communication for fault reporting are defined. It should consider in particular the way in which users are to report faults and how maintenance teams, or a network operator in case of a public network implementation, are to be informed. Streamlining of fault reporting will lead to a reduction of duplication and resource requirements and ultimately to a more efficient handling of the failures. In addition, feedback on progress needs to be considered.

6.6.5.12 Effective preventative maintenance/maintenance are essential to the successful operation of a GSM-R network. Aspects such as the training and qualification of maintenance staff need to be defined in detail by each national railway.

6.6.5.13 Persons, who are allowed to undertake maintenance work, must have the relevant training experience and supervision. Knowledge of the relevant standards, operating conditions, regulations and rules is also essential. Work instructions for each maintenance procedure need to be carefully defined, documented and disseminated to the staff responsible for undertaking the work. These work instructions need to cover the safety aspects of the work.

6.7 Network management

6.7.1 Introduction

6.7.1.1 As is the case with any telecommunications network, a network management system is a vital and fundamental part of system management as it is the means to streamline network operations processes, leading to correct and efficient operations.

6.7.1.2 Network management is the set of processes for the monitoring, control and co-ordination of all network elements within the communications system. Network management is therefore an integral part of the day-to-day running of the system.

6.7.1.3 In order to describe management operations on network elements in the GSM-R environment, the resources are viewed as managed objects with defined properties. Information required for network management purposes may be provided through local input, may result from input from other systems through network management (application layer) communication or may be a result of lower layer protocol exchanges.

6.7.1.4 The network management discussed in this document is based on the Telecommunications Managed Network (TMN) philosophy. TMN, which was developed by the ITU, is a management architecture framework that provides an environment for interfacing a telecommunications network with the management platforms that are used to manage it. Its architecture and interfaces are defined in the ITU-T M.3000 recommendation series. The basis for these recommendations is the ITU-T X.700 recommendation series, which define the ISO network management standards for the OSI reference model. Since their introduction, the standards have been promulgated by other standards bodies, most notably by the Network Management Forum (NMF) and ETSI.

6.7.1.5 The TMN architecture supplies a model of logical layers that partition management of a network into five domains, or layers. Starting at the top, the hierarchy consists of the following layers:

- **business management layer**: handles the specific business goals and deals with aspects related to high-level business planning, budgeting, external relationships and legal arrangements;
- **service management layer**: this handles the contractual aspects of services, such as the definition of required services to be provided, interfaces between customers and the service provider; service level agreements; what statistical data a customer should have access to, usage and billing, etc;
- **network management layer**: controls and co-ordinates all elements within the network. It permits network modifications and interacts with the service management layer in matters related to performance, usage and network availability;
- **network element management layer**: controls and co-ordinates a subset of network elements. It compiles statistics, logging data and other data related to the network elements;
- **network element layer**: this contains the functionality of managing at element level and providing the required data of an individual network element in a useful form to the network element management layer.

6.7.1.6 The requirements to be satisfied by network management activities within each of the management layers can conveniently be grouped into five functional areas, each of which gives rise to one or more standards covering one or more functions. These areas, as defined by the OSI Management Framework and adopted by the TMN architecture, are:

- **fault management**: used to detect, isolate and repair problems. It encompasses activities such as the ability to trace faults through the system, to carry out diagnostics and to act upon the detection of errors in order to correct faults;
- **configuration management**: this defines the procedures for initializing, operating and closing down the managed objects, and the procedures for re-configuring the managed objects;
- **accounting management**: this defines how network usage, charges and costs are to be identified;
- **performance management**: this supports the gathering of statistical data and applies the data to various analysis routines to measure the performance of the system;
- **security management**: this provides the rules for authentication procedures, the maintenance of access control routines, authorization facilities and security logs.

6.7.1.7 Many items of information, their associated management operations and the communication protocols are known to be common to more than one functional area. Therefore, in performing management activities, sets of management functions may be combined to effect a particular management policy. For these reasons, network management standards form a closely interrelated set of standards.

6.7.1.8 As a result, three main groupings within the set of network management standards are identified within the OSI framework. They are:

- a set of standards specifying network management functions;
- a set of standards relating to the specification of managed objects;
- a set of application layer service and protocol standards for communicating information relating to management functions.

6.7.2 Network management platform

6.7.2.1 The purpose of a TMN is to support the network operator in the management of the communications system in a flexible and efficient way. The TMN provides the telecom network with management functions and offers facilities for communication between the TMN and the telecom network. The basic principle underlying the TMN is therefore to provide an organized network structure that allows various types of Operations Support Systems, the system management platforms, to be connected to the telecommunications equipment.

6.7.2.2 The TMN is ***logically*** a separate network that interfaces the telecommunications network at several points to receive information from its elements and to control its operation. However, physically, a TMN often uses different parts of the network for its communications.

6.7.3 Network management specification

6.7.3.1 When developing the technical specification for the communications network, it is important to consider network management in detail. The way in which the network management functionality has been defined will, to a large extent, determine the flexibility in operations and maintenance of the system.

6.7.3.2 The technical specification for network management should, for each of the functional areas, define the specific requirements, state which parties should be allowed access to this functionality and how the access is to be achieved. In addition, the specification should consider aspects of interfacing the network management platform with management platforms of other network operators. This is of particular interest if the communications system is only partly outsourced.

6.7.3.3 Finally, the specification should not only include what information needs to be collected by the various network elements, but consideration should be given to how the collected data can be processed and presented by the system.

6.8 Numbering plan

6.8.1 Introduction

6.8.1.1 Although the EIRENE -SRS specifies the structure of the numbering plan to be used in GSM-R networks when using functional addressing, it does not address the way in which numbers are allocated. This depends on the national network implementation and the parties involved.

6.8.1.2 In general, it is the responsibility of the national railway to implement a numbering plan according to the EIRENE Specifications. This section will detail what is required under the various implementations. For more details on the use of functional addressing and call routing, please refer to sub-section 5.2of this document.

6.8.2 Overview of numbering requirements

6.8.2.1 The EIRENE numbering plan, which consists of the Functional Numbers, is in principle a private numbering plan, although provisions will have to be made in order to allow routing through public networks. The following sub-sections detail the implications of using, firstly, a fully private network and, secondly, a network comprising a public fixed network and/or a public GSM network.

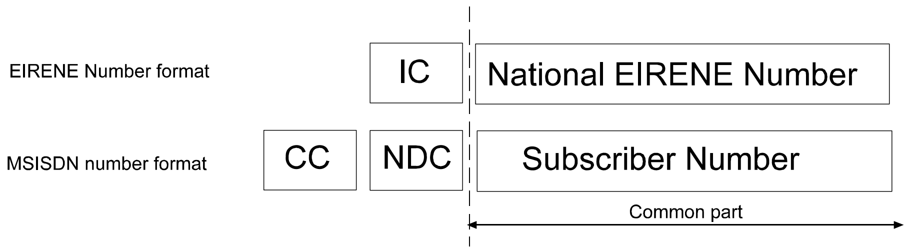
6.8.3 Allocation of numbers

Mobile numbers

6.8.3.1 The E-SRS mandates that each mobile is allocated an MSISDN number to allow authorized subscribers to call the mobiles using the appropriate MSISDN number rather than the Functional Number. Each railway will therefore be required to obtain MSISDN numbers for the mobiles from the relevant authorities.

6.8.3.2 There is an overlap between Functional Numbers and MSISDN Numbers. This overlap consists of the National Functional Number being equal to the Subscriber Number part of the MSISDN number as shown in the figure below.

6.8.3.3 The E-SRS mandates this overlap for Call Type = 8. However, railways may find that this overlap can also be achieved for other Call Types, depending on the implementation of the EIRENE numbering plan and the allocation of MSISDN numbers.



Functional Number - MSISDN number overlap

Fixed network extensions

6.8.3.4 Each fixed terminal connected to the GSM-R network requires an extension number. The exact requirements for number allocation depend on the national implementation of the communications network. If the fixed network is based on a public fixed network, then the numbers will probably be allocated by the fixed network operator. If the network is implemented as a private network, then no allocation is required and the railway will be free to allocate numbers to the fixed extensions as required.

6.8.3.5 Special care should be taken, however, that correct allocation of numbers is achieved when a public network is connected to a private network . In these situations, the railway needs to ensure that the overall numbering plan for the integrated radio communications system is unambiguous with the numbering plan used in the public networks.

Functional Numbers

6.8.3.6 The Functional Numbers allocated in the national network must comply with the structure as detailed in the E-SRS. This means that the railway must be careful in specifying the required numbers and achieving allocation of the numbers depends very much on the implementation and the availability of numbers.

6.8.3.7 The following specific situations need to be considered:

1 **Follow me in public network.** In this case, the Functional Numbers require routing through public networks and must therefore comply with the ITU-T E.164 numbering structure. The required numbers must be obtained from the network operators or, if the numbers are not available, from the national Administrator. With this implementation, there is a risk that the required numbers are not available, thus hampering a correct implementation of the EIRENE numbering plan. In addition, obtaining the correct numbers for future extensions may prove difficult.

2 **Intelligent Node implementation.** In this situation, if the IN is accessed before the Functional Number information is passed on to the node (i.e. by using the ENAN), then the railway only needs to obtain an ENAN and is then free to define the Functional Numbers according to the E-SRS. If the IN is ***not*** accessed via an ENAN, then the allocation requirements depend on the actual implementation of the network. If a public network solution is chosen, then the railway must obtain numbers as detailed in situation (1) above, otherwise the railway must obtain numbers as detailed in situation (3) or (4) below.

3 **VPN implementation.** If the network is based on public networks, but as a VPN, then the railway will have some flexibility in defining the required numbering scheme as the information is, in this case, passed transparently through the public networks. However, the railway must ensure that the numbers can be translated into the proper extension numbers as required.

4 **Private network implementation.** If the network is based on a private network, then the railway can design the numbering plan according to their own requirements (to ensure compliance with the EIRENE Specifications) and does not require allocation of numbers from any operator or the national Administration. It should be noted that this will only apply in those situations where both the fixed and mobile networks are private. If any part of the integrated radio network is based on a public network, then number allocation will be required as detailed in (1), (2) or (3) above, depending on the implementation.

Short codes

6.8.3.8 The railway must ensure that short codes are recognized by the network and this must be specified in the technical specifications.

6.9 Roaming aspects

In GSM a mobile is considered to be roaming if it has made a location update in visiting network (typically a mobile going to another country).

International roaming

In such a situation, the train may be contacted from its home network using its (national) Functional Number even after it has crossed an international border. However, in order for controllers in the GSM-R network that the train has roamed into to access the on-board mobile equipment, they will be required to use International Functional Numbers. The disadvantage of this is that it is undesirable for the signalers to have to look up the home networks of trains before they are able to contact them.

6.9.1 Any specific issues related to the hand-over of trains between the radio systems used need to be identified by the railway and addressed in the technical specification. Issues that will need to be considered here include:

- location of boundaries;
- registration and de-registration when crossing boundaries;
- dual equipping of cabs;
- use of location information systems and passing information between the systems when crossing a boundary;
- membership of CUGs;
- private numbering plan and VPN access/membership;
- operational procedures, both for signalers and drivers.

National roaming

6.9.2 In addition, there are situations where trains roam between an EIRENE and non-EIRENE network in the same country.

6.9.3 As part of a disaster recovery strategy it may be decided that mobiles be able to roam on to a public GSM network in case of a loss of service. Alternatively, a GSM-R network implementer may decide to only equip some railway lines with GSM-R leaving the remaining lines to be covered by one or more public operators (note that this can also be the case when a GSM-R network is rolled out in phases). This particular aspect is not covered by the EIRENE Specifications.

6.9.4 Such a strategic decision must be carefully planned as the implications to railway operations are signification. The enhanced features that are available under GSM-R would not be accessible for users. Features that would no longer be accessible to controllers and drivers include:

- railway emergency calls;
- functional addressing;

- group calls;
- broadcast calls;
- location dependent addressing.

6.9.5 Whilst a railway may decide that this is not a problem for operations, an essential element to consider is what happens to mobiles moving from GSM-R covered lines to non-GSM-R covered lines. The change in functionality needs to be clearly understood by all parties including the train driver and controller. A train starting its journey on a GSM-R equipped line will no longer have the ability to send and receive railway emergency calls for example when the mobile roams on to a non-EIRENE network. The driver needs to be aware at what moment the radio functionality changes (the use of lineside signage could be useful for example).

7 Requirements capture and Business case development

7.1 Introduction

7.1.1 This section discusses two main aspects to be carried out at the early stages of a project: requirements capture and business case development.

7.1.2 It is vitally important to provide an adequate statement of requirement at the outset, particularly where requirements have significant impact on the design of the core infrastructure. The operational and financial consequences of failing to get the initial specification right could have a major impact on the railway's ability to meet its business and operational objectives and would consequently lead to higher costs. Sub-section 6.2 provides an overview of the different stages that can be identified as part of the requirements capture process.

7.1.3 Of equal importance is the development of a business case as this is generally the only way in which funds for the development and implementation can be made available. It is without doubt that the business case must reflect as close as possible the true costs of the investment as any underestimate may lead to additional funds not being available, therefore leading to an inferior solution. Sub-section 6.3 considers the aspects of the business case development.

7.1.4 It should be kept in mind that this section only provides general guidelines as it is likely that each railway will have particular ways of dealing with these aspects.

7.2 Railway requirements

7.2.1 General

7.2.1.1 The requirements can be grouped as follows:

- business needs, drivers and priorities;
- European interoperability requirements;
- national railway requirements (associated with railway-specific operations and telecommunications).

Business needs, drivers and priorities

7.2.1.2 Each national railway will have its own individual requirements for a radio communications system depending on the business needs, drivers and priorities of that individual railway. It will therefore be important for each railway to clearly define these needs and ensure that they are accounted for in the specification of the system.

7.2.1.3 The EIRENE Specifications allow a high degree of flexibility in the implementation options available. It is the responsibility of each railway to ensure that the specified radio system provides the required functionality to meet their business needs, whilst complying with the European interoperability requirements discussed in the next sub-section.

European interoperability requirements

7.2.1.4 The E-FRS and E-SRS identify mandatory functional and system requirements to facilitate international interoperability. The following lists summarize the requirements identified as being vital for interoperability and those identified as desirable:

- **Requirements vital for interoperability**:
  - railway emergency calls (driver or controller initiated);
  - controller to driver communications (non-emergency calls);
  - driver to controller communications (non-emergency calls);
  - registration and de-registration procedures;
  - European Train Control System (ETCS);
  - driver to driver calls for assistance;
  - public emergency calls.
- **Requirements desirable for interoperability**:
  - shunting (although some shunting requirements are mandatory);
  - driver to ground (except controller);
  - driver to drivers of other trains in same area;
  - conductors and other onboard teams to ground;
  - DSD messages;
  - direct mode.

7.2.1.5 All of the requirements listed above are clearly covered by the EIRENE Specifications, both in terms of required functionality and in system specification. Other issues such as system maintenance, reliability, fall backs, availability of services and equipment, system management requirements and the meeting of operational requirements will have to be addressed according to the needs and discretion of each individual railway.

7.2.1.6 When specifying the national radio system, each railway must ensure that the requirements for European interoperability, as detailed in the EIRENE Specifications, are met in order for the system to be classified as EIRENE compliant. This implies that the system must comply with all mandatory requirements stated in the E-FRS and SRS. Any conflicts of these requirements with either national business needs or specific national railway requirements (see below) need to be resolved without compromising the interoperability requirements.

National railway requirements

7.2.1.7 The requirements that a national railway will place on an integrated radio system are mainly driven by their operational, safety and business requirements. They include the technical specification of communications network aspects such as:

- construction and manufacturing of equipment;

- interfaces to on-train systems;
- interfaces to ground-based systems;
- the specification of HMIs;
- requirements relating to specific national applications;
- environmental issues;
- installation, testing and commissioning of the system;
- provision of documentation;
- engineering and safety approvals;
- training of personnel.

7.2.1.8 It is outside the scope of this document to consider in detail the national requirements for each railway. However, when specifying the national requirements for an EIRENE-compliant network, the railway must ensure that the requirements placed on roaming trains do not exceed the requirements as specified in the EIRENE Specifications. If this were the case, then interoperability would be jeopardized.

7.2.2 EIRENE-related document overview

7.2.1 In order to produce a functioning GSM-R system, there are two main issues that need to be addressed. These are the issues of international interoperability and GSM compatibility. As a result of this, two types of documentation are considered; firstly, documents relating to the interoperability issues as directed by the European Commission and secondly, documents related to the implementation of a radio system based on GSM.

EC interoperability directive

7.2.2 The European Commission published a Council Directive on the interoperability of the Trans-European high-speed rail system (Council Directive 96/48/EC). The aim of this document is to establish the conditions that must be met in order to achieve interoperability within Community territory of the Trans-European high-speed rail system. In addition, Council Decision 2001/16/EC was made in relation to conventional rail.

7.2.3 As a result of the Directive, it has become a legal requirement for all Member States to meet interoperability requirements on international high-speed lines.

7.2.4 In order to meet the essential requirements of interoperability between sub-systems (as defined in the Directive), Technical Specifications for Interoperability (TSI) have been developed. These TSI provide details about the essential requirements in order to ensure that the sub-systems are able to meet interoperability.

7.2.5 The Control Command technical specification specifies core interoperability requirements for traffic management systems including communications. Annexe A of this TSI refers to a number of radio-related specifications and standards including the EIRENE FRS and SRS.

7.2.6 The E-SRS references the MORANE Sub-System Requirements Specification (SSRS), a number of low-level technical specifications developed by the MORANE Project including the Form Fit Functional Interface Specification (FFFIS) and a large number of GSM standards. The MORANE documents are largely concerned with the technical specifications of sub-systems and the interfaces between them. It should be noted that in order for a system to be EIRENE-compliant, it must also be compliant with these MORANE specifications and GSM standards.

7.2.7 An overview of the interoperability documentation hierarchy and the status of the EIRENE Specifications in respect to the EC Directive and other specifications is shown in figure 2-3. Further information about EIRENE-related documentation is available in appendix A.

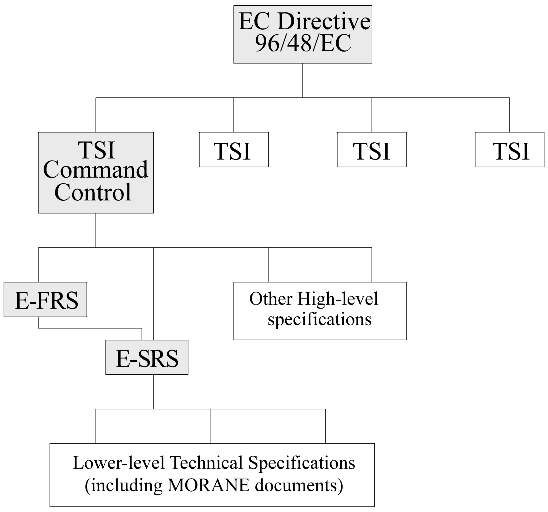


Figure 7-3: EIRENE interoperability documentation hierarchy

GSM related hierarchy

7.2.8 The relationship between the EIRENE Specifications and the GSM standards is shown graphically in figure 2-4. The upper part of the diagram relates to voice communication and the lower part to data communication. The left-hand side relates to the fixed equipment and the right-hand side concerns the mobile equipment. This shows that for both voice and data communication, the core specifications are the GSM air interface followed by the GSM network voice and network data services as specified by ETSI. These are built upon by the CENELEC EURORADIO specification for data communication.

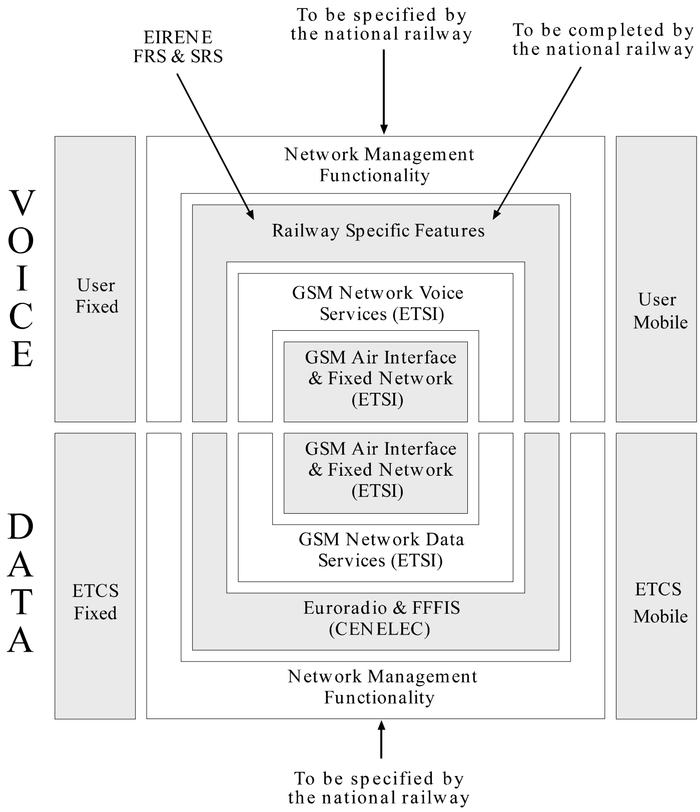


Figure 2-4: GSM specifications

7.3 Requirements capture

7.3.1 Introduction

7.3.1.1 The task of defining requirements for any major new system and of expressing these by way of a formal User Requirements Specification is complex. It is, arguably, the most critical stage of the procurement process in that the downstream consequences of failing to provide the chosen supplier with an adequate requirements specification can be severe. The costs of subsequent changes to resolve the differences, if indeed this is practical, are likely to be very much greater than the cost of preparing an adequate specification in the first place. Furthermore, the corrective action will result in delay of the successful utilization of the system.

7.3.1.2 Railway requirements considered in this document relate to the procurement of an integrated radio communications system, which meets an agreed set of performance criteria (e.g. coverage, capacity, grade of service, reliability, etc), partly specified by the EIRENE Specifications and partly the result of national railway requirements.

7.3.1.3 A number of important benefits stem from the development of a good requirements specification:

- its preparation forces the various interested parties within the railway organization to consider their specific requirements carefully and to review the integration and rationalization of the overall service within the context of each other's sets of requirements;
- the improved visibility of the requirements provides enhanced communication between the railway and supplier and provides a sound basis for contractual relationships;
- it provides a firm foundation for the design phase of the system;
- it enables the planning of validation, verification, and acceptance procedures to be made against a baseline for compliance;
- it provides a starting point for all subsequent control and management of the project, for example, estimates of cost, time and resource scheduling.

7.3.1.4 Requirements definition is the total process of moving from an initial statement of requirements to a precise and detailed requirements specification. In general, this process can be broken down into five sub-processes as follows:

- **Define terms of reference –** the scoping of the requirements definition process, comprising a clear statement of the objectives of the project, its scope, and the tasks to be carried out;
- **Requirements acquisition –** the process of extracting requirements from representative users, technical, management and support staff to ensure that all aspects of the requirement are defined;

- **Requirements capture and analysis –** the process of capturing these requirements in such a way as to facilitate analysis, checking, sorting, rationalizing, prioritizing and validating raw requirements to allow more meaningful information to be obtained;
- **Requirements specification –** the process of expressing the requirements in concise written form, comprising a series of higher level statements which are distilled from the individual user views. This represents the main output from the requirements definition process and serves as the basis for future procurement action;
- **Validation –** the process of ensuring that the requirements specification is complete and consistent, that it adequately reflects the requirements of users as agreed and endorsed, and that it is technically achievable taking into account any design constraints.

7.3.1.5 The remainder of this sub-section will consider the main aspects of each of these five steps in more detail.

7.3.2 Definition of 'terms of reference'

7.3.2.1 It is important at the outset to have a clear 'terms of reference' for the requirements definition task. This should be a straightforward description of:

- the objectives of the requirements capture process:
  - to raise awareness among users and other parties involved in the specification process;
  - to produce a high level Requirements Specification;
- the scope and boundaries of the user requirement:
  - identification of the core system/services to be procured;
  - identification of external systems with which the core system/services will interact (i.e. fixed networks, control rooms, information systems, terminals);
  - time period over which the service will be operational;
  - major dependencies and constraints;
- the tasks to be carried out:
  - requirements elicitation;
  - requirements capture and analysis;
  - requirements specification;
  - validation;
- the responsibilities of those involved in the process:
  - who provides information (user groups, technical staff etc);
  - who captures and interprets the information;
  - who reviews the requirements and checks validity;
  - who acts as the final approval authority.
- identification of likely timescales and resources.

7.3.3 Requirements acquisition

7.3.3.1 The main purpose of the requirements acquisition process is to obtain, through a variety of mechanisms (questionnaires, interviews, scenario workshops, activity logs, current system data, etc) the basic data and information from which to compile the Requirements Specification.

7.3.3.2 Typical inputs to the requirements acquisition process, and methods to be used, are likely to be:

- existing documentation and reports (e.g. Project Initiation Document, Feasibility Study Report, Business and Operational Strategy);
- the EIRENE Specifications;
- documentation defining the scope of the task and the methodology to be employed;
- interviews with selected users, technical staff, management and support staff;
- current system data (volume of voice and data traffic, etc).

7.3.3.3 The main outputs from the acquisition process will be:

- an initial problem/requirements catalogue;
- a logical description of the existing communications processes – ie who communicates with who, how frequently, for what reason etc (overall picture agreed with users and management);
- a set of raw data, obtained from the various sources including the E-FRS and E-SRS;
- identification of major issues requiring resolution and a record of the decisions made to resolve them.

7.3.4 Requirements capture and analysis

7.3.4.1 The aim of the requirements capture process is to establish a mechanism whereby most (if not all) of the data and information extracted during the requirements elicitation process can be recorded. This should be done in such a way as to facilitate the analysis of requirements (leading to the production of the Requirements Specification) and to ensure that all requirements are traceable back to its source.

7.3.4.2 The analysis of requirements should consist of detailed logical analysis, consolidation (i.e. grouping similar requirements from different sources together into coherent groups), consistency checking, and clarification. The use of a simple computer based tool to support this process can offer a number of significant benefits including:

- storage of all requirements data;
- cross-referencing and verification of requirements;

– production of summary statistics and data;

– data input into document production.

7.3.4.3 The planning stage of the requirements capture process involves determination of a structured method for collating and interpreting the raw requirements data, for example, establishing a requirements catalogue with entries containing:

- heading (descriptive title);
- identification of source (workshop, interview/name, etc);
- date that the information was acquired;
- labeling of requirement to enable it to be allocated to various categories (high level function, user group, application etc);
- initial priority assigned to the requirement;
- text description of the requirement;
- any measures or metrics associated with the requirement;
- follow up action required/clarification to be sought etc.

7.3.4.4 The execution stage of the requirements capture process involves the collation, analysis and validation of requirements.

7.3.4.5 Note that the requirements acquisition and requirements capture processes overlap. The planning stage for requirements capture will need to be completed before the requirements acquisition process gets underway in earnest.

7.3.4.6 The main output from the requirements capture process is a comprehensive set of system requirements, providing a complete and traceable record of the outputs from the requirements acquisition process.

7.3.5 Requirements specification

7.3.5.1 The main purpose of a requirements specification is to express, through a series of high-level requirements statements, a description of what the railway expects to be delivered. The specification should define at least the railway's requirements in terms of:

– function;

– performance;

– interfaces;

– design constraints.

7.3.5.2 The implications of under- or over specifying the service requirements must be considered. On the one hand, it is dangerous to under-specify as this will limit operational capabilities, and might lead to change requests which turn out to be expensive. On the other hand, any over-specification may lead to unacceptably high investments, which in turn will stress available budgets and/or limit operational capabilities due to tighter restrictions on use.

7.3.5.3 The complementary purpose of a requirements specification is to enable the system developer or designer who is required to deliver the service to understand exactly what it is that the purchaser wants. This bilateral understanding establishes the basis for agreement between the purchaser and supplier on what is required. It also assists the potential users in determining whether their needs will be met by the system as specified.

7.3.5.4 The aim of the requirements specification is to provide a clear, consistent, precise and unambiguous statement of the requirements. The requirements should be stated in such a way that it is possible to verify objectively whether the delivered system and services provided meet the requirements.

7.3.5.5 Thus it must be possible for the supplier to produce compliance matrices that relate their service components to specific requirements. It should also be possible to define the acceptance criteria and methods which will be used to test the conformance of the delivered service.

7.3.5.6 The following six characteristics should be borne in mind when preparing requirements specification. It should be:

- **Unambiguous –** every requirement should have only one interpretation. A glossary of terms can help, but in general, users must be aware of the potential pitfalls of requirements expressed in natural language;
- **Complete –** all significant requirements and aspects of the environment, whether relating to functionality, performance, design constraints, etc, should be included;
- **Verifiable –** used here in the sense that the requirement must be stated in such a way that the system or service can be checked that the requirement has been fulfilled;
- **Consistent –** there should be no conflict between individual requirements;
- **Traceable –** proper referencing is needed to allow backward traceability (to previous documents and databases) and forward traceability (to spawned documents);
- **Useable during operation and maintenance phase –** attention needs to be paid to operation and maintenance needs and the updating of the requirements specification to meet these needs especially where failure of a component of the system or service could be critical or where temporary changes are made.

7.3.5.7 The requirements specification should be reviewed as it is developed, and once agreed, should be put under change control.

7.3.6 Validation

7.3.6.1 Validation can be considered to be the process whereby individual requirements are checked for their relevance, clarity, accuracy, and their consistency with similar requirements expressed by other users. It is not unusual to find that requirements expressed by different individuals, even if they belong to the same user group, may be contradictory, and these will need to be resolved through further discussion.

7.3.6.2 An important aspect of validating requirements is to check that they fall within the scope of the service requirements as defined in the terms of reference for the requirements definition phase. Adherence to this is necessary to ensure that the requirements set does not become swamped with unnecessary information.

7.3.6.3 An important part of the validation process involves the circulation of the final requirements specification to end users to ensure that they are happy with the document and that their requirements are adequately represented.

7.3.6.4 However, the validation of requirements should not be seen as a one-off process at the end of the requirements definition phase. Validation is an ongoing process, and indeed, the whole of the requirements definition process from requirements elicitation through to validation can best be described as an iterative process of gathering and analyzing requirements until a final product (the Requirements Specification and it's supporting database) has been completed and checked for validity.

7.4 Business Case development

7.4.1 Introduction

7.4.1.1 The main method for allocating funds to the development and implementation of a new communications system is the business case. This should detail the particulars of the system, including the degree to which the solution can meet the requirements, how the solution was selected, the cost of such a solution and the way in which the solution is to be implemented.

7.4.1.2 It should be remembered that although the business case requires a large amount of detail, the main aim is to allocate the funds. The railway should therefore ensure that sufficient information is available to justify the funds for the solution chosen without going into too much technical detail, in particular regarding the implementation of the system.

7.4.1.3 This sub-section provides an overview of the business case document, indicating the main elements that should be part of such a document.

7.4.1.4 As the financial appraisal forms most likely the key part of the business case, since this will form the financial justification for the selection of a particular implementation, a separate sub-section has been dedicated to this aspect, highlighting the main aspects of the cost analysis.

7.4.2 Contents of the business case

7.4.2.1 Although each railway will have their own rules for writing the business case for new systems, the following overview may serve as a general guideline for the contents of a business case document:

1 Introduction

General introduction
Background
Requirements statement

2 Choice of solution

Approach taken to assess solutions
Overview of existing system(s)
Technologies, standards and architectures
Realization options
Overview of analysis of costs - based on the financial appraisal
Solutions shortlist

3 Financial appraisal

Approach
Definition of options under consideration
SWOT[5] assessment
Cost comparison
Recommended solution

4 Implementation of recommended solution

Approach
Procurement strategy
Ownership
Management
Migration
Risks

5 Conclusions and recommendations

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[5] SWOT = Strengths, Weaknesses, Opportunities and Threats

7.4.3 Financial appraisal

7.4.3.1 A crucial step in the procurement of an integrated radio communication system is the calculation of the potential financial impact of the system implementations under consideration. Attempting to compare the cost of different implementations is complicated by the differing nature of the expenditure on each. Procuring a private network is composed mainly of a large up-front investment, followed by a smaller expenditure on maintenance over the lifetime of the equipment. When outsourcing, service provision costs can be attributed to a constant, but not insignificant annual rental. In comparing the two implementations, it is necessary to derive either a total lifetime cost or an equivalent annual cost.

7.4.3.2 There are several methods to compare investments with each other. When evaluating total costing, which involve expenditure over a number of years, the best method for comparison is the Net Present Value (NPV) method. This method recognizes the cost of capital. Expenditure that does not occur for a period of time or is performed over several years should be discounted to reflect the fact that, for example, instead of making the expenditure now, capital could be invested so that by the time the expenditure is made, some additional capital has accrued. This discounting favors expenditures which can be postponed to the future and penalizes large initial investments.

7.4.3.3 Once the capital expenditure required for each year has been estimated, the NPV for each option under consideration can be derived as follows:

$$NPV = \sum_{n=0}^{m}\left[\frac{-E_n}{(1+i)^n} + \frac{R_n}{(1+i)^n}\right] \qquad 6\text{-}1$$

where E_n is the annual expenditure in year n, R_n the annual revenues in year n, i the discount rate and m the number of years considered (i.e. lifetime).

7.4.3.4 In order to perform these calculations for different options, it is necessary to agree the following parameters:

- the period over which to perform the costings (e.g. 10, 15 or 20 years);
- the discount rate;
- the moment at which payments are made (e.g. once a year at the beginning of the year[6]).

7.4.3.5 The following sub-section provides an extensive list of costs and revenues related to calculating the NPV for each possible network option, whereas the final part of this sub-section considers the way in which the information should be used.

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[6] In this context, a year is considered to be a 12 month period counted from the initial investment date. The initial investment date is considered to be Year 0.

7.4.4 Expenses

7.4.4.1 The life-cycle of a product begins as a decision is evaluated and a choice is made to acquire the product. Costs are then incurred throughout the acquisition process, throughout the use of the product, and due to disposal of any old equipment at the end of its lifetime. Cost components may be incurred immediately or they may be deferred.

The following types of costs can be identified:

- **Direct costs**: These are the costs that are typically included when options are compared in conventional cost analysis. These costs are typically attributed to the products under consideration and the processes in which they are used.
- **Indirect costs**: Those costs that are usually not attributed to or directly associated with a given product.
- **Uncertain costs**: Costs that may be incurred by the railway, and can be either direct or indirect. These potential costs are uncertain in magnitude and/or timing.

7.4.5 Direct and indirect costs

Capital expenditure

7.4.5.1 The capital expenditure (CAPEX) is the investment that the railway must make in the installation of the radio communications system during the lifetime of the system. The CAPEX consists at least of the following items:

- market price of transmission equipment and cables, cab radios, fixed network terminals, etc;
- cost of a network management system. The network management system is expected to be able to support fault management, configuration management, accounting management, performance management and security management;
- design costs for the telecommunications side of the project. If this is not clear, a percentage of overall project costs should be agreed upon;
- cost of project management;
- cost of labor;
- costs associated with installation, testing and commissioning. This should also include cost of possessions (when taken, how much notice was given, planning etc will lead to any discounts);
- general expenses (hire of goods, overnight accommodation etc);
- costs associated with provision of documentation;
- costs of initial stock of spares;
- recovery costs of current transmission equipment, cabling and any other equipment.

7.4.5.2 The railway should keep in mind that any subsequent investment once the initial system has been installed and commissioned should also be entered as CAPEX. These investments will be related to any major upgrades and modifications to be carried out during the lifetime of the system.

Operating expenditure

7.4.5.3 Once the asset is installed and put into service, there will be ongoing costs involved with its operation, the operating expenditure (OPEX). These costs include at least the following items:

- cost of maintenance (e.g. an annual figure of 10% of the initial capital expenditure for the transmission equipment, radios and fixed terminals and 5% of the initial capital expenditure for cables);
- insurance costs;
- costs related to managing and keeping the equipment in good working order;
- costs related to spares holdings;
- upgrades and replacements of equipment (due to new requirements, new technology etc);
- costs related to transfer of staff, training of staff etc.

Other costs

7.4.5.4 These are costs that need to be taken into account but cannot be categorised as either part of the initial outlay or annual ongoing costs. These costs include:

- depreciation: although this is not a cash flow, it is used to calculate corporate taxes to be paid, and should be regarded as an indirect contributable factor in the whole life cost calculations;
- taxes;
- inflation: this is not included directly into the NPV calculations. It must be taken into account when estimating the costs of renewal, maintenance, etc. This factor could, however, be taken into account as part of the discount rate;
- salvage value at the end of the normal life span of the asset;
- disposal/removal costs at end of equipment lifetime;
- recovery of assets when replacing the system.

7.4.6 Uncertain costs

7.4.6.1 Uncertain costs are those cost elements that are uncertain in magnitude and timing. These costs are mainly related to the operation of the system. Costs to be considered include costs related to reliability and availability of the system, leading to unscheduled maintenance and replacement.

7.4.7 Revenues

Asset residual value

7.4.7.1 In general, it is assumed that telecommunications equipment has a life span of 10 years, whilst cabling has a life span of 25 to 30 years.

7.4.7.2 There may be some residual value in the replacement of the current radio infrastructure.

7.4.7.3 Although it is not likely that any railway will consider provision of telecommunications services as a core business, opportunities may arise to provide mobile services to third parties once the GSM-R network is in place. Any proceeds from the service provision should be entered as revenues in the analysis.

7.4.8 Baseline whole life costs

7.4.8.1 Strictly, the NPV calculations should be carried out on changes in cash flows. This means that the allocation of costs and revenues should be relative to current expenditure and revenues. This may not always be easy to identify, in particular if the current implementation is significantly different from the new implementation.

7.4.8.2 As an alternative, it may be more practical to consider the current situation as a base case and compare the NPV figures for different implementation options against the NPV of the base case.

7.4.8.3 The initial step in the financial assessment is therefore to obtain an estimate of the costs of the current system(s) over the investment period under consideration. This should include all costs associated to the current system(s), including any modifications and upgrades that would be required to extend the lifetime of the current system(s).

7.4.9 Option comparison

7.4.9.1 Once the baseline has been established, option comparison can take place.

7.4.9.2 For each of the implementation options under consideration, a financial assessment needs to be carried out. It is important to perform the estimates as accurately as possible, as it will in most cases be difficult to justify further allocations of investment capital at a later stage.

7.4.9.3 For each of the options, the investments (initial and subsequent), OPEX and CAPEX need to be determined for each year over the assessment time interval. These values then need to be discounted to derive the NPV for each of the options. These values can then be compared against the NPV of the baseline and can be used to rank the options from a financial perspective.

8 Procurement strategy

8.1 Introduction

8.1.1 An important aspect of the implementation of a radio system is the nature of the procurement and contracting strategies that are to be followed. There are several approaches to this problem, which will be considered in this section. The procurement strategy will be considered first and this will lead on to the contracting strategy options.

8.2 Procurement strategies

8.2.1 The procurement strategy choices available fall into the following categories:

- staged versus non-staged procurement approach;
- the use of a turn-key contractor as opposed to a multiple contractor.

8.2.2 In a staged approach, the implementation of the integrated communications system is split into distinct phases and contracts for each of the phases will be awarded over a period of time. When a non-staged approach is chosen, the implementation may still be split into distinct phases, but the contract(s) for each of the phases will be awarded at the same time.

8.2.3 In a turn-key solution, the contract for implementation will be awarded to a single contractor. This contractor will be the responsible party towards the railway, although the contractor is most likely to sub-contract various elements of system implementation. In a multiple contractor situation, the railway will have to decide what elements of implementation are to be allocated to what type of implementer, and will have to award and maintain multiple contracts. In this situation, each of the contractors will have a direct responsibility towards the railway.

8.2.4 The railway will be required to define its approach towards the procurement of the radio system, deciding upon the phasing of the implementation and the aspects that need to be contracted to implementers.

8.2.5 Table 6-1 gives an outline of the benefits and drawbacks of employing the various combinations of these procurement approaches.

	Turn-key	Multiple
Staged	**Pro**: Able to keep track of each deliverable in turn. The specifications of the next deliverable may be subject to amendment by the contractor in order to ensure maximum compatibility with the deliverables so far received. Responsibility for the production of each deliverable lies with the contractor. The customer may be provided with partial system functionality (and the associated business benefits) at each stage. **Con**: Usually an expensive option. Little to no control over the project for the customer.	**Pro**: Option where the most control lies with the customer. The specifications of the next deliverable may be amended by the customer in order to ensure compatibility with the deliverables so far received. **Con**: Most time-consuming option for the customer to manage. If a mistake is made in the procurement process, the result will be the responsibility of the customer. Customer takes overall responsibility for system integration aspects.
Non-staged	**Pro**: A working system is to be handed over by the deadline if the contract is to be fulfilled. **Con**: No control over the process. Usually the most expensive option.	**Pro**: Usually one of the cheapest options. **Con**: Many contractors to keep track of, all of whom should deliver at the same time. If a single deadline slips, it will compromise the project schedule. If the final system does not work, it is the customer's responsibility to make the necessary amendments.

Table 6-1: Procurement strategy overview

8.3 Contracting strategy

8.3.1 The nature of the contracting strategy is largely defined by the procurement strategy that is employed. A contracting strategy, whereby contracts for the infrastructure supplier, the mobile equipment supplier, the Network Operator and the Service Provider are awarded in stages, may result in reduced risk. This risk is largely associated with contract boundaries and the impact of equipment development problems upon the time-scales and requirements of the later contractual elements.

8.3.2 One may further consider the benefits of in-house as opposed to outsourced service provision. Outsourcing has become popular and has been adopted by many organisations on the basis that:

- outsourcing can be more cost effective because the third party organization can obtain economies of scale;
- the third party has more flexibility to recruit staff with different terms of employment;

– the client organisation can concentrate its management and resources on its core business.

8.3.3 Inevitably, there are risks associated with these benefits which need to be carefully considered. It is also much harder to bring the service function in-house at a later stage because of the lack of skills. It is consequently essential to ensure at the outset that:

– which services are to be provided, and which not, are clearly specified and understood;
– the services provided by the third party will remain available on favorable terms;
– there are mechanisms for agreeing new services on favorable terms;
– there are mechanisms for monitoring the effectiveness of the service being provided.

8.3.4 Furthermore, there are a number of positive reasons to provide telecommunications services in-house. These include factors such as:

– using in-house service provision, the organization has direct control over the services provided. This is particularly important in those areas where an organization is dependent upon the operation of its telecommunications facilities for the functioning of its core business;
– it is likely to be easier to offer a rapid response time and tailored services using in-house staff;
– arrangements between the users and telecommunications staff can be less formal and constrained by contractual rigidity, since the parties have common business objectives;
– any 'profit' made by the service provider at the users' expense is kept within the organization.

8.3.5 The advantages and disadvantages will need to be carefully considered. It is possible that the optimum arrangement may be to continue to provide core services, which are essential to the operation of the business, in-house but less critical services could be organized with the assistance of third parties.

8.3.6 Assuming some telecommunications functions will be provided in-house, it will then be necessary to consider whether the provider should remain as a cost centre or to what extent it should operate as a profit centre and charge users for the services it provides.

8.4 Procurement legislation

8.4.1 The EC has set Directives related to the procurement of services. These Directives are issued to stimulate a competitive market mechanism within the European Community. The following Directives are concerned with service, supply and works contracts:

- 92/50/EEC: Directive of June 1992 relating to the co-ordination of procedures for the award of public services (ie all contracts other than works or supply contracts) contracts;
- 93/36/EEC: Directive of June 1993 co-ordinating procedures for the award of public supply (ie purchase, lease, rental or hire-purchase of products) contracts;
- 93/37/EEC: Directive of June 1993 co-ordinating procedures for the award of public works (ie building and engineering activities) contracts;
- 90/531/EEC: Directive of January 1993 on the procurement procedures of entities operating in the water, energy, transport and telecommunications sectors;
- 93/38/EEC: Directive of June 1993 co-ordinating the procurement procedures of entities operating in water, energy, transport and telecommunications sectors;
- 98/4/EC Directive of 16 February 1998 amending Directive 93/38/EEC co-ordinating the procurement procedures of entities operating in the water, energy, transport and telecommunications sectors.

8.4.2 The EC Directives 90/531/EEC, 93/38/EEC and 98/4/EEC will be the Directive relevant to the procurement of GSM-R networks as they apply to contracts for works, supplies and services relating to the water, energy, transport and telecommunications sectors.

8.4.3 As a result of these directives, utilities[7] are obliged to publish notices inviting interests to tender and make this information available in all EU member states. The legislation is applicable to the supply of products and services and the carrying out of works above particular threshold levels.

8.4.4 It should be noted that, where a contract is sub-divided into several lots, the value of the lots are aggregated. If the value of the aggregate reaches or exceeds the relevant threshold, the Directive applies to each of the lots.

8.4.5 In awarding contracts, the railway is obliged to follow one of the following procedures:

- **Open Procedure**: a Contract Notice to this effect is published in the EC Official Journal (OJEC Notice). All interested suppliers or contractors may submit tenders.
- **Restricted Procedure**: a Contract Notice is published in the EC Official Journal. Suitable suppliers are selected by the contracting authority from those who apply to tender. The shortlisted suppliers are then issued with an Invitation To Tender.
- **Negotiated Procedure**: the contracting entity consults suppliers or contractors of its choice, and negotiates the terms of the contract with one or more of them. This procedure is only allowed in certain limited circumstances.

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[7] Utilities are defined as being authorities and undertakings in the sectors of water, energy, telecommunication and transport. Although some railways may be a private company, they are still classified as a utility under EC law, and must as such comply with the relevant Directives when procuring services and/or infrastructure.

8.4.6 In addition, there is an Accelerated Procedure under which shorter advertising periods are permitted due to urgency. A justification must be published as part of the tender notice.

8.4.7 Contracting entities in the utilities sector have the 'privilege' to establish and operate a system of qualification of suppliers or contractors, with the idea of setting up a list of companies capable and willing to execute future contracts. It is understood that it is allowed to directly negotiate with these suppliers for the services required, as long as call-off contracts are in place. Care should be taken that the services to be procured fall within the scope of the terms set to compile the list of pre-qualified suppliers in the first place. If this is not the case, or if there is any doubt, then the procurement should follow the rules set by the EC. In those cases, it is possible to use the *Restricted Procedure*. This procedure leads to the award of a contract whereby only companies chosen in pre-selection by the contracting authority will be allowed to submit a tender.

Structure of Contract Notices

8.4.8 Under the Directives, the railways will be required to advertise the Invitation to Tender/Request for Proposal in the EC Official Journey in order to allow suppliers to apply or receive it.

8.4.9 Of particular interest to the railways are the following:

- **ITT/RFP notice**, the actual invitation outlining the contract (ITT) or outlining a general framework, inviting the tenderers to make proposals for the product or services they can offer.
- **Contract award notice**, indicating that the tender has been accepted, which company won the tender and for what price, although in selected cases the name of the company and/or the value of the contract are omitted due to confidentiality.
- **Pre qualification notice**, which is a notice that precedes, most commonly, restricted tenders. Only companies chosen in the pre-selection will be allowed to tender for the restricted tender.

8.4.10 The notices are published in the Supplement to the Official Journal of the European Communities, following standard templates, particular to the Directive applicable. The notices must contain specified items of information and must be presented in accordance with models published in the relevant Directive. The standard content and layout saves time and ensures that all tenders give the same amount of information.

8.4.11 Examples of the standard templates for the European Community ITT/RFP notices Type d - Water, energy, transport and telecommunications sectors (i.e. notices published pursuant to Council Directive 93/38/EEC, which abrogates Council Directive 90/531/EEC) are given in appendix C. The railways are, however, strongly advised to check the latest regulations regarding the templates and placement of OJEC notices.

Contact details

8.4.12 For particular aspects of the Directives and the procedures to be followed when placing an OJEC Notice, in particular the type and format of the Notice and the timescales, each railway should contact the Office for Official Publications of the European Communities in Luxembourg or their national representative.

8.4.13 The contact details for the Office for Official Publications of the European Communities are as follows:

Office for Official Publications of the European Communities
Sales Department
2 rue Mercier
L-2985 Luxembourg

Telephone: +352 29 29 42 563
Fax: +3 52 29 29 44 623

8.4.14 Further information can be obtained from the following web site: http://simap.europa.eu/index_en.html

8.5 Services required for private network implementation

8.5.1 In order to implement a private network solution, the following services will be required;

- coverage design;
- site selection, survey;
- construction;
- system integration and optimization.

8.6 Other aspects

8.6.1 In addition, there are several other aspects that need to be considered as part of the procurements strategy. These include:

- requirements on organizational changes;
- operations and maintenance contracts;
- migration and decommissioning of current systems.

These aspects should probably be considered as part of the definition and assessment of a suitable procurement strategy.

9 System Design

9.1 Overview

9.1.1 This section provides guidelines and information for National Railways to assist them in the development of the GSM-R network design. The information presented in this section is derived from a standard network planning methodology, with particular reference to the special circumstances of radio planning for the railway environment.

9.2 Radio

9.2.1 Spectrum considerations

9.2.1.1 One of the most important constraints on GSM-R network planning is the availability of spectrum.

9.2.1.2 The core UIC GSM-R spectrum allocation is as follows

- 876 – 880 MHz (mobile station transmit); paired with
- 921 – 925 MHz (base station transmit).

9.2.1.3 This equates to up to 19 pairs of useable frequencies, each frequency bearing 8 communication channels. The carrier frequency is designated by the absolute radio frequency channel number (ARFCN). For GSM-R carriers the following convention is used, where Fl(n) is the frequency value of the carrier ARFCN n in the lower band, and Fu(n) the corresponding frequency value in the upper band:

- $Fl(n) = 890 + 0.2*(n-1024)$ MHz $\quad\quad 955 \leq n \leq 973$
- $Fu(n) = Fl(n) + 45$ MHz

9.2.1.4 Each pair will henceforth be referred to as a "frequency channel".

9.2.1.5 Aside from the 19 channels, this allocation also includes a 200 kHz guard band to protect against interference between the GSM-R band and the adjacent E-GSM band at the upper end. In addition, a 400–600 kHz guard band is recommended to prevent interference with PMR/PAMR services below the GSM-R spectrum allocation, of which 100 kHz is taken from the UIC band (note, this has also been reserved for UIC Direct mode). The following figure provides an overview (not to scale) of how the spectrum is allocated:

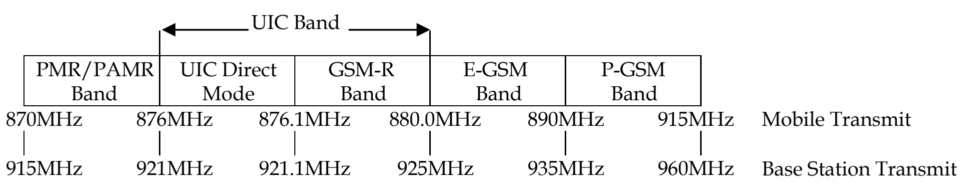


Figure 8-1: Overview of spectrum allocation

9.2.1.6 Where available, additional spectrum for railway use may be sought on a national basis. For example, the E-GSM band is suitable for this purpose because all GSM-R equipment will be capable of functioning at these frequencies. However, the remainder of this section focuses on the case where 19 useable frequency channels are available.

9.2.1.7 As additional information, lobby is done to obtain additional frequencies in the PMR/PAMR Band. At the hour of publishing this guideline version (Q1 2009), the matter has successful passed several stages, being in Public Consultation step (6 of March 2009 until 6 of May 2009). It is not foreseen to have a harmonized spectrum for the Railways, in a first step, due to the different implementation steps and different needs. This means, that if and when this possibility will be officialised, it will be an Option, therefore not possible to be used as a Network Access Criteria.

As Road Map, if all steps are going as planned, the modified European Laws [ecc (02)05 and (04)06] will appear Q2 2010.

9.2.1.8 European Legislation referring to the GSM-R Frequency designation:

1999 560 EC : COMMISSION DECISION of 28 July 1999. on the basic parameters for the command-and-control and signalling subsystem relating to the trans-European high-speed rail system

ECC Dec (02)05 ECC Decision of 5 July 2002, on the designation and availability of frequency bands
for railway purposes in the 876-880 and 921-925 MHz bands

9.2.2 Overview of cell and frequency planning for GSM-R

The cellular concept

9.2.2.1 The cellular network concept is founded upon the principle that breaking a large desired coverage area (served region) up into a series of much smaller coverage areas (cells) increases the available capacity and spectral efficiency of the system as a whole.

9.2.2.2 Envisage a service area (A), represented by the yellow hexagon in Figure 8-2, limited to the use of just two radio channels. The installation of a tall mast at the centre to provide wide area coverage would quickly become congested and overloaded by the subscriber base.

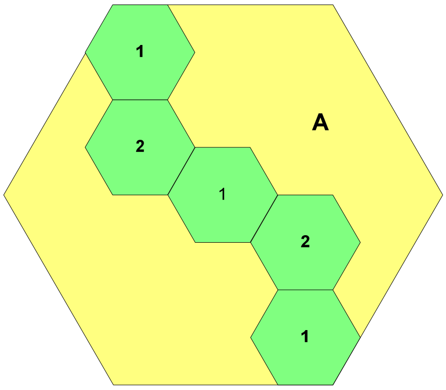


Figure 8-2: The basic cellular concept

9.2.2.3 The cellular concept allows smaller service areas to be deployed, each using a limited part of the available radio spectrum – in this example just one channel – to provide much more localised service. This is represented by the green hexagons in Figure 8-2, which could for example be used to provide service to a railway line. The key is that such an approach allows multiple re-use of the same radio channels in the same global service area, providing much more efficient service to the intended subscriber base and much more efficient use of the available radio spectrum.

9.2.2.4 The cellular solution is typically more expensive, but a network design process is employed to find an optimal position with respect to all system constraints. This will serve to maximize the subscriber base and therefore (in a commercial sense) increase the revenue that can be generated from the available spectrum.

Overview of radio planning

9.2.2.5 A key challenge for the radio engineer is to design the network to re-use the available frequencies so that the system is able to provide the radio capacity that is required in each area, whilst ensuring that the levels of service remain within acceptable limits for the applications it must support.

9.2.2.6 The following aspects are important inputs to the cell and frequency planning process (many of these will need to be visualized geographically):

- The radio capacity that is to be provided in each location by the network.
- The required quality of service for all of the applications to be supported (this encompasses coverage requirements, handover breaks, dropped calls, error rates, latencies, etc).
- Cell site planning considerations (e.g. available sites for construction of base stations, permitted mast heights, provision of power and communications to cell sites, permitted broadcast power, etc).

- Operational considerations that may dictate where cell boundaries need to be located (for example, emergency call areas, shunting areas, controller areas, etc)
- Terrain types and geographical features (e.g. hills, woods, urban areas, large buildings, cuttings and tunnels).
- The available frequencies (e.g. whether there are any limitations on the use of the UIC GSM-R spectrum allocation in the area and whether additional frequencies, for example, in the E-GSM band are available).

9.2.2.7 The cell and frequency planning process results in the generation of the following design information for each GSM-R base station:

- Geographic location of each site.
- Mast height.
- Antenna types and position.
- Required cabling, feeders and fixed links.
- Frequencies and transmission powers to be used.

9.2.2.8 It should be noted that the use of computer based radio planning tools is central to undertaking successful cell and frequency planning. These tools are discussed in more detail later in this section.

Simple illustration of GSM-R frequency reuse

9.2.2.9 Each frequency channel is divided into eight timeslots. A minimum of one timeslot is required per base station to serve as a control channel, leaving seven timeslots available to be used as traffic channels to support voice or circuit switched data calls. The addition of more frequency channels by the addition of more transceivers (TRXs) to each base station will add up to a further 8 traffic channels (alternatively, it could add 7 traffic channels and an additional control channel, depending on the amount of signalling traffic to be supported).

9.2.2.10 If coverage is required over a wide area, for example to support communications across a city with many railway lines and stations, a 7 cell repeat pattern[8] could be used of the type shown in the following diagram, where each circle represents a different radio cell and the colours (and the letters A-G) define 7 sets of cells in which the same frequencies are re-used:

[8] A 7 cell repeat pattern has been considered because this gives a reasonably close reuse pattern with signal to noise characteristics that are acceptable for many configurations.

A Documentation overview

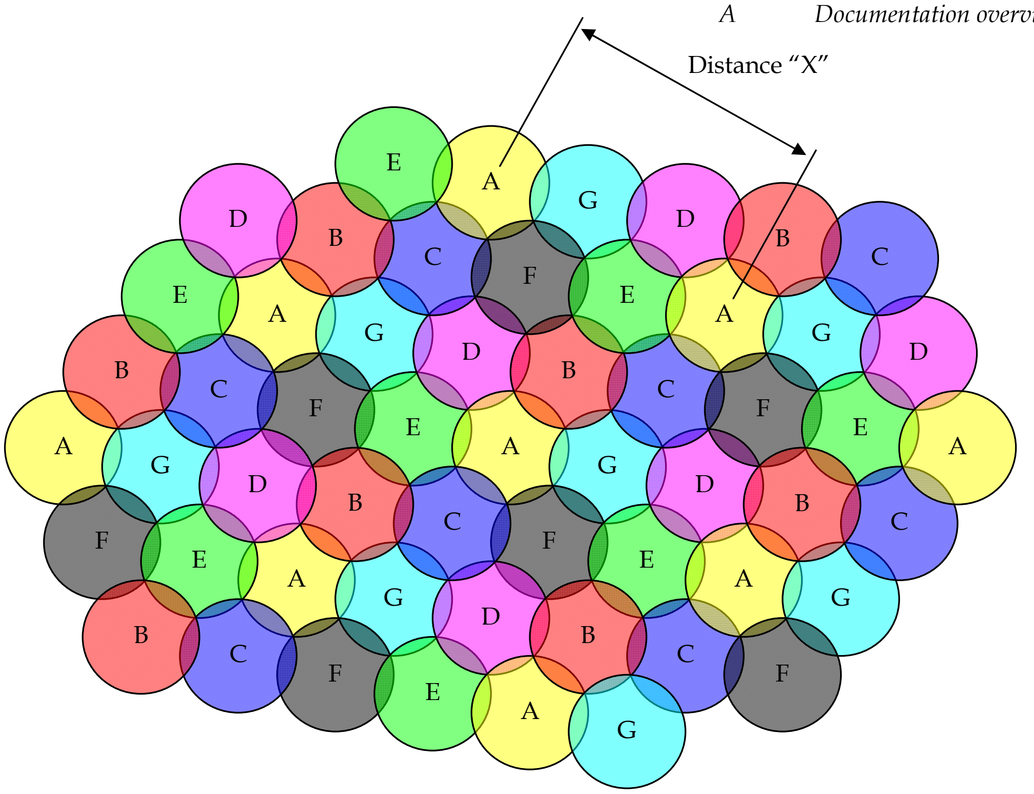


Illustration of a 7 cell repeat pattern

9.2.2.11 One of the most important considerations in the development of a viable cell and frequency plan is to maximize the distance between base stations transmitting/receiving at the same frequencies otherwise co-channel interference will arise, thus degrading service. Interference will also arise from adjacent channel assignments between neighboring cells and this too must be minimized. If this distance is too small, it will have a detrimental effect on the co-channel interference in the network (and hence the C/I and the bit error rate). In order to provide radio capacity, whilst minimizing the co-channel and adjacent channel interference, the 19 channels could be distributed between the differently colored cells as shown in the following table.

Cell	**Frequency Channels**	**No of traffic channels (No of signaling channels)**
Set A (Yellow)	n = 955, 962 & 969	22 (2) or 23 (1)
Set B (Red)	n = 956, 963 & 970	22 (2) or 23 (1)
Set C (Blue)	n = 957, 964 & 971	22 (2) or 23 (1)
Set D (Magenta)	n = 958, 965 & 972	22 (2) or 23 (1)
Set E (Green)	n = 959, 966 & 973	22 (2) or 23 (1)

Cell	Frequency Channels	No of traffic channels (No of signaling channels)
Set F (Grey)	n = 960 & 967	15 (1)
Set G (Cyan)	n = 961 & 968	15 (1)

Possible distribution of frequency channels for 7 cell repeat pattern

9.2.2.12 In a real situation, it is highly likely that some areas will need more capacity than others (for example, large stations). This and other factors such as geographical features, the need to optimize group call areas, and considerations related to location dependent addressing will also have an effect on the optimal cell and frequency plan. This is likely to result in a much less regular distribution of cells and channels than the one shown in this simplified example (in practice, a radio planning tool would be used to simulate the coverage and traffic capacity requirements).

9.2.2.13 The example of providing coverage over a wide area can be contrasted with that of providing coverage along a linear corridor (for example along a reasonably straight section of railway line). This is shown in the following diagram:

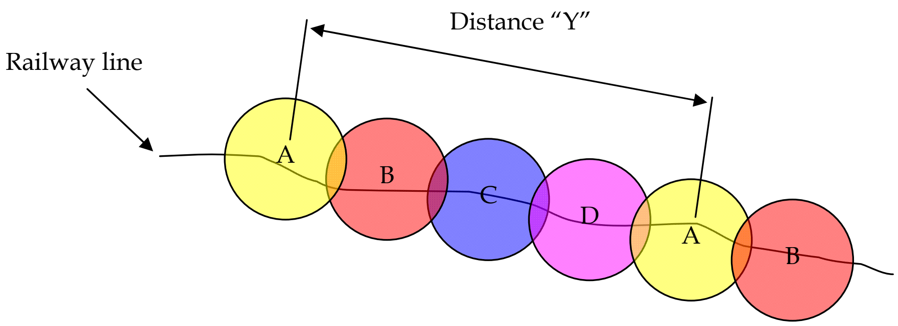


Illustration of a linear repeat pattern

9.2.2.14 It can be seen from the above example that a greater cell separation between cells of the same type can be achieved using a four cell repeat pattern than can be achieved with a seven cell repeat pattern in the previous example (compare distance "X" to distance "Y" in the two diagrams).

9.2.2.15 Since there are fewer cells in the repeat pattern, a larger number of channels can be allocated to each cell and hence greater radio capacity is achievable.

9.2.2.16 The following list gives examples of features that need to be given special consideration when planning coverage for the GSM-R network:

- Tunnels
- Cuttings
- Regions shadowed by structures such as bridges
- Obstructed sections of track that fall on a bend
- Railway stations
- Terrain height profiles
- Shunting areas
- Emergency call areas

9.2.3 Operational planning

9.2.3.1 Operational planning is vital to the design of a successful GSM-R network and encompasses the following elements:

- The number/types of applications that the network needs to support.
- Their quality of service requirements.
- The capacity demand that the applications will place on the radio system. This needs to be estimated for each proposed GSM-R cell site, based on factors such as the following:
  - the peak number of active trains that will occupy that cell;
  - the volume of voice and data traffic expected from these trains;
  - the volume of network traffic arising from handhelds and other devices such as possession management terminals, customer information systems, diagnostic systems, etc that are expected in that cell;
  - scope for future expansion.
- The locations where cell boundaries should be planned (supports cell dependent routing for location dependent addressing and group call functionality including emergency areas, shunting areas and controller areas).
- Planning of GSM-R location areas, MSC and BSC boundaries and border areas between national networks.
- Planning for the operational needs of ETCS including appropriate coverage, capacity, quality of service, support of RBC-RBC handovers, etc.

9.2.3.2 All of these operational planning aspects need to be considered when developing an appropriate cell and frequency plan for the area under analysis. This is covered in more detail in the remainder of this section.

9.2.4 Radio planning tools

9.2.4.1 Radio planning tools are used to develop more accurate predictions of pathloss, coverage and interference taking into account terrain data and clutter data for the areas under analysis and the presence of multiple base station sites. The software is used to model and develop viable GSM-R cell and frequency plans for specific areas.

9.2.4.2 Typically, radio planning tools incorporate Geographical Information System (GIS) software to allow the user to display digital mapping data overlaid with the model's calculations. This may include provision for the display of the following features:

- Map as backdrops suitable for display at various levels of magnification.
- Line (vector) data, for example railway lines, coastlines and roads.
- Terrain height (elevation) data, land usage (clutter) data and positional information (e.g. in longitude-latitude and national grid co-ordinates).
- Aerial photographs and building plans.
- Display of signal coverage and co-channel/adjacent channel interference predications overlaid onto the above mapping data.

Digital terrain model and clutter database resolution

9.2.4.3 A radio propagation planning tool requires one or more models, a digital terrain model and a clutter database in order to carry out predictions.

9.2.4.4 Both empirical and semi-deterministic models can be used as for standard GSM radio planning. The choice will depend on …

9.2.4.5 The choice of the resolution level of the digital terrain map and clutter database is important as the consequences on the final number of sites (and hence cost) are considerable. The simple rule is that the higher the resolution of the data, the more accurate the radio planning process. However, the cost also increases.

9.2.4.6 With a low resolution map, say 50m, a relatively high engineering margin needs to be included in the planning process. Whilst this will still result in a compliant design, it will also be a conservative design which means that sites will generally be closer together. With a high resolution map around the railway, 5m for example, the error of the prediction is reduced allowing operators to minimize the engineering margin hence resulting in a lower number of radio sites.

9.2.4.7 In addition the resolution of the digital model together with the margin calculation and the model calibration will typically reduce the number of measurements needed.

9.2.4.8 A very effective and well-calibrated propagation model is necessary, as well as a geographical data sufficiently detailed (a digital terrain model and clutter database). The resolution of the geographical data will result in the accuracy of elevation and field occupation.

9.2.4.9 The resolution of geographical data should typically be lower than the railway in order to be able to discern railway embankments or cuttings. A resolution of 5m enables this constraint to be fulfilled and also enables engineering margins to be kept as small as possible. Since the prediction threshold is lower and predictions close to reality, the number of sites is optimized. Additionally, the number of necessary qualification measurements is minimized as well.

9.2.4.10 Typically, the width of dual-track railway is about 10 to 15 m, a minimum of 2 samples are typically necessary to qualify precisely the elevation of railway, for that, a resolution of 5m is necessary and sufficient.

9.2.4.11 In contrast a lower resolution (such as 10m) could mean that in some cases certain railway lines (typically single-track lines) and features could be missed completely by the tool resulting in a less accurate prediction. For example, a cutting on a single-track line that is 8m wide and 15m deep could be ignored by the tool meaning that the additional attenuation as a consequence of the deep cutting would not appear in the prediction. The importance of this should not be underestimated since this problem may only be picked up during the coverage measurement campaign carried out once the sites have been commissioned.

9.2.4.12 To reduce the supply cost of geographical data (digital model of land and land use), 5m resolution can be used in the proximity of railway lines, and 100 m resolution can be used elsewhere. A comparison is shown below.

`100 m resolution` `5 m resolution`

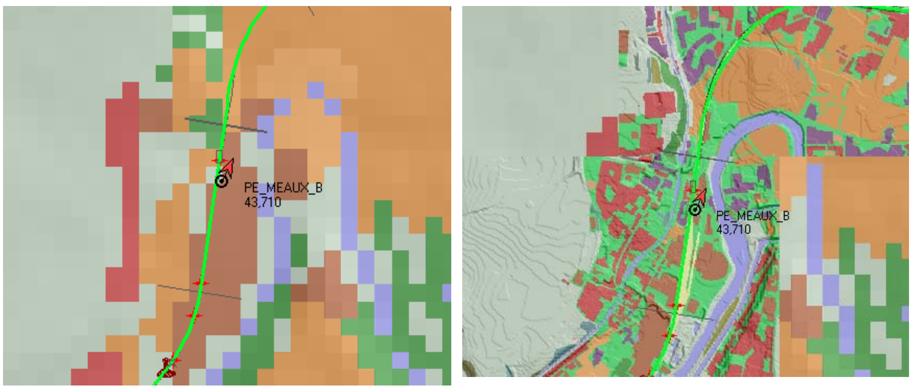


Figure 5: Comparison of different database resolutions

Clutter classes

9.2.4.13 The list below provides examples of clutter categories:

Land Use Category	Definition
BUILT-UP AREAS	
High-density urban areas	Blocks of buildings in town and city centres, high density
Medium-density urban areas	Blocks of buildings in town and city centres, medium density, some green areas
Lone buildings	Large, fairly tall buildings, isolated, such as flats or monuments
Medium-density buildings	Groups or rows of buildings, medium density (some spaces between buildings)
High-density buildings	Groups of high-density buildings, quite tall, little space between them
Town centres	Centres of villages or neighbourhoods, medium density, with low-rise buildings (a church surrounded by shops, etc.)
Industrial estates	Areas located on the outskirts of urban areas with one or more industrial-type buildings grouped together
High density residential areas	Residential areas or residential developments with high-density detached low-rise houses (houses are almost attached, less than the width of one house apart). Note: large-sized courtyards and back gardens.
Medium density residential areas	Residential areas or residential developments with low-density detached low-rise houses grouped together (houses the width of 1-2 houses apart)
Very low density urban areas (any developed housing sites, lone or low-density)	Lone dwellings or groups of low-density dwellings (dwellings the width of more than 2 houses apart), low-rise, that are not centres of urban areas, nor are residential areas or industrial estates (localities, farms, etc., etc.)
Covered railway lines	Railway lines covered by light buildings or constructions

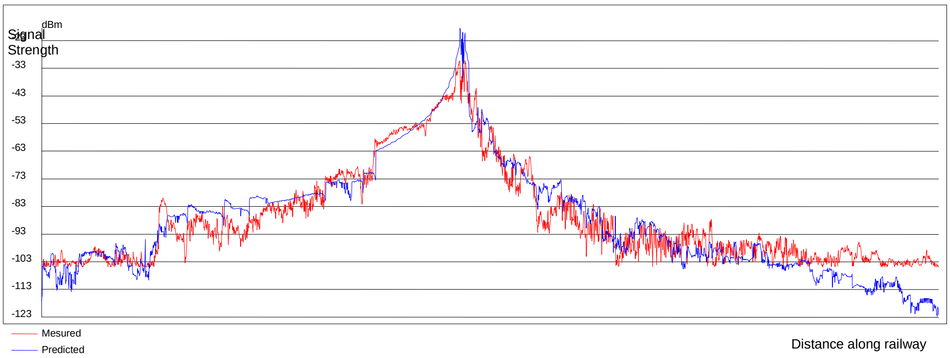
OTHER LAND USES	
Tall, high-density forests	Woods or forests, min. area 250m², ground hidden by foliage, height > 18m
Tall, low-density forests	Woods or forests, min. area 250m², ground visible through foliage, height >/= 18m
Low, high-density forests	Woods or forests, min. area 250m², ground hidden by foliage, height </= 17m
Low, low-density forests	Woods or forests, min. area 250m², ground visible through foliage, height </= 17m

Road bridges above railway	Roads on bridges above railway lines
Tunnels	Tunnels that partially cover railway lines
Rail bridges	Railway lines on bridges above roads or other feature (e.g. viaducts)
Open ground between built-up spaces	Land not built upon in the proximity of urban or residential areas (e.g. bare ground, roads, esplanades, cemeteries, sports fields, waste land, private gardens) = "the urban background"
Urban green areas	Green areas located in towns and cities (parks)
Open spaces, prairies	Prairies, meadows, fields, parks = "the background outside towns and cities"
Bodies of water, lakes, rivers	Bodies of water, excluding seas and oceans
Seas and oceans	Bodies of water, excluding inland bodies of water, i.e. lakes, rivers, etc.
Railways	Railway lines
Railway platforms	Railway platforms, may or may not be covered with light shelters
Railway embankments	Areas adjacent to railway lines which are at least 2m higher in relation to them
Railway cuttings	Areas adjacent to railway lines that are at least 2m lower in relation to them

Model calibration

9.2.4.14 The prediction model needs to be specially calibrated for EIRENE type coverage and for the database resolution (e.g. 5m). The method used to calibrate the model consists of rebuilding a virtual drive test created by the prediction model and comparing it with a real drive test result. The railway lines chosen for the measurements need to be a representative sample of the different types of environment as listed above in the clutter categories table.

9.2.4.15 The measurements need to be carried out using equipment on a train with an external antenna in order to replicate as closely as possible the end user conditions. Temporary radio sites should be erected at the relevant locations.



Comparison of predicted and measured field strengths along a section of railway

9.2.4.16 The measurements should then be imported into the planning tool and compared with the predicted results. The figure above shows the measured results in red and the predicted results in blue. Once the measurements have been validated the propagation model can then be calibrated. The model can now be used for the GSM-R radio planning process.

9.2.5 Frequency planning methodology

Overview

9.2.5.1 The fundamental problem to be addressed during the assignment of radio channels to planned cells is to ensure the allocation and reuse of any given channel maximizes usable radio signal and minimizes the interference generated.

9.2.5.2 Every plan will have an associated signal to noise ratio: represented in the radio environment as the carrier to interference ratio, or C/I, and is expressed in decibels (dB). The fundamental quality of a frequency plan is reflected in the C/I for a given area.

9.2.5.3 In the following methodology, it is assumed that there exists a proposed cell site distribution with an associated channel requirements profile (driven from the projected capacity demand in each area). It is also assumed that the software tools required for the processing and production of appropriate data sets are available.

Inputs

9.2.5.4 The following inputs are required:

1) The available radio spectrum.
   - Absolute radio frequency channel numbers that may be used.
   - Forbidden channels, test channels, guard bands.
   - Any other specific requirements.
2) A schedule of cells to be frequency planned.
   - Channel/transceiver requirements (driven by the demand for capacity).
3) An appropriate radio coverage model for the cluster of cells under consideration.
   - This cluster may be a few cells or many hundreds.
   - Typically represented as an 'nth Best Server' array, modeling the expected radio signal levels from all detectable cells in the immediate area at discrete geographical locations.
4) An appropriate 'Interference Table'.
   - This is derived from the nth Best Server Array and is a representation of the ability of each cell to interfere with any other.
   - The derivation from the best server array comes from the associated areas covered by each cell.
   - Typically this is represented as a proportion of overlap between different cells.
   - An interference table is not a carrier to interferer assessment, but simply an indication of potential inter-cell interaction.
5) Inter cell handover data (not essential).
   - A dataset showing the actual passage of mobile terminals from cell to cell.
   - Physical handover activity is represented by these data.
   - Used to validate theoretically defined neighbor cells.

Methodology

9.2.5.5 A classic algorithm used, is to define a set of rules for channel assignment with associated penalties – or costs – to be incurred should any rule be broken.

9.2.5.6 Initially channels are assigned in a quasi random fashion and the resultant plan modeled/evaluated in terms of its 'cost', then, by application of simple differential methods, the associated minimum cost function may be found by selective reassignment of individual radio channels.

9.2.5.7 Due to the nature of the problem and the fact that the associated cost is calculated on radio channels assigned, the determination of the cost function minimum is cyclical, and not instantaneous such as finding minima associated with least squares regression techniques.

9.2.5.8 A useful parallel may be drawn with the Newton-Rhapson approach for the solution of polynomial equations, where each successive iteration renders the solution closer to the ideal. The quality of the final plan is therefore highly dependant on the number of iterations permitted and the quality of the 'cost rules' assigned.

9.2.5.9 An example rule set may be as follows:

- Channel separation between TRXs in the same cell:
  - At least 3 channel separation
- Channel separation between control channels for first order neighbor cells:
  - At least 2 channel separation
- Channel separation between control channels for second order neighbor cells:
  - At least 2 channel separation
- Channel separation between traffic channels for first order neighbor cells:
  - At least 2 channel separation
- Handover data threshold counts:
  - Used to override theoretical neighbors
  - Apply same rules as first order neighbors

Assessment and the key performance indicators

9.2.5.10 Once radio channels have been assigned to the appropriate cellular transceivers one is then in a position to create a carrier to interference ratio matrix. With respect to cellular network engineering tools, these are produced in a similar way to coverage matrices, and evaluate the carrier to interference ratio across defined areas of given resolution (typically 50m squares).

9.2.5.11 Normally, this would be presented on a map and plotted in defined bands: 0, 3, 6, 12 and 15 dB. Typically, radio engineers would plan for at least 9 dB for voice and at least 12 – 15 dB for data applications.

9.2.5.12 It should be noted that adjacent channel allocation is typically modeled under C/I, assigning a C/A equivalent. In practice co-channel interference dominates but adjacent channel interference must still be considered. If 2 equal power GSM carriers are adjacent to one another, the power leaking from one into the other's bandwidth is approximately 18 dB below the wanted carrier's level by virtue of the GSM signal's sideband characteristics. 18 dB may therefore be used as an equivalent figure for C/A to C/I mapping.

9.2.5.13 Two key performance indicators are normally used to represent network performance with respect to interference control. These are

- **Carrier to interference ratio (C/I):**
  - This has been addressed above and is typically represented as geographical plots in predefined bands.
  - When implementing new plans this is the only indication of the likely performance of that formulated.
- **Received Signal Quality (RxQual)**
  - When frequency plans have actually been uploaded onto a given network, the BSS is capable of detecting real time interference.
  - This is captured as bit error rate (BER) and is then quantized and 'Received Signal Quality' (RxQual).
  - There are 8 indices ranging from 0 to 7. 0 reflects the lowest BER, 7 reflects the highest.

Outputs and documentation

9.2.5.14 Whilst formal documentation may vary from network to network and between operators, the inputs, method, and outputs above would typically give rise to the following documents, schedules or other deliverables:

- Spectrum Specification;
- Schedule Of Planned Cells;
- "n"th Best Sever Array;
- Interference Table;
- C/I and C/A Matrices;
- Inter-Cell Handover Profile;
- Appropriate Cost Schedule;
- Frequency Plan;
- Exception Report;

– Per Carrier Analysis;
– Co-Channel Assignment Schedule;
– Adjacent Channel Assignment Schedule;
– Pre and Post Implementation RxQual Data Set.

9.2.6 GSM-R cell and frequency planning at international borders

9.2.6.1 Issues related to cell planning at borders are covered in UIC fiche Number 75 X - "The co-ordination of GSM-R systems and radio planning at borders" (E- 2575, O-2578).

9.2.7 GSM-R and its role in switching international fixed network traffic

9.2.7.1 In addition to this, it should also be noted that GSM-R networks have a potentially important role to play in the switching of international fixed network traffic as well as mobile calls. For example, national GSM-R networks and the international connections between them could be used as the backbone for an international fixed railway network. This is being considered by the UIC's "IntergrERNST Project".

9.2.8 Link budget and coverage design levels

9.2.8.1 The link budget is a calculation encompassing all of the technical factors associated with the uplink, transceiver, and downlink to determine, amongst other things, the maximum permissible air interface path loss. The link budget can be separated into two calculations, one for the downlink and one for the uplink. These will be considered in the following subsections:

Link budget, downlink

9.2.8.2 In order to calculate the link budget for the downlink, the first step is to calculate the BTS EIRP (Effective Isotropic Radiated Power) this is the effective power that is radiated from the Base Station antenna. The following typical elements contribute to this (example values are provided for guidance):

Base Station

Base Station Transmit Power	45	dBm
Duplexer (Loss)	-1	dB
Internal Jumper (Loss)	-1	dB
Tx Filter (Loss)	-1	dB
Tx Power Splitter (Loss)	-3	dB
Antenna Feeder (Loss)	-3	dB

BTS Antenna (Gain)	15	dBi
Calculated EIRP	**51**	**dBm**

(The line items may vary according to the specific BTS configuration.)

9.2.8.3 The calculated EIRP is the sum of all of the above figures (losses are all negative, gains and power are all positive).

9.2.8.4 The next step is to calculate the Mobile Station's minimum permissible received signal. The following elements contribute to this (example values are provided for guidance):

Mobile Station

Mobile Receiver Sensitivity	-104	dBm
Mobile Antenna Feeder (Loss)	-2	dB
Mobile Antenna (Gain)	0	dBi
Antenna Position/Mounting (Loss)	0	dBi
Body Loss for Handhelds (Loss)	0	dB
Interference Margin (Loss)	0	dB
Fast Fading Margin (Loss)	-3	dB
Degradation due to Doppler Shift (Loss)	0	dB
Min Rx Signal	**-99**	**dBm**

9.2.8.5 Note the following:

- Body Loss is the attenuation of the received signal due to the Mobile Station being close to a human body (this chiefly applies to handhelds).
- Interference Margin accounts for the increased radio noise level due to mobile users located in other cells. This is not normally a significant factor unless the network employs frequency hopping.
- Antenna Position/Mounting accounts for attenuation due to non-optimal positioning of the antenna due to the presence of other equipment on the train roof and/or the shape of the roof itself.
- Losses due to the Fast Fading Margin principally affect slow-moving mobiles.
- Receiver sensitivity degradation due to Doppler Shift principally affects fast-moving mobiles.

9.2.8.6 The minimum permissible received signal is the Mobile Receiver Sensitivity minus the sum of the gains and the losses (where gains are positive and losses are negative). In the above case, this equates to -99 dBm.

9.2.8.7 The minimum permissible received signal should be lower (i.e. more negative in dBm) than the minimum coverage levels specified in the EIRENE SRS, otherwise the Mobile Station may not be suitable for operation on GSM-R Networks.

9.2.8.8 The following extract is from the EIRENE SRS for the required values:

3.2 Coverage

3.2.1 *For network planning, the coverage level is defined as the field strength at the antenna on the roof of a train (nominally a height of 4m above the track). An isotropic antenna with a gain of 0dBi is assumed. This criterion will be met with a certain probability in the coverage area. (The target coverage power level is dependent on the statistical fluctuations caused by the actual propagation conditions.) (I)*

3.2.2 *The following minimum values shall apply: (M)*

- *coverage probability of 95% based on a coverage level of 38.5 dBμV/m (-98 dBm) for voice and non-safety critical data;*
- *coverage probability of 95% based on a coverage level of 41.5 dBμV/m (-95 dBm) on lines with ETCS levels 2/3 for speeds lower than or equal to 220km/h.*

3.2.3 *The following minimum values are recommended: (I)*

- *coverage probability of 95% based on a coverage level of 44.5 dBμV/m (-92 dBm) on lines with ETCS levels 2/3 for speeds above 280km/h;*
- *coverage probability of 95% based on a coverage level between 41.5 dBμV/m and 44.5 dBμV/m (-95 dBm and –92 dBm) on lines with ETCS levels 2/3 for speeds above 220km/h and lower than or equal to 280km/h.*

3.2.4 *The EIRENE mobile installation shall be designed to operate in a network meeting the criteria in 3.2.2 and 3.2.3. (M)*

Note 1: The specified coverage probability means that with a probability value of at least 95% in each location interval (length: 100m) the measured coverage level shall be greater than or equal to the figures stated above. The coverage levels specified above consider a maximum loss of 3 dB between antenna and receiver and an additional margin of 3 dB for other factors such as ageing. (I).

Note 2: The values for ETCS levels 2/3 concerning coverage and speed-limitations are to be validated and, if necessary, reviewed after the first operational implementation of ETCS. (I)

9.2.8.9 The Maximum Pathloss is calculated from the difference between the calculated EIRP and the minimum Rx Signal. In this example, the Maximum Pathloss equates to 150dB.

9.2.8.10 However, in order to meet the EIRENE coverage requirements, the Maximum Pathloss should be calculated on the basis of the difference between the calculated EIRP and the applicable EIRENE coverage requirement at the stated probability.

Link budget, uplink

9.2.8.11 In order to calculate the link budget for the uplink, the first step is to calculate the EIRP (Effective Isotropic Radiated Power) for the mobile. This is the effective power that is radiated from the Mobile Station antenna. The following elements contribute to this (example values are provided for guidance):

MS

Mobile Transmitter Power (max 8W)	39	dBm
Mobile Antenna Feeder (Loss)	-2	dB
Mobile Antenna (Gain)	0	dBi
Antenna Position/Mounting (Loss)	0	dBi
Body Loss (Loss)	0	dB
Mobile EIRP	**37**	**dBm**

9.2.8.12 The next step is to calculate the Base Station's minimum permissible received signal. The following elements contribute to this (example values are provided for guidance):

BTS

BTS Receiver Sensitivity	-110	dBm
BTS Antenna (Gain)	17	dBi
Antenna Feeder (Loss)	-3	dB
Duplexer (Loss)	-1.5	dB
Rx Power Splitter (Loss)	-3	dB
Internal Jumper Losses (Loss)	-1.5	dB
Fast Fading Margin (Loss)	-3	dB
Degradation due to Doppler (Loss)	0	dB
Min Rx Signal	**-115**	**dBm**

9.2.8.13 The minimum permissible received signal is the BTS Receiver Sensitivity minus the sum of the gains and the losses (where gains are positive and losses are negative). In the above case, this equates to -115 dBm.

9.2.8.14 As before, the maximum permissible pathloss is the difference between the mobile EIRP and the minimum Rx signal at the BTS. In the above case, this equates to 152 dB.

9.2.8.15 In this example, the maximum permissible pathloss in the uplink and the downlink are reasonably similar. This helps to ensure that there is good balance between the qualities of reception at either end of the call. The link budget is slightly "downlink limited". This means that it is likely that the downlink of the call will break up before the uplink in areas of poor coverage.

9.2.9 Estimation of path loss

9.2.9.1 There are a number of mathematical models used for signal estimation but the Hata-Okumura model is the most widely used in cellular networks. The Hata-Okumura computation model is an empirical formula to provide an estimation of the path loss in certain types of propagation environments. This model is useful for initial estimates of typical cell size, etc but not for detailed planning.

9.2.9.2 Only a few parameters are involved in the calculation, making it very easy to work with. In order to keep the formula simple, Hata and Okumura made the assumption that the transmitters would be located on high ground. Furthermore, the model neglects the terrain profile between transmitter and receiver (i.e. hills and other obstacles between the base station and mobile are not considered in the calculation).

9.2.9.3 The four parameters with their valid limits are:

- Frequency f (150...2000 MHz)
- Distance between transmitter and receiver d (1...20 km)
- Antenna height of the transmitter h_{eff} (30...200 m)
- Antenna height of the receiver h_{RX} (1...10 m)

9.2.9.4 The following equations show how to calculate the basic path loss pl (in dB) with the model of Hata-Okumura.

$$pl = 69.55 + 26.16 \times \log(f) - 13.82 \times \log(h_{eff}) - a(h) + (44.9 - 6.55 \times \log(h_{eff})) \times \log(d)$$

The term $a(h)$ is a correction term, which can differ depending on the particular environment. For a basic suburban environment, the correction term $a(h)$ is calculated as follows:

$$a(h) = (1.1 \times \log(f) - 0.7) \times h_r - (1.56 \times \log(f) - 0.8)$$

9.2.9.5 This equation may be used to estimate the height gain associated with different train antenna mounting options (note that the EIRENE coverage level is defined as the field strength at an isotropic antenna with a gain of 0dBi on the roof of a train, nominally at a height of 4 meters above the track).

9.2.10 50% confidence design threshold

9.2.10.1 In general, mobile radio planning tools work to 50% confidence level. In order to convert the 95% confidence levels quoted in the EIRENE specifications to 50%, a conversion margin must be used.

9.2.10.2 The following diagram proposes a means of doing this. It assumes that the probability function follows a normal distribution. The standard deviation of this distribution is assumed to be equivalent to the standard distribution of slow fading (the long term variation in the mean signal level principally caused by shadowing).

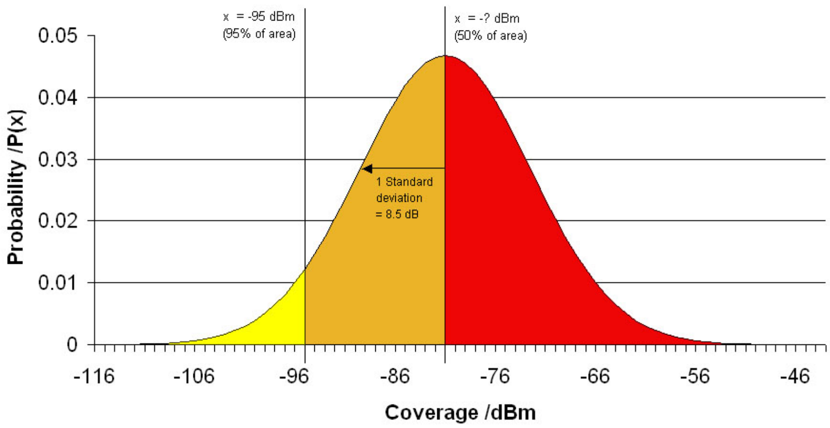


Figure 8-5: Conversion of 95% to 50% confidence level

9.2.10.3 In this example, the standard deviation of the prediction (analogous to the standard deviation of slow fading) is assumed to be 8.5dB. However, this value will vary depending on type of terrain, the type and density of vegetation/tree foliage present, the number of buildings, etc.

9.2.10.4 In this example, the following EIRENE requirement will be assumed:

– *coverage probability of 95% based on a coverage level of 41.5 dBμV/m (-95 dBm) on lines with ETCS levels 2/3 for speeds lower than or equal to 220km/h.*

9.2.10.5 We can calculate the number of standard deviations between the 95% confidence level and the 50% confidence level by using the =NORMSINV() function of Microsoft Excel. This function returns the inverse of the standard normal cumulative distribution. The distribution has a mean value of zero (i.e. is centered on the y-axis) and has a standard deviation of one. The required calculation is therefore as follows:

= NORMSINV(0.95) – NORMSINV(0.5)

9.2.10.6 Note that the "0.95" in the function relates to the probability (i.e. is equal to 95%). Please also note that NORMSINV(0.5) is equal to zero. This can therefore be simplified as follows:

= NORMSINV(0.95)

9.2.10.7 By multiplying this value by the standard deviation (in this example, 8.5dB), we obtain the margin required to convert between 95% and 50% confidence levels.

9.2.10.8 In this example, the corresponding 50% confidence level for the above requirement can therefore be calculated as follows:

≈ 8.5*NORMSINV(0.95) + -95dBm

≈ 14dB + -95dBm

≈ - 81dBm (at 50% confidence)

9.2.11 Direct mode considerations

9.2.11.1 The operational requirement for direct mode is to:

1) provide short range fall-back communications between train drivers and trackside personnel in the event of failure of all railway and/or public GSM services normally available;

2) provide short range communications for railway personnel operating in remote areas where no GSM facilities are available.

9.2.11.2 Direct mode implementation is optional.

9.2.11.3 Actual, the DMO SRS is under approval in TC RT (document RT d-08004r2).

9.2.12 Radio coverage in tunnels

9.2.12.1 Tunnel provision of radio coverage for cellular application requires special attention. Directional/high gain antennas may be used to direct a radio signal into a tunnel portal; however the actual propagation once inside the tunnel bore is limited. Under a pure railway application it is usually possible to gain access to the portal superstructure itself, thus eliminating dominant diffraction mechanisms with respect to signal entry, but in many cases this may be untenable due to catenary apparatus or other installations/physical (or other) restrictions.

9.2.12.2 Installation of rack mounted radiating cable is often a more suitable solution, particularly for longer tunnels or sites where access to the tunnel portals is limited. Radio coverage from radiating cables is highly reliable and the required signal levels easily calculated and realized. Loss per given length of the cable is easily measured as is that for train signal penetration. Transmission loss between cable and train is very small and due to the distances involved and there is little opportunity for Rician fading to manifest.

9.2.12.3 It is normal for coverage in tunnels to be provided to 200%, thus implementing 100% redundancy, across the radio element. The RAM metrics of radiating cable generally do not indicate the requirement of redundant cable installations or runs. Environmental conditions may impact this and should always be individually evaluated.

9.2.12.4 The technical solutions used today are:

Base Stations with directional antennas into the tunnel,

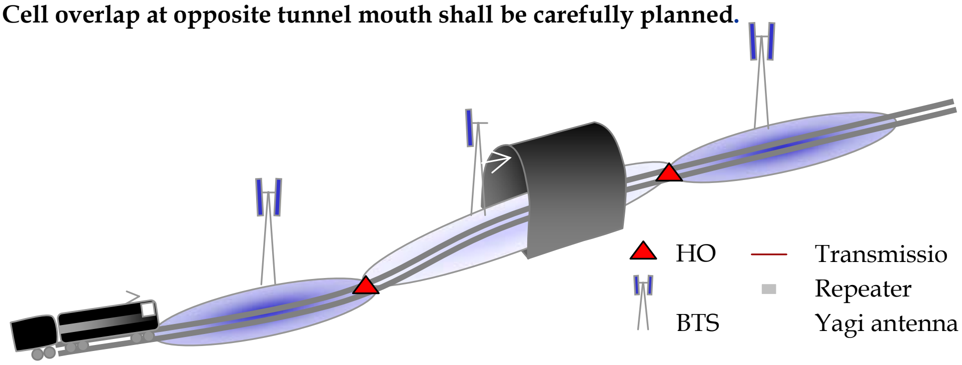
Base Stations with radiating cable inside the tunnel and handover antennas at the entrances

RF –feeded (feeded via the air) repeaters

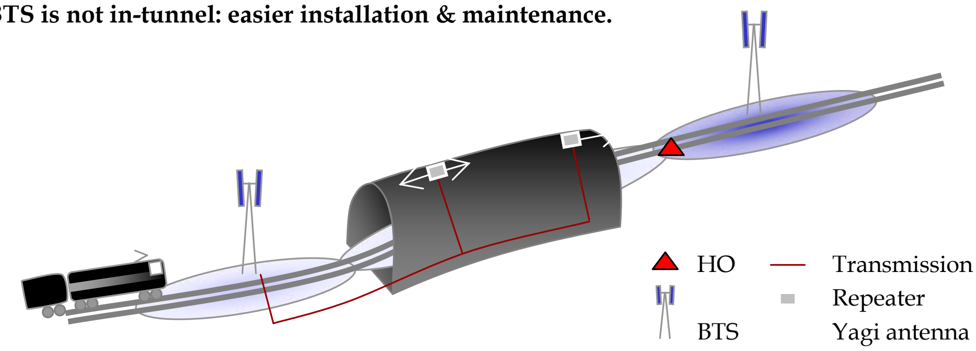
Rf-feeded, frequency converting repeaters

9.2.12.5. Here below, are general considerations on tunnel coverage, extracted from a dedicated workshop, slides offered by Klaus Konrad.

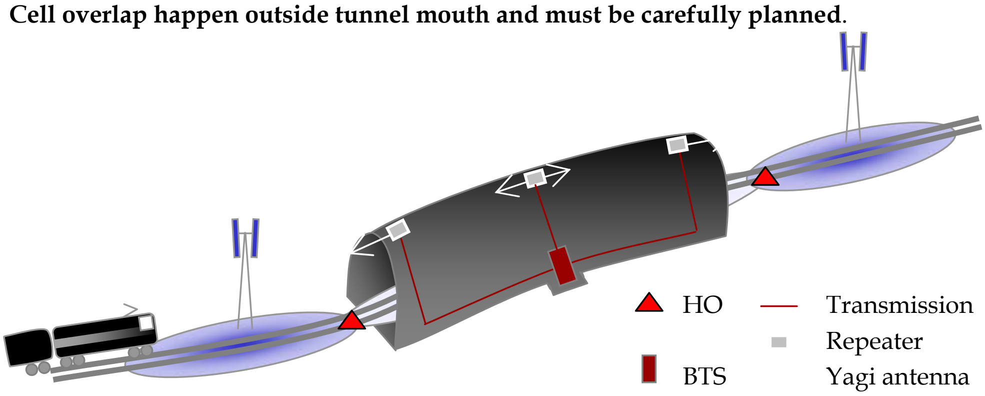
- **<u>Short tunnels</u> are the most frequent case.**
- **Coverage is ensured with a Yagi antenna shooting to the tunnel entrance.**
- **Max tunnel length for this solution depends on tunnel section, straightness, wall nature and train blocking effect.**
- **Low CAPEX, easy installation & maintenance (no tunnel access).**
- **Cell overlap at opposite tunnel mouth shall be carefully planned.**



- <u>Medium tunnels</u> **need in-tunnel repeaters.**
- **Signal is taken from the BTS covering the area outside the tunnel entrance.**
- **Various transmission options and antenna types are available.**
- **Cell overlaps happen outside tunnel mouth and must be carefully planned.**
- **In-tunnel equipment supervision allows a quick warning upon failure.**
- **BTS is not in-tunnel: easier installation & maintenance.**



- **Long tunnels need in-tunnel repeaters and BTS. Even the longest tunnels can be covered, provided in-tunnel BTS location are available.**
- **Signal is repeated from the in-tunnel BTS, via various transmission options**
- **Several antenna types are available.**
- **Cell overlap happen outside tunnel mouth and must be carefully planned**.



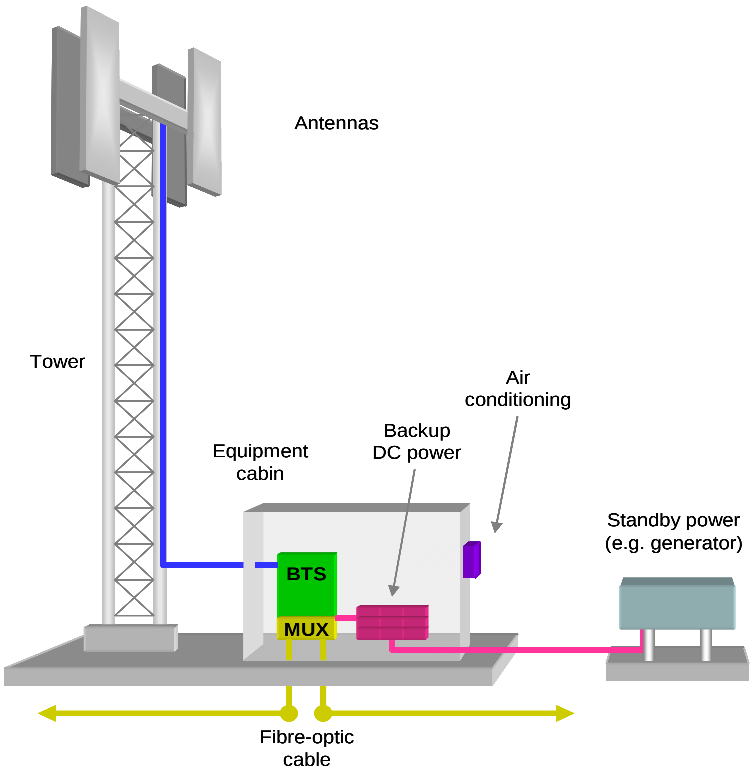
In-tunnel equipment supervision allows a quick warning upon failure.

9.2.13 Radio Site Design

A typical radio site comprises:

- Tower;
- Antennas;
- Feeder cable;
- Tower mounted amplifier (where required);
- Surge arrestors;
- Lightning finial;
- Earthing arrangement;
- Base station in a cabin;
- Batteries;
- Add-drop multiplexer (transmission), commonly referred to as a "Mux";
- Specific power supply (e.g. generator) where appropriate.

Typical GSM-R radio site layout (not to scale)



9.2.13.1 In order to reduce capital expenditure or to gain some modest revenue it is possible to share radio sites with public operators. This is where antennas from more than one operator are mounted on a single tower. At the base of the tower each operator has its own equipment housing. The various radio systems are completely separate.

9.2.13.2 Antenna System

9.2.13.1 High gain, narrow beam-width antennas are proposed for general use to avoid over-spill and to achieve high gain. Other types may be used in order to provide sufficient coverage for specific areas such as stations.

9.2.13.2 The antenna system also comprises the elements between the antenna and the bulk head connector at the entry to the equipment cabin including feeder cables, tail cables, connectors, splitters and surge arrestors.

9.2.13.3 Equipment cabin

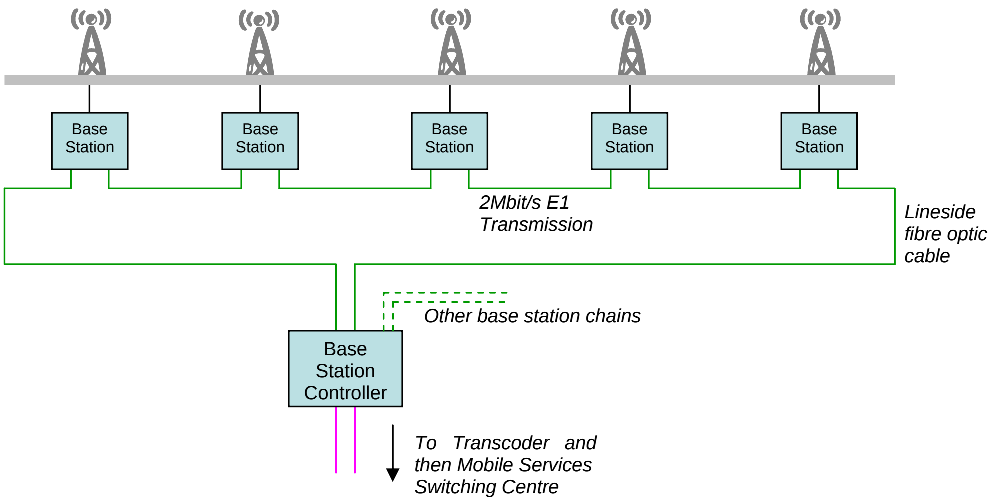
9.2.13.1 The base station sites may be in remote sites which are subject to harsh environmental conditions. The electronic equipment requires a stable atmosphere to operate and so protection is required against wide variations in temperature and humidity as well as dust. A cabin is proposed to house the equipment thus protecting it and maintenance technicians from the elements. As well as the base station, the cabin will need to house:

- Backup DC power supply;
- Transmission multiplexer;
- Environmental controls;
- Fixed telephone to allow calls to be made to the control centre in case of base station failure;
- LAN access point, where appropriate;
- First aid kit.

9.2.13.2 The general requirements for the environmental conditions have been defined. Depending on the precise nature of the equipment, The Contractor is responsible for providing an environment that is conducive for normal operation of the chosen equipment. This design is to take into account the power requirements for the radio site. Air conditioning, for example, requires a large amount of power which, for many sites, may be expensive. Power is one of the most critical aspects when building radio sites and has a considerable impact on the overall cost of the site particularly in rural areas.

9.3 Base Station Sub-system

9.3.1 A typical BSS architecture of the GSM-R system is outlined below.



Typical BSS loop architecture

9.3.2 Base stations (BTS) located along the track ensure a continuous radio signal for cab radios at all points on the railway. Repeaters could be used to provide coverage in specific areas. From a logical point of view a repeater merely extends the coverage of the base station and so the above architecture does not indicate any repeaters.

9.3.3 Depending on the traffic requirements it is possible to, for example, replace every other base station with a repeater to reduce cost. However repeaters typically have lower output power than base stations which means that sites need to be located closer together. This will result in an increased in the number of sites which is more costly. The cost of building a complete site with civil foundations and power is a major element of the overall GSM-R network capital expenditure.

9.3.4 Transmission chains linking a maximum of five base stations ensure that if the fibre optic cable is cut between two sites then service can still be maintained to all base stations. Five is generally considered the optimal number of sites in a chain. A chain of six for example, would take considerably longer to re-establish following a cable cut. Chains of less than five result in an inefficient transmission design.

9.3.5 As each BSC is responsible for a number of BTS, the choice of which BTS is connected to which BSC needs to be considered. Handovers occurring for calls from one base station to the next are different if the two BTS concerned are connected to the same BSC or not. Inter-BSC handovers take longer as they require additional network resources and it is therefore recommended for these to occur *wherever possible* in non-critical areas, e.g. along a stretch of line where there are no junctions or stations.

9.4 Network Sub-system

9.4.1 Dimensioning

9.4.1 The dimensioning of the NSS will generate a complete list of the hardware required, including cards within the equipment and links at the interfaces.

9.4.2 In order to dimension the NSS, a traffic model needs to be created, based on existing telecommunications systems in use, intended usage of the GSM-R network, and traffic increase forecast for the coming years.

9.4.3 The traffic model must include all call types (i.e.: Point to Point, Group Calls, calls to external networks...), messages (such as SMS), data calls, but also other applications such as Functional Number registrations that use the NSS resources.

9.4.4 The blocking factor used for dimensioning is then set depending on the criticality of each resource, and whether pre-emption can occur on them.

9.4.5 The NSS must also be designed such that there are no single points of failure, for at least all the critical components or interfaces. This is achieved by using equipment with redundant circuits, implementing N+1 redundancy on interfaces (such as E1 and SS7 links), and installing duplicated equipments.

9.4.6 For example, it is possible to install 2 or more HLRs, in separate locations, such that in the event of failure of one HLR, the other HLR(s) will take over all the subscribers.

9.4.2 Interfaces

9.4.1 The NSS is at the centre of the GSM-R network, and therefore has a large number of interfaces internally and with the other sub-systems. The physical and logical characteristics of all these interfaces need to be specified during the design phase of the NSS.

9.4.2 The following types of interfaces exist:

1. Standard interface between telecommunication nodes within the NSS or between the NSS and other sub-systems:

These interfaces are defined in international specifications (EIRENE, MORANE, 3GPP...). Operators must however obtain compliancy statements from equipment suppliers to ensure interoperability.

2. Non standard interfaces between the NSS and other sub-systems or external systems:
   These interfaces need to be specified carefully, in particular where the interface concerns different equipment suppliers. The specification must be based on existing standards as much as possible.

3. Interfaces to external networks:
   These interfaces are usually standard interfaces defined in international or national (or the connection to PSN for example) specifications. Operators must however obtain compliancy statements from equipment suppliers to ensure interoperability.

9.4.3 Functional Addressing – Use of Intelligent Network

9.4.1 The Intelligent Network is an optional part of the GSM-R architecture, used by most implementers to manage key services such as Functional Addressing (FA), and Location Dependant Addressing (LDA and eLDA).

9.4.2 However, there are other possible implementations for the Functional Addressing service:

- using Intelligent Network (IN) facilities;
- within the GSM network's HLR using the 'follow-me' supplementary service;
- implementation of a dedicated switch with associated databases.

9.4.3 The choice of implementation depends on a number of factors such as additional hardware required, specific development required at the interface with the dedicated switch, interoperability for roaming equipment from other networks, and exchange of Functional Numbering data across networks.

9.4.4 eLDA/eREC implementation

9.4.1 These two optional features make use of data from external systems (such as GPS, trackside train detection systems, balises) to provide greater accuracy on the position of the trains.

9.4.2 The Railway operators must consider these solutions in detail to find a suitable implementation in their network.

9.4.3 Whichever solution is used, an interface will need to be created between the GSM-R network and the external system. The Interface could be located at the Cab Mobile (for e.g. GPS), or at the NSS (for e.g. trackside train detection systems).

9.4.4 In the latter scenario, the location of the interface must be considered. It could be at the MSC, the IN equipment (if used), or even at the Dispatchers system.

9.4.5 Disaster Recovery

9.4.1 Railway operators must specify a Disaster Recovery strategy for their network that will be the basis of the NSS Disaster Recovery implementation.

9.4.2 The following requirements must be identified:

- Definition of a disaster;
- Target recovery time;
- Level of service to recover as a priority (such as call types, value added services);
- Recovery method (manual intervention, remote reprogramming of equipment, staff location...).

9.4.3 Based on the level service to recover as a priority, critical equipment of the NSS can be identified, and duplicated in the network.

9.4.4 The MSC and HLRs are at the centre of the network and should therefore be dimensioned with an N+1 implementation.

9.4.5 Other nodes may be considered for the Disaster Recovery solution, such as the IN system (if used) to preserve the Functional Addressing and LDA features, or Call Recording system to ensure that call recordings are always available for post-incident analysis.

9.4.6 The duplicated equipment can be installed on standby, physically disconnected from the network, or it could be active, and processing traffic.

9.4.7 In the case of the MSC, the network needs therefore to be dimensioned with an additional MSC. The 2 possible implementations are:

- **Load sharing**: Each MSC is physically connected to the network and active, and the BSCs are shared across the MSCs. As it is not possible to connect a BSC to more than one MSC, in the event of an MSC failure, all BSCs connected to that MSC will lose service until the traffic is rerouted to the remaining MSCs. This solution involves reconfiguration of the active MSC, BSCs, switching of transmission links, and update of VLR information. BSCs connected to the failed MSC are affected by the loss of service.

- **Standby**: The additional MSC is on standby, physically disconnected from the network. In the event of a failure of the MSC, service is lost on all the BSCs connected to the failed MSC. This solution involves configuration of the standby MSC to replicate the failed MSC (if the network only has one active MSC, standby MSC configuration is always ready), switching of transmission links, and update of VLR information. BSCs connected to the failed MSC are affected by the loss of service. The number of BSCs affected is greater than in the load sharing implementation. However, there is no configuration required on the BSCs as the standby MSC replicates the failed MSC.

9.4.6 Optional equipment

9.4.1 There are a number of non mandatory features that can be implemented with the addition of nodes in the NSS.

9.4.2 It is up to the operators to assess their requirements and the costs.

9.4.3 These include:

- Equipment Identification verification (EIR);
- Call Recording;
- Voice Mail service (VMS);
- Billing;
- Etc.

9.5 Fixed Terminal Sub-system

9.5.1 Dimensioning

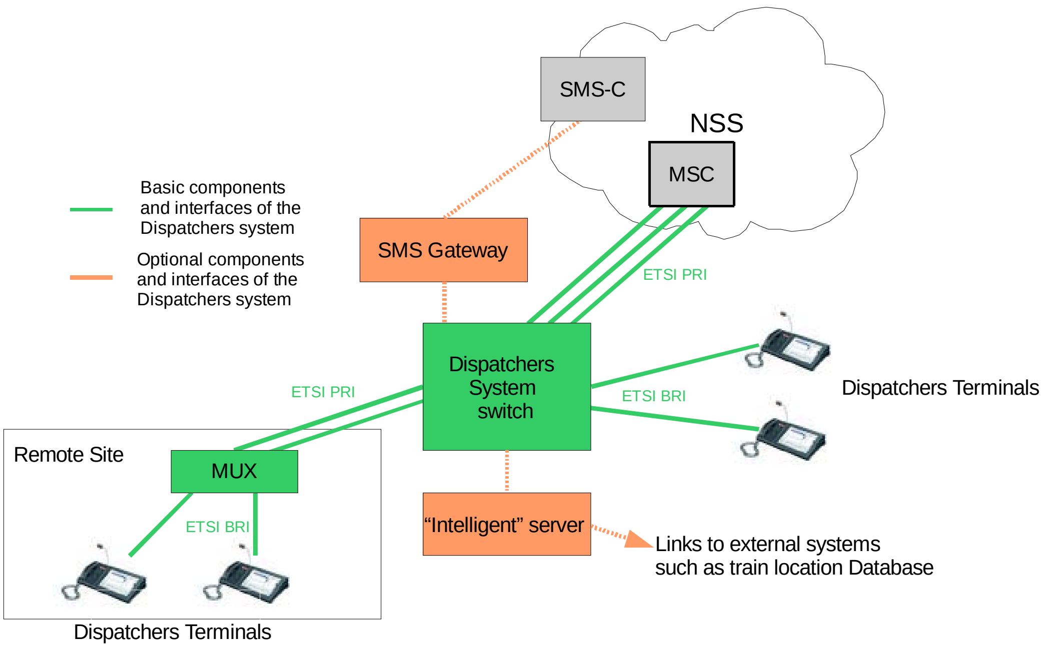
9.5.1 The purpose of the dimensioning of the FTS is to generate a complete list of the hardware required, including cards within the equipment and links at the interfaces.

9.5.2 The traffic data involving controllers can be extracted from the overall traffic model described in the NSS design section. It includes point-to-point calls to/from controllers, group calls with fixed dispatchers, SMS to/from controllers, and any operator's specific traffic involving the controller's equipment.

9.5.3 The blocking factor used for dimensioning is then set depending on the criticality of each resource, and whether pre-emption can occur on them.

9.5.4 The dispatchers' system must also be designed such that there are no single points of failure, for at least all the critical components or interfaces. This is achieved by using equipment with redundant circuits, implementing N+1 redundancy on interfaces (such as E1 and SS7 links), and installing duplicated equipments.

9.5.5 The general architecture of the Dispatchers system is shown in the following figure:



9.5.6 The basic architecture of the FTS includes a switch (such as a GSC or PBX) and the dispatcher terminals. The switch is connected via the MSC to the rest of the GSM-R network.

9.5.7 Dispatchers terminals collocated with the FTS switch are connected to the latter via an ISDN Basic Rate Interface (BRI).

9.5.8 Dispatcher terminals located in a remote site from the switch are connected locally to a multiplexer that converts BRI signals (terminal side) to PRI signals (switch side) and vice-versa.

9.5.9 The PRI signals between the switch and the multiplexer are transported over E1 interfaces across the transmission network.

9.5.10 It is also possible to implement radio dispatcher terminals for signal boxes in rural, low density areas or where the telecommunication infrastructure may not exist. Radio terminals use the GSM-R network to connect back to the FTS.

9.5.11 Some suppliers can offer more complete solutions over and above the basic call management such as role management, mobile registration information etc.

9.5.12 To implement these solutions, interfaces can be created to external systems and specific applications developed.

9.5.13 Examples of these interfaces are given below:

- Interface to the IN system with exchange of train registration data;
- Interface to train location databases;

9.5.14 The FTS switch is usually complemented by an "intelligent" server to implement these applications. The interface to the external systems is located on the server.

9.5.15 The specification of these features and the interfaces with the FTS varies for each railways depending on their requirements, their choice of implementation of the Functional Addressing feature, the train positioning system used etc.

9.5.2 SMS messages

9.5.1 To allow controllers to send and receive SMS messages, an interface can be created between the FTS and the SMS-C in the NSS.

9.5.2 This is implemented with the installation of an SMS Gateway: The role of the SMS gateway is to reformat and forward SMS messages between the FTS (over ISDN signaling) and mobile subscribers via the SMS-C (SMPP over IP or MAP over SS7).

9.5.3 Voice recording

9.5.1 Some operators require that all calls on the GSM-R network are recorded for safety and training purposes, while others only require calls involving dispatchers to be recorded. In this case, as an alternative to a call recording system in the NSS, a call recording facility can be implemented in the FTS.

9.5.4 Disaster Recovery

9.5.1 The switch is at the centre of the Fixed Terminal Sub-system. It is therefore recommended to implement a standby switch for disaster recovery. If present, the "intelligent" server should also be duplicated to preserve the specific network applications.

9.5.2 On the dispatcher terminal side, some components can not be duplicated, such as the terminal itself, or the line interface cards. Therefore, it is recommended to implement a fallback solution with one or more terminals where calls can be rerouted to in case of failure.

9.6 Location dependent addressing

9.6.1 EIRENE aims to offer a system of communication between driver and controller that allows the driver to contact the appropriate controller by the press of a single button or entering a common short dialing code. The driver must also be able to contact others (e.g. the power controller and the secondary controller) in a similar manner.

9.6.2 As the train progresses along its journey, it will pass through a number of different controlling areas. It is time consuming and dangerous, particularly as far as emergency calls are concerned, if the driver needs to manually determine where the train is located and then type this information into the handset before being able to make the call. Instead, an automatic updating process is required, which routes the driver's call to the correct controller at any given time. In order to be able to route the call correctly through the network, GSM-R requires train location information.

9.6.3 The called party number depends on that party's function and:

- location of train (railway area);
- track number that the train is running on;
- direction of the train running through the railway area.

9.6.4 Another parameter which may influence the routing procedure is:

- time of day and/or date.

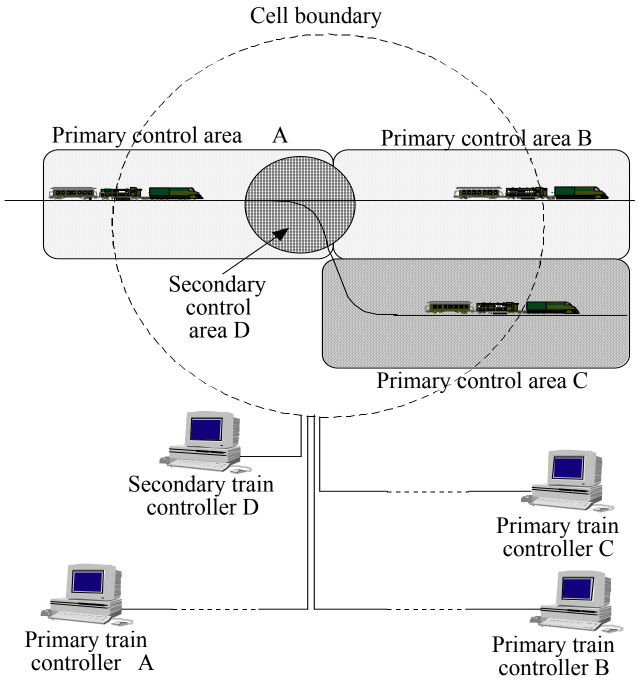
9.6.5 The call always has to be routed according to the information available when the call is initiated. The location dependent routing has to be done even if no additional information is available or necessary (eg tracks without balises or railway areas not matched to radio cells).

9.6.6 The call is typically initiated by the train driver using the cab radio, but the location dependent routing should ideally be supported for other functional calls, using other terminals (e.g. hand portable radios).

Method of location establishment

9.6.7 Correct routing of the call using a mobile station could be done by using the monitoring function of the radio cells which is an inherent part of the GSM functionality. If a call is being initiated, the cell in which the call originates should then allow the call to be routed to the correct operator. Although this may work under certain circumstances, there are some major disadvantages to this approach:

- cell boundaries do not always coincide with the area boundaries of the controller, as is shown in the figure below. This means that knowledge of the radio cell in which the mobile station originates the call alone will not necessarily lead to the correct controller;



Train controller areas

- cell boundaries are 'fuzzy', ie they vary in size and shape due to, for example, weather conditions;
- the cell structure and cell routing functionality does not allow for flexibility in cases where control areas are combined at times of less intensive traffic;
- the requirements for the design of mobile networks are independent of the layout of controller areas, which means that a change of GSM network design leads to a change in the relationship between cells and controller areas. This is of particular importance in those cases where a public GSM network is used.

9.6.8 As call routing based on cell routing may not meet all requirements (i.e. position may not be determined up to a desired accuracy), some other means of position information collection may be required by national railways.

9.6.9 In order to allow call routing to the appropriate controller, there is some combination of position information and routing algorithm required. Furthermore, there are interoperability considerations to be made about the choice of method by which the position information is obtained. Examples of possible methods are:

- track-side signaling systems (e.g. train describers);

- transponders: in this option, passive transponders (such as loops and balises) are located along the track and inform passing trains of their location. The transponders would be placed at the boundary between signalers' areas and potentially elsewhere if more accurate position information is required;
- navigation system (GPS, beacons etc);
- tagging system: passive transponders are mounted on each train. Track-side interrogators are then placed along the track in order to monitor the passing of trains.

9.6.10 The railway will have to consider these aspects in detail and specify the way in which position information is to be provided to the level of accuracy required by the railway.

Providing position data to routing database

9.6.11 Position information is held in some form of routing database to allow location dependent addressing. The information stored within the database can be obtained via either an on-train positioning system (e.g. balises or GPS) or via a track-side positioning system (eg train describers or ERTMS/ETCS RBC).

9.6.12 Train information is used within the network in which a train is currently operating to provide location dependent call routing from mobiles to controllers. Where information is provided from on-train systems, it is important that the requirements the E-SRS places on provision of position information are met in order to ensure that position information from international trains is of the correct format for use by national networks. For further details please refer to the eLDA specification.

9.6.13 The way in which information is provided to the routing database may be implemented in different ways as follows:

- via on-train positioning system:
  1. the positioning system collects the position information in the system specific format;
  2. this information is passed on to a formatter, which converts this system specific format into the required standard position format;
  3. the standard position information is passed on to the cab mobile radio, which adds to the data the train identity;
  4. this position data string is sent across the GSM network with the call setup;
  5. the routing database stores the information for use when the mobile originates a call requiring location dependent addressing.
- via track-side positioning system:
  1. the positioning system collects the position information in the system specific format;
  2. a train identifier is added;

3 the position data string is sent across the fixed telecommunications networks to the correct routing database via appropriate data links;

4 the routing database stores the information for use when the mobile originates a call requiring location dependent addressing.

Figure 4-9 gives an overview of these two possible mechanisms and shows how the relevant systems would relate to each other.

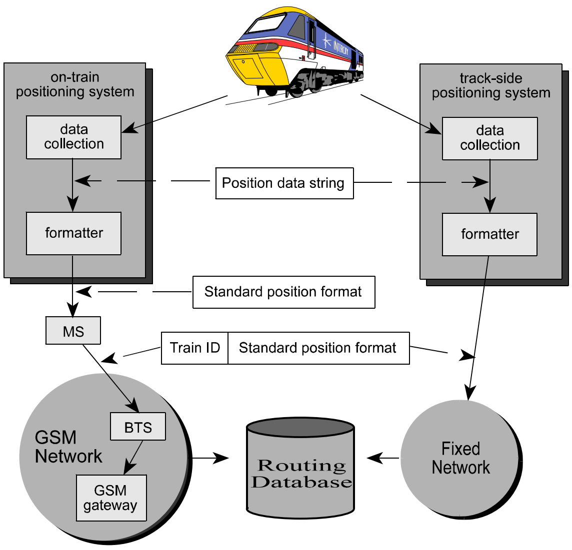


Figure 4-9: Providing train position information to the routing database

9.6.14 When collecting position information it is important to consider the requirements for the accuracy of the location information held in the routing database, and how frequently this should be updated. This will affect the probability that a call is routed to the correct controller, and will be affected by considerations such as controller area size, train speed and the performance of the external system providing the location data. In the case of position information from on-train systems, sufficient capacity will be required in the radio system to allow trains to update their location at the required frequency.

Interoperability aspects

9.6.15 As far as implementation of positioning systems is concerned, the railway should consider the four situations detailed in the table below with regard to trains roaming from their home network into foreign networks and the associated issues related to interoperability. The principle is that a train fitted with eLDA equipment roaming on to a foreign network without eLDA should not encounter any interoperability issues and vice-versa.

		Foreign network	
		Track-side	**On-train**
Home network	**Track-side**	Interoperability issues relating to balises.	Will lead to interoperability problems
	On-train	Aspect of suppression of position information of on-train system to avoid congestion of network should be considered	No specific interoperability issues

Position information interoperability issues

9.6.16 In those circumstances where a train with an on-train positioning system roams into a network that primarily relies on track-side train position information, a choice has to be made on whether the on-train position or track-side position information is to be accepted by the gateway switch and routing database. Both systems will provide the same position information, which means that the information provided by the track-side equipment is sufficient. This solution avoids additional implementation cost. However, the on-train equipment has to be informed that no position information is required from this system. This is to avoid the waste of bandwidth caused by sending position messages, which are not needed by the system.

Specification requirements

9.6.17 Each railway will have to specify the method by which train position information provision is to be implemented, taking into account the following main aspects:

– the E-SRS specifies location dependent routing based on cell routing as a minimum requirement. This option should be available as a fall-back scenario if the railway wishes to implement a more sophisticated system;

– train position information may be obtained by means of either an on-train or track-side system. If the railway decides to use an on-train system, then consideration must be given to international trains roaming into GSM-R networks that rely on a track-side positioning system. In any event, cell routing must be available as a fall-back;

- if a more accurate positioning system is required, then the railway will have to specify the level of accuracy with which position information is required. In addition, there will be a requirement to specify the following:
  - the division of the railway into areas which are allocated to, for example, primary and secondary controllers. This division should also take into account dynamic aspects such as the grouping of areas during times of low traffic intensity;
  - the way the call routing database is to be populated and managed;
  - performance elements for both the system providing the location data and the system processing the data. The interface specifications should include consideration of time delays, processing capacity, etc;
- the requirements for the routing database, which include:
  - location of the routing database;
  - interaction of the routing database with the implemented telecommunications network, in particular in those situations where the mobile network implementation is based on a public network;
  - management of the information contained within the routing database.

9.6.18 It is important to note that controller areas may change from time-to-time. Furthermore, in some regions, controller areas may change on a daily basis. There must therefore be mechanisms in place to manage these changes (either manually or automatically). In addition railways need to consider the following:

- fallback in the case of a busy operator;
- fallback in the case of a fixed terminal failure;
- sudden changes required, eg in the event of an incident occurring.

9.6.19 In addition, railways should give consideration to the overlap aspects and whether more than one terminal should be the destination for these calls if cell based routing is used.

9.7 Numbering Plan

9.7.1 The EIRENE Numbering Plan provides a range of number types to meet railways addressing requirements. These number ranges include functional numbers, short codes, and group call addresses and as well the physical numbers for mobile and fixed end devices. It specifies the structure of the GSM-R numbering plan, but not the way in which numbers are allocated. This depends on the national network implementation and the parties involved.

9.7.2 It is the responsibility of the national railway to implement a numbering plan according to the EIRENE Specifications. This guarantees interoperability of the GSM-R networks across borders.

9.7.3 The EIRENE Numbering plan is in principle a private numbering plan, but provisions have to be made to allow routing to and from public networks.

9.7.4 The EIRENE SRS mandates that each mobile is allocated an MSISDN number to allow authorized subscribers to call the mobiles using the appropriate MSISDN number rather than the functional number. Each railway is therefore required to obtain MSISDN numbers for the mobiles from the relevant national authorities.

9.7.5 Each fixed terminal connected to the GSM-R network requires an extension number. If the network is implemented as a private network with no connection to public networks then the railway will be free to allocate numbers to the fixed extensions as required. If the private network connects to public networks, the extension number will need to be allocated by the public network operator or relevant national authorities.

9.7.6 GSM-R calls are typically routed using the GSM-R features functional addressing, LDA or eLDA. In addition, the EIRENE numbering plan also defines a structure of access codes, and breakout codes to route calls to other networks.

9.7.7 Each operator needs to further refine the call routing on its network by specifying access rules for each type of users. This involves defining the address format each user is allowed to dial to make a call over the GSM-R network, call types or destinations that are barred, etc ... A number of features are available from the equipment suppliers to implement these rules, including the GSM-R access matrix defined in EIRENE.

9.7.8 If the GSM-R network is to be connected to public networks or other GSM-R networks, the railway operator must obtain appropriate SS7 point code(s) for the gateway MSC from the relevant national authorities.

9.7.9 To set up and analyze the required SS7 messages network internally and for interconnection purpose the railway operator must obtain an CC/NDC code from the relevant national authorities. The CC/NDC forms the basis of the MSISDN number (E.164) configured in the NSS network elements.

9.7.10 The GSM-R network must also obtain an MCC/MNC code from the relevant national authorities. The MCC/MNC forms the basis of the IMSI number (E.212) configured on SIM cards.

9.8 SIM Cards

9.8.1 Subscriber Identity Modules commonly referred to as "SIM Cards" are small memory devices that are configurable according to a defined structure.

9.8.2 SIM cards contain information and service rights of access for the subscriber. New SIM cards require configuration with respect to access numbers, Group Call Ids, barred services, ...

9.8.3 The GSM-R SIM card implementation is specified in the "MORANE FFIS for GSM-R SIM Cards". It complements the 3GPP specification "GSM11.11 version 8.2.0" and defines the optional GSM files that are mandatory for GSM-R, as well as defining specific GSM-R files.

9.8.4 Configuration of the SIM cards is typically achieved via a computer with dedicated card writing interfaces.

9.8.5 Remote or broadcast SIM card update can be provided as an "Over The Air" (OTA) facility. This allows packets of SIM card update commands and information to be individually addressed to a card or to a group of cards in order to change their configuration. This may be anything from a group call Id addition to activation of GPRS service.

9.8.6 The OTA facility requires an OTA server that sends the update in the form of an SMS message. The use of the facility therefore requires the presence of an SMS-C in the network.

9.8.7 The SIM toolkit mechanism is an optional GSM-R feature recommended in the E-FRS and E-SRS. It facilitates the OTA management via menus. This operation will require designing an "ad hoc" applet with the development tools.

9.8.8 In order to prepare SIM cards orders, user profiles are be created: For each type of GSM-R user in the network (for example: Cab Mobiles, Test OPH ...), it provides a template showing the data to provision in the files.

9.8.9 The GSM-R SIM cards have a minimum memory of 16Kbytes. This capacity may be increased following the requirements of the railway operators for additional information based on their national implementations (such as an extensive phone book). 32, 64, and 128 Kbytes SIM cards are currently available.

9.8.10 Functional details of the SIM card are defined in the FFFIS for GSM-R SIM cards which can be found on the UIC GSM-R website:

http://www.uic.asso.fr/uic/spip.php?article677

9.9 Network Management Centre and Operational Maintenance Centre

9.9.1 The Network Management Centre (NMC), sometimes called the Network Operations Centre (NOC), and the Operational Maintenance Centre (OMC) would typically be co-located since responsibility of the OMC normally falls under the remit of the NMC.

9.9.2 The NMC should provide access to all facilities and resources that may be required during the course of day-to-day running of the network. Access to emergency facilities or services and disaster recovery resources is also necessary.

9.9.3 The OMC normally consists of a terminal interface providing direct access to the network operating system, via software applications that are shipped with the network hardware. Technically the OMC is part of the core network equipment and most OMCs are mounted on the UNIX operating system.

9.10 Interconnection with other GSM-R networks

9.10.1 National GSM-R networks may be interconnected to provide a consistent service across a number of countries (roaming).

9.10.2 The point of interconnection between the GSM-R networks is located at the gateway MSC (GMSC).

9.10.3 The interface needs to support the standard voice and data bearer services specified in the EIRENE System Specification.

9.10.4 As a consequence of stringent requirements for secured operation of the GSM-R system, a redundant connection should be implemented.

9.10.5 Two types of physical interconnections between GSM-R networks.

Direct interconnection: A direct interconnection is always a physical connection, defined by one (at least) 2 Mbit/s (E1) physical connection link(s) between two GMSCs directly connected to each other. This link(s) may consist of one or more sections provided by one or more carriers. The different ways to implement the interconnection links are described in more detail in sub-section 6.2.2.2.

Transit interconnection: A transit interconnection is always established via at least one GSM-R neighbor in transit. These GSM-R neighbors are connected via direct interconnection links. This kind of interconnection type requires corresponding routing tables in all transit nodes. No physical through connection of timeslots, so called nailed up connections, are used.

9.10.6 For more details please refer to the UIC Guideline - Common Design Document – provided by the ENIR working group. A guideline for design and realization of the international GSM-R interconnection network.

9.10.7 In order to keep transparency in functionality and costs, the roaming and interconnection services are fixed in the subscriber profiles in the home network. For this reason all calls from a roaming subscriber to public numbers are routed via the home network. This means that not the roaming network, but only the home network operator has control about the communication profile of a subscriber.

9.11 Interconnection with public networks

9.11.1 The GSM-R network once implemented is a completely self-contained radio network that allows various users to talk to each other. If users are to be able to talk to users outside of the network then an interconnection would be required to the public telecommunications networks.

9.11.2 One of the simplest ways of allowing calls to the outside world is by connecting the GSM-R MSC to a PABX (private automatic branch exchange). Railways typically have their own private telephone network comprising of one or more PABXs. If the MSC were to be connected to the PABX network it would then be possible to connect the PABX (if it is not already) to a public telecommunications operator (PSTN).

9.11.3 An alternative way would be to connect the MSC to the MSC of a public GSM operator who would already have connections to the PSTN.

9.12 Functional number re-registration

9.12.1 EIRENE mandates that re-registration of on-train functional numbers based on the train number is performed every time a train leaves one GSM-R network and enters into another. Re-registration consists of a registration followed by a de-registration.

9.12.2 Both networks must agree on a number of items regarding the re-registration such as:

- Re-registration operational procedure;
- Method of detecting the border crossing;
- When the deregistration takes place;
- Manual vs automatic re-registration.

9.12.3 Ongoing calls cannot be maintained across network changes. It is therefore important to implement coverage overlap at the border to allow conversations to continue for some time after the crossing.

9.12.2 Train positioning information

9.12.1 There are a number of solutions available to obtain train positioning information, but Railway operators must always consider interoperability implications of their implementation. In addition, operators must consider a solution allowing them to detect trains about to enter their networks.

9.13 Disaster recovery

9.13.1 Disaster recovery needs to be planned from the highest level components of the network down to elements such as individual cards and fixed telecommunications links. The highest level components of the GSM-R network are the MSC(s) and gateway(s) to external networks. In the case of an MSC failure, the whole part of the GSM-R system dependent on that MSC would fail unless redundancy is provided. Therefore a standby MSC is recommended, particularly for networks supporting ETCS.

9.13.2 Where practical, redundant routing should be adopted for all fixed telecommunication links and redundant equipment should be installed within critical components (for example additional transceivers in radio cell sites and additional redundant cards at the BSC/TRAU).

9.13.3 Activation (and, where necessary, reconfiguration) of redundant equipment should be possible in the 'live' environment, ideally with the facility to initiate these procedures remotely from the NMC/OMC.

9.14 Migration

9.14.1 For many railways the introduction of GSM-R is as a replacement for an existing radio system, typically used for driver to controller communications and other railway operations. In these cases the introduction of GSM-R needs to be handled very carefully in order to minimize the impact on safety, railway operations and cost.

9.14.2 The method of migration will depend heavily on the nature of the railway. It is recommended that a dedicated study be undertaken as there are considerable consequences on safety, for example, of dual-mode working. This can be where a railway line operates with both the existing and GSM-R radio systems in service with some trains using the existing system and others using GSM-R. One of the first questions to be asked is how is emergency calls treated by the controller?

9.14.2 Option1: Dual infrastructure (direct switchover from analogue to digital)

9.14.1 This option requires the whole GSM-R network to be brought into operational service on one date. This would then allow a certain period to replace the train mobiles in all trains with GSM-R radios. During this period existing and GSM-R radio systems would operate in parallel providing duplicate coverage. One by one each train can have its existing radio replaced by a GSM-R radio. This could be carried out a pace that suits railway operations such as when trains come in for planned maintenance. Once a train has had its analogue radios replaced it could use the GSM-R radio system straight away.

9.14.2 Two terminals or a dual-mode controller's terminal would have to be developed and installed in all controller positions. The dual mode terminal would take some time and would involve development costs as well as a detailed testing process.

Advantages

9.14.3 This would give the flexibility to carry out the train fitment to a programme to suit the rolling stock maintenance schedule, for example. The whole process could be planned in advance. There would be no need for extra space in the cabs for the GSM-R train mobile as it would replace the existing radios.

Disadvantages

9.14.4 Bringing GSM-R into service would be delayed until the entire rail network is covered by GSM-R. For a short railway network or for regions or lines where rolling stock is captive this is not too much of a disadvantage. The GSM-R system could be brought into service line by line or region by region if the rolling stock only remain on these lines.

9.14.3 Option 2a: Dual fitment of trains – two radios in each cab

9.14.1 This option would involve bringing into service the GSM-R system along particular sections as soon as the infrastructure is available to go live. The GSM-R infrastructure rollout would remain the same. When a section of route is covered it would be brought into service straight away.

9.14.2 For this to option to succeed, trains would need to be fitted with both analogue and digital train mobiles. When a train enters a GSM-R area, indicated by new marker boards situated at the side of the track, either a manual or automatic switch over would take place and the correct train mobile would be chosen so that only one mobile would be in use at any one time (depending on operating procedures). Two train mobiles would be necessary in every cab. Once the analogue radio systems are switched off, the redundant radios could be removed.

9.14.4 Option 2b: Dual fitment of trains – one dual-mode radio in each cab

9.14.1 An alternative to two train mobiles is to have a dual-mode radio which is a single unit that works on both the existing and digital systems. This may be appropriate where space is very limited in cabs and so the scope for installing two radios is quite limited. This means that a dual-mode radio would have to be developed.

Advantages

9.14.2 These options allow for GSM-R to be brought into service rapidly. As soon as particular routes have been covered the system could go live in those areas soon afterwards. This would mean that the time between the installations of base stations and bringing them into service is optimized hence reducing OPEX costs for maintenance prior to going live.

Disadvantages

9.14.3 This option requires two radio systems in each cab. Drivers would need to know how to operate both systems and ensure that they are using the correct system for a particular line (assuming there is no automatic switchover system that has been specifically developed).

9.14.4 In the case of two radios in each cab, each train would have to be taken out of service twice, once to fit the GSM-R radio and once to remove the analogue radio. The timing of removal of the redundant radio is not critical and so can be taken out at a time that is convenient once the analogue systems have been switched off.

9.14.5 For the dual-mode radio, in addition to the cost of development, the radio would require extensive testing and type approval before it can be introduced. Type approval could take a long time.

9.15 Test Platform

9.15.1 It is recommended to allow for a test platform for the GSM-R system for:

- carrying out tests until commencement of the fault-free period prior to bringing into service,
- on commencement of the fault-free period:
  - on a priority basis for training of maintenance technicians, to test each update and upgrade (hardware and software) before installation on the active system,
  - on a secondary basis for training of shuttle drivers and controllers, to simulate operational use of the system.

9.15.2 A test platform that could also be used in the event of recovery following a disaster (for example, for the loss of the active NSS site or OMC).

9.15.3 The test platform shall generally consist of at least one copy of each element within the GSM-R system, including transmission and cabling.

9.16 Operations and Maintenance

9.16.1 General Structure

9.16.1 The following aspects need to be considered as a minimum for the operation and maintenance of the GSM-R system:

- human resources: composition of teams, level of skills and experience;
- equipment resources: vehicles, tools, information systems;
- procedures: supervision, escalation, work orders, performance measurements, analysis reports, maintenance instructions;
- management of reference systems: subscribers, sites, equipment items, transmission links, etc.

9.16.2 Depending on the requirements it is necessary to ensure 24 hours a day, seven days a week that the GSM-R system equipment and user service operate satisfactorily so as to:

- keep the operational system in operational condition (after commencement of the VSR phase, with maintenance of the system during construction being required until the commencement of the fault-free phase): permanent real-time supervision of the status of the system; management of incidents; maintenance; system administration (back-ups, archiving, etc.)
- user service: management of subscribers; supply, configuration and support for GSM-R portables
- provision of system upgrades: commissioning of new sites, new equipment, new software upgrades, new features;
- management of performance (control of service quality and analysis reports).

9.16.3 From commencement of the fault-free phase (prior to operational service), the GSM-R system will need to be monitored and managed from a NOC. The NOC will provide for the exchange of information about the status of the network with the operational managers for the railway.

9.17 System Operation

9.17.1 Monitoring of the Network and Services

9.17.1 It is necessary to monitor the equipment within the GSM-R system from end to end and to monitor the services supported via use of the equipment in the OSS sub-system (“mobile access” OMC, core network OMC, other monitoring servers). Additional tools may be implemented and where applicable so as to achieve the expected performance levels.

9.17.2 The O&M plan needs to be consistent with the railway operating plan.

9.17.3 Two types of supervision need to be provided:

- Real-time supervision: real-time detection of malfunctions in the equipment or deterioration in service quality (including radioelectric coverage) in particular from the OMCs, onboard platforms or equipment items provided by the original equipment manufacturers or any other monitoring platform. It must be possible to verify all radio parameters (e.g. signal level and voice quality) in real time and on an ad-hoc basis, automatically without having to operate test trains.
- Non-real-time supervision: detection of malfunctions or deterioration in service quality using statistical tools. It must be possible to perform post-processing of performance meters or trace sensors on the various interfaces of the BSS and NSS sub-systems.

9.17.2 Management of Incidents

9.17.1 A plan of corrective actions needs to be written for the purpose of resolving an incident, in compliance with the performance objectives, and therefore minimise the impact on rail services.

- Level A: service interruptions without a standby solution;
- Level B: loss of redundancy for an item of GSM-R equipment without service interruption;
- Level C: fault (opening of a door, etc.) without service interruption.

9.17.2 An escalation process needs to be in place based on the severity of the incidents, identifying the contacts according to the event and proposing an action plan appropriate for the situation.

9.17.3 It should be possible to analyze the severity of the event, which is not only linked to the GSM-R equipment but may depend on other factors associated with operation within the rail network. The following should be taken into consideration in particular:

- The level of non-availability of the service for users (which will not apply in all cases as equipment items may have back-ups);

– the impact on commercial services (depending on the geographical area concerned and the duration of non-availability).

9.17.4 This analysis will result in a determination of the origin of the fault and the parties responsible for resolution of the incident.

9.17.5 The assessment of the impact on the service and the forecast duration of non-availability shall be sent to the NOC using this incident management process.

9.17.3 Management of Modifications, Upgrades and Services

9.17.1 So as to keep the GSM-R system in operational condition, modifications will be required, such as the following:

- system optimization;
- changes in topology;
- service extensions;
- new integrations;
- modifications to rail parameters;
- software upgrades;
- works of all kinds.

9.17.2 Each request for a modification will be planned and shall be based on a modification management process.

9.17.3 The GSM-R operator will need to analyze each modification request and perform a detailed analysis assessing its impact on the GSM-R system and rail services. The railway operator needs to validate the modification and will propose a range of possibilities for performance on the basis of operating constraints. The GSM-R operator makes the modification, providing a formal work request using the works management process.

9.17.4 A modification management process needs to be put in place which will incorporate communication with the various parties involved so as to ensure consistency of an overall reference system making it possible to trace all modifications throughout the system.

9.17.5 The GSM-R operator needs to record its analysis of any modification, for example in a log-type IT application; this will cover the following items in particular:

- prerequisites before the modification;
- breakdown of stages (parties involved, tasks, place of performance, equipment item concerned);
- criterion for validation of the modification;

- analysis of the potential impact on the service;
- process for providing feedback.

9.17.6 The validation and planning process for works will be suitable for the level of risk for the service. Any modification will be subject to approval from the railway operator.

10 Performance of the GSM-R Network A Documentation overview

10.1.1 The specification of the performance of the GSM-R needs to be carefully calculated. Once this has been specified it needs to be measured prior to bringing the network into service. It is equally important to ensure that the performance does not degrade over time. It is for this reason that regular performance testing is recommended.

10.2 Quality of the Radio Coverage

The GSM-R operator needs to check monthly from commencement of the fault-free phase up to the date of final acceptance of the system in the case of railway rolling stock, and annually in the case of road vehicles and personnel, that the following values are achieved:

- Radio coverage criteria:
  - No coverage hole (i.e. result below the required threshold indicated in EIRENE SRS) greater than a total 5m is tolerated in each 100 metre location interval (in 1m increment steps).
  - The results are calculated on all the samples collected on the BCCH transmitter.
  - The Contractor shall describe and justify the measurement procedure, the post-processing and the tools used.
- Received Signal Quality “rxQual UL & DL”:
  - 95% of the results must be level ≤ 4
- Received Signal Level “rxLev UL & DL”:
  - 95% of the results must be level ≥ 15
- Location of Handover (point-to-point call):
  - 95% of Handover initiations must be located no more than 50m from the previous measurements.
  - No ping-pong handover is permitted, the sequencing of cells following Handovers occurring in accordance with the initial radio design.
- Location of Cell Reselection (idle mobile):
  - 95% of Cell Reselection initiations (idle mobile) must be located no more than 50m from the previous measurements.
  - No ping-pong Reselection is permitted, the sequencing of cells following Handovers occurring in accordance with the initial radio design.
- Location of Cell Reselection (listener mobile):
  - 95% of Cell Reselection initiations (listener mobile) must be located no more than 50m from the previous measurements.
  - No ping-pong reselection is permitted, the sequencing of cells following Handovers occurring in accordance with the initial radio Design.

A measurement report should contain at least the following:

– Hardware and software inventory list for status of the measuring tools used (e.g. software version number, hardware number).
– All the cells covering the line or section of line considered (line identifier, site identifier and name, site kilometer point and GPS, BSIC, ARFCN, Cell-ID) and the location of overbridges and tunnels.
– A surface and linear radio coverage map of the network indicating the field level received, the Handover and Reselection areas (idle and listener) and server cells encountered.
– The attenuation induced by the measurement chain.
– The statistical criteria for acceptance of the result.
– A comparative analysis against previous reports and trends.

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10.3 Measurement

10.3.1 Performance needs to be measured under realistic operational conditions (e.g. commercial running, staff moving around in the workshops, etc.).

10.3.2 Runs to be carried out are:
– at normal speed,
– in commercial trains,

10.3.3 on all or part of the fixed infrastructure, and with the GSM-R onboard hardware for which the acceptance certificate for the dynamic integration tests and a finalised verification report for these requirements shall be available.

10.3.4 Mobile radio acquisitions need to be measured simultaneously with:
– A test mobile in idle mode,
– A test mobile for point-to-point communication,
– A test mobile for group call communication (Listener mode),
– An operational mobile (cab radio and OPH).

These measurements are to be taken:
– on board railway rolling stock,
– on board road vehicles,
– on foot.

The following is recommended:
– for the static test, a type 1 error α of 5%; the type 2 error risk β of 5%.

    - for each parameter, to collect at least 500 samples on the network and/or terminal interfaces defined before providing the final result with operational or trace mobiles;
    - the "Transmission interference period" (TTI) and "Error-free period" (TREC) indicators must be established with a minimum of 1500 samples per kilometer.
- For on-board equipment:
    - for each parameter, to collect at least 100 samples on the end-to-end and/or user interfaces defined in order to confirm the final result with the operational handportables.

Example: If 500 measurements of the HO Duration KPI are collected (<300ms @95%), the target must be reached in at least 96.6% of cases before the performance requirement can be deemed to have been met. If the target is reached in no more than 93.4% of cases, the performance requirement is not met. Lastly, if the target is achieved in at least 93.4% of cases, but no more than 96.6% of cases, no decision can be taken and a second measurement campaign must be carried out.

10.4 Degraded Mode

10.4.1 Deleted.

10.4.2 GSM-R services shall be maintained even in degraded mode, e.g. following failure of an element of the GSM-R system.

10.4.3 The controller shall be able to call a driver's standby radio using the same mission number:

- via the standby cab radio as the preferred means,
- via the semi-fixed handportable radio in the cab as the secondary means.

10.4.4 Depending on the railway operating rules it may be acceptable to enter the stock number when the mission number is not available.

10.4.5 Degradation of the GSM-R service may be acceptable in certain circumstances following a failure. It is recommended that a list of features that must still be available in degraded mode is defined and included in the specifications for the GSM-R system. For example, redundancy of the following features is not considered critical to the GSM-R service:

- Remote updating of users,
- Recording mobile-to-mobile voice calls.

10.4.6 In the event of a complete loss of GSM-R service along one section of line, it may also be possible to fallback on to a public GSM network. From an equipment point of view the GSM-R mobile terminals are able to roam on to a GSM900 network without any technical modification.

10.4.7 The features available to users of the public GSM system would be limited compared to GSM-R, however in a degraded mode situation these may be sufficient (e.g. point-to-point calls to a regional control centre).

10.4.8 A solution where it will be possible for cab radios and handheld radios to communicate on a public GSM900 network would require an agreement with a public operator.

10.5 Disaster Recovery

10.5.1 The GSM-R system architecture needs to be designed to minimise loss of service due to failures in one or more elements. This is achieved through a combination of equipment redundancy and network resilience to remove single points of failure resulting in a high availability of service.

10.5.2 In addition to equipment failures, other events "external" to the system may result in interruption of the GSM-R service, particularly events associated with a disaster. The definition of a disaster is a sudden and catastrophic event such as a fire, flood, lightning or terrorist act seriously damaging a building housing telecommunication equipment.

10.5.3 The consequence of a disaster is a GSM-R service interruption across the whole rail network for a longer period of time than the maximum repair time defined. This would have a knock-on effect railway operations.

10.5.4 In most cases, a disaster will be loss of the:

- Active NSS site;
- FTS core site;
- BSC site;
- OMC site (mobile access or core network) – this is not immediately service affecting.

10.5.5 It is recommended that a disaster recovery plan (DRP) is written and rehearsed on a regular basis. The aim of the DRP is to minimize the time required to restore the GSM-R service.

10.5.6 It is essential to have systems and procedures for detecting disasters exhaustively and quickly.

10.5.7 The loss of the active NSS site must not impact on the information stored in:

- HLR;
- IN;
- SMS-C.

10.5.8 A number of railways deploying GSM-R have decided to build a duplicate site in case of such a disaster. Depending on the configuration and complexity of the network it is possible to restore full service within 4 hours. This does come at a price as the cost of the NSS is doubled.

10.5.9 In order to evaluate the most appropriate system it is necessary to first estimate the probability of such disasters occurring and then to assess the impact on railway safety and operations.

10.5.10 A total loss of the GSM-R system for a few months (the time necessary to fully restore an NSS that has no disaster recovery) would have a considerable impact on the operation of the railway:

- No voice communication for the railway lines covered by the NSS. In many cases, as there is only one NSS site responsible for the entire railway network, the loss of service would considerable.
- If present, the signaling system, ETCS Level 2 or 3 is fully reliant on the GSM-R being available. If there is no GSM-R, train operations would be perturbed.

10.5.11 The options to minimize the operational impact of a loss of the equipment are:

10.5.12 Duplicate all core network systems at a remote location. Following a disaster, operations could be resumed relatively quickly. The disadvantage is however the cost of procuring duplicate equipment and building a suitable site which is remote from the main site but is easily accessible. Disaster recovery procedures and tests would have to be devised and carried out on a regular basis. Additional telecommunications links would also be necessary.

10.5.13 Rely on a third party to provide a disaster recovery service. This could be at a supplier's premises or with another railway. If another railway were to provide such a service, this would be much simpler to administer compared to option 1 as all the internal interfaces would be managed by this third party who may already have a disaster recovery plan in place. For the GSM-R NSS there would be an added complication as the BSS and NSS equipment would need to be compatible between the two parties.

10.5.14 Build a remote disaster recovery site with power and telecommunications links but no equipment installed inside. One of the reasons why the recovery from a disaster takes so long (where there is no backup) is the physical housing of the equipment. In the event of a disaster, the various suppliers would be asked to rapidly provide replacement equipment to this redundant site. Compared to solution 1 this is a cheaper option and would reduce the time to restore service by several weeks. However, the disruption to railway operations would still be measured in weeks. Suppliers would need to make sure that they kept compatible equipment in stock for the life of the GSM-R system so that the disaster recovery site can be up and running swiftly. This will come at a price (OPEX).

10.5.15 Distribute all key equipment to different locations thus reducing the impact of the loss of a single site. This would increase building costs and result in a less efficient GSM-R system design. In some cases the loss of one system would still have consequences on other systems. For example, the loss of a major node of the fixed transmission network affecting one or more sections of the railway, would have a knock-on effect on the GSM-R and other communications systems.

10.5.16 Ensure that the NSS site is secure. This is a common practice where the building in which the critical equipment is housed is built to withstand events such as a bomb attack. The cost of the building would be increased but would remain small compared to many of the other options.

11 Implementation

11.1 Overview

11.1.1 The main activities once all the design work has been completed concern the installation and commissioning (by the individual contractors) of the equipment and the test and acceptance (by the system implementer). This is then followed by the bringing into service of the GSM-R system in a carefully controlled manner.

11.2 Radio sites

11.2.1 The deployment of GSM-R radio sites is a major and costly activity. Depending on the size of the network one or more dedicated projects may need to be established to oversee the roll out of the sites. In order for each site to be deployed a considerable number of different and interrelated tasks need to be carried out by several parties.

11.2.2 In order to reduce the time required to carry out works at each site, it is recommended to have pre-installed equipment cabins which can be brought on to site for installation. The integration of the BTS, transmission and DC power equipment can be carried out in a factory which means that the tasks needing to be realised by the side of the track are reduced as the main activities are the delivery and installation of the cabin, the connection of power and transmission to the cabin. This also reduces the risk of finding out at the last minute that one of the equipment is faulty as most of the testing could be carried out in the factory.

11.2.2 Site Acquisition and Planning Approvals

11.2.2.1 For many railways the majority of new radio sites will be built on railway land along the railway line and so site acquisition is not necessary. The other advantage is that either existing or new railway fixed transmission infrastructure that passes along the railway can be used.

11.2.2.2 Limitations on the height and location of the towers by local planning authorities will need to be taken into account in the design. Particular attention is necessary to be paid to urban, protected and military areas. Typically a maximum height of 40 m is used for the towers. Going above this height would not yield significantly greater benefit as the limiting factor in the radio system is likely to be the uplink between the mobile (relatively low power) and the base station (relatively high power and sensitivity).

11.2.2.3 The reuse of existing radio sites will help with planning approvals as upgrading an existing site is easier to get approved than a new site with an imposing tower which may not please local residents.

11.2.2.4 Due to its nature, the number of radio sites will be minimized in sensitive areas since access to this zone may be limited for construction and for maintenance. Some form of camouflage may be necessary in protected areas where a new tower may have a detrimental visual impact on the environment.

11.2.2.5 If low flying aircraft are present in this area agreement will need to be reached with the relevant authorities to ensure smooth operation. This could mean moving sites away from sensitive areas or installing warning lights on the towers. Similarly, the area around airports will need to be planned taking into account the additional constraints.

Figure 1: 42 m tower

11.2.3 Site survey

11.2.3.1 As with public operator radio sites, detailed construction site surveys need to be carried out prior to construction. Railways will generally have their own set of requirements for the construction work along the track.

11.2.4 Power and accommodation

11.2.4.1 Potentially one of the single biggest contributors to the overall cost of a radio site is the provision of electrical power. For radio sites in urban areas this is not generally a major issue. However, in rural areas, the cost of getting power to a site could be considerable as long runs of copper cable may be necessary for each site.

11.2.4.2 An assessment should be carried out for each site to ensure that the most efficient solution is chosen. If the cost of getting copper cable is prohibitive, one solution is the use of diesel generators. The cost of refueling the generators must be calculated particularly in difficult to access areas.

11.2.2 Existing radio sites should be reused wherever possible in order to reduce the cost of building sites. Accommodation may already be available but the most important factor is that a connection to a power supply will probably be present.

11.3 Site installation

Site installation (where it is for a radio site for core network equipment) should be planned in advance to ensure that all on-site activities can occur in a timely manner. In particular the following needs to be checked:

– Method statements for the delivery;
– Floor plans (spatial planning, cable trays, ...);
– Power supply and grounding specifications;
– Cabling and wiring;
– Interfaces;
– Cable terminal equipment, distribution frames, connectors etc.

11.4 Radio coverage verification

11.4.1 Once all of the sites along a particular railway line have been commissioned and prior to operational service coverage verification can take place on site to check the air interface performance and to tune RF performance as needed. The intention is to verify that the radio equipment and BSS parameters meet the requirements. This should not be confused with static functional testing which is a separate activity that verifies that the GSM-R system provides all the EIRENE features such as point-to-point and railway emergency calls.

11.4.2 Debug

11.4.2.1 Once GSM-R sites are constructed and it is certified that the sites are built to the original design, the individual site commissioning activity can start. This includes loading the BSS datafill on to the BTS and to energise the site. Field strength measurements are taken at and around the site to ensure that no additional risk is being imparted on operational infrastructure.

11.4.2.2 The debug phase is started after installation and commissioning have been successfully completed. This activity checks that, from a radio and BSS point of view, the sites perform in line with the specifications. Since most of problems occur over the air interface, debug activities are focused on radio aspects.

11.4.2.3 The debug phase is a necessary phase to check the network state and to carry out any necessary corrective actions before the beginning of the RF acceptance phase.

11.4.2.4 Measurements are carried out on a test train which is able to travel back and forth over the railway line. The purposes of the tests are to check:

- Coverage (RxLev DL);
- Quality (RxQual DL);
- Handovers and cell reselections.

11.4.2.5 Where results are found to be unsatisfactory, corrective actions are requested and recorded.

11.4.2.6 Once they implemented, further measurements need to be carried out to validate the solution.

11.4.3 RF Acceptance

11.4.3.1 The purpose of the RF acceptance phase is to demonstrate that the technical requirements in terms of coverage and quality of service are met.

11.4.3.2 Two kinds of tests are performed:

- Coverage tests;
- Quality of Service (QOS) tests.

11.4.3.3 The RF acceptance activity is based on performance at a network level. It is carried out to prove that the engineering requirements (with respect to the radio interface) are achieved.

11.4.3.4 All the contractual key performance indicators (KPI) are measured in order to ensure that the target values are met.

11.4.3.5 During the RF acceptance phase, KPIs are measured with a significant number of samples. Wherever possible, several KPI are measured simultaneously when using the same test protocol (continuous call or repetitive call for example).

11.4.3.6 During this phase several drive tests are needed, in order to have the most significant results from a statistical point of view.

11.5 Test and Acceptance

11.5.1 The principles applied during the test and acceptance process are the application of an organized series of actions intended to gradually commission the basic systems in a manner that guarantees safe operation at all times, and which demonstrates that the system deployed therefore meets the requirements.

11.5.2 These works can be broken down as follows:

- Phase 1: individual testing by sub-system;
- Phase 2: static testing by installation and test batch;
- Phase 3: static integration testing;
- Phase 4: dynamic integration testing;
- Phase 5: in-service verification.

11.5.3 A process of final meetings and reports will generally constitute recognition of the end of each phase, which will allow passage to the following phase.

11.5.2 Contractor Responsibility

11.5.2.1 Each contractor is responsible for the testing and commissioning for the equipment items and works relating to phases 1 to 4 (inclusive).

11.5.2.2 It is helpful if one of the contractors is responsible for overall system integration for phase 5 and for this purpose:

- That contractor should draw up a “master” plan for testing incorporating the entire system after consultation with the other contractors and adjacent networks.
- The contractor should co-ordinate each contractor’s testing plans for each contractor and the elements put in place by the adjacent rail networks.
- The contractor should prepare a breakdown of the installation and testing procedures into individual lots.
- The contractor should prepare the corresponding testing logic, incorporating the test lots and the various phases, until completion of all functional testing and all geographical testing.
- The contractor should incorporate plans from the other contractors and adjacent rail networks.
- The contractor should co-ordinate integration testing with the other contractors and adjacent networks, draft the corresponding testing specifications with the support of the other contractor or adjacent networks and prepare the corresponding test reports.
- The contractor should provide the necessary assistance for the purpose of obtaining approval of the GSM-R system.

11.5.2.3 For each phase and sub-phase, the contractor responsible needs to propose detailed specifications for testing and date for these tests.

11.5.3 Phase 1: Individual testing by sub-system

Factory Hardware Acceptance

11.5.3.1 The factory acceptance tests (including qualification and routine testing) needs to be performed before dispatch of any hardware and software to site so as to verify that the sub-system and its components are suitable for their intended use, and that they comply with the contract.

11.5.3.2 The factory acceptance tests should be performed by the contractor according to the contractor's quality control methods as described in the quality assurance plan, the testing plan and the test specifications applied by the contractor.

11.5.3.3 The factory acceptance tests will be recognized as successfully completed via an acceptance report drafted by the contractor and supplemented by any reservations and decisions by the system implementer, who will sign the report. The clearance of any reservations formulated at this stage by the system implementer, notified by the system implementer, is deemed to constitute authorization for site installation of the equipment items concerned for the purpose of moving on to *Functional Platform Testing*.

Qualification Testing

11.5.3.4 Qualification testing is a series of tests to demonstrate the quality and operational safety of an item of hardware (representing its exact configuration) to the system implementer, and in particular that the hardware is capable of withstanding the most severe service environment without sustaining any damage.

11.5.3.5 Where the sub-system or its components are not an approved commercially-available product, or where there are no existing or appropriate standards or certificate to demonstrate the suitability of its use for the system implementer, the contractor needs to perform a qualification test to demonstrate that this type of component is suitable for its use on the basis of the appropriate standard and quality level so as to comply with the contract. The test specification written by the contractor is submitted to the system implementer in advance.

11.5.3.6 When a component is already certified by another body, this test is not mandatory if the appropriate certificates verifying compliance of the component with the contract are provided and if these are accepted by the system implementer. Such a certificate would not be accepted, for instance, if it is not demonstrated that:

- the component is or will be suitable for the envisaged purpose,
- the component is of the required level of quality and conforms to the required standards.

Routine Testing

11.5.3.7 Routine tests are a series of tests performed on a certain number of equipment items selected from a single batch, and making it possible for the system implementer to verify to what extent those equipment items satisfy requirements.

11.5.3.8 For all components that must be installed on site, the contractor should perform routine testing in a manner acceptable to the system implementer.

11.5.3.9 One reason for non-acceptance of a routine test is that it does not comply with the appropriate test method or the agreed test specification.

Functional Platform Testing

11.5.3.10 Functional acceptance tests should be performed before dispatch to site for any functionality or software item so as to verify that that sub-system and its components comply with the requirements according to which they have been specified and in particular with the functional requirements specifications.

11.5.3.11 The functional acceptance tests are performed by the contractor in the presence of the system implementer on the basis of the test specifications drafted by the contractor and previously approved by the system implementer.

11.5.3.12 Compliance of installation for the installation batch in question, and in particular the exhaustiveness of the design documents, is verified during this sub-phase.

11.5.3.13 The functional acceptance tests will be recognized as successfully completed by a report drawn up by the contractor to which will be added any reservations and decisions from the system implementer, who will sign the report. The clearance of any reservations formulated at this stage by the system implementer, notified by the system implementer, should be deemed to constitute authorization for site installation of the features or software items concerned for the purpose of moving on to *Phase 2: Static testing by installation and test batch.*

11.5.4 Phase 2: Static testing by installation and test batch

11.5.4.1 Static tests on hardware and sub-systems and the associated works is performed by the contractor following installation, so as to ensure that the equipment installed will not disrupt existing sub-systems.

11.5.4.2 At this point, the interfaces between the sub-systems of the contractor or contractors, and the neighboring rail networks or host network are tested via simulation; the contractor or contractors will be responsible for providing an ad-hoc simulator.

11.5.4.3 So as to verify the feasibility of the operations performed following migration, tests subsequent to replacement of the analogue units by the GSM-R cab radio are performed by the contractor during this phase.

11.5.4.4 With respect to the mobile access infrastructure (i.e. BSS), these tests are performed by complete cluster of BTSs installed. A cluster is considered to be fully installed where the maximum number of BTSs per Abis transmission loop and the associated radio propagation infrastructure (i.e. including the final number of repeaters required) are deployed. The completion of installation for the cluster in question is accompanied by a site visit and a joint inspection with the system implementer.

11.5.4.5 The static tests by sub-system are performed by the contractor on the basis of the test specifications drawn up by the contractor and previously accepted by the system implementer.

11.5.4.6 The contractor will provide the system implementer with the operating manuals (including training manuals) before completion of static testing.

11.5.4.7 Static testing will be completed in the following three sub-phases:

Static Testing With Power Off

11.5.4.8 The purpose of these tests is to verify that the hardware and sub-systems have been installed according to the terms of the contract in accordance with ad-hoc analysis, and that the next test sub-phase may commence without damaging equipment belonging to the system implementer, adjacent rail networks or the host network. This phase also includes all verifications relative to the completion of installation.

11.5.4.9 In particular, compliance of installation for the installation batch in question is verified during this sub-phase, and in particular the following:

- The exhaustiveness:
  - of the installation records
  - of the drawings modified on site, in agreement the designs
  - of the quality assurance data package for the installation.
- The continuity and insulation of the cables,
- The radio verification of the installation of the antenna system via:
  - measurements of "Voltage standing wave ratios" (VSWR) (including jumper, feeder and antennas),
  - measurement of "Distance to fault" (DTF),
  - verification of system loss for the antenna system (e.g. cable loss, connectors) and fixed transmission (copper cables, fiber optic cables),
  - compliance of the installation with the design.
- Compliance of the hardware installed with the approved hardware and software reference systems.

11.5.4.10 During static testing with power off, neither the sub-systems nor their components is supplied with power.

11.5.4.11 Completion of the static testing with power off will be recognized as successfully completed by a site inspection organized by the contractor's quality manager, to which the system implementer will be invited, and by an installation completion meeting. During this meeting, any reservations will be reviewed and a level of severity will be assigned to them. Critical reservations must be cleared before the following test phase can be commenced.

11.5.4.12 Static testing with power off will be recognized as successfully completed by a report drawn up by the contractor and supplemented by any reservations and decisions of the system implementer, which will sign the report.

11.5.4.13 The resolution of each critical and non-critical reservation should be recognized by a certificate signed by the contractor's quality department.

11.5.4.14 The resolution of all critical reservations that may be formulated at this stage by the system implementer, notified by the system implementer, should be deemed to constitute authorization to move on to the next sub-phase: *Static Testing With Power On*.

Static Testing With Power On (Simulated Interfaces)

11.5.4.15 The purpose of these tests is to verify that the hardware and sub-systems of the installation batch in question operate in accordance with requirements.

11.5.4.16 Static testing with power on is performed where the sub-systems or their basic components are supplied with power.

11.5.4.17 The interfaces between the various systems involved will only be tested by simulation as these systems are yet be connected to each other.

11.5.4.18 Static testing with power on will be recognized as successfully completed by a report drawn up by the contractor to which will be added any reservations and decisions from the system implementer, which will sign the report. The resolution of any reservations formulated at this stage by the system implementer, notified by the system implementer, will constitute authorization to move on to *Phase 3: Static Integration Testing*.

11.5.5 Phase 3: Static Integration Testing

11.5.5.1 Static integration testing on hardware and sub-systems is performed by the contractor so as to ensure the satisfactory operation of the sub-systems under the operational conditions where they will be used jointly.

11.5.5.2 The operating manuals are finalized by the contractor in a format and subject to a standard acceptable to the system implementer before the end of *Phase 3: Static Integration* so as to ensure that they can be applied at the beginning of *Phase 4: Dynamic Integration Testing*.

11.5.5.3 Static integration testing is performed by the contractor in the presence of the system implementer on the basis of the test specifications drawn up by the contractor and validated by the system implementer.

11.5.5.4 The test specifications should take into account at least the following:

- At least one test per functionality defined in the specifications document;
- At least one test per constraint or limitation defined in the specifications document;
- At least one test per envisaged fallback mode (degraded operating environments).

11.5.5.5 Static integration testing will be recognized as successfully completed by an acceptance report drawn up by the contractor to which will be added any reservations and decisions from the system implementer, which will sign the report. The clearance of any major reservations that may be formulated at this stage by the system implementer, notified by the system implementer, should be deemed to constitute authorization to move on to *Phase 4: Dynamic Integration Testing*.

11.5.6 Phase 4: Dynamic Integration Testing

11.5.6.1 Dynamic integration testing on the hardware and associated sub-systems is performed by the contractor so as to guarantee that the design and installation of the hardware and sub-systems and the works performed are in accordance with this contract, and that all the system interfaces operate and are integrated such that the overall system operates correctly and without risk, and complies with the requirements of the contract, including the performance requirements in a context with trains traveling up to maximum speed.

11.5.6.2 The contractor takes part in the demonstration of the stability of the overall system performed throughout this phase during a test run. The participation of the contractor is necessary throughout the observation period and during any extension of this phase, if this is extended as a result of a failure in a system installed by the contractor.

11.5.6.3 The dynamic testing also covers the following:

- radio transition tests at the boundaries with adjacent rail networks;
- compliance with the performance requirements.

11.5.6.4 The contractor performs commissioning on the system on all of the rail network so as to demonstrate the stability and performance of the system:

- during test operation, travel of test personnel in workshops, etc.
- over the entire rail network,
- on each type of rail rolling stock (i.e. at least one locomotive for each class).

11.5.6.5 Dynamic integration testing is performed by the contractor in the presence of the system implementer on the basis of the test specifications drawn up by the contractor and approved by the system implementer.

11.5.6.6 Dynamic integration testing will be recognized as successfully completed by an acceptance report drawn up by the contractor to which will be added any reservations and decisions from the system implementer, which will sign the report. The clearance of any reservations formulated at this stage by the system implementer, notified by the system implementer, for both contractors should be deemed to constitute authorization to move on to *Phase 5: In-Service Verification*.

11.5.7 Phase 5: In-Service Verification

11.5.7.1 The purpose of this phase is to verify the correct operation of the overall system under normal operating conditions and to allow operation of the system by the system implementer users without interruption to commercial services.

11.5.7.2 A fault-free period of typically three months begins following a substantiated decision from the system implementer.

11.5.7.3 This phase may only begin when the contractor has provided the principles, plans, schedule and detailed instructions relative to maintenance of the system in question.

11.5.7.4 In the event that the installation of the equipment items envisaged has not been completed, a restricted in-service verification phase may be announced (subject to functional or hardware restrictions), in which case the system implementer reserves the right to request an extension to this period of three months so as to complete this phase.

11.5.7.5 Throughout this phase, while the contractor, in the presence of the system implementer, operates and is responsible for the overall system, the contractor has the opportunity to train the system implementer personnel in its sub-systems so as to enable the system implementer personnel to use the overall system according to the operations and maintenance requirements.

11.5.7.6 The in-service verification phase will have been successful if, following this period, the requirements in terms of performance and availability are achieved.

11.5.7.7 If these requirements are not met, a new in-service verification period of the same duration will be commenced on the date on which the system implementer recognises that service has resumed following non-availability, and so on until compliance with this condition is recorded.

11.5.7.8 Furthermore, operating incidents may generate reservations that are classified as minor with the agreement of the system implementer and treated as such. The period for performance and qualification of the corresponding corrections is not taken into consideration in the in-service verification period.

11.5.7.9 An extension to the in-service verification period following lengthy or repeated non-availability or performance of corrections as a result of minor reservations may entail the cancellation of that verification and the resumption of the full qualification process after rectification by the contractor.

11.5.7.10 The in-service verification period will be recognized as successfully completed by a report drawn up by the contractors to which will be added any reservations and decisions from the system implementer, which will sign the report. The clearance of any reservations formulated at this stage by the system implementer, notified by the system implementer, should be deemed to constitute authorization to move on to Acceptance of the System.

11.5.8 Acceptance of the System

11.5.8.1 Where the in-service verification period has been successfully completed, the documentation updated in the context of the As-Built Documents (ABD) and any minor reservations appearing during this period resolved, the contractor may then envisage the possibility of submitting the system for provisional acceptance.

11.5.8.2 A new jointly-prepared inventory needs to be prepared so as to determine responsibility for any deterioration in the system during the in-service verification period and to release the contractor from liability, if applicable. This will take the form of a report notified by order to proceed.

11.5.8.3 Acceptance will be decreed if:

- The testing has been performed successfully, with all reservations having been cleared;
- All of the hardware and software components have been upgraded and the configuration has been updated accordingly;
- The final contractual documentation has been supplied by the contractor and approved by the system implementer.

11.5.8.4 Declaration of acceptance should entail the transfer of ownership of the system to the system implementer and commencement of the warranty period.

11.6 Border crossing

11.6.1 Mobiles traveling from one GSM-R network to another (for example by moving from one country to another) will have to cross a border which will have implications on the GSM-R service.

11.6.2 The most obvious impact is that a call in progress will be dropped when the mobile moves from one network to the next. There will also be a time taken for the mobile to be registered on the new network (as a visitor if it is a foreign network). This implies that there may be a gap in GSM-R service of several seconds.

11.6.3 From an implementation point of view, the most appropriate method to mitigate this loss in service would be to have overlapping network areas (cells) giving a mobile traveling at speed time to register on to the new network whilst still being in the coverage area of the previous network.

11.6.4 Depending on local legislation there may be constraints for network operators from one country to radiate into a neighboring country. If there are no such constraints then an overlap distance needs to be calculated based on the speed of the train to allow sufficient time for registration.

11.6.5 Once the principles have been agreed by all parties the next step is to carry out the radio planning to ensure that there is no interference between the two networks who are using the same frequency band.

11.6.6 Once the cells have been defined the final step is to define the group call areas in this overlap zone.

11.6.7 The UIC ad-hoc working group on border crossing has produced a specification, an extract of which can be found in annex D.

11.7 Real-time performance monitoring

11.7.1 Network performance equipment are supplementary equipment (not covered under EIRENE) that can be used in order to have real time data on the performance of the network, being capable on one part to offer rapid information on issues affecting the network, as well as dissemination on the performance of the network, for instance the average value of the handover duration, as well as the maximum values, for a given period.

11.7.2 Tools are used to monitor the GSM-R network, tackle roaming issues, and enhance the network quality level. It is a real-time solution working as a supervision system. Data is directly available for user analysis.. It also provides historical information and KPI trend analysis. This enables radio and optimization teams to measure the impact of network changes, and it also can provide alarms to abnormal network changes.

11.7.3 The performance tool can provide dedicated statistics regarding optimization on radio engineering: special care is needed when validating neighbor cells declaration, hand-over sequence, radio resources availability, dropped calls. Both statistical and per transaction analysis is possible for GSM-R services, allowing operators to check for their equipment validation and configuration: cells implied in REC and other voice group calls, call establishment duration, functional addressing. Dedicated troubleshooting features, to easily track drive testers and to manage functional numbering registration.

Time	Time from begining (s)	Source Lac	Source Ci	Source Name	Target Lac	Target Ci	Target Name	HO Type	Cause
2006-11-16 11:33:17+01	184	20200	23808	Unknown Cell	20200	23811	Unknown Cell	HO Performed	Better cell
2006-11-16 11:35:02+01	289	20200	23811	Unknown Cell	20200	23814	Unknown Cell	HO Performed	Better cell
2006-11-16 11:36:34+01	381	20200	23814	Unknown Cell	20200	23820	Unknown Cell	HO Performed	Better cell
2006-11-16 11:38:09+01	476	20200	23820	Unknown Cell	20200	23823	Unknown Cell	HO Performed	Better cell
2006-11-16 11:39:07+01	534	20200	23823	Unknown Cell	20200	23826	Unknown Cell	HO Performed	Better cell
2006-11-16 11:40:10+01	597	20200	23826	Unknown Cell	20200	23829	Unknown Cell	HO Performed	Better cell
2006-11-16 11:40:50+01	637	20200	23829	Unknown Cell	20200	23832	Unknown Cell	HO Performed	Better cell
2006-11-16 11:41:33+01	680	20200	23832	Unknown Cell	20200	23835	Unknown Cell	HO Performed	Better cell
2006-11-16 11:42:10+01	717	20200	23835	Unknown Cell	20200	23838	Unknown Cell	HO Performed	Better cell
2006-11-16 11:43:01+01	768	20200	23838	Unknown Cell	20200	23841	Unknown Cell	HO Performed	Better cell
2006-11-16 11:43:57+01	824	20200	23841	Unknown Cell	20200	23844	Unknown Cell	HO Performed	Better cell
2006-11-16 11:44:41+01	868	20200	23844	Unknown Cell	20200	23853	Unknown Cell	HO Performed	Better cell
2006-11-16 11:45:56+01	943	20200	23853	Unknown Cell	20200	23856	Unknown Cell	HO Performed	Better cell
2006-11-16 11:46:30+01	977	20200	23856	Unknown Cell	20200	23859	Unknown Cell	HO Performed	Better cell
2006-11-16 11:47:36+01	1043	20200	23859	Unknown Cell	20200	23862	Unknown Cell	HO Performed	Better cell
2006-11-16 11:48:39+01	1106	20200	23862	Unknown Cell	20200	23865	Unknown Cell	HO Performed	Better cell
2006-11-16 11:49:40+01	1168	20200	23865	Unknown Cell	20200	23868	Unknown Cell	HO Performed	Better cell

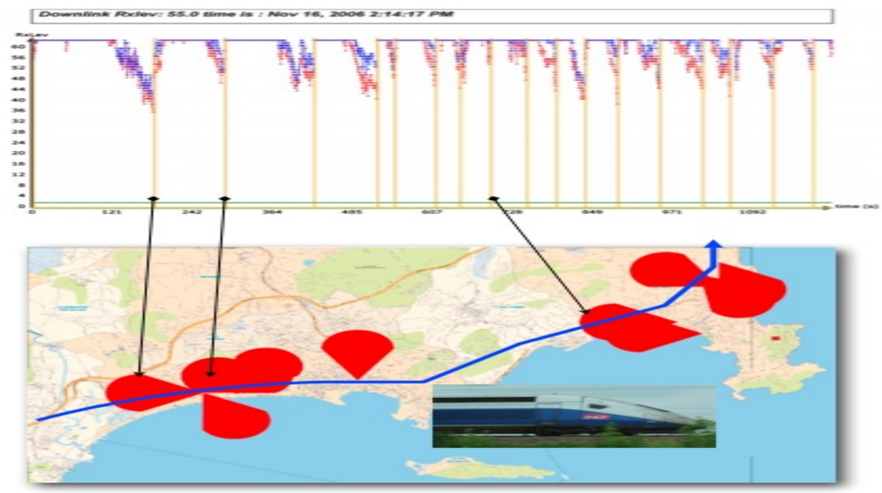
Example: Hand-over

11.7.4 Systems are available that allow both statistical ov erview and detailed analysis of radio conditions. This example outlines how the tools can be used for radio monitoring and troubleshooting based on the A_{bis} interface.

11.7.5 Calls can be found by entering the IMSI, MSISDN, functional number, calling / called number and time frame. Their hand-overs can be listed per call, to verify, for example, that hand-overs take place correctly.

11.7.6 A message flow can display all messages between the BTS and the BSC, and between the BSC and the MSC with the aim of showing how each monitored equipment talks one to another.

11.7.7 Radio measurements (uplink and downlink RxLev, RxQual, power control, timing advance) can be viewed for a complete call. In the figure below each bar represents a hand-over and can be clicked to zoom in on a specific radio channel during call, showing also neighbors cells radio measurements. This representation is very useful to check at first glance the radio conditions on real traffic with real users.



A Documentation overview

A.1 Introduction

A.1.1 Currently, there exist a number of documents related to the GSM-R system that have an impact on the development of the national system specification. This section provides an overview of the documentation available to date.

A.1.2 There will be a requirement for regular amendments to this guide in order to keep up to date with changes in the EIRENE Specifications and related documents as a result of future developments both in service provision and technologies available. This will not only include updates in the formal documentation listed in this appendix, but may also include amendments to the contents of the previous sections of this document. This will be one of the responsibilities of the European Radio Implementation Group.

A.1.3 Furthermore, it should be noted that there will be a number of national projects and regulations which will have an impact on each national railway implementing EIRENE-compliant systems. It is, however, outside of the scope of this guide to provide a detailed summary and explanation of these national regulations and projects.

A.2 Relevant documentation

A.2.1 All approved documents are available from the GSM-R web site at the following address:

http://gsm-r.uic.asso.fr/specifications.html

A.2.2 In addition to the EIRENE-specific documents, there are a number of other European initiatives, which may have an impact on the development of the national system, for example ETCS.

B Examples of available equipment and accessories

This section provides a list, which illustrates the range of GSM-R equipment and accessories that are currently available. For full details of available equipment, national railways should contact representatives of the supply industry. Contact details are provided on the GSM-R web site at http://gsm-r.uic.asso.fr/.

B.1 List of principal suppliers in each area (non-exhaustive list)

B.1.1 Network suppliers

- Nortel
- Siemens
- Huawei

B.1.2 Cab radio suppliers

- Alstom
- Center Systems
- Hörmann Funkwerk Kölleda
- Kapsch
- Selex
- Siemens

B.1.3 Operational radio and General purpose radio suppliers

- Sagem
- Selex
- Triorail (without ASCI)

B.1.4 Modem suppliers

- Kapsch
- Sagem
- Triorail

B.1.5 Data card suppliers

- Kapsch
- Sagem
- Triorail

B.1.6 Dispatch and control centre suppliers

- Frequentis
- Kapsch

– Siemens
– Hörmann Funkwerk Kölleda

B.2 Cab Radio Variants

B.2.1 Cab Radio Box Standard for Train Radio - Shunting- Data Transmission

Consists of:

	Qty
Standard box with control software	1
MS 8 W	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	1
Power-Smoother PSM	1
2 Analogue interfaces for connection of operator equipment	1
2 Digital Interfaces for connection of operator equipment	1

B.2.2 Cab Radio Box Air-Conditioned for Train Radio - Shunting- Data Transmission

Consists of:

	Qty
Air-conditioned box with control software	1
MS 8 W	1
Peltier Module (PLM)	1
PS - Module A/2E-T//9	1
2 Analogue interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1

B.2.3 Cab Radio 19″ Rack Standard for Train Radio – Shunting – Data Transmission

Consists of:

	Qty
19“ Rack with control software	1
MS 8 W	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	1
Power-Smoother PSM	1
2 Analogue interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1

B.2.4 Cab Radio Box Standard (tall unit) for Train Radio – Shunting – Data Transmission

Consists of:

	Qty
Standard box (tall unit) with control software:	1
(Pos.12 may be fitted with ETCS)	
MS 8 W	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	1
Power-Smoother PSM	1
Power Supply PS - 2 (2x12, 0V, 5A)	1
Secondary voltage: 2x12V / 2x5A	
2 Analogue interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1

B.2.5 Cab Radio Box Air-Conditioned (tall unit) for Train Radio – Shunting – Data Transmission

Consists of:

	Qty
Air-conditioned box (tall unit) with control software	1
(Pos.12 may be fitted with ETCS)	
MS 8 W	1
Power Supply PS - 5 (2x5, 0V / 5x12, 0V) / max power 350VA	1
Peltier Module (PLM)	1
2 Analogue interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1

B.2.6 Cab Radio Box Standard (tall unit) for Train Radio - Shunting- Data Transmission and ETCS

Consists of:

	Qty
Standard box (tall unit) with control software:	1
MS 8 W	3
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	2
Power-Smoother PSM	1
Power Supply PS - 2 (2x12, 0V, 5A)	1
2 Analogue interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1
1 Interface (FFFIS for Euroradio) for ETCS	2

B.2.7 Cab Radio Box Air-Conditioned (tall unit) for Train Radio - Shunting- Data Transmission and ETCS

Consists of:

	Qty
Air-conditioned box (tall unit) with control software	1
MS 8 W	3
Power Supply PS - 5 (2x5, 0V / 5x12, 0V) / max. Power 350VA	1
Power Supply PS - 1 (1x5, 1V, 12 A and 2x12, 0V, 3 A)	2
Power Supply PS - 2 (2x12, 0V, 5A)	1
Peltier Module (PLM)	3
2 Analogue interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1
1 Interface FFFIS for Euroradio for ETCS	2

B.2.8 Cab Radio Box Standard (tall unit) for Dualmode, GSM-R Train Radio – Shunting - Data Transmission and Analogue Train Radio

Consists of:

	Qty
Box with control software: *(Germany, Austria, Switzerland, analogue and GSM-R)*	1
MS 8 W	1
Transceiver, analogue	1
Power Supply PS - 1 (1x5, 1V, 12 A and 2x12, 0V, 3A)	2
Power-Smoother PSM	1
Power Supply PS - 2 (2x12, 0V, 5A)	1
2 Analogue interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1
1 Interface UIC 568	1
Evaluation and filter unit (EFU)	1
CI - Control-IF (CI)	1

B.2.9 Cab Radio 19'' Rack Standard (tall unit) for Dualmode, GSM-R Train- Shunting- Data Transmission and Analogue Train Radio

Consists of:

	Qty
Box with control software: *(Germany, Austria, Switzerland, analogue and GSM-R)*	1
MS 8 W	1
Transceiver, analogue	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	2
Power-Smoother PSM	1
Power Supply PS - 2 (2x12, 0V, 5A)	1
2 Analogue interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1
1 Interface UIC 568	1
Evaluation and filter unit (EFU)	1
CI - Control-IF (CI)	1

B.2.10 Cab Radio Box Air-Conditioned (tall unit) for Dualmode, GSM-R Train Radio - Shunting- Data Transmission and Analogue Train Radio

Consists of:

No information available.

B.2.11 Cab Radio 19'' Rack (tall unit) for Dualmode, GSM-R Train Radio - Shunting- Data Transmission and Analogue Train Radio

Consists of:

	Qty
19'' Rack with control software: *(Germany, Austria, Switzerland, analogue and GSM-R)*	1
MS 8 W	1
Transceiver, analogue	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	2
Power-Smoother PSM	1
Power Supply PS - 2 (2x12, 0V, 5A)	1
1 Controller card with 2 Interfaces for connection of operator equipment	1
2 Digital interfaces for connection of operator equipment	1
1 Interface UIC 568	1
1 Analogue train radio controller card inc. evaluation and filter unit (EFU)	1

B.3 Accessories pack for base Cab Radio

B.3.1 Interfaces FFFIS consists of:

	Qty
Card with 2 Interfaces FFFIS RS 422	1
Interface cable with connector in box	2

B.3.2 Interfaces UIC 568 consists of:

	Qty
An additional 2 analogue operator equipment interfaces plus 1 UIC 568 *(Optionally, may have just 2 additional operator equipment interfaces instead of a UIC interface)*	1
Interface cable with connector in box	1

B.4 Accessories pack for installation with one user MMI

B.4.1 Kit 1 for driver console consists of:

Controls

Dualband - Controls for digital and analogue train radio
inc. application software module for handling train and shunting radio
- incl. Data interface
- LC - Display (Technology: FSTN black and white with backlighting)
- Keyboard consists of hard and soft keys
- Interfaces
    - NF analogue and data interfaces
    - Interface to handset
    - Interface to loudspeaker
    - Power supply for GPH charging bracket
    - Interface for turn around switch
- Front panel
- Housing

B.4.2 Complete cabling for 1 driver console with Antenna K 70 20 61 consists of:

	Qty
Cable loom and 1 driver console	1
Antenna K 70 20 61 with coaxial cable *(Frequency range 450 – 470 MHz and 806 – 960 MHz)*	1

B.4.3 Hand set and loudspeaker for 1 driver console consists of:

	Qty
Hand set 750	1
Loudspeaker	1

B.4.4 Bracket for Driver Handheld consists of:

	Qty
Charging bracket for GPH	1
Cable loom	1

B.5 Accessories pack for installations with two user MMIs

B.5.1 Kit for 1st and 2nd driver console consists of:

	Qty
User MMI	2

B.5.2 Complete cabling for 1st and 2nd driver console with Antenna K 70 20 61 consists of:

	Qty
Cable loom and 1st driver console	1
Antenna K 70 20 61 with coaxial cable *(Frequency range 450 – 470 MHz and 806 – 960 MHz)*	1
Cable loom for 2nd driver console	1

B.5.3 Hand sets and loudspeakers for 1st and 2nd driver console consists of:

	Qty
Hand set 750	2
Loudspeaker	2

B.5.4 Bracket for Driver Handheld for 1st and 2nd driver console consists of:

	Qty
Charging bracket for GPH	2
Cable loom	2

B.6 Accessories pack: Antennae for Cab Radio Box Standard (tall unit) for Train Radio – Shunting – Data Transmission and ETCS

B.6.1 Antennae and cable consists of:

	Qty
Antennae K 70 20 61 with coaxial cable *(Frequency range 450 – 470 MHz and 806 – 960 MHz)*	2

B.7 Accessories pack for Dualmode/Shunting vehicles

B.7.1 Accessories for Shunting vehicles

	Qty
"Swan's neck" microphone	1
Foot switch	1
Cross over switches for up to 2 "swan's neck" microphones and foot switches including cable loom (for 1 MMI)	1

B.8 Accessories pack duplexer for Dualmode

Duplexer 728 954 with Coaxial cable for Dualmode consists of:

	Qty
Duplexer Type 728 954 with 2 Coaxial cables complete with plug/connector	1

- Frequency range Input 1: 68 - 470 MHz
- Frequency range Input 2: 870 - 970 MHz
- Output loss: < 0.5 dB
- Coupling loss: > 45 dB
- VSWR: < 1,2
- Impedance: 50 Ohm
- Input power: < 50 W
- Working temperature: -20°C to +50°C
- Connector: N–type female
- Mounting: over 4 bolts (M3)
- Measurements: (W x H x D) 296 x 32 x 112 mm (incl. connectors)

Accessories pack - "Country-specific" software for Dualmode with licence

Austria
Switzerland
Sweden
Italy

B.8.1 Country-specific software for 0.7m band (450 MHz – Frequency band), Packet consists of:

	Qty
Software module and licence for EURO-Analogue, one-off payment for corporate licence for the following package:	1

7.1.1 Netherlands (450 MHz – Frequency band)
7.1.2 France
7.1.3 Belgium
7.1.4 Luxembourg
7.1.5 Denmark
7.1.6 Poland (450 MHz – Frequency band)
7.1.7 Czech Republic (450 MHz – Frequency band)

B.8.2 Country-specific software for 0.7m-Band (450 MHz – Frequency band), on request consists of:

	Qty
Software module and licence for EURO-Analogue, one-off payment for corporate licence. Available on request:	1

7.2.1 Norway

- 7.2.2 Croatia
- 7.2.3 FYR
- 7.2.4 Slovakia
- 7.2.5 Slovenia
- 7.2.6 Bulgaria

B.8.3 Country-specific software for 2m-Band (160 MHz – Frequency band), on request consists of:

	Qty
Software module and licence for EURO-Analogue, one-off payment for corporate licence. Available on request:	1

- 7.3.1 Hungary
- 7.3.2 Poland
- 7.3.3 Czech Republic
- 7.3.4 The Netherlands

B.9 Accessories pack 160 MHz Antenna only for Dualmode for country pack for Hungary, Poland, Czech Republic and The Netherlands

B.9.1 160 MHz radio equipment in separate housing or as a 19'' rack insert consists of:

	Qty
Radio equipment 160 MHz	1
Cabling	1

B.9.2 Antenna 160 MHz

	Qty
Antenna type 733 707 with Coaxial cable *(Frequency range 146 – 147 MHz and 166 – 172 MHz)*	1

B.10 Upgrades

B.10.1 Upgrade UIC 568 Interface consists of:

	Qty
Card with 1 UIC 568 Interface	1
Interface cable with connecting socket	1

B.10.2 Upgrade FFFIS (RS422) Interfaces consists of:

	Qty
Card with 2 FFFIS (RS422) Interfaces	1
Interface cable with connecting socket	2

B.11 Cab Radio for ETCS

B.11.1 Cab Radio basic unit Standard for ETCS consists of:

	Qty
Standard Box	1
MS 8 W	2
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	2
Interface FFFIS for Euroradio for ETCS	2

B.11.2 Cab Radio basic unit Air-Conditioned for ETCS consists of:

	Qty
Air-conditioned box	1
MS 8 W	2
Peltier Module (PLM)	2
PS - Module A/2E-T//9	2
Interface FFFIS for Euroradio for ETCS	2

B.11.3 Cab Radio basic unit in 19'' Rack for ETCS consists of:

	Qty
19" Rack	1
MS 8 W	2
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	2
Interface FFFIS for Euroradio for ETCS	2

B.12 Accessories pack - Cable loom and antennae for Cab Radio ETCS

B.12.1 Antennae and cable consists of:

	Qty
Antenna K 70 20 61 with coaxial cable *(Frequency range 450 – 470 MHz and 806 – 960 MHz)*	2

B.12.2 Cable loom for connection to onboard power supply and ETCS computer consists of:

	Qty
1 x cable (10m) for voltage supply (one end fitted with plugs, 2nd end finished with sleeved wire)	1
1x cable (10m) for ETCS application (one end fitted with plugs, 2nd end is unwired, plug connectors are enclosed)	1

B.13 General Purpose Handheld

B.13.1 GPH consists of:

	Qty
Standard GSM-R GPH	1
Standard battery (Li-Ion battery or same/higher value)	1
Journey charger	1
User instructions	1
Packaging	1

B.13.2 Accessories for GPH

Accessories for (GPH) consist of:

		Qty
1	Table-top charger	1
2	Car-kit with hands-free	1
3	Portable hands-free kit	1
4	PC data cable	1
5	PC data cable for car-kit	1
6	Li-Ion battery (880mAhrs)	1
7	Leather pocket	1
8	Cable for cigarette lighter	1
9	Journey charger	1

B.14 Operational Purpose Handheld (OPH)

B.14.1 OPH consists of:

	Qty
Standard GSM-R OPH	1
Standard OPH battery	1
Charger	1
User instructions	1
Packaging	1

B.14.2 Accessories for OPH consist of:

		Qty
1	Standard OPH battery	1
2	Table-top charger	1
3	Charger with charging control	1
4	Leather pocket	1
5	Car-kit with hands-free	1

B.15 Operational Purpose Handheld-Shunting (OPS)

B.15.1 OPS consists of:

	Qty
Standard GSM-R OPS	1
Standard OPS battery	1
Charger	1
User instructions	1
Packaging	1

B.15.2 Accessories for OPS consist of:

		Qty
1	Standard OPS Battery	1
2	Table-top charger	1
3	Charger with charging control	1
4	Leather pocket	1
5	Mounting with additional speech button, connection protection, dead-man's button, emergency button, microphone, battery mounting, status display and harness in accordance with requirements from the shunting workgroup	1

B.16 Data Transmission Module 2 Watt

B.16.1 MS2 consists of:

MS2
Area of application still open

B.17 GSM-R Data Terminal equipment

B.17.1 GSM-R Data terminal equipment for ETCS with one Mobile (MS) in Standard Box

Consists of:

	Qty
Standard box	1
MS 8 W	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	1
Interface FFFIS for Euroradio for ETCS	1

B.17.2 GSM-R Data terminal equipment for ETCS with two Mobiles (MS) in Standard Box

Consists of:

	Qty
Standard box	1
MS 8 W	2
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	2
Interface FFFIS for Euroradio for ETCS	2

B.17.3 GSM-R Data Terminal equipment for ETCS with one Mobile (MS) in Air-Conditioned Box

Consists of:

	Qty
Air-conditioned box	1
MS 8 W	1
Peltier Module (PLM)	1
PS - Module A/2E-T//9	1
Interface FFFIS for Euroradio for ETCS	1

B.17.4 GSM-R Data Terminal equipment for ETCS with two Mobiles (MS) in Air-Conditioned Box

Consists of:

	Qty
Air-conditioned box	1
MS 8 W	2
Peltier Module (PLM)	2
PS - Module A/2E-T//9	2
Interface FFFIS for Euroradio for ETCS	2

B.17.5 GSM-R Data Terminal equipment for ETCS with a Mobile (MS) in 19" Rack

Consists of:

	Qty
19" Rack	1
MS 8 W	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	1
Interface FFFIS for Euroradio for ETCS	1

B.17.6 GSM-R Data Terminal equipment for ETCS with two Mobiles (MS) in 19" Rack

Consists of:

	Qty
19" Rack	1
MS 8 W	2
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	2
Interface FFFIS for Euroradio for ETCS	2

B.18 Accessories pack - Cable loom and antenna for fixed GSM-R Data Terminal equipment for ETCS with one Mobile

B.18.1 Antenna, antenna mast and accessories consist of:

	Qty
Antenna K 75 11 61 and coaxial cable *(Frequency range 806 – 960 MHz)*	1
Antenna mast and accessories *- Aluminium telescopic mast: maximum length 5.40m with 2 positions for wall fastening* *- Extension* *- Lightning protection connection with 3m ribbon conductor*	1

B.18.2 Cable loom consists of:

	Qty
1x cable (10m) for voltage supply (one end fitted with plugs, 2nd end finished with sleeved wire)	1
1x cable (10m) for ETCS application (one end fitted with plugs, 2nd end is unwired, plug connectors are enclosed)	1

B.19 Special speech equipment

B.19.1 OPH (without charger)

	Qty
Standard GSM-R OPH	1
Standard OPH battery	1
User instructions	1
Packaging	1

B.19.2 Accessories for OPH

		Qty
1	Standard OPH battery	1
2	Table-top charger	1
3	Charger with charging control	1
4	Leather pocket	1
5	Car-kit with hands-free	1

B.20 GSM-R vehicle equipment (data only)

B.20.1 GSM-R vehicle equipment (data only) for Train Control Network in Standard Box

Consists of:

	Qty
Standard box	1
MS 8 W	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	1
Interface FFFIS for Euroradio for ETCS	1

B.20.2 Vehicle equipment GSM-R (data only) in 19" rack for Train Control Network in passenger vehicles

Consists of:

	Qty
19" Rack	1
MS 8 W	1
Power Supply PS - 1 (1x5, 1V, 12A and 2x12, 0V, 3A)	1
Interface FFFIS for Euroradio for ETCS	1

B.20.3 Cable loom consists of:

	Qty
1x cable (10m) for voltage supply (one end fitted with plugs, 2nd end finished with sleeved wire)	1
1x cable (10m) for ETCS application (one end fitted with plugs, 2nd end is unwired, plug connectors are enclosed)	1

C Examples of available network equipment and accessories

In later versions of this document, this section will provide a list to illustrate the range of GSM-R network equipment and accessories that are available. For full details of available equipment, national railways should contact representatives of the supply industry. Contact details are provided on the GSM-R web site at the following address:

www.ertms.uic.asso.fr

www.gsm-rail..com

D Voice and data service functionality when crossing borders between GSM-R networks

D.1 The following is an extract from the FFFS for Voice and Data Services Functionality at borders between GSM-R networks and is included to show the evolution planned in order to improve the process of crossing GSM-R network boundaries.

1 Voice Services Functionality at borders between GSM-R Networks

1.1 Prerequisites

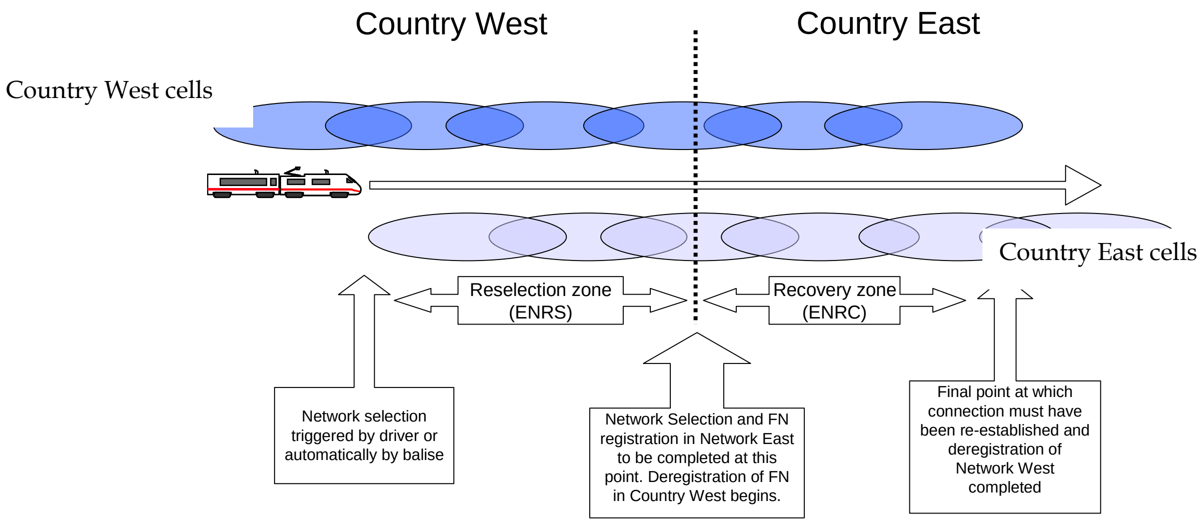
1. The Mobile Station MS is equipped with one single MT and is used for EIRENE voice services
2. Parameters with the subscript H (e.g. CC_H , NDC_H) refer to the home EIRENE network of the MS (the HPLMN). Parameters with the subscript 'W' (e.g. CC_W , NDC_W) refer to "Network West" and parameters with the subscript 'E' (e.g. CC_E , NDC_E) refer to "Network East". Network West or East could be the home EIRENE network or they could both be 'foreign' EIRENE networks.
3. The MS is assigned a MSISDN "CC_H+NDC_H+*CT8*", hence can be reached from terminals within all foreign networks under this number (if the usage of MSISDN is allowed and there is no barring against this configured) or from the home network under CT8 (if the usage of this number is allowed and there is no barring against this configured). However, the use of the MSISDN for this purpose is not envisaged.
4. … and from terminals in foreign EIRENE networks under "*900+*IC_H*+CT8*" or from terminals in the home-EIRENE network under "CT8" (if the usage of this number is allowed and there is no barring against this configured). Again, the use of the MSISDN for this purpose is not envisaged.
5. The user (driver, conductor etc) is registered to a Functional Number (FN) in Network West –"*CT2+UIN+FC*". It can therefore be reached from terminals within Network West under this number …
6. … and from terminals in other EIRENE networks under "*900+*IC_W*+CT2+UIN+FC*". Note:CT3 and CT4 are permanently registered to the MSISDN in the home network. Thus the "900+IC_H" is needed if calling an engine or coach number not belonging to the network where the call originates from.
7. For group communications (VBS and VGCS) the international Group call Identifiers (GID) included in E-SRS (Table 9-8: Function Code field format for CT=5), including "299" for Train Emergency Call need to be stored on the SIM of the MS
8. Where the rail track crosses the (operational) border between Networks East and West[9] there is a segment of rail track with radio coverage from both Networks. In this Two Network Coverage Area (TNCA), both Networks East and West can be used. The TNCA is dimensioned to provide coverage during approximately 2 minutes (this value is subject to Network Operators' operational requirements) train drive at the maximum limited speed of the line (e.g. 300 km/h would require 10 km TNCA). In the TNCA EIRENE Network ReSelection (ENRS) shall take place.

[9] This (operational) border follows railways' operational needs and does not necessarily coincide with the political border of the two adjacent countries.

1.2 Single MT Cab radio

1.2.1 Prerequisites

1.
2. The Cab radio is configured to manual GSM network selection



1.2.2 Cab radio in idle mode

1. The idle Cab radio is situated in network West and moving towards the adjacent network East.
2. The Cab radio is able to receive regular point-to-point calls (whereby the calling party uses the MSISDN or one of the FNs of the Cab radio)
3. The Cab radio is able to initiate regular point-to-point calls (dialling FN or MSISDN or ISDN of the called party) based on the internationally agreed access matrix
4. The Cab radio is able to recognise and join interoperable group calls (VBS and VGCS with GID as stored on the SIM of the Cab radio)
5. The Cab radio is able to initiate interoperable group calls (VBS and VGCS with GID as stored on the SIM of the Cab radio). It should be noted that other GIDs may also be present.
6. When entering the TNCA the idle Cab radio is triggered to perform an EIRENE Network ReSelection ENRS from network West to network East
7. The trigger can be a MMI action by the train driver who is following an operational instruction
8. The trigger can alternatively be a balise or similar (track-side) device, which transmits a signal to the Cab radio (via some external device(s)) when the train passes the balise when

the train passes a specific point on the line (This is termed directed network selection in the EIRENE FRS v7 section 5.2.3.25ii to 5.2.3.25v).

9. Upon reception of the network selection trigger (see above) the Cab radio starts the procedure to get attached to Network East. Since relevant info about Network East is available in the Cab radio (was provided together with the trigger signal or was pre-configured in the Cab radio) this procedure described in BX13_CabsingleMTvoice v0.10ii is to be optimised or an alternative solution shall be defined so that a maximum delay of 10 seconds can be achieved for 99% of attempts. (The fallback situation is described in BX13_CabsingleMTvoice v0.10ii). – This is referring to the network selection procedure section 10.5 of E-FRS 7 whereby EIRENE networks are given preference.
10. During execution of the network selection procedure, i.e. after leaving Network West and until joining (attaching to) Network East, the Cab radio is unable to receive any incoming point-to-point calls and to recognise and join any group calls (incl. REC). During this silent period, which shall last no longer than the maximum network selection delay specified in 2.2.2.9), the Cab radio is also unable to initiate any point-to-point calls or group calls (incl. REC). Operational rules (TSI OPE) regulate how to handle this silent period.
11. After the silent period, , the Cab radio attaches to Network East.
    a. If this could not be completed before leaving the ENRS segment, thereby entering the ENRC segment, the recovery procedure specified in 2.2.7 will apply.
12. The idle Cab radio, now visiting Network East (the VPLMN), has the same communication possibilities as described under 2, 3, 4, and 5 above.
13. After having attached to Network East the Cab radio will perform Functional Re-registration automatically for the CT2 functional numbers associated with the Cab radio (the international train number as well as international functional codes as defined in Table 9A.1 of E-SRS are identical in both networks West and East so the Cab radio holds all necessary data and no intervention by the Driver is required).
14. Firstly, functional registration of the train number to Network East is done by issuing the appropriate USSD string ““**214*IC$_E$+CT2+UIN+FC#”
    a. If this could not be completed before leaving the ENRS segment, thereby entering the ENRC segment, the recovery procedure specified in 2.2.7 will apply.
    b. This completes the EIRENE Network ReSelection ENRS procedure
15. Secondly, functional deregistration from Network West is done by issuing the appropriate USSD string "##214*IC$_W$+CT2+UIN+FC#" Deregistration should not occur until the train physically leaves the control area of Network West
16. During the USSD dialogue with the network as described under 15 and 16 above the Cab radio is intermittently unable to receive any incoming point-to-point calls and to recognise and join any group calls (including REC). The silent period will typically consist of up to 4 second breaks for each FC.
17. The driver is now registered to a Train Number in Network East “*CT2+UIN+FC” and* hence can be reached from terminals within Network East under this number and from other terminals in other EIRENE networks under “900+IC$_E$+CT2+UIC+FC”.

1.2.3 Cab radio in dedicated mode (busy in point to point call)

1. The busy Cab radio is situated in network West and moving towards the adjacent network East.
2. The Cab radio is able to receive further regular point-to-point calls utilising the Call Waiting Supplementary Service
3. The Cab radio is able to recognise and join group calls (VBS and VGCS with GID as stored on the SIM of the Cab radio)
4. When entering the TNCA the busy Cab radio is triggered to perform an EIRENE Network ReSelection (ENRS) from network West to network East
    a. The trigger can be a MMI action by the train driver who is following an operational instruction. In this case the Train Driver first terminates the ongoing point-to-point call in accordance with international harmonized operational rules (TSI OPE) after entering the TNCA. He will then trigger the now idle Cab radio to perform the ENRS, the procedure specified under 2.2.2 will apply
    b. The trigger can alternatively be a balise or similar, which transmits a signal to the Cab radio (via some external device(s)) when the train passes the balise. In this case the Cab radio will inform the Train Driver about the occurrence of the trigger and the Train Driver will terminate the ongoing point-to-point call in accordance with international harmonized operational rules (TSI OPE). He will then trigger the now idle Cab radio to perform the ENRS. The procedure specified under 2.2.2 will apply.
5. Automatic termination under a timer control has not been factored into the FRS7 SRS15 – it simply states that if termination does not occur the driver will lose network coverage and the call will be dropped. There is a need for specification.

1.2.4 Cab radio in dedicated mode (busy as first talker in VGCS or VBS)

1. The Cab radio in dedicated mode as first talker in VGCS or VBS is situated in network West and moving towards the adjacent network East.
2. The Cab radio is able to receive a regular point-to point call.
3. The Cab radio is able to recognise and join further group calls (VBS and VGCS with GID as stored on the SIM of the Cab radio)
4. In case the Train Driver is the first talker in a Railway Emergency Call (REC) he will stay in this group call also after entering TNCA and make sure that the train remains in the TNCA as long as the REC continues (and follow instructions by the controller), since the emergency call area at the border consists of the adjacent cells in Networks West and East to be defined by bilateral agreements.
5. When entering the TNCA the busy Cab radio is triggered to perform an EIRENE Network ReSelection (ENRS) from network West to network East
    a. The trigger can be a MMI action by the train driver who is following an operational instruction. In this case the Train Driver first terminates or leaves the ongoing group call in accordance with international harmonized operational rules (TSI OPE) after entering the TNCA. He will then trigger the now idle Cab radio to perform the ENRS, the procedure specified under 2.2.2 will apply

b. The trigger can alternatively be a balise or similar, which transmits a signal to the Cab radio (via some external device(s)) when the train passes the balise. In this case the Cab radio will inform the Train Driver about the occurrence of the trigger and the Train Driver will terminate or leave the ongoing group call in accordance with international harmonized operational rules (TSI OPE). He will then trigger the now idle Cab radio to perform the ENRS. The procedure specified under 2.2.2 will apply.

1.2.5 Cab radio in group transmit mode (subseq. talker in VGCS)

1. The Cab radio in group transmit mode (subsequent talker in VGCS) is situated in network West and moving towards the adjacent network East.
2. The Cab radio is able to receive a regular point-to point call utilising FACCH inband signalling.
3. The Cab radio is able to recognise and join further group calls (VBS and VGCS with GID as stored on the SIM of the Cab radio)
4. In case the Train Driver is subsequent talker in a Railway Emergency Call (REC) he will stay in this group call also after entering TNCA and make sure that the train remains in the TNCA as long as the REC continues (and follow instructions by the controller), since the emergency call area at the border consists of the adjacent cells in Networks West and East.
5. When entering the TNCA the busy Cab radio is triggered to perform an EIRENE Network ReSelection (ENRS) from network West to network East
   a. The trigger can be a MMI action by the train driver who is following an operational instruction. In this case the Train Driver first terminates or leaves the ongoing group call in accordance with international harmonized operational rules (TSI OPE) after entering the TNCA. He will then trigger the now idle Cab radio to perform the ENRS, the procedure specified under 2.2.2 will apply
   b. The trigger can alternatively be a balise or similar, which transmits a signal to the Cab radio (via some external device(s)) when the train passes the balise. In this case the Cab radio will inform the Train Driver about the occurrence of the trigger and the Train Driver will terminate or leave the ongoing group call in accordance with international harmonized operational rules. He will then trigger the now idle Cab radio to perform the ENRS. The procedure specified under 2.2.2 will apply.

1.2.6 Cab radio in group receive mode (listener in VBS or VGCS)

1. The Cab radio in group receive mode is situated in network West and moving towards the adjacent network East.
2. The Cab radio is able to receive a regular point-to point call utilising FACCH inband signalling..
3. The Cab radio is able to recognise and join further group calls (VBS and VGCS with GID as stored on the SIM of the Cab radio)
4. In case the Train Driver is listener in a Railway Emergency Call (REC) he will stay in this group call also after entering TNCA and make sure that the train remains in the TNCA as

long as the REC continues (and follow instructions by the controller), since the emergency call area at the border consists of the adjacent cells in Networks West and East.

5. When entering the TNCA the listening Cab radio is triggered to perform an EIRENE Network ReSelection (ENRS) from network West to network East
   a. The trigger can be a MMI action by the train driver who is following an operational instruction. In this case the Train Driver first terminates or leaves the ongoing group call in accordance with international harmonized operational rules (TSI OPE) after entering the TNCA. He will then trigger the now idle Cab radio to perform the ENRS, the procedure specified under 2.2.2 will apply
   b. The trigger can alternatively be a balise or similar, which transmits a signal to the Cab radio (via some external device(s)) when the train passes the balise. In this case the Cab radio will inform the Train Driver about the occurrence of the trigger and the Train Driver will terminate or leave the ongoing group call in accordance with international harmonized operational rules (TSI OPE). He will then trigger the now idle Cab radio to perform the ENRS. The procedure specified under 2.2.2 will apply.

1.2.7 EIRENE Network Recovery, ENRC

In case it was not possible to perform EIRENE Network ReSelection (ENRS) in Network East (the manual GSM network selection failed) within the ENRS segment (and the train enters the ENRC segment) the operational rules as described in the TSI OPE shall apply.

In case it was not possible to perform the Functional Registration to Network East within the ENRS segment the operational rules as described in the TSI OPE shall apply.

In case it was not possible to perform the Functional Deregistration from Network West within the ENRS segment the operational rules as described in the TSI OPE shall apply.

1.3 Operational Radio Handheld OPH

Some initial remarks:
The OPH is configured for automatic GSM network selection, but this may be overridden manually
Due to the nature of GSM and if the TNCA is engineered correspondingly the OPH will stay in Network West when the Cab radio is changing from Network West to East – this could eliminate most negative effects of the silent period

This aspect is for further study.

1.4 General Purpose Radio Handheld GPH

Same as for 2.3

1.5 Shunting Radio OPS

1. Same as for 2.3

2 ETCS Data Services Functionality at borders between GSM-R Networks

2.1 Dual MT EDOR for ETCS Level 2/3

2.1.1 Prerequisites

1. When the train enters the first segment of the TNCA, the Dual MT EDOR shall change network and, where necessary, shall perform an "international RBC handover". The remaining segment is used for recovery procedures in case this could not be accomplished.
2. The Dual MT EDOR is configured to manual GSM network selection
3. In the dual configuration one of the MTs is the Active MT busy in a dedicated mode data connection with the ETCS RBC
4. The other MT is the Standby MT, which is idle.

2.1.2 "Standard procedure"

1. The Dual MT EDOR is situated in network West and moving towards the adjacent network East.
2. The Standby MT is idle, the Active MT is connected with a RBC in Network West (RBC West)
3. When entering the TNCA the Standby MT is triggered to perform an GSM Network ReSelection from network West to network East
4. The trigger is sent by the Euroradio interface to the Cab Radio by an AT command as defined in FFFIS for EuroRadio.
5. Upon reception of the network selection trigger, the Standby MT starts the procedure to get attached to Network East.
6. After the break, the Standby MT attaches to Network East and responds in accordance with the FFFIS for Euroradio interface specification.
7. Euroradio will now trigger the Standby MT to establish a dedicated mode data connection with a RBC in Network East (RBC East).
8. The Standby MT will act as instructed and shall respond in accordance with the FFFIS for Euroradio interface specification.
9. The ETCS application now is connected with both RBC West and RBC East and will perform an international RBC handover from West to East.
10. On crossing the border, the previously Standby MT now becomes Active MT and in dedicated mode data connection with RBC East.
11. The previously Active MT becomes Standby MT
12. The ETCS application will instruct the Standby MT to disconnect RBC West and to perform an GSM Network ReSelection from network West to network East
13. Upon reception of the network selection instruction the Standby MT starts the procedure to get attached to Network East.

14. After the break, normally in the range up to 40 seconds, the Standby MT attaches to Network East and informs the ETCS application about this
15. Now, both the Active MT and the Standby MT are attached to network East. This completes the ETCS border crossing procedure.

E Example set of radio planning guidelines

E.1 Swiss railways' GSM-R radio planning guidelines

E.1.1 Swiss railways have kindly allowed reproduction of their GSM-R radio planning guidelines as an annex to this document in order to provide some further detail on this complex subject.

E.1.2 Please note that any such document is only relevant to specific requirements, constraints and is valid for a individual environment and cannot be directly applied elsewhere.

E.1.3 Radio planning documents in particular cannot be transposed from one railway to another due to the nature of radio propagation as described in sub-section 9.2.

Planning Guidelines

GSM-Rail

Version 5.0

Contents

3 Introduction

3.1 General

The European railways have chosen the GSM-R standard, which can be used internationally, for the introduction of new radio networks. The GSM-R standard builds upon the GSM standard that has already been in use for years. The GSM standard is used in public networks. The specification has been expanded for railway-specific applications. The air interface is however largely the same for both standards.

However, the requirements of the GSM-R network differ from those of the current public networks. The following features and properties are different:

- The availability of the GSM R-network must be significantly higher because railway operations can be massively disrupted in the event of poor availability (ETCS). Emergency calls are also made over the GSM-R network.
- The trains have very high speeds.
- Very different device types and applications must be taken into account.

All these features and properties require careful planning. The following criteria therefore require special consideration:

- The level of provision (field strength) must be maintained within the defined length intervals. The prescribed length intervals of 20 metres and an availability of 95% within this length interval are very high compared with a public network.
- The interference distances must be strictly adhered to.
- The handover zones must be carefully planned in order to perform the cell changeover reliably at high speeds, preferably without any negative effect upon the ETCS application.

3.2 Scope

The planning guidelines listed here relate exclusively to the GSM-R air interface (Um interface). These guidelines are used in radio network planning for the precise definition of the transmitter locations and the associated frequency planning.

3.3 Planning guidelines (external planning)

3.3.1 Provision level (field strength)

There are two provision levels for the external planning:

- Provision level ETCS
- Provision level Mobile phone covered

For driver's cab signalling (ETCS Level 2) the minimum level is assured by the ETCS provision level. If there is redundancy this level must always be assured.

All applications, with the exception of in-train provision, are covered by the 'mobile phone covered' provision level. This level need only be assured in normal operation (no redundancy).

In-train provision is only prescribed in tunnels. Tunnel provision is described in a separate document.

Different mobile stations with different transmission powers are used in the GSM-R network:

- Cab radio 8 Watt => Provision level: ETCS
- Mobile phone 2 Watt => Provision level: mobile phone covered

This gives rise to an asymmetry of approx. 3 dB when calculating the link budget. The following guidelines exist to take this into account in radio network planning:

BTS power	**=**	**45**
Damping TX - combiner	**=**	**2.5 dB**
ETCS provision level	**=**	**49 dBuV/m**
Mobile phone covered provision level	**=**	**68 dBuV/m 1)**

1) The power of the BTS is set for the higher-power mobile station (cab radio => 8 watts). At the same time, the 'mobile phone covered' provision level is set 3 dB higher to take the weaker uplink into account.

Based upon these guidelines the radio network planning system can perform the calculations using the planning tool with standard settings.

All field strengths [dBuV/m] are quoted as a median value!

3.3.2 Interference gap

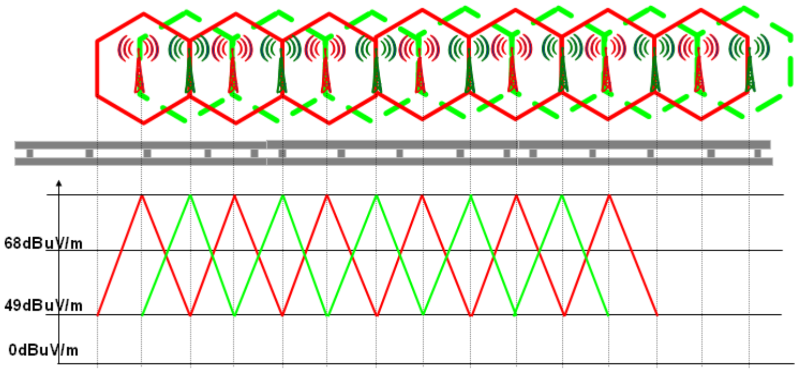
The interference gap differs depending upon the fading margin. A fading margin of 12 dB is defined for the planning principles. This gives a **C/ Ic (median)** of **29 dB**.

3.3.3 Multipath propagation

The conditions of multipath propagation should be taken into account in the planning. These should not exceed a running time difference of **15us**. This should be given particular consideration in tunnel provision since optical broadband systems with high delays are used.

3.3.4 Handover

For the definition of the handover range it must be possible to receive the two cells without interference for **8 seconds**. At a speed of **200 km/h** this works out at a distance of **450 metres**.
Another important consideration in the planning of the radio network is that it is necessary to ensure that within the range of registration balises or any MA balise devices, GSM-R is not directly in a handover state before and after the balise.



The diagram above shows the planning strategy for assuring the provision of redundancy. The following preconditions exist for the dimensioning of cells where balises are located in the supply perimeter:

Average coverage of a cell in the event of redundancy: approx. 3000m – 3500m
It is assumed that approx. 4s is required at the cell boundaries so that the system returns to a stable condition after the handover.
At 200km/h this means that the balises should be no more than approx. 1300m away from the antenna.

4 Technical principles / guidelines

4.1 Telecom SBB guidelines

The following guidelines have been developed with Telecom SBB, I-TC-D. The group has a great deal of experience in the field of modern train radio and had a lot of input regarding train-specific requirements and characteristics.

4.1.1 Availability

The local availability was defined as follows:

- Length interval **20 metres**
- Probability **95 percent**

Within 20 metres the following specifications must be adhered to in 95% of all cases:

- Minimum field strength for the relevant service (5.1)
- Minimum interference gaps (5.2)
- Conditions for multipath propagation (5.3)

4.1.2 Mobile phone damping values

The mobile phone damping value describes the loss of reception field strength compared to the reference antenna of the radio testing and recording car (Section 3.1). These losses are influenced by the following variables, amongst others:

- Height difference between testing and recording car antenna (4 metres) and mobile phone (1.5 metres)
- Polarisation loss
- Cover by railway wagon
- Body loss (method of carrying => mobile phone at chest)
- Shunter kneeling between two wagons

All these factors are taken into account in the damping values that follow and are not listed individually.
Some variables were verified by measurements (see Section 5.1.1).

Two methods of carrying are defined for the use of mobile phones in the track area:

- Mobile phone on body, outdoor normal
- Mobile phone on body, outdoor covered

Mobile phone on body, outdoor normal

In this method of carrying the mobile phone is worn on the body with a carrying strap. This method of carrying is used in the public area and on the track installations and has the following damping value:

Body loss with height difference	11	dB
Shadowing by railway coach/wagon	6	dB
Total damping value	17	dB

Mobile phone on body, outdoor covered

In this method of carrying the mobile phone is also worn on the body with a carrying strap. It is used in shunting operation, where the user is often shielded between wagons, standing or kneeling. The following damping value has been defined for this method of carrying:

Body loss with height difference	11	dB
Shadowing by railway wagon	6	dB
Kneeling between wagons	5	dB
Total damping value	22	dB

Wagon damping values

The damping value was defined by Telecom SBB based upon a measurement campaign.
Telecom SBB performed measurement trials with Telecom (currently Swisscom) in 1994 and defined damping values for individual coach/wagon types. Furthermore, Telecom SBB has already carried out trials with new wagon types and thus obtained values based upon experience:

Damping value **34 dB**

Mobile phone indoor

This damping value is used for the determination of the field strength in the indoor area. The method of carrying is the same as that for public networks (mobile phone at the ear)

Damping value **7 dB**

4.2 System parameters

4.2.1 BTS

Sensitivity of BTS	-104	dBm	GSM 05.05
Cable damping of BTS	-3	dB	SBB
Combined damping	-2.5	dB	Siemens
Diversity gain	3	dB	SBB / Section 7.2.1

4.2.2 MS

Sensitivity of MS (mobile phone)	-104	dBm	GSM 05.05
Sensitivity of MS (Cab Radio)	-104	dBm	GSM 05.05
Antenna gain of MS (locomotive)	-5	dBd	1)
Antenna K factor of MS (MEWA)	30	dB	
Antenna gain of MS (MEWA)	0	dBd	SBB
Power of MS (class 4)	33	dBm	GSM 05.05
Power of MS (class 2)	39	dBm	GSM 05.05
Cable damping of locomotive	3	dB	Inventis /SBB
Cable damping of MEWA	3	dB	Inventis / SBB

1) The diagrams were drawn using measurements from antennas on various coaches/wagons and locomotives. These measurements have demonstrated that in the case of locomotives, severe indentations must be taken into account in the horizontal diagram. These indentations result from the fact that various elements, for example the pantograph, are installed on the roof of the locomotive. The average loss compared to the antenna on a coach/wagon (MEWA SBB) is 5 dB.

   => See Section 5.4 [1]

4.2.3 Propagation parameters

Fading margin, outdoor	10 - 12	dB	Section 4.3.1
Fading margin, in-train	10 - 12	dB	Section 4.3.1
Fading margin, indoor	10 - 12	dB	Section 4.3.1
Margin for usage channel type voice	0	dB	Section 7.1.3
Margin for usage channel type data 2.4	-4	dB	Section 7.1.3
Margin for usage channel type data 4.8	-2	dB	Section 7.1.3
Margin for usage channel type data 9.6	1	dB	Section 7.1.3

4.3 Propagation and provision parameters

4.3.1 Fading margin

Normally the provision prediction using a planning tool supplies the median value of field strength for an area element. In order to take into account signal collapse due to fading and local shadowing, a fading margin must be added to this value in the link budget. The size of this margin depends upon the statistical amplitude distribution over the area and the required availability of the service. Based upon figures from experience in previous GSM plans and the results of measurements (see 5.1.2), a **fading margin of 12 dB** is used.

4.3.2 Usage channel margin

Various usage channels with various channel codes are used. This means that different level requirements also apply. These differences were determined using measurement trials (see 5.1.3). The values are listed in Section 2.2.3.

4.4 ETCS link budget

Downlink ETCS	Quasi-Omni		
BTS Power	45.0 dBm		
Dämpfung Combiner	2.5 dB		
Dämpfung Kabel	3.0 dB		
Pegel Antennenfusspunkt	39.5 dBm		
Gewinn Antennensystem	10.0 dBd		NISV < 250W
Abgestrahlte Leistung ERP	49.5 dBm		178
Pathloss (95%)		142.5 dB	
Empfangsfeldstärke (50%)	49.0 dBuV/m		
Fading Marge (50% => 95%)	10.0 dB		
Empfangsfeldstärke (95%)	39.0 dBuV/m		
Gewinn Antenne Lok	-5 dBd		
K Faktor Antenne (Dipol)	30.0 dB		
Pegel Antennenfusspunkt	-103.0 dBm		
Dämpfung Kabel	3.0 dB		
Pegel Empfängereingang MS	-106.0 dBm		
Marge Nutzkanal TCH/F4.8	2.0 dB		
Empfindlichkeit MS	-104.0 dBm		

Uplink ETCS		
MS Power	39.0 dBm	
Dämpfung Kabel	3.0 dBm	
Pegel Antennenfusspunkt	36.0 dBm	
Gewinn Antenne Lok	-5.0 dBd	
Abgestrahlte Leistung ERP	31.0 dBm	
Pathloss (95%)		144.0 dB
Empfangsfeldstärke (50%)	27.0 dBuV/m	
Fading Marge (50% => 95%)	10.0 dB	
Empfangsfeldstärke (95%)	17.0 dBuV/m	
Gewinn Antennensystem	12.0 dBd	
K Faktor Antenne (Dipol)	30.0 dB	
Pegel Antennenfusspunkt	-108.0 dBm	
Dämpfung Kabel	3.0 dB	
Gewinn Diversity	3.0 dB	
Pegel Empfängereingang BTS	-108.0 dBm	
Marge Nutzkanal TCH/F4.8	2.0 dB	
Empfindlichkeit BTS	-106.0 dBm	

Pathloss DL - UL	**-1.5 dB**

4.5 Link budget, mobile phone, covered

Downlink Handy covered	Quasi-Omni		
BTS Power	45.0 dBm		
Dämpfung Combiner	2.5 dB		
Dämpfung Kabel	3.0 dB		
Pegel Antennenfusspunkt	39.5 dBm		
Gewinn Antennensystem	10.0 dBd		*NISV < 250W*
Abgestrahlte Leistung ERP	49.5 dBm		178
Pathloss (95%)		121.5 dB	
Empfangsfeldstärke (50%)	65.0 dBuV/m		
Fading Marge (50% => 95%)	10.0 dB		
Empfangsfeldstärke (95%)	55.0 dBuV/m		
Gewinn Antenne Handy	0 dBd		
K Faktor Antenne (Dipol)	30.0 dB		
Pegel Antennenfusspunkt 1)	-82.0 dBm		
Dämpfung Body Loss	22.0 dB		
Pegel Empfängereingang MS	-104.0 dBm		
Marge Nutzkanal TCH/F4.8	0.0 dB		
Empfindlichkeit MS	-104.0 dBm		

Uplink Handy covered		
MS Power	33.0 dBm	
Dämpfung Body Loss	22.0 dBm	
Pegel Antennenfusspunkt 1)	11.0 dBm	
Gewinn Antenne Handy	0.0 dBd	
Abgestrahlte Leistung ERP	11.0 dBm	
Pathloss (95%)		117.0 dB
Empfangsfeldstärke (50%)	29.0 dBuV/m	
Fading Marge (50% => 95%)	10.0 dB	
Empfangsfeldstärke (95%)	19.0 dBuV/m	
Gewinn Antennensystem	12.0 dBd	
K Faktor Antenne (Dipol)	30.0 dB	
Pegel Antennenfusspunkt	-106.0 dBm	
Dämpfung Kabel	3.0 dB	
Gewinn Diversity	3.0 dB	
Pegel Empfängereingang BTS	-106.0 dBm	
Marge Nutzkanal TCH/FS	0.0 dB	
Empfindlichkeit BTS	-106.0 dBm	

1) virtuelle Antenne auf 4 Meter Höhe

Pathloss DL - UL	**4.5 dB**

Abgestrahlte Leistung ERP	Radiated power ERP
BTS Power	BTS power
Dämpfung Combiner	Damping of combiner
Dämpfung Kabel	Damping of cable
Empfangsfeldstärke	Reception field strength
Empfindlichkeit BTS	Sensitivity of BTS
Empfindlichkeit MS	Sensitivity of MS
Fading Marge	Fading margin
Gewinn Antenna Lok	Gain of locomotive antenna
Gewinn Antennensystem	Gain of antenna system
Gewinn Diversity	Diversity gain
K Faktor Antenne (Dipol)	Antenna K factor (dipole)
Marge Nutzkanal TCH/F4.8	Usage margin channel TCH/F4.8
MS Power	MS power
Pathloss	Path loss
Pegel Antennenfusspunkt	Antenna base point level
Pegel Empfängereingang BTS	Receiver input level, BTS
Pegel Empfängereingang MS	Receiver input level, MS
1) Virtuelle Antenne auf 4 m Höhe	1) Virtual antenna at a height of 4 m

5 Principles of planning guidelines

5.1 Field strength / reception level

The following variables have been defined for the conversion of level values into field strength values:

- dBµV → dBµV/m = **30** **dB** (900 MHz)
- dBm → dBµV = **107** **dB** (Z_0 = 50 Ohm)
- Measurement antenna gain, MEWA = **0** **dBd** (2 dBi)
- Cable damping, MEWA = **3** **dB**

Example for the calculation of the field strength:

Measured level at the measurement receiver (MEWA) = **-80 dBm**

Field strength FS = -80 [dBm] + 107[dB] + 30 [dB] + 3[dB] = **60 dBµV/m**

5.2 Interference gap

The interference gaps specified in the rec. GSM 05.05 (reference interference level), must be adhered to at a length interval (observation interval) of 20 metres in 95% of all cases (see 2.1.1):

C/Ic	=	9 dB	(cochannel interference)
C/Ia1	=	-9 dB	(adjacent (200 kHz) interference)
C/Ia2	=	-41 dB	(adjacent (400 kHz) interference)
C/Ia3	=	-49 dB	(adjacent (600 kHz) interference)

If the interference gaps are determined using median values, the fading margin should be taken into account (see 7.2.2).

Furthermore, based upon experience in public networks a tolerance and system reserve of 3dB should be included.

Example for C/I value for median values

- Reserve = 3dB
- Fading margin = 12dB => C/Ic (median) = 26dB (see 7.2.2)

C/Ic (median + reserve) = 26dB + 3dB = 29dB

5.3 Multipath propagation

The following specifications apply in multipath reception:

- Within 15 µs the level differences of the different reception paths are irrelevant.
- All reception paths with a running time difference higher than 15 µs in relation to the main path are interference. These must adhere to the guidelines for the interference gaps (see 3.2).

5.4 Handover

The handover range in which both cells are received is dependent upon the speed of travel. The mobile station must be able to receive both cells for approx. 8 seconds without interference (Section 2.1.1). This yields the following handover ranges:

Speed of travel	Handover range
40 km/h	90 metres
80 km/h	180 metres
120 km/h	270 metres
160 km/h	360 metres
200 km/h	450 metres
250 km/h	560 metres

The 8 seconds for reception with no interference is obtained from the sum of the following two factors:

- Recognition of the adjacent cell
  If the mobile station moves in the provision zone of the new cell, it recognises the new cell. The mobile station requires on average 4 seconds to recognise the new cell. This time was verified with the aid of practical experiments (Section 5.1.4)
  If this cell is recognised (BCCH, BSIC and level), BSC is notified of this information (measurement report).

- Averaging time for measured values
  The measured values (BCCH, BSIC and level) are transmitted by the mobile station of the BTS or the BSC. The interval in which these measured values are transmitted is 1 SACCH period (480ms). The averaging time or decision time for a handover should be defined in the BSC.

  The following assumptions have been made:
  The averaging time in which the adjacent cell and the serving cell must be measured is defined as 8 SACCH periods (8 x 480 ms = **3.84 seconds**).

Tunnels
In tunnels the transition from the outer to the inner zone must always be carefully planned. In shorter tunnels the outer cells can be carried through the tunnel. If the outer cells used are not the same at both ends of the tunnel, a suitable level profile must be used to ensure that the cell changeover takes place inside the tunnel to prevent departure from the tunnel on the wrong cell.

In the case of longer tunnels with their own cell, the outer cells must be carried into the tunnel for the length of the overlap zone. Only thus is a reliable changeover from outer to inner cell upon entry possible. The inner cell must be designed such that it is possible to switch to the outer cell in good time upon departure from the tunnel. In the case of tunnels with several tubes and various inner cells (e.g. NEAT) a common outer cell must carried into the tubes. The tubes must be negotiable in any direction.

The overlap zones can only be optimised for one reception antenna type. If, for example, the overlap zone is dimensioned for operation in the inside of the wagon, it is much too long for receivers with an external antenna, which means that the changeover to the outer cell upon departure from the tunnel takes place too late. The overlap zones must therefore be optimised for the critical service: failures for other services cannot be avoided.

6 Overview of minimum field strength

All field strengths [dBuV/m] are quoted as a median value!

GSM Voice and data								
	Minimum field strength [dBuV/m] (median value)							
	Outdoor normal				Outdoor covered	Indoor 1)	In-train	
	TCH/FS	TCH/F2.4	TCH/F4.8	TCH/F9.6	TCH/FS	TCH/FS	TCH/FS	TCH/F4.8
ETCS level 2		47	49	52				
Train radio	60					50	77	
Shunting radio	60				65	50	77	
Service radio	60					50	77	
Emergency call	60		58				77	75
Train data transmission			49					
Remote control in service areas: regulation => line			49					
Remote control in service areas: regulation => junctions			58					
Remote control in service areas: telemetry => line			49					
Remote control in service areas: telemetry => junctions			58					

TCH Traffic Channel
TCH/FS A full rate speech TCH
TCH/F2.4 A full rate data TCH (≤2.4kbit/s)
TCH/F4.8 A full rate date TCH (4.8kbit/s)
TCH/F9.6 A full rate data TCH (9.6kbit/s)

Mobile phone BTS Power = 42 dBm 2)
Mobile station, locomotive BTS Power = 45 dBm

1) FS Indoor
2) The quoted powers (BTS power) are selected such that the uplink and downlink are symmetrical for the MS classes in question. In radio network planning, wherever calculations are based upon BTS power = 45 dBm, minimum field strengths for mobile phones should be increased by 3 dB.

7 Annex

7.1 Measurements

7.1.1 Damping values

The receiving antenna of the SBB testing and recording car is located 4 metres above the ground. Since in several services the terminal device is used on the ground and is, at most, worn on the body, an appropriate supplement must be taken into account.
The different reception levels were recorded using a test mobile phone at several locations. The mobile phone was first fitted to a 4-metre mast, then carried loose and lastly worn on the body. For each carrying method a distance of approx. 10 metres was negotiated or walked, in order to reduce the influence of local fading gaps.

The differences between 4 metres and 1.5 metres reception height lie between 1 and 8 dB with an accumulation in the range 5 – 7 dB.

7.1.2 Fading margin

To estimate the fading margin, several trips were made between Thun and Berne with the SBB testing and recording car. Two transmitters were installed at the Allmend Uetendorf and at Allmendingen for this purpose, which transmitted a CW signal and a signal with **GSM modulation**. In the testing and recording car, the reception level was recorded and saved every 6 cm of the route. This raw data forms the basis for the calculation of the statistics for the reception level distribution.

In the evaluation, the raw measured values are grouped in route sections of 20m length. In each route section, the median value (50% local WSK) is calculated, along with the level that is exceeded by 95% of the readings. The worst case, i.e. the point with the greatest signal variations, is decisive for the evaluation of the fading margin.

In the analysis no differences were found between the measurements in the track area and those measurements of normal measurements (measurements with PW).

In the case of measurement with a CW signal a difference of up to 15 dB was measured.
In the case of measurement with a GSM signal a difference of up to 7 dB was measured.

Based upon practical experience and with the measurement results underlying these experience-based values, a **fading margin of 12 dB** is taken into account for the planning principles.

7.1.3 Data transmission

In order to record the differences in minimum reception level for the different data rates, measurements were performed with a SAGEM OT-96 test mobile phone. In

these measurements only the transparent transmission mode was used because in the non-transmission mode (with RLP) there were no bit errors, but extended transmission times did occur, which are more difficult to record from a measurement point of view. For time-critical applications (e.g. ETCS) the transparent mode is used anyway.
The table lists the minimum necessary reception levels as a function of various BER limit values:

	9600 bits/sec	4800 bits/sec	2400 bits/sec
BER < 0.01	-104 dBm	-106 dBm	-109 dBm
BER < 0.001	-101 dBm	-104 dBm	-106 dBm
BER < 0.0001	-98 dBm	-101 dBm	-103 dBm

The minimum level for a voice connection with RXQUAL less than 4 is 102 dBm with the same test mobile phone.
These absolute sensitivity values depend upon the terminal device used. Only the differences between the different services are relevant for the planning guidelines. The following sensitivity gain can be expected in relation to a voice connection (Base BER < 0.001, RXQUAL < 4):

9600 bits/sec:	-1 dB
4800 bits/sec:	+ 2 dB
2400 bits/sec:	+ 4 dB

7.1.4 Adjacent cell measurement for handover

The time for the recognition of the new adjacent cell is determined by measurement. The average time for the mobile station to recognise the new adjacent cell and send the measured values to BSC by means of the measurement report was **4 seconds**. Four different Sagem test mobiles were used for this trial:

- OT 55 R — GSM rail device
- OT 75 M — GSM dual band device
- OT 95 M — GSM dual band device
- OT 96 M GPRS — GSM / GPRS dual band device

The signal of the new adjacent cell was generated with a mobile tester (CTS55 Rohde & Schwarz) and switched on and off by means of a HF switch.

7.2 Simulations

For the analysis of diversity gain and interference situations a simulation program was created that simulates the summation of useful and interference signals with different statistical parameters.

7.2.1 Diversity gain

Diversity is used to reduce the influence of fading gaps. In the simulations two statistically independent signals with a log normal distribution and a dispersion of 5 dB were assumed. There are different procedures for combining these signals:
Simple summation without phase compensation:
The two signals are added via a power divider. In addition to the 3 dB damping of the divider the summed signal can be further reduced if the two partial signals cancel each other out.

Maximum:
The stronger of the two signals is always selected.

Summation with phase compensation:
The two signals are added by means of a power divider. The phases of the partial signals are adjusted to the maximum output signal before the summation using variable phase shifters. A loss of 3 dB again arises here in the power divider. The additional damping of the phase shifters was not taken into account in the simulation.

The diversity gain for the various summation procedures and for several amplitude ratios is compiled in the following table. The difference between the 95% local WSK level with and without diversity is termed the diversity gain here. The two signals have a log-normal distribution and a dispersion of 6 dB.

Level difference	Summation procedure		
	Summation without phase compensation	Maximum	Summation with phase compensation
0 dB	-0.8 dB	+ 5.4 dB	+ 6.7 dB
3 dB	-2.0 dB	+ 4.0 dB	+ 5.4 dB
6 dB	-3.0 dB	+ 2.9 dB	+ 4.0 dB
10 dB	-3.2 dB	+ 1.6 dB	+ 2.5 dB

It is assumed that in practise the level differences are reliably greater than 3 dB. Based upon this assumption and the available simulation results for the different summation procedures a **diversity gain of 3 dB** is assumed.

7.2.2 Interference gap

The GSM system requires a minimum signal-to-interference gap of 9 dB. This value must be attained in 95% of cases. For the conversion to the signal-to-interference ratio of the median values (planning value) a statistical distribution of the signal amplitudes must be assumed.
Under the prerequisite of a log-normal distribution for both the useful and the interference signal, the following amplitude ratios of the median values are necessary to ensure that the C/I is greater than 9 dB in 95% of cases.

Fading margin	Ratio of the median values
12 dB	26 dB
11 dB	24 dB
10 dB	23 dB
9 dB	22 dB
8 dB	20 dB
7 dB	19 dB
6 dB	17 dB
5 dB	16 dB

The fading margin describes the difference between the median value of the reception level and the level that is exceeded by 95% of the measured values in the monitoring interval.

If a Rayleigh distribution is a precondition, the minimum ratio of the median values is 22 dB.

7.3 Abbreviations

BCCH	Broadcast Control Channel
BER	Bit Error Rate
BSIC	Base Station Identity Code
BTS	Base Transceiver Station
C/Ia1	Adjacent (200 kHz) interference
C/Ia2	Adjacent (400 kHz) interference
C/ia3	Adjacent (600 kHz) interference
C/Ic	Cochannel interference
CS1	Coding schemes 1 (GPRS)
CS2	Coding schemes 2 (GPRS)
EIRP	Effective Isotropic Radiated Power
ETCS	European Train Control System
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
GSM-R	GSM – Rail
MS	Mobile Station
RLP	Radio Link Protocol
SACCH	Slow associated control channel
TCH	Traffic Channel
TCH/F2,4	A full rate data TCH (≤2.4kbit/s)
TCH/F4,8	A full rate date TCH (4.8kbit/s)
TCH/F9,6	A full rate data TCH (9.6kbit/s)
TCH/FS	A full rate speech TCH

7.4 References

GSM 05.05	Radio transmission and reception	ETSI TS 100 910
GSM 05.08	Radio subsystem link control	ETSI TS 100 911
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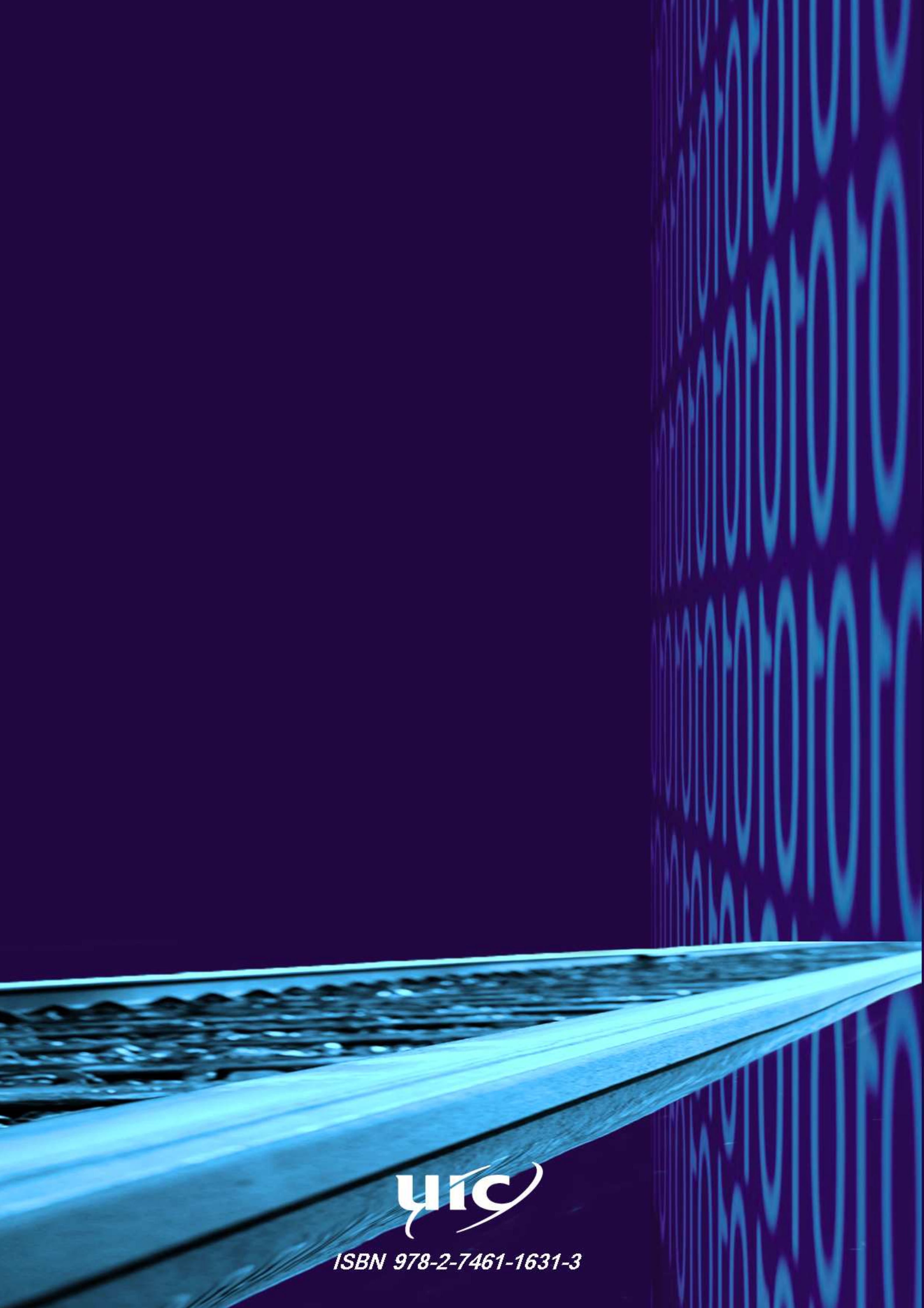

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