



ECC Report **294**

Assessment of the spectrum needs for future railway communications

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0 EXECUTIVE SUMMARY

The purpose of this ECC Report is to assess the spectrum needs for the successor to GSM-R. Essential input documents to this Report are “FRMCS Traffic Analysis” [10] and ETSI TR 103 554 “LTE radio performance simulations and evaluations in rail environment” [11]. The estimation of the throughput needed and of the spectrum needs for the successor to GSM-R are to a major extent based on the findings of these documents. These early considerations may need to be refined when results of proposals and studies from ETSI and ECC become available. Detailed frequency band options and harmonised technical conditions will be described in future ECC deliverables.

0.1 ABOUT THE NEED FOR PARALLEL OPERATION OF GSM-R AND ITS SUCCESSOR

Railway interoperability, i.e. ability for trains and staff to operate uninterruptedly across borders and railway networks, must be ensured. Requirements related to interoperability are legally binding in Europe since they are part of the Control-Command and Signalling Technical Specification for Interoperability (CCS TSI), which is published in the European Regulation 2016/919/EU [4].

The principles laid down in that CCS TSI do not allow actions such as a mandatory retrofit of cab-radios (unless specific rules are agreed). In addition, an overnight switchover would not leave the possibility to perform the necessary field tests to check whether the railway requirements are met.

Therefore, GSM-R and its successor will have to operate in parallel for a period of time. For these reasons, there is a need of additional spectrum at least during the migration period. This additional spectrum will also be required to cover railway’s long-term needs after the migration period in combination with the 2x4 MHz currently harmonised for GSM-R. The overall migration throughout Europe is expected to take place between 2022 and 2035.

0.2 ABOUT SPECIFIC RAILWAY REQUIREMENTS

Interruption of radiocommunication can have an impact on railway operation and/or safety. A continuous availability of and accessibility to the railway radio network is required in order to transmit and receive a Railway Emergency Call everywhere along the rail tracks. Further, a persistent interruption of radio communication in the context of ETCS Level 2 and beyond will simply lead to the stopping of trains causing consecutive delays in the public transport system.

Historically, GSM-R networks have been designed and validated against formal and stringent availability and reliability requirements such as 95% probability coverage in time and space over any track section of 100m. At the time of writing, the availability and reliability requirements for the successor to GSM-R are not yet specified, but equivalent criteria are anticipated, provided that the technical principles and the safety approach of ETCS are not changed.

0.3 ABOUT SPECTRUM NEEDS

Railways currently use the 876-880 MHz / 921-925 MHz band as the harmonised spectrum for GSM-R at CEPT and EU levels. The band 873-876 MHz / 918-921 MHz is not harmonised for GSM-R within CEPT, but it is used for GSM-R on a national basis by some CEPT countries. Existing GSM-R is an application within the primary mobile service and needs to be protected. In addition, as specified in Article 3 of Commission Implementing Decision 2018/1538 [15], EU Member States shall refrain from introducing new uses in the 874.4-876 MHz and 919.4-921 MHz sub-bands until such time as harmonised conditions for their use are adopted under Decision 676/2002/EC [16].

Noting that having the possibility to reuse as much as possible the current radio network infrastructure (sites) would save costs and reduce operational burden, the spectrum in 874.4-880 MHz / 919.4-925 MHz is the preferred band for a harmonised solution for the successor to GSM-R for the migration and beyond. This is

also recognised in the EC Mandate to CEPT on FRMCS [7]. This scenario includes use of 4G/5G as well as in-band¹ and/or adjacent channel arrangement of GSM-R and FRMCS in the whole 2x5.6 MHz.

In dense railway networks, border areas and high density areas, the capacity brought by adding 2x1.6 MHz of spectrum is not enough during the migration. The conclusion is that access to complementary spectrum, e.g. 10 MHz in 1900-1920 MHz, is a prerequisite for many countries in order to manage the migration with dual networks operating in parallel. The frequency band 1900-1920 MHz, or parts of it, is currently licensed to mobile operators in many CEPT countries. After the migration, the complementary band(s) will still be required in order to cover railway's long-term needs (including critical sensing/video), border and hotspot areas.

0.4 ABOUT SHARING

From a technical point of view, network sharing with MNO is possible for critical applications under the condition that the relevant parts of the MNO's network fulfils the stringent coverage and availability requirements of railways. However, current MNO processes do not cover safety-related and interoperability assurance which currently requires extensive certification.

Key questions remain unanswered so far: MNO agreement to take railway legal obligations and liabilities, MNO's willingness to assume the risk; how, in the legal contract, risk assessment would be dealt with.

MNO networks that do not fulfil these requirements could be used for low-train traffic lines with less stringent requirements and for non-critical railway communications.

In order to offer some flexibility beyond the spectrum harmonised for railway interoperability, a flexible approach would rely on the possibility to identify on a national basis how much additional spectrum in which frequency ranges and under which implementation model (sharing access, national licence model, etc.) could be granted.

Sharing with PPDR networks using dedicated spectrum is not an option applicable to all European countries because, noting the various solutions implemented at national level, no harmonised approach exists for PPDR networks in Europe. Furthermore, it would require sufficient spectrum resources for both PPDR and railway users as well as a clear assignment of priorities and of legal and criminal liabilities.

Geographical spectrum sharing with PMR/PAMR could be envisaged when limited to certain areas, like in stations, shunting yards or depots. Network sharing with PMR/PAMR can also be of interest to obtain complementary traffic capacities.

¹ as for NB-IoT

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ARPU	Average Revenue per User
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
BCCH	Broadcast Control Channel
CCS	Control-Command and Signalling
CEPT	European Conference of Postal and Telecommunications Administrations
EC	European Commission
ECC	Electronic Communications Committee
EDOR	ETCS Data Only Radio
EDP	European Deployment Plan
EIRENE	European Integrated Railway Radio Enhanced Network
ERA	European Union Agency for Railways
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETSI	European Telecommunications Standardisation Institute
EU	European Union
FRMCS	Future Railway Mobile Communication System
FRS	Functional Requirements Specification
GBR	Guaranteed Bit Rate
GNSS	Global Navigation Satellite System
GoA	Grade of Automation (4 levels)
GSM	Global System for Mobile communications
GSM-R	GSM for Railway
IAS	Internet Access Service
IC	Interoperability Constituent
IM	Infrastructure Manager
IMS	IP Multimedia Subsystem
KPI	Key Performance Indicator
LAS	Link Assurance Signal
MA	Movement Authority

Abbreviation	Explanation
MFCN	Mobile/Fixed Communications Networks
MI	Mandatory for Interoperability
MIMO	Multiple Input – Multiple Output
MNO	public Mobile Network Operator
MVNO	Mobile Virtual Network Operator
NSA	National Safety Authority
PAMR	Public Access Mobile Radio
PCC	Policy and Charging Control
PMR	Private Mobile Radio
PPDR	Public Protection and Disaster Relief
QoS	Quality of Service
RAN	Radio Access Network
RBC	Radio Block Centre
REC	Railway Emergency Call
RED	Radio Equipment Directive
RFC	Rail Freight Corridors
R-GSM	Railways GSM (876-915 MHz / 921-960 MHz as defined by ETSI)
RU	Railway Undertaking
RxQual	Reception Quality
SLA	Service Level Agreement
SpS	Specialised Service
SRS	System Requirements Specification
TC RT	Technical Committee for Rail Telecommunications (ETSI)
TCH	Traffic Channel
TRX	Transceiver
TS	Time Slot
TSI	Technical Specification for Interoperability
UIC	Union Internationale des Chemins de fer
UNISIG	Union Industry of Signalling
URCA	Unified Railway Communication and Applications

1 INTRODUCTION

The aim of this ECC Report is to assess the spectrum needs for the successor to GSM-R.

To do so, the Report sets out the following points:

- why there is a need for parallel operation of GSM-R and its successor for a period of time;
- what the specific railway requirements are;
- what the railway traffic demand is;
- what amount of spectrum is required for critical applications;
- what the possibilities are to share spectrum and/or network with MNO, PPDR or PMR/PAMR.

2 RAIL SPECIFICITIES

2.1 DEFINITIONS

Term	Definition
ATO (Automatic Train Operation)	Functions otherwise assigned to the train driver
ATP (Automatic Train Protection)	System that ensures automatic compliance with railway signalling
ERTMS (European Rail Traffic Management System)	European railway system, including trackside and on-board control-command and signalling subsystem as well as operation and traffic management, relying on a common radio access technology (today GSM-R) and ETCS
ETCS (European Train Control System)	Applicative protocol for railway signalling and train protection to enable railway interoperability at European level
GSM-R (GSM for Railway)	Current radiocommunication network for railways, which provides voice services (including emergency voice calls) and carries ETCS and other data services
Infrastructure Manager	The entity who administrates the rail track network and the associated radio access network (today GSM-R)
M (Mandatory)	Designates mandatory requirements to allow that the technical characteristics of the network and fixed terminals are compatible with each other and with terminals on-board the trains or handheld
MI (Mandatory for Interoperability)	Designates mandatory requirements on lines under the scope of the Interoperability Directive [1] to ensure technical compatibility between Member States and safe integration between train and track
Movement authority	Information about where the train is allowed to safely move
Railway interoperability	Ability for trains and staff to operate uninterruptedly across borders and railway networks (requirement defined in the EU Directive 2016/797 [1], supplemented by Commission Delegated Decision (EU) 2017/1474 [17], formerly EC Directive 2008/57)
Railway signalling	Speed limits and movement authorities (provided by trackside signals, balises or wireless communications)
Railway Undertaking	A company which operates trains and thus uses the radio access network (today GSM-R) provided by the Infrastructure Manager
RBC (Radio Block Centre)	A centralised safety unit that receives train position information via radio and sends movement authorities via radio to trains

2.2 INTEROPERABILITY

Parts of this section are extracted from the Railway Interoperability Directive 2016/797/EU [1], formerly Directive 2008/57/EC [2], and the associated Commission Regulation 2016/919/EU [4] (CCS TSI), as well as EIRENE specifications [5],[6].

2.2.1 Principle and Directive

Today, the competitiveness of the railways is curbed by the differences between EU Member States in terms of rolling stock, technology, signalling systems, safety regulations, braking systems, traction currents and speed limits. This state of affairs forces international trains crossing several States to stop at frontiers.

Historically, these technical differences met the need to protect Member States' own interests or those of their rail industry. At the same time, the road transport industry took advantage of its freedom from technical barriers to reinforce its position on the market.

Railway transport occupies a core position in Europe's overall transport sector, and the interoperability of the rail system within the European Union is the cornerstone of the establishment of a single European railway area. The concept of one single signalling system at EU level, to enhance interoperability, dates back to 1989, when the Commission launched an analysis of signalling issues across the EU Member States. The first legislative acts serving that objective were issued in 1996 with the so-called Interoperability Directive related to trans-European high-speed trains and in 2001 with another Interoperability Directive, this time related to trans-European conventional rail system.

The interoperability of the European railway system is ensured today by the Railway Interoperability Directive [1] and the Technical Specifications for Interoperability (CCS TSI) [4] which provide the regulatory framework.

In the Directive 2016/797/EU [1] on the interoperability of the railway system within the Community, the definition of railway interoperability can be found in its Article 2:

'interoperability' means the ability of a rail system to allow the safe and uninterrupted movement of trains which accomplish the required levels of performance;

The technical details required for railway interoperability are included in the Technical Specifications for Interoperability (CCS TSI [4]). The definition, also in Article 2 of the Interoperability Directive 2016/797/EU, explains its content:

'technical specification for interoperability' (TSI) means a specification adopted in accordance with this Directive by which each subsystem or part of a subsystem is covered in order to meet the essential requirements and ensure the interoperability of the Union rail system;

The so called "essential requirements" are defined in Article 2 of the Interoperability Directive:

'essential requirements' means all the conditions set out in Annex III which must be met by the rail system, the subsystems, and the interoperability constituents, including interfaces;

Together with the "basic parameters":

'basic parameters' means any regulatory, technical or operational condition which is critical to interoperability and is specified in the relevant TSIs;

As a concrete example, consider the requirements set up for the radio communication system to be used by railways. In the Control-Command and Signalling (CCS) TSI (Regulation 2016/919/EU [4]), there are two subsystems described: the trackside subsystem and the on-board subsystem. Both of them have elements related to radio communication.

The features of the subsystems, contained in the CCS TSI, are:

- the functions that are essential for the safe control of railway traffic, and that are essential for its operation, including those required for degraded modes;
- the interfaces;
- the level of performance required to meet the essential requirements.

The CCS TSI specifies only those requirements which are necessary to assure the interoperability of the trans-European rail system and compliance with the essential requirements.

2.2.2 Application to technology

The radiocommunication system to be used is currently GSM-R. This is stated in the basic parameters included in the CCS TSI, section 4. The air interface is also characterised and it is specifically specified that the interfaces shall operate in the R-GSM band (see table 3-A in 3.5.1 of the EIRENE SRS [6]).

EIRENE specifies the requirements for a digital radio standard for the European railways, although it is also applicable worldwide. It consists of FRS (Functional Requirements Specification) [5] and SRS (System Requirements Specification) [6]. EIRENE has a direct link with the relevant ETSI specifications, which cover the technical details of the GSM radio technology used.

One of the main objectives of EIRENE FRS and SRS is to ensure interoperability for trains and staff crossing national borders or other borders between systems. It defines the requirements and conditions for the provision of harmonised functionality along the railway lines.

The requirements in EIRENE FRS and SRS which are classified as (MI) are mandated by the CCS TSI.

Some of the requirements in the EIRENE specifications, related to interoperability, are legally binding in Europe since they are part of the Control-Command and Signalling Technical Specification for Interoperability (CCS TSI), which is published in the Commission Regulation 2016/919/EU [4].

It is mandatory that each railway subsystem (train and infrastructure) in the European Union meets these requirements on lines under the scope of the Railway Interoperability Directive [1], it is to ensure technical compatibility between Member States and safe integration between train and track. Radio related requirements on spectrum, coverage and signal strength are amongst these ones.

The word "interoperability" is used in different sectors with a sense that may not always be the same. In the railway environment, the focus is placed on the fact that trains should be able to run uninterruptedly across railway networks and without the need to modify their configuration, so no technical barrier is found by them when travelling between two locations.

2.2.3 Application to migration timeframe

The application of the Control-Command and Signalling Technical Specification for Interoperability does not have retroactive effect. In general, new TSIs are developed ensuring the compatibility with the existing authorised systems, to avoid the requirement of upgrading them, as per the "*Whereas (16)*" of the Interoperability Directive [1]. **This discards in general actions such as a mandatory retrofit of cab-radios** (unless specific rules are agreed).

Infrastructure Managers will still be rolling out and operating GSM-R networks as the successor to GSM-R is introduced; thus both technologies will have to operate in parallel as Infrastructure Managers move from GSM-R to the new technology. Migration will require implementation on both infrastructure (network) and on rolling stock.

Each Infrastructure Manager adopts its own strategy for trackside migration, e.g. line by line, area per area. Where an area of a country or a specific line has migrated to the successor to GSM-R, there may still be a requirement to operate in parallel both systems to welcome trains coming from areas where the migration has not yet occurred. Until all trains (even foreign ones) that are entitled to run on the line are ready to use the new system, the Infrastructure Manager cannot stop the operation of GSM-R. Therefore, it is difficult to predict when the migration ends.

Until now, GSM-R is the only radio access technology allowed as per Regulation 2016/919/EU [4]. This will change when a new CCS TSI will be published with provisions for the successor to GSM-R. There is an opportunity to have FRMCS included in the CCS TSI in 2022.

With regard to the successor to GSM-R, the required level of interoperability has to be realised on multiple layers including the following items:

- cross-border sections (including border crossing points) have to be implemented;

- multiple-band and multiple-radio user equipment (UE) for track-to-train and train-to-train radio communication have to be implemented;
- adoption of common technical standards (i.e. LTE/5G);
- certification aspects;
- interoperability specifications (i.e. TSI).

The railway community has stated that FRMCS should be part of the global 3GPP LTE/5G ecosystem from a technical standard point of view. This presents several advantages including for example, a wider choice of terminals, potentially lower costs for chipsets and duplex filters, benefits derived from economies of scale achieved in commercial networks and the commitment to develop mission-critical capabilities into the standard. Other benefits include possible roaming² over commercial networks and long-term developments within 3GPP. The work on developing LTE/5G technologies to support the FRMCS specific functionalities has already started in 3GPP, ETSI and other international organisations. It is expected to take several years before those functions, which the railway community has identified as key features, are fully specified, implemented, tested and integrated into the LTE/5G solutions from most infrastructure and terminal suppliers. In this respect, the railway community is taking advantage of the ongoing standardisation work related to PPDR mission-critical functionalities.

2.3 ACCESS TO THE RAIL NETWORK

The Network Statement is a description of the railway network and it contains the information for the charges and fees for the services available in the network. It is defined in the Directive 2012/34/EU (Access Directive) [14] as follows:

'network statement' means the statement which sets out in detail the general rules, deadlines, procedures and criteria for charging and capacity-allocation schemes, including such other information as is required to enable applications for infrastructure capacity;

The network statement shall set out the nature of the infrastructure which is available to railway undertakings, and contain information setting out the conditions for access to the relevant railway infrastructure. The network statement shall also contain information setting out the conditions for access to service facilities connected to the network of the infrastructure manager and for supply of services in these facilities or indicate a website where such information is made available free of charge in electronic format. The content of the network statement is laid down in Annex IV.

No legal requirement is set in the Network Statement. Exclusions can be derived from the description of the infrastructure: e.g. if a vehicle is electrified and not hybrid, it will be able to run on the lines that are electrified; if there is a bridge with supports a maximum load, only vehicles under that load will be able to run; etc.

The Network Statement can mainly be seen as a tool to provide the information on track charges and fees. It shall include the way how coordination amongst requests for a path should be handled (priorities, etc.).

Member States shall ensure that the network statement contains the charging framework and charging rules or indicates a website where the charging framework and charging rules are published.

The principles governing the coordination process shall be set out in the network statement. These shall, in particular, reflect the difficulty of arranging international train paths and the effect that modification may have on other infrastructure managers.

Note: It could be indicated that a specific type of train has priority/incentives for allocation of a slot compared to another one (e.g. train equipped with FRMCS). For example, it is agreed that trains with ETCS installed will have a "deduction" in the fees.

² Roaming = FRMCS radio terminal equipment can obtain mobile communication services under coverage of another radio communication network (the "visited network").

The infrastructure charges for the use of railway corridors which are specified in Commission Decision 2009/561/EC shall be differentiated to give incentives to equip trains with the ETCS compliant with the version adopted by the Commission Decision 2008/386/EC and successive versions. Such differentiation shall not result in any overall change in revenue for the infrastructure manager.

For detailed information on the content the Network Statement shall contain, please refer to Annex IV of the Access Directive [14].

Usage of the Network Statement for the migration

As can be seen from the previous definitions, the information in the Network Statement is only providing information related to the Infrastructure Manager. No information coming from the Railway Undertakings is described.

As no legal requirement is described in the Network Statement, it could not be used to mandate nor to schedule a retrofit of the cab-radios.

However, it could be considered that an incentive is given to the trains that have a specific fitting (i.e. that have FRMCS) by lowering the fee compared to trains only equipped with GSM-R.

The CCS TSI might define deadlines for announcement of the decommissioning of GSM-R. In this case, the scheduling of retrofit for the trains running on the areas affected will have to be done taking into account that information. The Network Statement may refer to such an announcement (for information) since it may affect the fees and coordination between requests, but the announcement cannot be done directly in the Network Statement.

Note: The CCS TSI does not refer to the Network Statement, which is a further evidence that legal requirements and information on the Infrastructure Manager network are decoupled.

2.4 LEGAL FRAMEWORK

Before a vehicle can run on a railway infrastructure, there are a number of steps that have to be completed, which include the verification of the technical characteristics required in the different legal texts, in the standards and a number of processes that have to be followed in order to ensure the safe integration of the elements in the vehicle and of the vehicle with the infrastructure it will run in.

These processes for placing on the market and placing in service of the vehicles are regulated in the corresponding Directives. The time and resources required to fulfil these processes, together with the logistic restrictions of modifying the fleets that are already in service, cannot be neglected, as they impose some restrictions to the rhythm of the adoption of modifications in the vehicles.

2.4.1 Train authorisation framework

The Interoperability Directive (2016/797/EU [1]) will be applicable in each EU Member State after its transposition, and will derogate the former Interoperability Directive 2008/57/EU [2] in June 2020) describes the steps required in order to get the authorisation for placing in service of the railway subsystems.

In the Control-Command and Signalling TSI (Regulation 2016/919/EU [4]), there are two subsystems described: the trackside subsystem and the on-board subsystem. Both of them have elements related to radio communication.

Each Member State shall authorise the placing in service of the subsystems to operate in its territory.

In order to grant the above mentioned authorisation, the National Safety Authority (NSA) considers the EC declaration of verification (based on a certificate issued by a Notified Body) that is included in the application

for the authorisation; the documents in this application ensure the compliance with the corresponding TSI, the integration with the infrastructure and the compliance with additional national rules (if applicable).

When a train (on-board subsystem) has been authorised and it is modified, the Member State shall receive a description of the modifications performed (Article 20 of the Interoperability Directive). The Member State shall examine this file and, taking account of the implementation strategy indicated in the applicable TSI, shall decide whether the extent of the works means that a new authorisation for placing in service is needed.

Such new authorisation for placing in service shall be required whenever the overall safety level of the subsystem concerned may be adversely affected by the works described. If a new authorisation is needed, the Member State shall decide to what extent the TSI needs to be applied to the project.

This decision has to be taken no later than four months after the submission of the complete file to the NSA.

When a modification to a subsystem is performed, the Notified Body that has issued an EC certificate of verification for the subsystem has to be also contacted, and an assessment has to be done by it in order to either reissue a certificate containing the modification or to issue a new certificate if the changes are considered as significant.

A similar exercise is required for the defined Interoperability Constituents (ICs) (for the on-board subsystem: cab-radio, EDOR). When an IC is going to be placed on the market, it requires a prior "conformity or suitability for use". The Member States shall consider that an IC meets the essential requirements laid in a TSI based on the corresponding certificate, issued by a Notified Body or the entity indicated in the corresponding TSI. When the IC is also subject to other regulation (such as the Radio Equipment Directive), the certificate issued shall contain the compliance with the requirements set in other regulations or Directives.

When an IC already placed on the market is modified, this modification has to be communicated to the assessment body (Notified Body or the entity indicated in the TSI), who will consider if the change is significant and if there is a need to issue a new certificate or to reissue the existing one, containing the modification.

These processes (certification, authorisation) are laid down in the Interoperability Directive [1], but there is no indication on the timescale of some of them. For the authorisation of placing in service of vehicles, the times are described in Art 21.4 onwards in the Interoperability Directive 2016/797/EU [1] (Art 23.7 in 2008/57/EC [2]).

As a consequence, changes in the railway and GSM-R environments must follow a stringent process which can take time.

2.4.2 Radio Equipment Directive (RED)

GSM-R equipment falls under the scope of the Radio Equipment Directive (RED) 2014/53/EU [3]. Under the RED, providers/manufacturers of radio equipment have to provide a declaration of conformity that includes the information about the intended use and usage restrictions in relation to the radio equipment. The RED applies according to the "*Whereas (10)*" below:

(10) "In order to ensure that radio equipment uses the radio spectrum effectively and supports the efficient use of radio spectrum, radio equipment should be constructed so that: in the case of a transmitter, when the transmitter is properly installed, maintained and used for its intended purpose it generates radio waves emissions that do not create harmful interference, while unwanted radio waves emissions generated by the transmitter (e.g. in adjacent channels) with a potential negative impact on the goals of radio spectrum policy should be limited to such a level that, according to the state of the art, harmful interference is avoided; and, in the case of a receiver, it has a level of performance that allows it to operate as intended and protects it against the risk of harmful interference, in particular from shared or adjacent channels, and, in so doing, supports improvements in the efficient use of shared or adjacent channels."

As of 13 June 2016, in compliance with the RED, harmonised standards include receiver parameters.

Passive elements however, which could be placed separately on the market such as passive antennas or filters are *a priori* not considered as 'radio equipment' falling under the scope of the RED. These elements can make a declaration of conformity invalid, when they would lead to the creation of harmful interference or have a negative impact (not sufficient protection against harmful interference) on the spectrum usage.

In case of the addition of a passive filter (i.e. a filter containing exclusively passive components) in the GSM-R receiving chain, this has no impact on the conformity declaration under the RED [3].

These elements are also subject to the train authorisation framework, as described in section 2.4.1.

2.5 USAGE OF GSM-R FOR RAILWAY RADIOCOMMUNICATIONS

As per the Command-Control and Signalling Technical Specification for Interoperability, Regulation 2016/919/EU [4], GSM-R is the only radio access technology allowed. It supports the specific railway needs and consists of additional functions and amendments, and represents an enhancement of the commonly used GSM technology.

For the use of GSM-R, Commission Decision 1999/569/EC [8] and ECC Decision (02)05 [9] harmonises the frequency bands 876-880 MHz (train-to-ground) and 921-925 MHz (ground-to-train). The designation of a dedicated harmonised frequency band enabled the creation of pan-European radiocommunication network for both passenger and freight trains to travel across EU borders without the need to install any other national radiocommunication systems. This fulfils the requirement of the Interoperability Directive [1]. Furthermore, a dedicated frequency band is essential to ensure continuous reliable and available access to the network thus supporting critical, interoperable and safety-related applications.

This radio network is used to fulfil the operational requirements of railway communications, especially for voice and data communications both supporting safety related applications. These services are conventional voice services (driver-controller calls, railway emergency calls, group calls, etc.) and data services for ERTMS/ETCS signalling systems.

GSM-R networks have been rolled out within Europe but they are still growing and some countries are still in the rollout process. Current figures show that 139 859 km of network are planned or in progress, 96 124 km of lines are now in service with some 75 000 terminals integrated in the dashboard of the trains (cab-radios) within Europe³.

Today, GSM-R coupled with ETCS, as constituents of ERTMS, provides an interoperable railway signalling and communication system for all the European railway networks. The ERTMS European Deployment Plan (EDP) sets deadlines (2020-2030) for the implementation of ERTMS and its aim is to ensure the progressive deployment of ERTMS along the main European rail routes.

Regarding railway transport infrastructure, the requirement for full deployment of ERTMS (among others) was established. The deadline is 2030 for core network corridors and 2050 for the comprehensive railway line network.

The ERTMS Corridors, later extended in Rail Freight Corridors (RFC)⁴ are defined along the main European rail routes and playing a determinative role in Europe due to their geographical locations. Initially, six ERTMS Corridors, named A to F were defined. Table 1 shows the currently defined ERTMS Corridors:

³ Figures from a data collection performed in 2015

⁴ REGULATION (EU) No 913/2010 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 22 September 2010 concerning a European rail network for competitive freight

Table 1: ERTMS corridors

ERTMS Corridors	ERTMS Corridor description
Rhine-Alpine	Rotterdam/Amsterdam/Zeebrugge - Genova
Scandinavian- Mediterranean	Stockholm/Oslo - Napoli
North Sea-Mediterranean	Glasgow/Edinburgh/Amsterdam – Marseille Belfast – Cork
Mediterranean	Valencia/Sevilla - Budapest
Rhine-Danube	Mannheim/Strasbourg - Constanta Praha - Košice
North Sea-Baltic	Tallinn - Roosendaal
Baltic-Adriatic	Poznań/Gdańsk - Bologna/Koper
Atlantic	Porto/Lisboa/Algeiras – Le Havre/ Strasbourg/Mannheim
Orient/East-Med	Rostock/Hamburg/Bremen - Athens



Figure 1: ERTMS corridors

On 5 January 2017, the European Commission adopted an implementing regulation on the new ERTMS European Deployment Plan (EDP)⁵. It sets target dates until 2023 by which about 30-40% of the Core Network Corridors shall be equipped with ERTMS. In 2023, the ERTMS EDP will be updated again setting out the precise implementation dates for the remaining part of the Corridors between 2024 and 2030. This EDP constitutes a good reference to understand the commitment taken in each Member State to deploy ETCS over the different railway lines and the deadlines established.

2.6 AUTOMATIC TRAIN OPERATION & RAILWAY DIGITALISATION

It is expected that recent technological advances in the fields of e.g. sensing, machine learning, high-precision positioning and wireless communication technology will provide a unique opportunity to the rail

⁵ COMMISSION IMPLEMENTING REGULATION (EU) 2017/6 of 5 January 2017 on the European Rail Traffic Management System European deployment plan

sector to perform a technology leap towards substantially improved quality, capacity and efficiency in rail operation, for instance characterised by:

- automated real-time scheduling and dispatching of rail traffic with conflict resolution and optimisation;
- virtual coupling;
- ETCS L2/L3;
- automated train coupling, marshalling and shunting, and an increasing degree of automated driving in general (GoA3, GoA4);
- automated real-time situation and condition monitoring including evaluation;
- predictive maintenance.

ETCS implementation on main lines, requested by the EU, as well as the additional implementation of ETCS at national level are an essential step towards increased rail efficiency. For instance, ETCS increases rail capacity by minimising the distance between trains, significantly reduces the number of trackside elements as well as helps overcoming the interoperability barriers and therefore gaining a competitive advantage over road traffic. ETCS cab-signalling minimises the trackside equipment (e.g. lineside signals). In the longer term, these aspects need to further evolve towards a full digitalisation and high level of automation in rail operation, which will require various additional technical enablers such as:

- high precision positioning of trains based on multiple-modal input (e.g. GNSS), possibly making use of infrastructure-side support, but ideally not requiring anymore expensive trackside infrastructure elements such as balises;
- sophisticated sensors (e.g. video, radar, lidar) and related signal / information processing to automatically detect objects on tracks and monitor passenger boarding / disembarking at stations, in order to reach at least the same level of safety as in classical driver-based operation;
- means to perform video-based or sensor-based remote train control;
- interconnected sensors to monitor the state of the rail infrastructure.

Some technologies, such as predictive maintenance, have rather relaxed latency and reliability requirements and may use services offered by MNOs. Conversely, the ETCS rollout in a dense railway network and all these enablers are highly dependent on a reliable and well-dimensioned communications infrastructure. Many of the technology enablers listed before, for instance ETCS Level 2, the automated detection of objects on tracks or the remote control of trains in degraded mode, will be directly related to the safety-related and real-time rail operation.

As the longer-term trends towards full digitalisation and a high level of automation in rail operations have a substantial impact on the requirements of related critical applications, it is essential that the dimensioning of dedicated spectrum for rail operation takes these trends well into account.

2.7 AVAILABILITY AND RELIABILITY OF RADIO REQUIREMENTS AND THEIR IMPLICATION ON THE MIGRATION

A high level of availability and reliability is essential as an interruption of radio communication can have a significant impact on railway operation and/or safety. As examples related to GSM-R, the following aspects should be mentioned:

- According to EIRENE SRS and FRS, the Railway Emergency Call (REC) shall be established in 95% of cases within 4 seconds and in 99% of cases within 6 seconds, anywhere along the rail tracks.
- According to UNISIG Subset 093, the update time for a 250 octet Movement Authority (MA) message shall not exceed 12s with a minimum probability ranging from 98.1576% of cases to 99.9967% of cases depending on the category of the railway line.
- As per EIRENE SRS, GSM-R radio design is built on a 95% probability coverage in time and space over any track section of 100m.
- GSM-R must comply with a bit error rate corresponding to an RxQual strictly below 4 for voice.

At the time of writing, the equivalent availability and reliability requirements for the successor to GSM-R are not yet specified.

For railways it is essential (and in some EU Member States legally obligatory) to demonstrate that the track-to-train radio system performs in compliance with the performance requirements specified.

Therefore, several field tests have to be performed using measurement trains before a railway line is put into operational service with GSM-R or its successor. These radio network tests are aimed at checking in real life conditions the coverage and quality performance, checking if availability requirements are met and ensuring by doing so that specific railway applications run properly.

The described procedure above is one of the reasons why an overnight switchover from GSM-R to its successor over the same frequency band is not possible. Even if an upgrade in advance of all on-board terminals would be performed, including their validation on an isolated railway line equipped with the successor system of GSM-R, an overnight switchover does not offer the possibility to perform the tests mentioned above.

In addition to the point addressed above, an overnight switchover might cause an issue to the interoperability of railway networks. From spectrum management point of view, the same issue applies here: it is necessary to have, for a period of time, sufficient spectrum for both FRMCS and GSM-R to run both systems in parallel in any given area.

Because of the reasons described above, there is a strong need for additional spectrum during the migration period. This additional spectrum will also be required to cover railway's long-term needs after the migration period in combination with the 2x4 MHz currently used for GSM-R.

3 ASSESSMENT OF THE SPECTRUM NEEDS

Spectrum needs are assessed for the period where railways will migrate from GSM-R to its successor, as well as for after the migration.

The amount of spectrum required most notably depends on the supported applications and its associated traffic volume, the aggregated traffic in an area, the characteristics of the used radio access technology and the location of the frequency band within the radio spectrum.

For the purpose of assessing the spectrum needs for FRMCS, critical railway applications have been considered. Critical applications are defined as “*applications that are essential for train movements and safety or a legal obligation, such as emergency communications, shunting, [human] presence [e.g. LAS], trackside maintenance, ATC, etc.*” [12].

Three types of railway segments are considered:

- a low density rail segment;
- a high density rail segment;
- a high speed rail segment.

Furthermore, a reference train (including on-train staff and on-board systems) is defined to calculate the amount of traffic on each type of rail segment. Whereas the reference railway station is to be considered independently from the rail segments above. Traffic at the reference railway station will be handled within the designated spectrum, plus the use of complementary frequency bands, network densification, or the use of other technologies.

The traffic requirement is compared to the estimated LTE data throughput⁶ in a rail environment taking into account the radio network design, the characteristics of the radio access technology used and the location of the frequency band within the radio spectrum.

In addition, hotspots and border areas are specifically addressed in section 4 of this ECC Report.

Sources:

- for traffic analysis, see “FRMCS Traffic Analysis v2” [10];
- for throughput estimation in railway environment, see “ETSI TR 103 554 V1.1.1 on LTE radio performance simulations and evaluations in rail environment” [11].

3.1 TIMELINE PERSPECTIVE FOR THE MIGRATION

The overall migration throughout Europe is expected to take place between 2022 and 2035. The migration scenarios will depend on plans from Transport Ministries to replace the current GSM-R infrastructure (e.g. reinvestment might be an option in certain countries), and on agreements between Infrastructure Managers and Railway Undertakings on the timeline for deployment of both trackside and on-board. A large variation between Member States of deployment timelines for FRMCS is expected.

ERA investigates what can be done to help with the negotiation between IMs and RUs for the migration towards the successor to GSM-R. The CCS TSI could potentially be used to allow IMs to signal to all RUs in a specific country: a notification of start and end dates for FRMCS rollout, and the switch-off date for GSM-R, so that a minimum duration is ensured for parallel operation of GSM-R and FRMCS as well as a maximum duration for FRMCS rollout. This could help to minimise the migration period while avoiding to force Railway Undertakings to retrofit on-board equipments.

⁶ ETSI TR 103 554 is based on LTE at 900 MHz. Results with 5G NR are expected to be similar under equivalent assumptions (e.g. MIMO and QAM configurations).

3.1.1 Financial incentive scheme

In order to facilitate the migration, a national administration may consider setting up a financial incentive scheme. During a predefined period of time, railway undertakings would benefit from a full or partial funding for the upgrade of their on-board equipment to FRMCS. The level of reimbursement could decrease gradually as time passes. This shall be made applicable to both national and international railway undertakings.

The funding program can act as an effective “carrot” in a situation where doubts about timeline and costs are raised.

3.2 LIST OF CRITICAL APPLICATIONS

Spectrum needs are evaluated for two packages of applications:

- Package #1, which must be supported during the migration:
 - Roughly current GSM-R critical applications: Voice (including emergency calls), ETCS L2;
 - Train positioning⁷;
 - ATO up to GoA2;
 - Remote control of engine;
 - On-board intelligence and sensing (e.g. for ATO and object/person detection);
 - Critical video (e.g. for remote control in shunting yards and in degraded mode).
- Package #2, which must be supported after the migration:
 - Package #1;
 - ETCS L3;
 - ATO up to GoA4;
 - Virtual coupling;
 - etc.

The following table provides an overview of the critical applications that are required during the migration period.

Table 2: List of the critical applications (based on [10])

Critical application	Applicable to the migration?
Operational voice	Yes
Shunting voice	No
Emergency call 112	Yes
Alert from the public	No
Alert to the public	No
ETCS	Yes
ATO	Yes
Remote control of engine	Yes
Train integrity	No
Advisory messaging	No

⁷ to replace the use of the Cell-ID

Critical application	Applicable to the migration?
On-train telemetry & equipment control	No
Critical sensing/video (e.g. object/person detection or video in degraded mode)	Yes

This table is a condensed version of the applications on which the traffic model [10] has been developed.

3.3 THROUGHPUT REQUIRED BY CRITICAL APPLICATIONS DURING THE MIGRATION

Based on the subset of critical applications required during the migration period, see Table 2, the following tables show the traffic to be handled.

Table 3: Traffic during the migration for each area type, including critical video

	DL traffic per ref. train (Mb/s)	UL traffic per ref. train (Mb/s)	Nb. of trains per km	Cell size (km)	DL traffic per cell (Mb/s)	UL traffic per cell (Mb/s)
Low density rail segment	3.5	3.49	0.33	8	9.24	9.22
High density rail segment			0.67		18.77	18.73
High-speed rail segment			0.5		14.00	13.97

Note: The cell size reflected in this table are based on typical GSM-R networks currently in use. So this assumes that FRMCS would be deployed on the same radio sites without further densification.

Table 4: Traffic during the migration for each area type, excluding critical video

	DL traffic per ref. train (Mb/s)	UL traffic per ref. train (Mb/s)	Nb. of trains per km	Cell size (km)	DL traffic per cell (Mb/s)	UL traffic per cell (Mb/s)
Low density rail segment	0.2	0.19	0.33	8	0.53	0.51
High density rail segment			0.67		1.08	1.04
High-speed rail segment			0.5		0.80	0.77

Note: The cell size reflected in this table are based on typical GSM-R networks currently in use. So this assumes that FRMCS would be deployed on the same radio sites without further densification.

The reason for isolating a scenario without critical video is to see the conditions on one side for the evolving continuity of the services today ensured through GSM-R, and on the other side the progressive impact within the next 15 years of the introduction of autonomous trains and related modernisation applications. These are constitutive elements of the European railway strategy⁸, which will occur at a very different pace in the various European countries. The sub-scenario “evolving continuity of GSM-R” can be seen somewhere as an “upgrade” of the current situation where the railway operators will look for preserving their existing infrastructure in terms of design in order to minimise major cost impacts overall Europe. The sub-scenario “game changer” will not impact the totality of the European railway infrastructures, at least within the next 15 years, justifying their focus and progressive investments in terms of infrastructure.

3.4 THROUGHPUT REQUIRED BY TARGET CRITICAL APPLICATIONS

The target critical applications include the current critical GSM-R functionality as well as the new critical applications foreseen for the successor, which are ETCS L3, relevant subset of Automatic Train Operation, Virtual Coupling, etc.

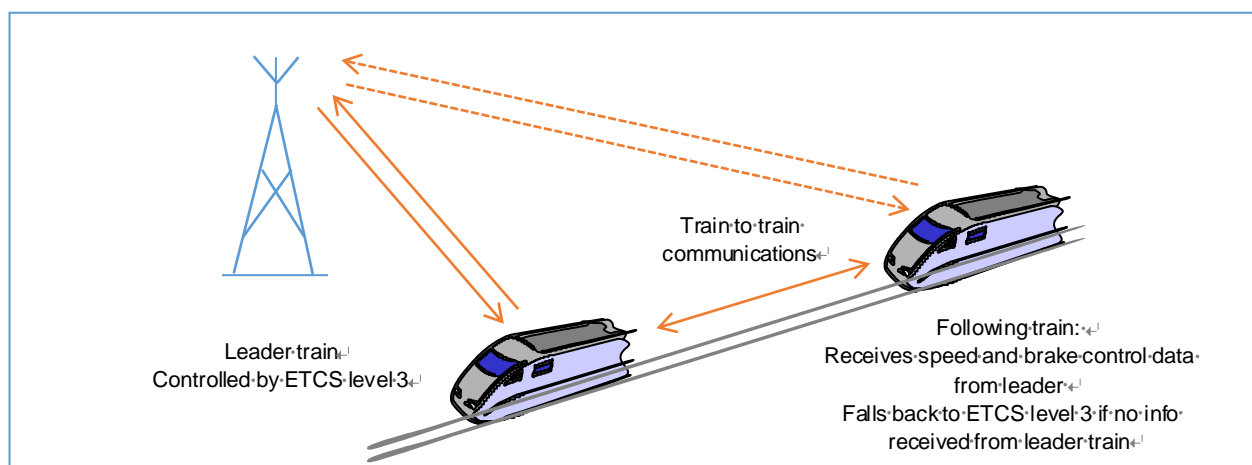


Figure 2: Principle of Virtual Coupling

Virtual Coupling: The following train receives speed and brake control data from leader (train-to-train communication). This system allows a reduction of the distance between trains and increases the capacity of transport.

The following tables show the traffic to be handled after the migration period, which includes additional new applications (as presented in section 3.2).

Table 5: Target traffic for each area type, including critical video

	DL traffic per ref. train (Mb/s)	UL traffic per ref. train (Mb/s)	Nb. of trains per km	Cell size (km)	DL traffic per cell (Mb/s)	UL traffic per cell (Mb/s)
Low density rail segment	4.38	7.42	0.33	8	11.55	19.60
High density rail segment			0.67			

⁸ known under the name of “game changers”, see

https://www.era.europa.eu/sites/default/files/library/docs/ex_post_evaluation/era_rep_150_ertms_longer_term_perspective_report_en.pdf

	DL traffic per ref. train (Mb/s)	UL traffic per ref. train (Mb/s)	Nb. of trains per km	Cell size (km)	DL traffic per cell (Mb/s)	UL traffic per cell (Mb/s)
High-speed rail segment			0.5		17.50	29.70
Note: The cell size reflected in this table are based on typical GSM-R networks currently in use. So this assumes that FRMCS would be deployed on the same radio sites without further densification.						

Table 6: Target traffic for each area type, excluding critical video

	DL traffic per ref. train (Mb/s)	UL traffic per ref. train (Mb/s)	Nb. of trains per km	Cell size (km)	DL traffic per cell (Mb/s)	UL traffic per cell (Mb/s)
Low density rail segment	0.42	3.46	0.33	8	1.10	9.15
High density rail segment			0.67		2.22	18.57
High-speed rail segment			0.5		1.66	13.86
Note: The cell size reflected in this table are based on typical GSM-R networks currently in use. So this assumes that FRMCS would be deployed on the same radio sites without further densification						

3.5 GUARD-BAND BETWEEN GSM-R AND ITS SUCCESSOR

‘Guard-band’ is defined as the minimum channel edge to channel edge frequency separation.

The 200 kHz guard-band defined in the EC Decision on 900/1800 MHz (latest amendment of EC Decision 2009/766/EC⁹ [18], [19]) corresponds to an uncoordinated deployment between two mobile network operators, one using UMTS/LTE and the other using GSM. It is related to blocking and out-of-band emissions phenomena. For co-located/coordinated deployment, MNOs do operate without a guard-band (uplink power control activated).

It is expected that GSM-R radio sites will often be used for FRMCS rollout (coordinated deployment with co-located base stations).

The critical case is interference from a GSM-R terminal to an FRMCS base station when uplink power control is not activated for GSM-R. There is confidence that a 200 kHz guard-band is sufficient between FRMCS and GSM-R, assuming co-location and similar EIRP for both systems.

Whether a smaller or no guard-band can be implemented for railway still requires further work, including the possibility for GSM-R to activate uplink power control.

With co-siting, no intermodulation phenomenon is expected in railway terminals, assuming similar or close values of EIRP for both systems.

3.6 THROUGHPUT OFFERED BY LTE IN RAILWAY ENVIRONMENT

The simulations being conducted within ETSI TC RT and documented in ETSI TR 103 554 V1.1.1 give indications that a 2x1.4 MHz LTE channel should be studied as a possibility for FRMCS for the migration.

⁹ In the point of time of publication of this ECC Report, the latest amendment was set into force by Commission Implementing Decision (EU) 2018/637.

This does not preclude use of 5G as well as in-band and/or adjacent channel arrangement of GSM-R and FRMCS in the whole 2x5.6 MHz.

Noting that having the possibility to reuse as much as possible the current radio network infrastructure (sites) would save costs and reduce operational burden, the spectrum in 874.4-880 MHz / 919.4-925 MHz is the preferred band for a harmonised solution for the successor to GSM-R for the migration and beyond. This is also recognised in the EC Mandate to CEPT on FRMCS [7].

In dense railway networks, border areas and high density areas, the capacity brought by adding 2x1.6 MHz of spectrum is not enough to support the frequency demand for GSM-R and FRMCS during the migration. It is difficult to do a more detailed analysis of the need for access to additional spectrum during the migration since it is also highly dependent on the design, the topology and the radio technology of the new network, for example a possible site densification in high traffic areas. The conclusion is however access to complementary spectrum, e.g. 10 MHz in 1900-1920 MHz, is a prerequisite for many countries in order to manage the migration with dual networks operating in parallel.

After the migration, the complementary band(s) will still be required in order to cover railway's long-term needs (including potential critical video), border and hotspot areas.

These early considerations may need to be refined when results of proposals and studies from ETSI and ECC become available.

The data throughput assumptions for the future railway mobile radio communications depend very much on the assumptions for critical real-time video. This is expected to play an instrumental role in future rail operations, especially in the context of automated train operations (ATO). It should be noted that the term "video" in this context refers to "classical" video, but also the data obtained from other sensors, or pre-processed and/or combined forms of such data within sensor fusion platforms used in automated railway systems, mostly for the purpose to detect hazards and ensure safety. Assumptions for such critical video applications are at an early stage and the data throughput for a single train on the uplink can vary, with current estimates in the order of 1 Mb/s in normal mode up to several Mb/s in degraded mode. Hence, it is not possible to conclude at this stage on the necessary throughput needed in the railway environment.

4 HOTSPOTS AND BORDER AREAS

Some GSM-R radio network operators are currently facing the problem of insufficient radio resources in the harmonised GSM-R band to support their operational needs, especially in railway hubs / hotspots and border areas. In such areas, additional radio resources are required. For GSM-R, the band 873-876 MHz / 918-921 MHz may be used on a national basis¹⁰. For FRMCS, a complementary frequency band, such as 1900-1920 MHz, or maybe access to a commercial mobile network may be used.

Examples of the most complex railway hubs / hotspots are:

- Mannheim area in Germany;
- Brussels-Antwerp-Ghent area in Belgium.



Figure 3: Railway hub in Mannheim (Germany)

In border areas, the available spectrum for GSM-R has to be shared between two or more GSM-R operators, thus the radio frequency planning process must be supplemented by proper network coordination. This cross-border coordination becomes a major challenge for the radio network planning and rollout. Today, cross-border coordination agreements for railway radio communication are established and being used by default, giving GSM-R network operators some flexibility for their frequency planning. The impact on these cross-border coordination agreements as well as the effects of the single frequency network architecture of the future railway radio system in border areas is for further study.

For GSM-R network operators, the situation of the coordination between neighbouring countries varies considerably, depending on the number of parties.

Examples of the most complex border regions are:

- Germany / Switzerland / France (e.g. Basel area);
- Germany / Switzerland / Austria (e.g. Lake Constance);
- Germany / Belgium / The Netherlands (e.g. Aachen/Maastricht);
- Baltic Sea coastline;
- Switzerland / Germany / Liechtenstein / Austria (border area);
- Switzerland / Italy (e.g. Chiasso area);
- Switzerland / France (e.g. Geneva area);
- Switzerland / France (e.g. Lausanne area);
- Netherlands / Belgium / Luxembourg / France.

¹⁰ This band is not harmonised neither at EU level nor at CEPT level. Three CEPT countries, Germany, Switzerland and Liechtenstein, are currently using the band 873-876 MHz / 918-921 MHz for GSM-R. Belgium is in the process of granting rights of use to GSM-R in the band 873-876 MHz / 918-921 MHz by 1st February 2019.

5 ACCESS TO COMMERCIAL AND OTHER NETWORKS

This section studies the legal, contractual, technical, and operational implications of sharing with other spectrum/network owners in the context of the Future Railway Mobile Communication System (FRMCS).

When considering network sharing schemes, five essential notions come into play:

- Licence conditions or Service Level Agreements
- What to share: spectrum, radio sites, Radio Access Network (RAN), transmission, core network, etc.
- For what purpose: critical vs. non-critical traffic, low/medium vs. high throughput, etc.
- With whom to share: which spectrum/network owners might be potential partners for sharing their spectrum/network
- On what basis:
 - “Exclusive sharing” (such as geographical network sharing): the sharing parties have an exclusive use of the network resources at a particular location and/or at a particular moment in time
 - “Open sharing” (e.g. based on listen before talk or pre-emption): potential conflicts between sharing parties are handled via coordination, prioritisation and pre-emption capabilities
 - Sharing based on capabilities provided by 4G/5G technologies such as radio network resource allocation and congestion control mechanisms, e.g. “network slicing”, etc.

Licence conditions and/or Service Level Agreements: They are intended to cover the railway specific requirements, legal obligations and liabilities, in such a way that the shared network would meet the requirements for railway operations. As an example of such sharing, some European countries have already implemented or are in the process of implementing MNO networks capable of delivering the high quality required by PPDR networks. The practicality and the economic impact needs to be assessed at a national level. Special care should be given to ensure that the infrastructure manager has adequate recourse and legal certainty.

What to share? Sharing with external communication network infrastructure owners can be addressed at different levels in the overall system architecture:

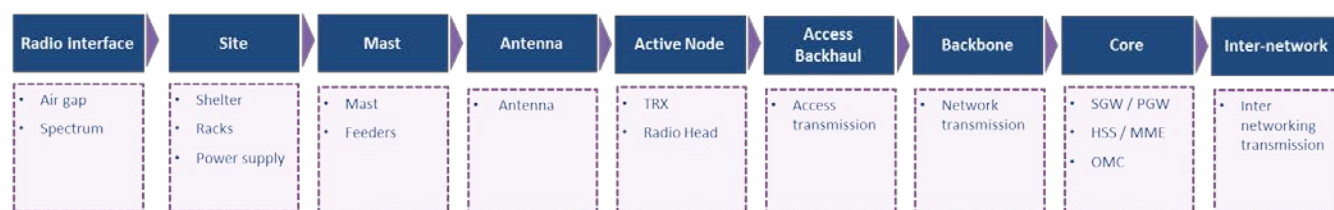


Figure 4: Network/infrastructure decomposition

For what purpose to share? The study of each possible spectrum/network sharing scenario may be dependent on the railway applications that are envisaged. The analysis of each sharing scenario will therefore consider each application category as defined in the User Requirements Specification (URS) [12]:

- Critical: applications that are essential for train movements and safety or a legal obligation, such as emergency communications, shunting, human presence, trackside maintenance, ATC, etc.
- Performance: applications that help to improve the performance of the railway operation, such as train departure, telemetry, etc.
- Business: applications that support the railway business operation in general, such as wireless Internet, etc.

With whom to share? In the present study, two types of spectrum/network owners are considered:

- Public Mobile Network Operators (MNO);

- Public Protection and Disaster Relief (PPDR).

Table 7 summarises the generic characteristics of these network owners in comparison to railways. Adequate national regulatory framework and/or Service Level Agreements may fill the gaps towards railway requirements, when considering sharing with MNO or PPDR.

Table 7: Generic characteristics of network owners considered

	MNO	PPDR	Railways
Coverage target	Currently mainly designed to maximise consumer population coverage, at the expense of occasional not-spots.	Designed for nationwide coverage with urban areas as a main target.	Designed for railway lines and railway-related premises (shunting yards, railway stations, etc.).
Cellular model	Hexagonal	Hexagonal	Mostly Linear/Curvilinear (1D, 1.5D) Hexagonal in station areas and shunting yards
Resiliency to (cell) coverage outage	Urban: currently high density of cells to cover traffic requirements including some overlap of the cell coverage for capacity purposes. Rural: currently low density of cells having a limited overlap.	Areas of importance may offer forms of cell resiliency. Additional Direct Mode Operation may also offer resilient coverage (in full dependency of frequency range (limited power in uplink)).	Urban/Rural: Typically, usage of double coverage to improve service availability for most ETCS lines, notably for high speed lines. High amount of equipment redundancy to improve service availability. Backup via MNO possible at national level e.g. for voice communications.
Orientation and specific features	Massive broadband data services	Group communication (voice, video, data) Proximity-based services Emergency calls Addressing based on fleet maps, etc.	Critical data communication for semi-automatic/automatic train operation (Emergency brake, Voice Group Calls, Emergency Calls, etc.) Functional Addressing, Location-based Addressing
System Availability Requirements	Currently mainly designed for an overall statistical approach, at the expense of occasional failures. Emphasis on bringing new features Frequent maintenance windows	High availability requirements	Fault tolerant/ high-availability requirements Limited maintenance windows

	MNO	PPDR	Railways
Service Guarantee	<p>QoS features and support are implemented for various traffic profiles and subscriber contracts.</p> <p>Optimal statistical multiplexing of the users to the available bandwidth</p> <p>Emphasis on service guarantee based on voice requirements</p>	<p>Support of critical communications having strong access control, prioritisation and QoS constraints</p>	<p>Critical (Safety) applications having very strong QoS constraints (refer to KPIs in EIRENE, typically in Subset-093)</p> <p>Service guarantee at the cell edge (e.g. at the handover points)</p>
Uplink versus downlink ratio	<p>Asymmetric since currently optimised for downlink capacity</p> <p>In TDD, the UL/DL frame configuration needs to be maintained over a whole contiguous coverage area</p>	<p>For future applications, asymmetric with a higher utilisation of the uplink than the downlink</p>	<p>For future applications, asymmetric with a higher utilisation of the uplink than the downlink</p>

Table 8 shows the usual strategy and goals of the network owners. They may be aligned with railways if adequate national regulatory framework and/or Service Level Agreements are available.

Table 8: Objectives of the different parties

Party	Strategy / goals
MNO	The current strategy of MNOs is usually to optimise their services for a group of mass-market customers.
PPDR	The strategy of PPDR may be to give priority to their safety applications in case of conflicting use of the same communication resource in order to ensure smooth and efficient rescue operations.
Railways	<p>The strategy of railways is:</p> <ul style="list-style-type: none"> ▪ to ensure a proper railway operation respecting the QoS requirements on an extensive network of railway lines (e.g. adequate cell dimensioning); ▪ to guarantee service continuity to meet the safety obligation associated with critical communication services (e.g. adequate resiliency); ▪ to maintain a reasonable cost (adequate value for tax payer money), ▪ to establish a coherent and common strategy at European level in order to achieve interoperability of cross-border operation and achieve economy of scale; ▪ to find synergy with external parties in order to diversify and complement its communication means for its own operations and for its passengers.

On what basis? Railway lines are pervasive on the European territory, especially in dense urban areas, even if they represent a small amount of the overall geographical surface.

Railways may require either an exclusive use of the shared resources, or an open sharing basis that shall ensure the highest priority for their critical applications, in order to maintain the continuity of railway services.

Geographical sharing of spectrum may be envisaged, as it is already the case with military applications in some European countries in the current harmonised band.

With PCC and its evolution to network slicing, multiple logical networks with different service level requirements can run virtually on a common physical infrastructure. LTE/5G networks may be able to satisfy the requirements of different vertical user segments, including railways. Special care should be given to radio network resource allocation and congestion control mechanisms, as well as adequate radio network coverage and availability meeting specific railway requirements as a basis for slicing, etc.

5.1 SHARING ACCESS WITH MNO

In this scenario, railways would either be users of the MNO’s network or operate as an MVNO (with network slicing). This would be part of a contractual commitment between railways and the MNO. Adequate national regulatory framework and/or Service Level Agreements may fill the gaps towards railway requirements, when considering sharing with MNO.

Table 9: Comparison between MNOs and Railways

	Mobile Network Operator	Railways
Bandwidth	Optimal statistical throughput	Cell edge throughput guarantee
Coverage Target	Designed to maximise consumer population coverage, at the expense of occasional not-spots	Designed for railway corridor and railway-related premises (shunting yards, railway stations etc.)
Coverage resiliency	Optimal geographical coverage having minimum overlap. Coverage resiliency is expected to improve on highly-circulated railway lines	Medium-to high overlap of coverage Double coverage based on availability requirements e.g. High Speed Lines Formal verification of coverage (KPI according to EIRENE) Subset 093 type of specifications for transport system QoS
Traffic QoS	Best-effort for data communication Priority for VoLTE services using packet oriented transport. QoS is expected to be improved with 5G for some verticals.	GBR for some specific applications such as ETCS Communication priority handling guaranteed

The coverage of the railway lines by MNOs:

It is expected that the coverage of railway tracks by MNOs will be greatly improved in the upcoming years. In some countries, licence conditions have been issued with some requirements to cover all or parts of railway tracks for passenger services. There are also other countries where MNOs have already committed to improve their coverage along railway lines. However, in countries where licence conditions do not require coverage of the railway tracks, the coverage objective of MNOs is usually related to the percentage of the covered population, and not of the area and is greatly influenced by the expected ARPU (Average Revenue Per User). However by having an appropriate national regulatory framework including a Service Level Agreement, it might be possible to meet the coverage requirements of railways.

In networks not designed and built for railway use, the suitability of MNO coverage needs to be assessed against railway requirements (high radio availability and quality, UL/DL traffic ratio). Coverage enhancement will require to assume responsibility for investments for e.g. additional radio sites; this cost needs to be taken into account when performing the overall cost/benefit analysis.

The reliability, availability, maintainability and continuity of service of the MNO network:

MNO networks may be able to provide the level of Quality of Service for critical communications with appropriate licence conditions, service level agreements and choice of technology. Main concerns from railways are the ability of MNOs to ensure the safety-related services necessary for railway operation. This question is related to whether MNOs will assume the risk and how, in the legal contract, risk assessment is dealt with.

Prioritisation and pre-emption are necessary to ensure the rail communication availability especially in emergency situations.

In all cases, public mobile networks can be envisaged to support less-stringent railway applications, or to act as a backup, however assuming a lower quality if railway mobile communication facilities are unavailable.

Sharing can also be envisaged to offer some flexibility beyond the spectrum harmonised for railway interoperability. Such a “flexible harmonisation” would rely on the possibility to identify on a national basis how much additional spectrum in which frequency ranges and under which implementation model (either sharing access but also multiple-band support) could be granted.

A social-economic evaluation should be performed. The position of the MNO would need to evolve from purely commercial motives to having social responsibility as well as commercial drive.

Issues to be solved when sharing with MNOs are:

- In case of railway accidents, the assignment of responsibility on legal and juridical matters, or related penalties, where malfunctioning of e.g. the radio network is involved;
- Management of MNO technology evolutions, including 3GPP releases and other regular software updates, which may need to be certified before introduction on live network (this process could have major impact on MNO evolutions and operations);
- Congestion in case of major incidents or accidents;
- A dependency between the railway infrastructure manager and the MNO arises (“operator lock-in”) with the investments the MNO needs to do in order to meet the railway requirements, e.g. extension of radio coverage, enhanced battery backup, operational procedures, etc. These investments might be paid by the railway infrastructure manager as an entry fee or as a monthly fee in a long-term contract. When switching to another MNO, these investments have to be made again. This is an issue if the depreciation period is not over. Some of these investments could be owned by the railway infrastructure manager thus reducing the dependency upon the MNO, e.g. IMS core network and applications, complementary radio network, etc.;
- The railway infrastructure manager needs a stable long-term relationship with the selected MNO. When an MNO is acquired by another one, the new entity inherits the previous commitments. But a risk exists that services are terminated and existing contracts are not prolonged;
- Long-term guarantee for technology support related to available hardware, software and support services for the track side infrastructure, as well as for railway terminal retro-compatibility.

From a technical point of view, network sharing with MNO is possible for critical applications under the condition that the relevant parts of the MNO’s network fulfils the stringent coverage and availability requirements expected by railways. Railway authorities can set up rules so that the dependency upon the MNO is limited. An MNO network not fulfilling the railway requirements can be envisaged for most performance and all business applications defined in [12] where the coverage of MNOs is sufficient.

However, sharing with MNO is yet to be proven in the context of critical applications for railways. Coverage of railways by MNOs without railway oriented national regulatory framework remains identified in a 2018 joint report by BEREC and RSPG as a "challenge area" for mobile connectivity, see pages 11-14 in [13].

An MNO with obligation to support railway needs would deploy infrastructure in required locations including tunnels and thus improve signal strength along railway lines and other railway-related premises as needed. Such a network would also be designed to handle handover issues from cell to cell in a robust way without loss of the communication link. In addition to provide full coverage, the MNO would also need to satisfy other requirements, such as network resilience and availability which would entail specific engineering, long-term investments (additional radio sites, power backup, overall strengthening of the radio transmission, redesign of backhaul and core network) as well as operational and field maintenance from MNOs. The willingness of MNOs to take legal obligations and liabilities remains to be seen. Current MNO processes do not cover safety-related and interoperability assurance which currently requires extensive certification.

5.1.1 Net neutrality

The net neutrality regulation makes the distinction between two kinds of services: Internet Access Service (IAS) and Specialised Service (SpS). These are regulatory terms.

With regard to IAS, by default all traffic shall be treated equally. In exceptional cases, such as network congestion, discrimination between traffic is allowed on a temporary basis, and subject to specific rules.

With regard to SpS, optimisation / traffic management is allowed to meet a specific level of quality, only if it is not to the detriment of the availability or general quality of IAS for end-users. Railway sharing MNO's resources would be a good candidate for the SpS category. But it is for further study whether priority mechanisms or network slicing (i.e. partitioning of radio resources) would be compatible with the net neutrality regulation.

5.2 SHARING ACCESS WITH PPDR

This option could apply to some countries where exclusive spectrum has been assigned to PPDR. In such a scenario, railways would either be users of the PPDR network or operate as an MVNO. This would be part of a contractual commitment between railways and PPDR.

In some European countries there is no PPDR dedicated network planned, so this solution cannot be European-wide. Thus sharing with other critical communication operators, like PPDR, may be an option to consider on a national basis, provided that the set of harmonised frequency bands for railways include all PPDR bands used in Europe.

From an operational, organisational and legal standpoint it might be challenging as no single solution exists for the PPDR networks across Europe. It is in particular challenging to define which communication service should have priority of use against the other in case of major incidents.

Issues to be solved when sharing with PPDR are:

- Even if PPDR requirements are typically greater than those of public mobile networks, they are not as high as those from railways. It has to be noted that a PPDR agent is likely to be able to move in order to leave an interfered area, whereas a train cannot leave its track. This would imply that the availability, the robustness and the resiliency of the PPDR network may need to be improved for the railway needs;
- Areas to be covered may not be the same, except in urban areas including railway stations. Railways would need to roll out a complementary radio network along the rail tracks, meaning additional investments. So financial saving for railways can be questioned;
- Legal and criminal liability sharing as well as adequate network governance and certification processes between PPDR and railways need to be defined, taking into account the specific railway and PPDR

requirements. Additionally, priorities and responsibilities need to be defined. These aspects shall be established on a national basis;

- Although there may be agreements for the use of PPDR solutions by various organisations (e.g. military), this use is limited to specific security and safety missions and services falling outside the scope of these missions cannot be covered;
- Because of the potential competition between railway and PPDR users for accessing the radio resources, the contractual agreement required between the infrastructure manager and the PPDR operator shall answer the following question: In common areas such as urban areas, who has priority? A railway or a PPDR critical communication? Or is it possible and acceptable to partition the resources?
- Total capacity and/or spectrum requirement for both railways and PPDR may be difficult to meet with frequency spectrum dedicated to PPDR.

5.3 SHARING SPECTRUM WITH PMR/PAMR

PMR/PAMR users, like in logistic plants, airports, electrical supply companies, and the rail sector appear to have similar needs for spectrum. As a matter of fact, PMR/PAMR also intends to use radio communications for the continuity or performance of their operations at their industrial sites.

Sharing spectrum with PMR/PAMR could be an option that can be applied when considering rail communication networks whose locations are not geographically overlapping with the PMR/PAMR network locations. For instance, shunting voice communications, communications at stations and depots, train departure related communications, emergency help points in stations are possible communication scenarios in a limited geographical area of use.

It might be difficult to find PMR/PAMR that are not geographically overlapping with railways, as most infrastructure are interconnected through multi-modal hubs for instance in the case of transport, or are following parallel paths with railway lines like electricity supply networks.

It has also to be considered that a spectrum sharing option with PMR/PAMR may require a harmonisation at EU/CEPT level in order to enable cross-border compatibility and the interoperability of rail communication.

A spectrum sharing option with PMR/PAMR would also cause a significant impact on the cab-radio capabilities because various frequency bands may be relevant (see also section 5.4). A harmonised implementation of PMR/PAMR frequency bands is difficult because of legacy systems in these bands.

5.4 MIMO AND MULTIPLE-BAND SUPPORT IN RAILWAY TERMINALS

In trains or engines, on-board radio systems are made of radio modules, an antenna system and some cabling between them, unlike mass-market handheld terminals where everything is integrated together.

Due to the limited space for antennas on train roof where various equipment is installed (e.g. electrical devices such as air conditioning on the roof to design low floor rolling stock facilitating access to people with restricted mobility), the number of antennas that can be installed may be small. Since MIMO requires adequate separation between antennas to benefit from spatial diversity, its use may be limited if keeping the current antenna system; this is for further study.

Multiple-band support is actually to be realised through the availability of multiple-band on-board radio modules and antennas as well as handheld devices, the adoption of common technical standards (i.e. LTE/5G), possibly utilising different sharing network types, and also by standard conformance and interoperability specifications.

To allow the use of complementary spectrum, the on-board radio systems as well as handheld devices will need to have the ability to support multiple frequency bands. This will imply multi-band antenna systems and multi-band terminals. Due to the specificities of railways, there will be several limitations that need to be considered.

Although antenna systems can support more than one frequency band, there may be limitations on the total range of spectrum that can be covered at sufficient performance level; this is for further study.

As the train antenna system will need to be capable of supporting both the existing GSM-R and the FRMCS, and the fact that current GSM-R system implementations are based on a maximum loss between the GSM-R antenna and the GSM-R receiver input (6 dB according to EIRENE SRS), the introduction of FRMCS when reusing that very same antenna may degrade the quality of the GSM-R system; this is for further study.

In case of sharing with MNO, PPDR or PMR/PAMR, not all bands would be selected; only some of them which would then need to be referenced in the CCS TSI to ensure railway interoperability. It would be necessary to integrate all the frequency options selected within MNO, PPDR and PMR/PAMR frequency bands in the railway terminal equipment to fulfil the railway interoperability requirement.

In some cases, some frequency bands may not need to be supported by all trains:

- frequency band(s) for local, regional and historical trains;
- frequency band(s) for extra capacity;
- frequency band(s) for applications not related to railway interoperability.

Note: Carrier Aggregation / Dual Connectivity is not covered neither in this section nor in this Report; this topic is for further study.

5.5 CONCLUSION

From a technical point of view, network sharing with MNO is possible for critical applications under the condition that the relevant parts of the MNO's network fulfils the stringent coverage and availability requirements of railways (including prioritisation and pre-emption). Sharing with an MNO needs to be tested in real life conditions to prove that coverage, quality and availability requirements of railways are met. Such a scenario is dependent on the full coverage of rail tracks, and the requirements on network resilience and availability. This would entail long-term investments as well as specific engineering, operational and field maintenance from MNOs. Current MNO processes do not cover safety-related and interoperability assurance, which currently requires extensive certification.

Key questions remain unanswered so far: MNO's agreement to take railway legal obligations and liabilities; MNO's willingness to assume the risk, how, in the legal contract, risk assessment would be dealt with.

MNO networks that do not fulfil these requirements could be used for low-train traffic lines with less stringent requirements and non-critical railway communications, i.e. for performance and business applications probably with limited coverage, availability and QoS.

Sharing can also be envisaged to offer some flexibility beyond the spectrum harmonised for railway interoperability. Such a "flexible harmonisation" would rely on the possibility to identify on a national basis how much additional spectrum in which frequency ranges and under which implementation model (either sharing access but also multiple-band support) could be granted.

Sharing with PPDR networks using dedicated spectrum is not an option applicable to all European countries because no harmonised approach exists for PPDR networks in Europe. Furthermore it would require sufficient spectrum resources for both PPDR and railway users. Legal and criminal liability sharing as well as adequate network governance and certification processes between PPDR and railways need to be defined, taking into account the specific railway and PPDR requirements. Additionally, priorities and responsibilities need to be defined. These aspects would be established on a national basis.

Geographical spectrum sharing with PMR/PAMR could be envisaged when limited to certain areas, like in stations, shunting yards or depots. Network sharing with PMR/PAMR can also be of interest to obtain complementary traffic capacities, provided that coverage requirements are fulfilled, to deal with railway hotspots.

6 CONCLUSION

The purpose of this ECC Report is to assess the spectrum needs for the successor to GSM-R. Essential input documents to this Report are “FRMCS Traffic Analysis” [10] and ETSI TR 103 554 “LTE radio performance simulations and evaluations in rail environment” [11]. The estimation of the throughput needed and of the spectrum needs for the successor to GSM-R are to a major extent based on the findings of these documents. These early considerations may need to be refined when results of proposals and studies from ETSI and ECC become available. Detailed frequency band options and harmonised technical conditions will be described in future ECC deliverables.

6.1 ABOUT THE NEED FOR PARALLEL OPERATION OF GSM-R AND ITS SUCCESSOR

Railway interoperability, i.e. ability for trains and staff to operate uninterrupted across borders and railway networks, must be ensured. Requirements related to interoperability are legally binding in Europe since they are part of the Control-Command and Signalling Technical Specification for Interoperability (CCS TSI), which is published in the European Regulation 2016/919/EU [4].

The principles laid down in that CCS TSI do not allow actions such as a mandatory retrofit of cab-radios (unless specific rules are agreed). In addition, an overnight switchover would not leave the possibility to perform the necessary field tests to check whether the railway requirements are met.

Therefore, GSM-R and its successor will have to operate in parallel for a period of time. For these reasons, there is a need of additional spectrum at least during the migration period. This additional spectrum will also be required to cover railway's long-term needs after the migration period in combination with the 2x4 MHz currently harmonised for GSM-R. The overall migration throughout Europe is expected to take place between 2022 and 2035.

6.2 ABOUT SPECIFIC RAILWAY REQUIREMENTS

Interruption of radiocommunication can have an impact on railway operation and/or safety. A continuous availability of and accessibility to the railway radio network is required in order to transmit and receive a Railway Emergency Call everywhere along the rail tracks. Further, a persistent interruption of radio communication in the context of ETCS Level 2 and beyond will simply lead to the stopping of trains causing consecutive delays in the public transport system.

Historically, GSM-R networks have been designed and validated against formal and stringent availability and reliability requirements such as 95% probability coverage in time and space over any track section of 100m. At the time of writing, the availability and reliability requirements for the successor to GSM-R are not yet specified, but equivalent criteria are anticipated, provided that the technical principles and the safety approach of ETCS are not changed.

6.3 ABOUT SPECTRUM NEEDS

Railways currently use the 876-880 MHz / 921-925 MHz band as the harmonised spectrum for GSM-R at CEPT and EU levels. The band 873-876 MHz / 918-921 MHz is not harmonised for GSM-R within CEPT, but it is used for GSM-R on a national basis by some CEPT countries. Existing GSM-R is an application within the primary mobile service and needs to be protected. In addition, as specified in Article 3 of Commission Implementing Decision 2018/1538 [15], EU Member States shall refrain from introducing new uses in the 874.4-876 MHz and 919.4-921 MHz sub-bands until such time as harmonised conditions for their use are adopted under Decision 676/2002/EC [16].

Noting that having the possibility to reuse as much as possible the current radio network infrastructure (sites) would save costs and reduce operational burden, the spectrum in 874.4-880 MHz / 919.4-925 MHz is the

preferred band for a harmonised solution for the successor to GSM-R for the migration and beyond. This is also recognised in the EC Mandate to CEPT on FRMCS [7]. This scenario includes use of 4G/5G as well as in-band¹¹ and/or adjacent channel arrangement of GSM-R and FRMCS in the whole 2x5.6 MHz.

In dense railway networks, border areas and high density areas, the capacity brought by adding 2x1.6 MHz of spectrum is not enough during the migration. The conclusion is that access to complementary spectrum, e.g. 10 MHz in 1900-1920 MHz, is a prerequisite for many countries in order to manage the migration with dual networks operating in parallel. The frequency band 1900-1920 MHz, or parts of it, is currently licensed to mobile operators in many CEPT countries. After the migration, the complementary band(s) will still be required in order to cover railway's long-term needs (including critical sensing/video), border and hotspot areas.

6.4 ABOUT SHARING

From a technical point of view, network sharing with MNO is possible for critical applications under the condition that the relevant parts of the MNO's network fulfils the stringent coverage and availability requirements of railways. However, current MNO processes do not cover safety-related and interoperability assurance which currently requires extensive certification.

Key questions remain unanswered so far: MNO agreement to take railway legal obligations and liabilities, MNO's willingness to assume the risk; how, in the legal contract, risk assessment would be dealt with.

MNO networks that do not fulfil these requirements could be used for low-train traffic lines with less stringent requirements and for non-critical railway communications.

In order to offer some flexibility beyond the spectrum harmonised for railway interoperability, a flexible approach would rely on the possibility to identify on a national basis how much additional spectrum in which frequency ranges and under which implementation model (sharing access, national licence model, etc.) could be granted.

Sharing with PPDR networks using dedicated spectrum is not an option applicable to all European countries because, noting the various solutions implemented at national level, no harmonised approach exists for PPDR networks in Europe. Furthermore, it would require sufficient spectrum resources for both PPDR and railway users as well as a clear assignment of priorities and of legal and criminal liabilities.

Geographical spectrum sharing with PMR/PAMR could be envisaged when limited to certain areas, like in stations, shunting yards or depots. Network sharing with PMR/PAMR can also be of interest to obtain complementary traffic capacities.

¹¹ as for NB-IoT

ANNEX 1: FINNISH CASE

A1.1 BACKGROUND

The project to build the GSM-R network in Finland started in year 2002 and was completed in 2011. The network covers currently approximately 5100 km of railway with 400 base station sites and provides service to approximately 5000 mobile users. The network was designed and built before the current CCS TSI specifications were adopted, with the goal that it could be used for all operational railway communications including shunting, offering trackside radio coverage also for 2W handheld equipment.

Since the existing GSM-R equipment used in Finland will reach the end of its life cycle at the latest by the end of 2018, Finland could not wait for the next generation of railway radio network to emerge before making a decision on how to continue with railway radio communications, a solution had to be developed and implemented in advance of other European countries. Investing in new GSM-R network equipment was considered to be uneconomic, since the GSM-R system would relatively soon be replaced by the next generation of railway radio.

Considering the above, a solution needed to be developed quickly, noting that the Finnish railway network is separated from the respective networks of the rest of the European Union due to different track gauge as well as lack of roaming between Finnish GSM-R users and other EU GSM-R networks.

A1.2 SOLUTION

The question was whether the railway specific core functionalities could be implemented without GSM-R. The following functionalities and core features were identified as a minimum set based on a safety analysis:

- Role registration procedure, functional numbering ("I am the driver of train 3456")
 - Safety: Who is speaking to whom - e.g. permission to proceed
- Lists of registered users in the control area
 - Trains, Shunting units, Maintenance teams
- Location based group and point-to-point calls
 - Punctuality: Easy and quick to reach the responsible train traffic controller
- Pre-emption
 - Safety: Important call has to be connected
- Railway Emergency Call
 - Safety: Stop the traffic in a predefined area

It was considered that all of the functions above are possible to be implemented without GSM-R, using the existing VIRVE network designed to be used by authorities and security operators for efficient and secure communications. Furthermore, a data application between train driver and dispatcher was developed that uses public mobile networks for communication.

Railway users and PPDR users didn't require any priority scheme in accessing the radio resources from the VIRVE operator. Capacity planning and monitoring is performed to ensure the proper sharing.

A1.2.1 VIRVE (PPDR) network

The VIRVE network is based on TETRA technology and uses frequency bands 380-385 MHz and 390-395 MHz, it consists of approximately 1300 base stations leading to a 100% population coverage and 97% area coverage and it has over 37 000 subscribers.

Since VIRVE is also approaching the end of its lifecycle around year 2030, the solution to be developed needed to be technology neutral and future proof, therefore a Unified Railway Communication and Applications system (URCA) was developed.

A1.2.2 Unified Railway Communication and Applications system (URCA)

Voice and data services for railways are made independent from railway radio technology with the Unified Railway Communication and Application system. This system will ease the on-going migration from GSM-R to TETRA as well as enable connectivity to the next generation of railway network and other networks that may be used for railway communication. URCA will pave the way for railway bearer independent communications and applications approach and provide railway users access to several mobile networks and technologies now and in future.

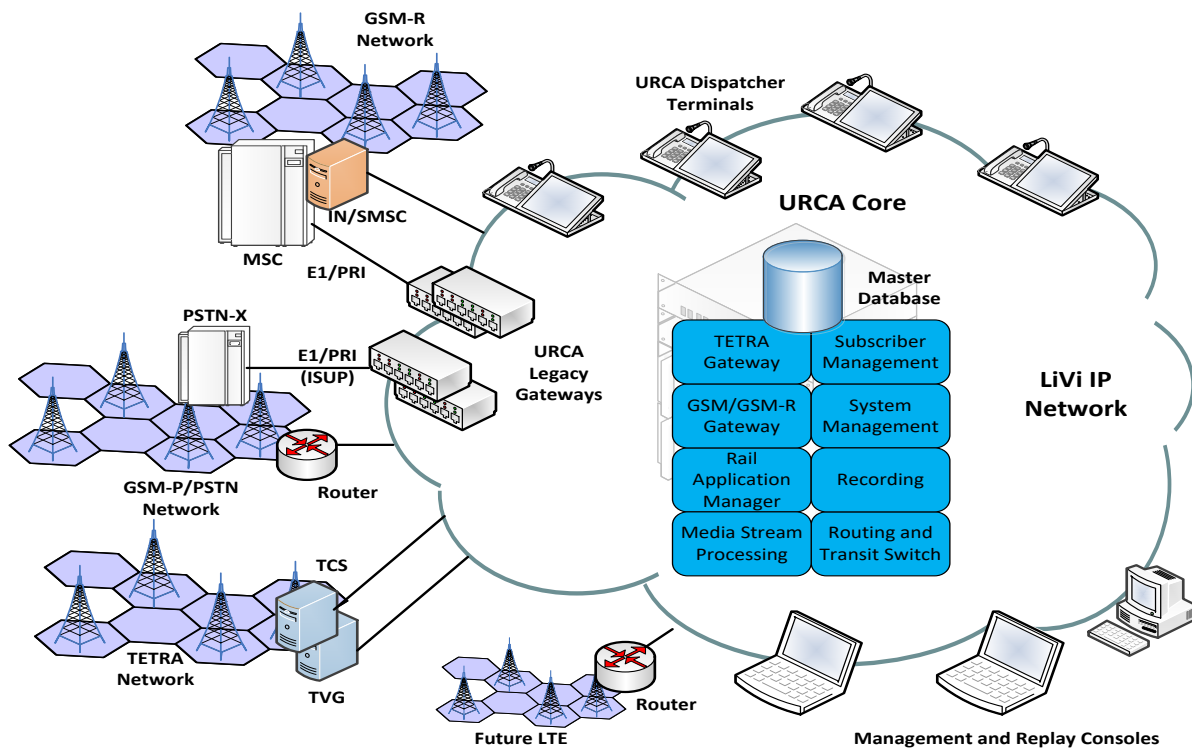


Figure 5: Unified Railway Communication and Application system

The plan is to switch off GSM-R by the end of year 2018. In order to enable a controlled switch over of railway radio traffic to VIRVE network, several intermediate steps have been performed which are in general described in figure 6 below. In particular, 1000 VIRVE-specific cab-radios and 500 shunting handheld terminals are being rolled out. The Finnish transport administration pays for all direct expenses, including cab-radios, related to the migration to the VIRVE network.

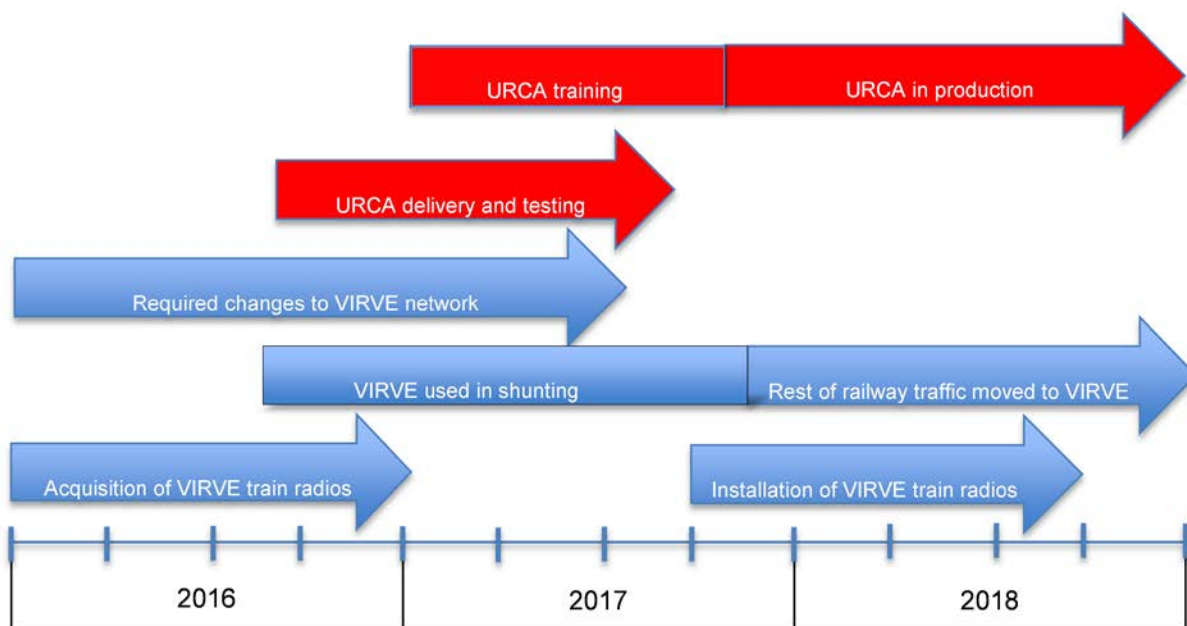


Figure 6: Timetable for GSM-R switch off

Thus, the URCA system will operate in parallel over GSM-R and VIRVE networks till the switch-off of GSM-R planned for the end of 2018.

ANNEX 2: SNCF RÉSEAU SPECTRUM REQUIREMENTS AND COMPARISON WITH GSM-R THROUGHPUT

A2.1 GSM-R CURRENT SITUATION

- a) SNCF Réseau is using 2x4 MHz in the 876-880 MHz / 921-925 MHz band for 19 GSM-R channels;
- b) A large majority of the rollout costs comes from the radio sites search and construction, in line with the findings at European scale of the Systra migration study¹²;
- c) The GSM-R network rollout was performed in France between 2006 and the end of 2017. Without prejudice of the actual pace of technology obsolescence and of how the railway regulatory environment on ERTMS will evolve, it is expected that GSM-R will continue to be operational until 2035 and perhaps later, at least on some lines;
- d) Current GSM-R BS radio configuration use 1 frequency per site (BCCH) on classic railway lines and 2 frequencies per site for double coverage on HSL (High Speed Line). Double coverage configuration has been chosen in France to increase availability and capacity of radio access network on HSL. The maximum number of TCH available per site is:
 - Simple coverage, voice applications: 6 TCH;
 - Double coverage (case of the HSL in France), voice + ETCS Level 2 applications: 12 TCH (total capacity of the 2 layers can be used by using appropriate option such as “Directed Retry”).
- e) As a result, the current GSM-R network provides a maximum capacity per site (CSD) in the vicinity of 60 kbps (voice and ETCS)¹³.

A2.2 GPRS EVOLUTION

- a) SNCF Réseau is studying GPRS evolution in order to increase the available capacity on the GSM-R network (mainly for ETCS Level 2 applications).
- b) The target date for rollout of GPRS is mid 2019 (for only a limited area of the network). This situation is specific to the French network and might differ from other railway networks.
- c) The maximum data throughput expected with GPRS is in the vicinity of 150 kbps (per site with double coverage and 2 active TRX on HSL). This estimation is based on a maximum of 4 TS dedicated to packet data transmission par active TRX (assuming a modulation scheme CS-2).

A2.3 DATA THROUGHPUT COMPARISON BETWEEN GSM-R AND LTE-R 1.4 MHZ

- a) It is expected that the limiting factor in terms of requirements will be the uplink, both for throughput to be accommodated and for radio link performance.
- b) In the LTE – GSM-R coexistence study done for ERA¹⁴, it is estimated on a planning case study that a LTE 1.4 MHz carrier would provide 200 kbps uplink throughput at the cell edge. Preliminary ETSI results indicate that a LTE 1.4 MHz carrier at 900 MHz in a railway environment could accommodate UL traffic in the vicinity of 300 kbps for UL¹⁵.

The following table provides a summary of the expected uplink throughput under various network configurations.

¹² ERA_RS1_DL023, Study on migration of Railway radio communication system from GSM-R to other Solutions, by Systra, May 2016

¹³ Assuming CSD 4800 bps x 6 TCH x 2 TRX

¹⁴ Coexistence of GSM-R with other communication systems, final report for ERA (ERA 2015 04 2 SC), 2016, page 119

¹⁵ Draft ETSI TR 103 554, May 2018

Table 10: Expected uplink throughput

Configuration	Uplink throughput
Maximum current data throughput available on existing GSM-R network	60 kbps / site (with double coverage configuration on HSL)
Expected maximum data throughput including evolution to GPRS on existing GSM-R network	150 kbps / site (with double coverage configuration on HSL)
Estimated data throughput for a LTE 1.4 MHz carrier at 900 MHz range and in a railway environment	200 kbps /site (LS Telecom study) 300 kbps / site (preliminary estimation done by ETSI TC RT)

A2.4 MIGRATION PERIOD (DOUBLE RAN GSM-R AND FRMCS)

- a) To save costs, it is essential for SNCF that the FRMCS can be introduced using as much as possible the current network radio infrastructure (sites): therefore main spectrum requirements are for spectrum close to GSM-R (below 1 GHz) because it would have similar propagation characteristics.
- b) According to the previous table, a 2x1.4 MHz LTE channel would be necessary and in theory sufficient to accommodate the same capacity for SNCF Réseau main lines if the spectrum is fully available, i.e. without interference from adjacent services and without spectrum constraints at borders.
- c) In the specific and preferred case of the spectrum immediately adjacent to current GSM-R spectrum:
 - Adjacent service compatibility with GSM-R on the one-hand and SRD on the other hand requires at least 2x1.6 MHz, providing a measure of protection to be confirmed after the studies in SE7¹⁶.
 - Several neighbouring countries (Germany, Belgium and Switzerland) have indicated that they intend to roll out GSM-R in the 873-876 MHz / 918-921 MHz band. While not yet studied, co-channel interference situation between GSM-R and FRMCS at the borders may require in some cases the rollout in a local area of a complementary band for FRMCS.
 - Co-channel interference between FRMCS and FRMCS at the border may also require the roll out of a complementary band in some local areas.
- d) In addition a complementary band for FRMCS would provide a solution for higher throughput in areas which will require it during the migration (e.g. large stations, or areas with early implementation of new applications). The complementary band should therefore allow locally a capacity comparable to the long term RMR (FRMCS) (e.g. 2x5 MHz or 10 MHz TDD, see below).

A2.5 LONG-TERM SITUATION

- a) The FRMCS may serve over a period extending from 2025 to 2050. While not all applications are sufficiently mature, today, it is already possible to substantiate a long-term need over main lines for 500 kbps to 1.1 Mbps according to the traffic model in this ECC Report.
- b) Assuming a capacity 3 to 4 times larger than the capacity assessed in the ETSI preliminary analysis for 2x1.4 MHz, it is expected that 2x5 MHz in LTE or 5G technology will allow to meet those needs on main lines.
- c) It seems prudent for the long term to retain the requirement for 2x5.6 MHz for RMR which will also be needed for the migration. It is slightly in excess of the 2x5 MHz but would provide adequate

¹⁶ This would allow for instance 200 kHz separation between GSM-R and RMR (FRMCS) and 100 kHz separation with SRD envisaged in the draft EC SRD decision. While some contributions have questioned the need for a guard band between RMR (FRMCS) and GSM-R, the question of the protection from SRD has not been studied and might require in fact a larger separation.

separation from SRD, possibly additional capacity for RMR (FRMCS) and potential evolution margin for upcoming RMR generations.

- d) On the other hand, limiting the RMR (FRMCS) long-term bandwidth (e.g. 2x3 MHz) would put undue constraint on long-term applications supported by the RMR (FRMCS). It is to be noted that deciding today on such a constraint would not provide any gain for the next 20 years of the upcoming transition period, during which at least 2x5.6 MHz of spectrum will be required for RMR.
- e) The complementary frequency band would allow to provide higher capacity in areas where it is needed and alternative capacity in borders areas as necessary for network coordination. Long-term needs in dense areas is expected to be 2 Mbps to 6 Mbps.

A2.6 IN SUMMARY

Table 11 summarises the spectrum demand and expected supply solutions.

Table 11: Spectrum demand and expected solutions

	Demand	Supply
Main lines, migration to FRMCS	Capacity identical or above that of GSM-R (including with GPRS)	2 x 1.6 MHz at 900 MHz, over 8 km cell 200-300 kbps UL [tbc]
Complex areas, migration to FRMCS	Solution for borders, dense areas and pioneer new application lines	Complementary band
Main lines and long-term RMR	Present report: 500 kbps - 1.1 Mbps UL	2 x 5.6 MHz at 900 MHz, over 8 km cell 900 kbps-1200 kbps UL [tbc]
Dense areas and long-term RMR	Present report: 2.3 Mbps UL + 3 Mbps DL	10 MHz TDD at 2 GHz over 2 km cell

An interference free 2x1.4 MHz LTE carrier operated at 900 MHz under rail conditions is likely to provide an uplink capacity similar to the one achievable with GSM-R (including GPRS option) but probably not more. This situation is specific to the French rail network which will have a limited ETCS rollout. This might differ from other railway networks.

Taking into account necessary guard-bands, this substantiates a spectrum need for at least 2x1.6 MHz at 900 MHz for FRMCS for the transition period with a double RAN (GSM-R/ FRMCS) and the need for a complementary resource at higher frequency to address border areas and dense or pioneer areas where FRMCS requirements will be higher.

Over the long term, a 2x5 MHz LTE carrier operated at 900 MHz could accommodate the traffic requirements identified for main lines in the current traffic model in the present ECC Report, but not the requirements for dense areas. Including some protection with adjacent services and some margin, this substantiates a spectrum need for at least 2x5.6 MHz at 900 MHz for the long term and a minimum complementary spectrum resource of 10 MHz TDD for dense areas and/or border areas.

On the other hand, limiting the RMR (FRMCS) long-term bandwidth (e.g. 2x3 MHz) would put undue constraint on long-term applications supported by the RMR (FRMCS) without any spectrum gain during the long transition period.

ANNEX 3: DEUTSCHE BAHN SPECTRUM REQUIREMENTS

A3.1 CURRENT SITUATION

DB Netz AG is the railway infrastructure manager of Deutsche Bahn AG, and is responsible for the approximately 33 000 km rail network, including all operational necessary installations. An average of 40 000 trains are using DB Netz AG's infrastructure per day. The main task is to make available a high-quality, high-availability and non-discriminatory railway infrastructure to the around 420 railway undertakings. GSM-R based services and applications do contribute to the overall safety of railway operation. Therefore, highest quality for GSM-R voice and data communication providing low interference and high speech quality is needed today and during the migration period, particularly for emergency calls, shunting communication, ETCS Level 2 and other railway specific services and applications.

- a) DB Netz AG is using 2x4 MHz in the 876-880 MHz / 921-925 MHz band and 2x3 MHz in the 873-876 MHz / 918-921 MHz band for 19 + 14 GSM-R channels.
- b) Spectrum demand for GSM-R continues to grow:
 - ETCS implementation is in accordance with the European Deployment Plan continuously extended.
 - The migration of voice and partly data services – in particular in shunting areas where voice is partly still supported by legacy analogue VHF radio networks – to GSM-R is still ongoing.
- c) DB Netz AG is facing specific challenges:
 - Transit railway traffic and a strong growth in passenger traffic are increasing the pressure to enhance efficiency. The railway traffic growth is expected to continue; this process will even speed up by politics since it is seen as a key means to fulfil environmental goals (see FM56(18)030_Digital Rail for Germany). As a result, the evaluation and introduction of new services as, e.g. automation of train operation will be early, i.e. already starting during the transition phase.
 - The large number of neighbouring countries with their individual RMR deployments might result in restrictions on network migration plans.
 - Cross-border coordination, multiple dense areas, six TEN-T Core Network Corridors (see figure 7) and major tracks crossing downtown areas result in frequent high RMR demand areas in combination with deployment restrictions.
 - National operator agreements: pre-assigned and fixed GSM-R frequencies to prevent MNO interferences.
 - The heavily used sub 2GHz spectrum for public mobile communications results in coexistence problems. In addition, acquiring new base station sites (in competition with the MNOs) is difficult, expensive, and takes time.
- d) Current GSM-R radio BS configurations typically use one or two GSM-R radiofrequency carriers per cell. In dense areas, up to 4 GSM-R radiofrequency carriers per cell are necessary. The GSM-R deployment in Germany is designed to meet the EIRENE specifications. The GSM-R cell radius is in the range of a few hundred meters to several kilometres and varies significantly. Densification of radio sites is expensive, time consuming and not always possible.
- e) As recommended in ECC Report 229 (*Guidance for improving coexistence between GSM-R and MFCN in the 900 MHz band*), DB Netz AG has successfully established a national coordination and cooperation process between MNOs and GSM-R operator. The whole 2x7 MHz GSM-R spectrum as of today is covered by the national coordination process. Coordinated deployment of all 900 MHz radio sites takes place in an area of up to 2075m around operational railway lines. DB Netz AG strongly recommends national operator agreements to prevent an uncoordinated deployment of different radio systems in the rail environment.

- f) DB Netz AG is in an ongoing nation-wide reinvest programme for all GSM-R base stations since 2015. The programme involves the total length of ca. 30 000 km of the German railway network with GSM-R radio coverage. The new base station technology has been tested in a specialised test floor at DB premises and is being rolled out since summer 2018 in first test areas under railway-operational conditions. After finalising the nation-wide reinvest programme, every GSM-R base station will be able to use the full range of 2x7 MHz GSM-R spectrum. Due to the coordinated deployment in railway environment, DB Netz AG does not expect additional power restrictions for BS operating below 921 MHz.
- With the implementation or further development of the six rail Freight Corridors leading through Germany, DB Netz AG is actively involved in the implementation of the EU regulation. An overview of the Rail Freight Corridors running through Germany (content of EU Regulation 913/2010) is shown in figure 7 below.

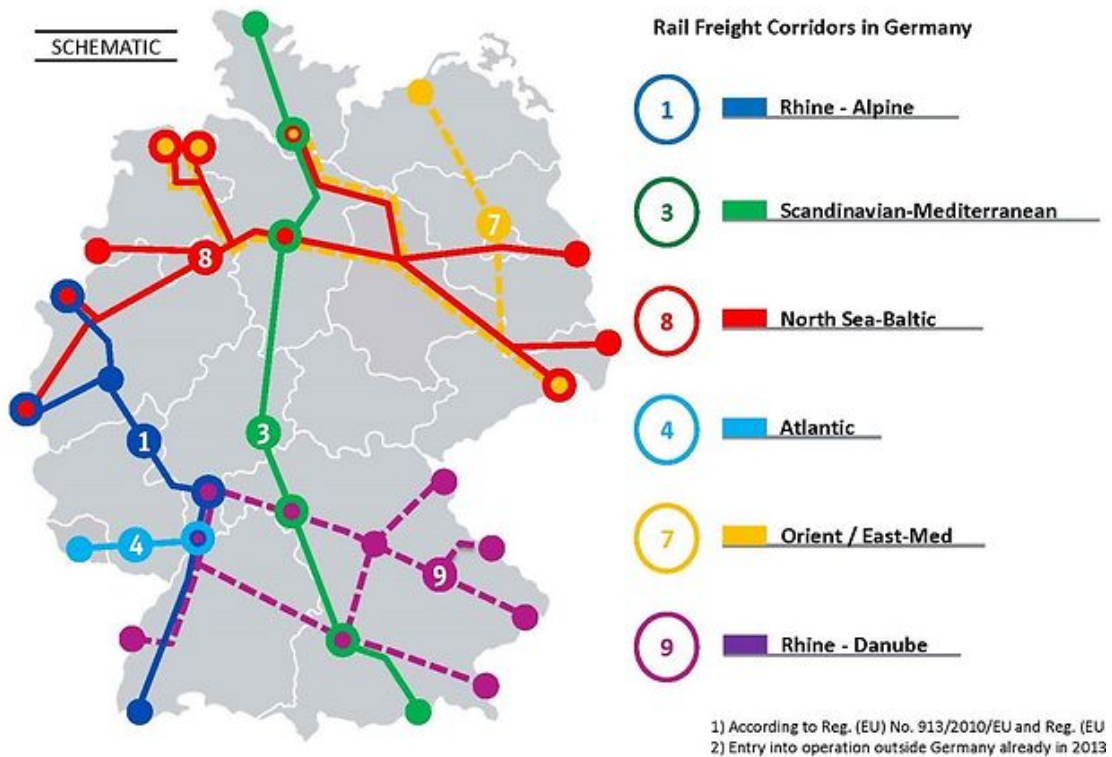


Figure 7: Rail Freight Corridors in Germany¹⁷

Considering the key aspects of capacity, frequency co-ordination and coverage planning, the operational GSM-R network of DB Netz AG shows a heterogeneous structure. Up to a distance of 50 km from the borderline, frequency co-ordination limitations are present. Derived from the highest categories of railway stations with high amount of trains and the largest train formation yards, the multiple dense areas and the cross border areas in the GSM-R radio network of DB Netz AG are shown in the following figure.

¹⁷ https://fahrweg.dbnetze.com/fahrweg-en/customers/international/europ_corridors/europ_corridors_allg-1418368

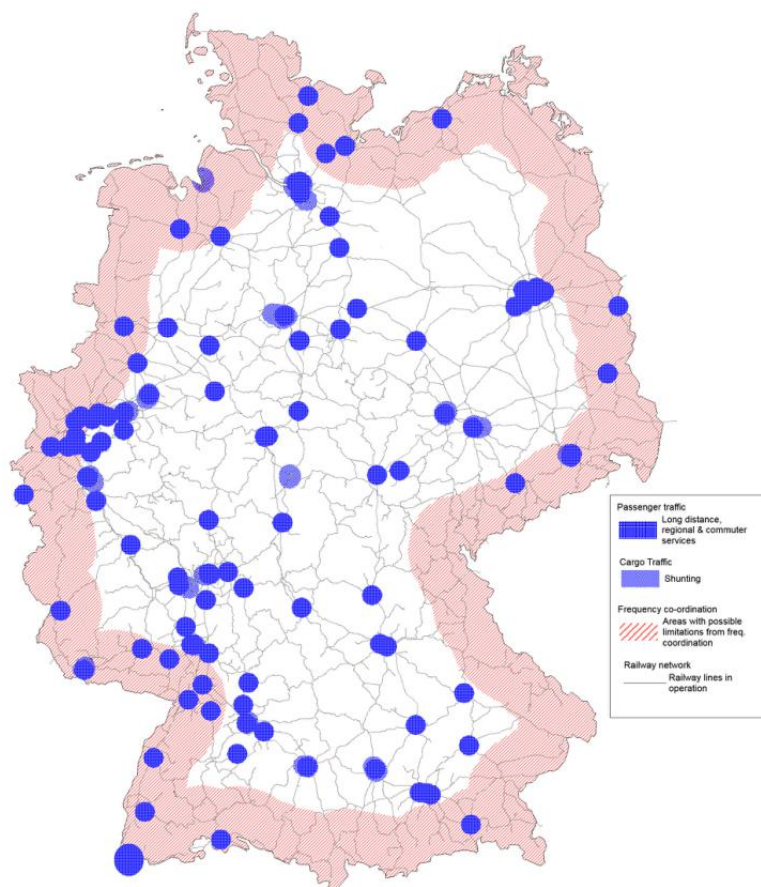


Figure 8: Multiple dense areas and cross-border coordination areas

The evaluation of the areas as shown in the figures 7 and 8 results in the necessity of additional RMR spectrum. Further constraints result from the fact that some dense traffic areas are located in the cross-border coordination areas. Additionally, the heavy transit rail traffic on the rail freight corridors contributes to the demand of spectrum needs. This leads to an even worse frequency shortage.

From today to the end of the migration period, several of the increasing services and applications running on the GSM-R radio network are mission-critical and therefore safety related. Therefore, highest quality for GSM-R voice and data communication is needed, particularly for emergency calls, shunting communication, ETCS Level 2 and other railway specific services and applications. During the migration period, which is expected to last from five to ten years, both the current GSM-R radio network and the successor technology need to be operational in parallel. Therefore, interference-free frequency bands for both GSM-R and FRMCS are essential.

A3.2 GPRS EVOLUTION

For selected parts of the network, DB Netz AG is evaluating a potential migration towards GPRS in order to increase the available capacity of the GSM-R network and to resolve some of the cases of today's spectrum and capacity shortage (mainly targeting ETCS Level 2 operation in dense areas). The achievable capacity gains are, however, limited by the availability of a sufficient PS¹⁸ backbone and the limitations of the link budget which do not allow to use all modulation and coding schemes. Densification and backbone retrofitting are expensive, not always possible, and result in critical timing and planning uncertainties. The need for trans-European interoperability results in additional restrictions.

¹⁸ packet switched

A3.3 DATA THROUGHPUT COMPARISON BETWEEN GSM-R AND 1.4 MHZ / 3 MHZ LTE CARRIERS

- a) DB Netz AG considers 5G as the preferred FRMCS technology. Since performance results for 5G railway solutions are not yet available, LTE is used as reference within this Annex.
- b) It is expected that the limiting factor in terms of requirements will be the uplink, both for throughput to be accommodated and for radio link performance.
- c) In the LTE/GSM-R coexistence study done for ERA¹⁹, it was estimated on a planning case study that a LTE 1.4 MHz carrier would provide 200 kbps uplink throughput at the cell edge. ETSI results indicate that a LTE 1.4 MHz at 900 MHz in railway environment could accommodate UL traffic in the range 0,3..0,4 Mbit/s²⁰.
- d) Table 12 provides a summary of the expected uplink throughput under various network configurations for an existing GSM-R site. As representative dense area scenario, the region of Seelze is considered. Seelze is located in the northern part of Germany near Hannover and is an important turntable for railway traffic. In order to meet today's traffic demand, four GSM-R radiofrequency carriers (TRX) are in use for the radio site "Seelze Rbf" in order to support the capacity requirements for the large shunting yard and train formation area. The envisaged additional ETCS traffic will require a fifth carrier to be deployed in the 873-876 MHz / 918-921 MHz.

Table 12: Expected uplink throughput

Traffic supported and implementation	Uplink throughput
Maximum current data throughput available on a DB Netz AG existing GSM-R radio site 4 TRX in the harmonised 2x4 MHz Voice applications: train radio, shunting radio, operational radio; data applications	24x12,2 kbit/s (voice) + 6x9,6 kbit/s (data) + 8 kbit/s (signalling) ⇒ ca. 360 kbit/s (net)
Expected maximum data throughput including evolution to GPRS on modernized GSM-R network GPRS system multiplexing gain: up to 4 ETCS concurrent sessions 4 TRX in the harmonised 2x4 MHz and 1 TRX in the 2x3 MHz below GSM-R applications as above + additional ETCS deployment as planned for dense areas (without future services)	24x12,2 kbit/s (voice) + 6x9,6 kbit/s (data) + 8 kbit/s (signalling) + 4x4 kbit/s ETCS PS-mode + 4x4,8 kbit/s ETCS CS-mode ⇒ ca. 400 kbit/s (net)
Reference: Estimated data throughput for a LTE 1.4 MHz carrier at 900 MHz range and in a railway environment	200 kbit/s /site (LS Telecom study) 300 to 400 kbit/s / site (ETSI TR 103 554 V1.1.1)

It can be concluded that neither today's traffic nor the traffic demand expected from the continuing ETCS deployment (combined with GPRS) can be covered by even the most optimistic LTE 1.4 MHz carrier capacity.

¹⁹ Coexistence of GSM-R with other communication systems, final report for ERA (ERA 2015 04 2 SC), 2016, page 119

²⁰ ETSI TR 103 554 V1.1.1 (2018-08) [11]

A3.4 TRANSITION PERIOD

- a) The main coverage spectrum for FRMCS should be in the sub-GHz range.
- b) DB Netz AG has designed its GSM-R network in accordance with the EIRENE requirements. Migrating to a higher frequency band would require acquiring a significant amount of new radio sites. This will be costly, result in timing uncertainties, legal disputes and might in some cases where tracks are crossing dense urban areas, even be impossible. Thus, it is essential for DB Netz AG that FRMCS allows reusing as much as possible existing sites and infrastructure.
- c) For the transition period, DB Netz AG will – in particular as Germany is an important transit country – have to support GSM-R in parallel to FRMCS.
- d) DB Netz AG has already announced an early deployment of future services, starting before or during the transition period e.g. developing of fully automated S-Bahn line in Hamburg. Under the "Digital S-Bahn Hamburg" project, trains will operate on the future European Automatic Train Operation (ATO) standard in combination with European Train Control System (ETCS) Level 2²¹.
- e) According to table 12, two 2x1.4 MHz LTE (or equivalent) or one 3 MHz LTE carrier channel would be necessary to support the capacity already today supported by GSM-R in dense areas taking already planned ETCS Level 2 deployments but also capacity gains achievable by GPRS into account.
- f) It is expected that the deployment of future services, such as critical video based automated train operation, will also in the longer term and in rural areas only be economically viable when using spectrum below 1 GHz. Even if it is assumed that critical video transmission will initially only apply to a subset of trains, and that this will be able to adapt to instantaneous connectivity conditions and gracefully degrade down to data rates around 1 Mbps per train, it is hence obvious that during the migration period and at least for rural areas 2x7 MHz spectrum below 1 GHz has to be maintained.
- g) In dense areas, where the penetration of critical video usage is expected to pick up early in the migration phase, an additional spectrum of at least 10 MHz at below 2 GHz will be needed.

A3.5 LONG-TERM SITUATION

- a) DB Netz AG is in mid- to long-term expecting a continuing significant growth in railway traffic and a need to increase the train operation efficiency. This trend is strongly promoted by the transport policy of the German government as well as a growing railway capacity is seen as a significant means to address several societal challenges as European integration and climate goals.
- b) DB Netz AG is expecting future additional services as the automation of train operation as key enabler to meet these societal requirements. Additional and new RMR services (e.g. critical video services) will be required to implement these services and applications.
- c) In order to be able to smoothly introduce these new RMR services while preserving the support for existing services within the existing planning and economic framework, it is necessary to reuse the existing infrastructure and to limit in particular the time consuming and costly acquisition of new radio sites to the absolute minimum extent possible.
- d) Therefore, keeping the 2x7 MHz spectrum below 1 GHz is essential. Future spectrum should be in a spectrum as close as possible to this spectrum, preferable below 2 GHz.
- e) DB Netz AG is committed to support the UIC efforts to identify future services (including their traffic demand) and the options to implement them. It foresees that only for a part of the future services the traffic demand can be identified today and that future spectrum demand will become obvious during the introduction of future services. For the already foreseeable future services an additional 20 MHz spectrum band below 2 GHz might be sufficient.
- f) A need for spectrum in the 40.5-43.5 GHz range is currently not identified. This spectrum band would not allow to support applications currently supported in the sub 1 GHz or even sub 6 GHz band.

²¹ <https://www.railjournal.com/index.php/metros/db-and-siemens-to-develop-fully-automated-s-bahn-line-in-hamburg.html?channel=532>

A3.6 IN SUMMARY

Table 13 summarises the spectrum demand and expected solutions.

Table 13: Summary

	Demand	Supply
Today including already planned ETCS deployments		
Main lines	1 to 4 GSM-R carriers (including planned ETCS Level 2 deployments)	2x4 MHz GSM-R (or below 1 GHz)
Dense areas	1 to 4 or more GSM-R carriers (including planned ETCS Level 2 deployments and taking into account ongoing migration of services still supported by analogue networks)	2x7 MHz GSM-R (or below 1 GHz) already taking GPRS performance gains into account
During migration period towards FRMCS		
Main lines	Capacity identical as above + same capacity for FRMCS + additional ETCS Level 2 deployments + initial deployments of future services	2x4 MHz GSM-R (or below 1 GHz) + 2x1.4 MHz below 876/921 MHz (or below 1 GHz) + 10 MHz below 2 GHz or 2x4 MHz GSM-R (or below 1 GHz) + 2x 2x1.4 MHz / 2x3 MHz below 876/921 MHz (or below 1 GHz)
Dense areas	Same as above with even more future service deployments	2x7 MHz GSM-R (or below 1 GHz) + at least 10 MHz below 2 GHz
Long-term RMR (additional demand might become identified long-term)		
Main lines	Same as above, which needs to be implemented below 1 GHz + significant future service deployments	Same as above, but minimum of 20 MHz below 2 GHz
Dense areas	Same as above, which needs to be implemented below 1 GHz + significant future service deployments	Same as above, but minimum of 20 MHz below 2 GHz

ANNEX 4: LIST OF REFERENCES

- [1] Directive 2016/797/EU on the interoperability of the rail system within the European Union
- [2] Directive 2008/57/EC on the interoperability of the rail system within the Community
- [3] Directive 2014/53/EU on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC
- [4] Commission Regulation 2016/919/EU on the technical specification for interoperability relating to the 'control-command and signalling' subsystems of the rail system in the European Union
- [5] EIRENE FRS v8.0.0: "Functional Requirements Specification"
- [6] EIRENE SRS v16.0.0: "System Requirements Specification"
- [7] Mandate to CEPT on spectrum for the future railway mobile communications system, RSCOM18-05 rev.3 Final
- [8] Commission Decision 1999/569/EC on the basic parameters for the command-and-control and signalling subsystem relating to the trans-European high-speed rail system
- [9] ECC Decision (02)05: "The designation and availability of frequency bands for railway purposes in the 876-880 MHz and 921-925 MHz bands"
- [10] FW-ATwG 1903 v2.2.0 / FM56(18)065: "FRMCS Traffic Analysis"
- [11] ETSI TR 103 554: "LTE radio performance simulations and evaluations in rail environment"
- [12] FRMCS User Requirement Specifications, UIC, v3.0
- [13] BEREC and RSPG joint report on Facilitating mobile connectivity in "challenge areas", BoR (17) 256 / RSPG18-001
- [14] Directive 2012/34/EU of the European Parliament and of the Council establishing a single European railway area
- [15] Commission Implementing Decision (EU) 2018/1538 of 11 October 2018 on the harmonisation of radio spectrum for use by short range devices within the 874-876 and 915-921 MHz frequency bands (OJ L257, 15 Oct. 2018, p. 57)
- [16] Decision 676/2002/EC of the European Parliament and of the Council of 7 March 2002 on a regulatory framework for radio spectrum policy in the European Community (Radio Spectrum Decision)
- [17] Commission Delegated Decision (EU) 2017/1474 of 8 June 2017 supplementing Directive (EU) 2016/797 of the European Parliament and of the Council with regard to specific objectives for the drafting, adoption and review of technical specifications for interoperability
- [18] Commission Decision 2009/766/EC of 16 October 2009 on the harmonisation of the 900 MHz and 1800 MHz frequency bands for terrestrial systems capable of providing pan-European electronic communications services in the Community (OJ L274, 20 October 2009, p. 32)
- [19] Commission Implementing Decision (EU) 2018/637 of 20 April 2018 amending Decision 2009/766/EC on the harmonisation of the 900 MHz and 1800 MHz frequency bands for terrestrial systems capable of providing pan-European electronic communications services in the Community as regards relevant technical conditions for the Internet of Things (OJ L105, 25 April 2018, p. 27).