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1 INTRODUCTION

The purpose of this document is to help railway Infrastructure Managers (IMs) in making their decisions for the migration scenario from their current GSM-R network to a new FRMCS network, focusing specifically on the radio network aspects. In addition to this document that focusses on the migration itself, the accompanying whitepaper radio network technical aspects O-8868 addresses various technical aspects relevant for the FRMCS radio network.

Based on the EU Decision 2021/1730 [Ref 1], which itself is based on ECC Decision (20)02 [Ref 2], Member States shall designate and make available on a non-exclusive basis radio spectrum for FRMCS in the 900 MHz and 1900 MHz frequency bands. Both bands are intended to be used both during and after the migration from GSM-R to FRMCS.

With these spectrum options the question arises what the pro's and con's are of using these bands for performing the migration from GSM-R to FRMCS.

This document first introduces possible migration scenarios at a high level and continues with considerations regarding the use of the 900 MHz and 1900 MHz frequency bands within the IMs home country. At the time of writing the usage of MNO services has not been addressed as this is regarded to be For Further Study (FFS). A separate chapter is dedicated to cross-border scenarios. After this, a separate chapter addresses aspects related to the train on-board equipment. Additional detailed information is provided in Annexes 2, 3 and 4.

Please note that the starting point for this document is the general end-to-end architecture and 5G mechanisms as described in the UIC FRMCS v1 specifications.

With the information in this document IMs should be enabled to optimize their migration strategy and usage of FRMCS / 5G capabilities reflecting their operation needs. This document does not intend to propose a single solution for an IM. It identifies some possible approaches for the migration from GSM-R to FRMCS with some technical background information. It is expected that each IM, considering their specific national constraints and opportunities, will be able to determine the most desirable migration strategy with this document in combination with the accompanying more technical document O-8868 UGFA Report technical aspects FRMCS RAN [Ref 12].

As it is expected that over time additional insight and subjects will be developed this document will be a living document.

2 MIGRATION OPTIONS

2.1 WHERE DO WE START FROM?

Railway IMs are operating, and in some cases still installing or expanding, their GSM-R networks. For the introduction of FRMCS not only the network infrastructure but also the train on-board equipment needs to be either enhanced or replaced to support FRMCS. As this is a complex and time-consuming process, in most cases it will be necessary to operate the GSM-R and FRMCS radio network in parallel for a period of time to ensure continuous railway operations for national and for international trains.

Some IMs may still be operating other mobile radio networks (e.g., analogue, TETRA or MNO based) for non-interoperable services, that they may also want to migrate to FRMCS. This document focuses only on the migration of interoperable services from GSM-R to FRMCS.

A key requirement for migration is that the impact on the railway operation is minimized, hence the impact on the operation of the existing GSM-R networks needs to be minimized. More specifically this implies that during the migration (unless decided differently at a national level):

- GSM-R service interruption must be avoided
- the GSM-R Service quality and coverage levels should be kept at or above a minimum quality requirement according to EIRENE or be maintained at a level equivalent to the situation before migration as determined by national needs.
- railway interoperability must be maintained.

This document will highlight several aspects related to these needs.

In addition to the above, an IM's migration strategy will need to reflect the requirements and constraints implied by the new CCS TSI of 2023 [Ref 3] and its evolution.

2.2 MIGRATION OPTIONS

For the migration several main options or scenarios can be identified as indicated below. These scenarios may be applied on a railway line, regional or national basis.

a) Scenario A: Migration using the 900 MHz band: simultaneous operation of both GSM-R and FRMCS in the 900 MHz band. After the migration period the GSM-R network will be switched-off.
b) Scenario B: Migration using the 1900 MHz band: operation of FRMCS only in the 1900 MHz band and continued operation of GSM-R in the 900 MHz band. After the migration period the GSM-R network will be switched-off and FRMCS deployed in both the 900 MHz and 1900 MHz bands.
c) Scenario C: Migration using both 900 MHz and 1900 MHz bands: simultaneous operation of both GSM-R and FRMCS in the 900 MHz band plus FRMCS in the 1900 MHz band. After the migration period the GSM-R network will be switched-off. Both the 900 MHz and 1900 MHz FRMCS bands will continue to operate.
d) Scenario D: Migration using MNO services: simultaneous operation of FRMCS based on MNO services, using one or more MNO frequency bands, in parallel with GSM-R during the migration period. After the migration period the GSM-R network will be switched-off. After GSM-R switch-off, the FRMCS system will continue operation, using the MNO services.
e) Scenario E: Migration using a hybrid configuration: hybrid operation using both GSM-R in the 900 MHz band and FRMCS in the 1900 MHz band together with MNO based services.

This document will only address scenarios A, B and C. As scenario D has no specific implications for the existing GSM-R network other than the switch-off process it will not be further discussed in this document apart from the MNO service usage aspects which are FFS. The hybrid scenario E is also FFS.

Of course, all these scenarios may be combined within an IMs national network.

In addition to these scenarios an IM may need to provide additional traffic handling capacity (e.g., for less critical applications) by using MNO services in one or more MNO frequency bands. As this too does not have migration implications it also is out of scope of this white paper.

The suitability of these scenarios and their implementation characteristics are expected to vary for urban, rural, and high-speed cases. Also, the availability of RMR spectrum may vary within an IM's country.

Furthermore, several local, regional, or country specific constraints may impact the selection of a migration scenario, possibly related to factors such as:

- Constraints on duration of migration phase (e.g., related to GSM-R end of life)
- Ability and timeline of Railway Undertakings (RUs) to implement FRMCS
- To what extend existing infrastructure assets can be re-used, and new infrastructure e.g. masts need to be introduced
- Interoperability constraints
- The growth rate of railway critical applications / services
- Functional and/or technical constraints on available infrastructure or user equipment
- Financial constraints.

For any migration scenario it is essential that appropriate equipment is available, both for the network infrastructure and for the on-board and, where considered, handheld devices. For these it is essential that the two RMR frequency bands are supported whilst meeting the requirements from 3GPP and the EU Decision 2021/1730. Especially for the on-board and handheld devices this implies that the current market available chipsets need to be enhanced. Discussions on this subject have been started with chipset vendors. Following current plans for FRMCS introduction, the chipsets for On-Board FRMCS are needed for latest mid-Q2 2025.

3 MIGRATION WITHIN A COUNTRY

3.1 INTRODUCTION

For the migration from GSM-R to FRMCS within the IM's home country both the RMR 900 MHz band (3GPP band n100: 874.4- 880 MHz paired with 919,4 – 925 MHz) and the 1900 MHz band (3GPP band n101: 1900 – 1910 MHz) may be used. This section will address several aspects related to the use of these two bands.

The potential usage of FRMCS based on MNO services using one or more MNO frequency bands is FFS.

3.2 MIGRATION USING THE 900 MHZ BAND

3.2.1 Introduction

Both scenarios A and C will make use of the 900 MHz band, therefore this section will address some specific aspects applicable to this band, notably:

- Possibilities to migrate in the 900 MHz band
- Differences between 5G NR and GSM-R

3.2.2 Possibilities to migrate in the 900 MHz band

The current GSM-R networks of all European IMs (except Finland) use the full 2x4MHz of the UIC GSM-R band. That would leave 2x1.6 MHz of spectrum in the RMR 900 MHz band that could be used for FRMCS. Note that some IMs even use (part of) the E-GSM-R band.

However, as FRMCS is based on 5G NR technology the current smallest channel bandwidth for RMR is 5 MHz. To solve this mismatch two possible approaches have been identified:

- The use of a 5G NR channel bandwidth smaller than 5 MHz
- The use of a smart combination of both GSM-R and 5G NR carriers in the 2x5.6 MHz

3.2.3 5G NR Channel bandwidth smaller than 5 MHz

During the course of the design of 5G New Radio (NR), an assumption was made that 5 MHz would be a reasonable minimum bandwidth. However, this had the inadvertent effect of locking out specialized mobile networks having less than 5MHz of spectrum from the 5G ecosystem and the benefits of 5G and left the already deployed networks with no upgrade path for the future. These networks include, other than the railways, smart utility grid control and emergency services.

3.2.3.1 Concept for 5G NR Channel bandwidth smaller than 5 MHz Scheme

Several design changes are necessary to facilitate the deployment of 5G NR in spectrum narrower than 5 MHz, but these changes should be minimized so that the established 5G NR ecosystem of devices and infrastructure can be efficiently leveraged without major changes in implementation. All of these changes will be made within 3GPP, thereby ensuring full interoperability between vendors and minimum guaranteed performance for RF and demodulation aspects.

The current, planned timeline for this work item in 3GPP is as follows: the RAN WG4 led work item will be completed by mid-2024. After that group is finished, the specifications are ready for the network side, however, RAN WG5 will need an additional 3-6 months to work on the UE specifications. When RAN WG5 has completed their work, the specifications are ready for supplier implementations, which is expected for the second half of 2024 as part of 3GPP R18..

An illustration of the in-band coexistence for n100 during the migration from GSM-R to FRMCS using this approach can be seen in the following figure:

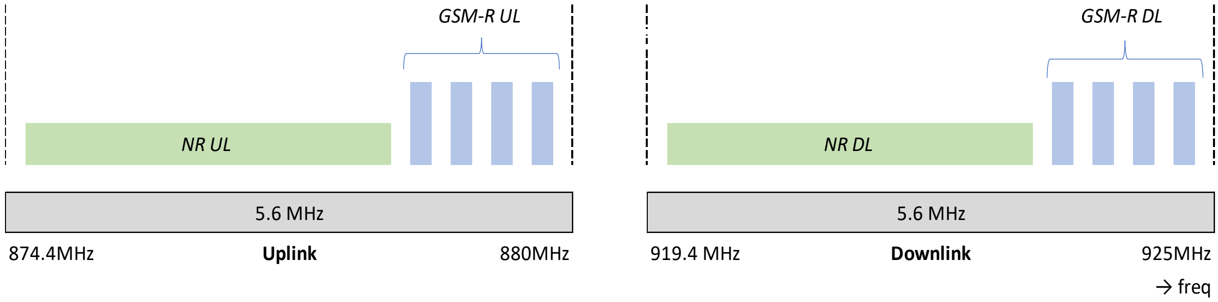

Figure 1: Planned frequency arrangement for the co-existence within n100.

As can be seen in figure 1, the NR carrier with the narrower than 5MHz bandwidth is to be located at the lower end of the spectrum[1], while the higher end remains to be utilized by GSM-R carriers. This allows GSM-R to continue using at least part of its current spectrum portion. The gaps within the GSM-R block are intended to illustrate that not all GSM-R channels may be actively used in all of the deployments.

This approach is envisaged to support a block of up to 12 contiguous GSM-R carriers at the upper edge of the band, while providing at least 15 PRBs of contiguous spectrum for FRMCS at the lower edge of the band, or a block of up to 14 contiguous GSM-R carriers with at least 12 PRBs of contiguous FRMCS spectrum.

At the time of writing, work is ongoing in 3GPP RAN WG1/WG4 on this topic, and the accepted minimum FRMCS bandwidth depends on the outcome of the group's work. In both cases, GSM-R ARFCN 973 is assumed to be the highest channel number. The number of GSM-R carriers which can be supported will also depend on the required guard band width[2] between FRMCS and GSM-R. As the migration progresses, and more traffic is shifted to FRMCS from GSM-R, the concept allows the reduction of the number of GSM-R carriers and the additional spectrum could be allocated to FRMCS by replanning. The operation of both GSM-R and FRMCS is fully independent from the other, thereby enabling multi-vendor deployments.

3.2.4 900 MHz 5G NR overlay to GSM-R

Another approach to enable migration within the 900 MHz RMR band may be to use a smart combination of both GSM-R carriers and 5G NR resource blocks (RBs) in the 2x5.6 MHz band. In ETSI TC RT this has been addressed by the so-called Concept for GSM-R and LTE Coexistence Scheme proposed by Kontron (RT(21)082035_Kontron_Final_Whitespace_report [Ref 4])

[1] Note that this lower part of the frequency band may be subject to a somewhat lower max. EIRP as per the EU Decision 2021/1730.

[2] Note that the necessary guardband between FRMCS and GSM-R is assumed to be 200kHz but also is for further study.

3.2.4.1 *Concept for 5G NR overlay to GSM-R Scheme*

The concept for the 5G NR overlay to GSM-R scheme entails deploying a 5G NR carrier over the GSM-R spectrum on GSM-R sites to offer extra services thanks to 5G technology while preserving GSM-R KPIs.

This is achieved through advanced scheduling techniques (e.g., reflecting the actual GSM-R usage; basic assumption being a static 5G NR RB allocation) in the base station to protect GSM-R carriers while remaining compatible with standard 5G NR FRMCS handsets and cab radios while providing a capacity of the magnitude of several hundred kbps.

The main goal of this scheme is to allow a smooth introduction of the FRMCS technology inside the GSM-R band without impacting the GSM-R performance.

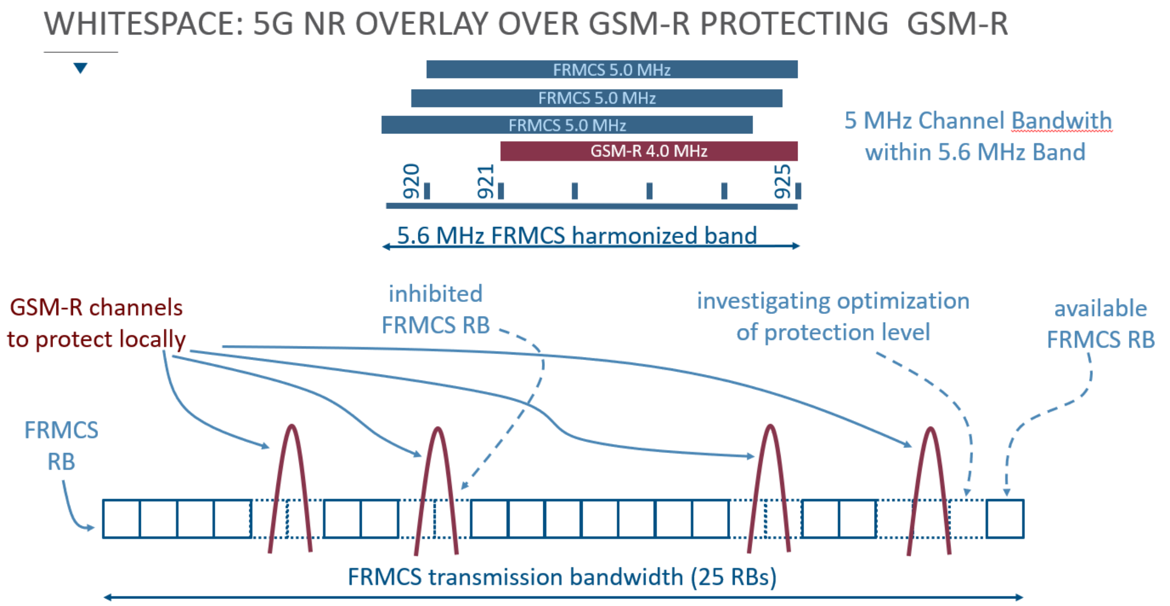

Figure 2: The concept for 5G NR overlay to GSM-R scheme.

This concept has been discussed within ETSI TC RT and test results have been provided in TC RT documents, see document ETSI TC RT RT(21)082035_Kontron_Final_Whitespace_report [Ref 4]. Although the work in ETSI TC RT was focussed on coexistence with LTE, at the time of writing, work is ongoing to verify the performance of this scheme for 5G NR.

Furthermore, at the time of writing, work is ongoing in a French – German project (5G-RACOM) until 2025 to verify the performance of this scheme for 5G NR.

3.2.5 900 MHz traffic distribution

For both above-described solutions it is important to understand the traffic distribution between GSM-R and FRMCS in the 900 MHz band. During the migration period, train on-board equipment will need to be updated to support FRMCS. To enable switch-off of the GSM-R network, an IM will have to issue a notification to the Railway Undertakings (RUs) prior to the planned switch-off date, as per the conditions laid down in 2023 CCS TSI. Until that date the RU's vehicles may, for example, be able to use a mix of GSM-R and FRMCS for their operational tasks, e.g. using GSM-R for voice and FRMCS for data (ETCS, ATO) instead of using either GSM-R or FRMCS for *all* the operational traffic needs of a train.

Such a split of traffic may create an uncertainty for the IM's 900 MHz band network planning. (as example, minimum number of timeslots required to operate ETCS over CSD depending on traffic density, or minimum radio resources required to support services like a REC call).

As the CCS TSI 2023 does not impose a restriction on such traffic split and given the IMs possible need to limit the usage of GSM-R, an IM could beneficially incentivise the RUs to make full use of FRMCS as soon as it becomes available.

3.2.6 Differences between 5G NR and GSM-R

When comparing the characteristics of a GSM-R network with an FRMCS 5G NR network several key differences can be noticed:

- Different link budget leading to densification
    - In GSM-R networks using 39dBm / 200kHz GSM-R cab radio the uplink and downlink link budgets are usually in balance which means that downlink and uplink coverage are similar.
    - In FRMCS 900 MHz network the system in principle is uplink limited even with +31 dBm / 5MHz UE transmitting power.
    - The FRMCS 900 MHz network coverage range may be made approximately the same as GSM-R, but the limiting factor may be the required date rate at the cell edge. The achievable coverage and data rate are depending on many different factors and need to be verified on a case-by-case basis using radio network planning tools.
    - Additional information on the link budget will be provided it the accompanying Whitepaper Radio network technical aspects O-8868.
- Need for equal power GSM-R and 5G NR: there is a need to have equivalent downlink signal levels in order to limit the mutual disturbance between 5G NR and GSM-R UE/mobile stations where both systems are used simultaneously in the same area. This implies to have the same location of 5G NR gNode B and GSM-R BTS and almost same EIRP for both systems. These technical coexistence conditions are described in document doc O-8786 FRMCS coexistence with GSM-R in the UIC/E-UIC band [Ref 10].
- Need to determine the radio coverage based on the required service set per track instead of the GSM-R EIRENE predefined coverage signal level
- Uplink MIMO and/or CoMP may be used to enhance Uplink performance in 5G NR, Downlink MIMO can be used to enhance Downlink throughput (see IEEE VTC paper "Field Study on Multi-Antenna Radio Technologies for Future Railway Communications at 1.9 GHz" by DB Netz) and/or: ETSI RT(22)086027 Field Trial Results for Uplink Receiver Diversity / Uplink SIMO and Uplink CoMP at 1.9 GHz).

3.2.7 Impact of 900 MHz migration approaches on existing GSM-R network

3.2.7.1 Impact on number of GSM-R channels

For both migration approaches described in sections 3.2.3 and 3.2.4 there may be a need to reduce the number of GSM-R channels from the currently used number of channels. This clearly is related to the traffic capacity requirements on the IM's GSM-R network. In Annex 2 some IM information is provided on the GSM-R capacity needs and hence the ability to limit the number of GSM-R channels. This leads to the following high-level conclusions:

- Some IMs make use of the full set of 19 GSM-R channels in some areas (e.g., high-density, urban) to provide the needed traffic capacity at the desired QoS level while there is no possibility to transfer critical traffic from GSM-R to FRMCS. In these cases, insufficient spectrum is available to support a 5G NR channel bandwidth smaller than 5 MHz.
- Some IMs could free up some GSM-R channels, however that would require replanning and adjustment in the field of the existing GSM-R radio network with potential impact on GSM-R Service quality.
- Some IMs only use a subset of the 19 GSM-R channels in some areas and therefore probably have sufficient unused spectrum to support both their few GSM-R channels plus the 5G NR channel within the 5.6 MHz RMR spectrum.

The available number of GSM-R channels may further be impacted by the size of the guard band that is necessary between the 5G NR carrier and GSM-R. This subject is FFS.

3.2.7.2 Impact on GSM-R radio planning and certification

Any reduction in the number of used GSM-R channels will require a replanning and adjustments in the field of the existing GSM-R radio network with potential impact on GSM-R Service quality. Annex 3 provides additional information on this network replanning aspect. It is to be noted that the GSM-R frequency replanning can cause a domino effect to adjacent areas of the radio network when the IM wants to preserve the QoS.

As GSM-R networks contribute to the safety of railway operation, replanning the radio network may necessitate the formal renewal of the national safety authority's approval for both GSM-R and ETCS level2 operation. This would require dedicated measurement campaigns with measurement reports for each railway track during the migration period.

3.2.8 Listing of characteristics

The following table provides an objective overview of the various key characteristics applicable to the smaller than 5MHz channel bandwidth respectively the 5G NR overlay to GSM-R approaches. It is up to each IM to determine the respective benefits of these approaches related to the IM's specific needs and constraints.

Topics	Smaller than 5MHz channel bandwidth	5G NR overlay to GSM-R
Co-existence with GSM-R site	Both transmitters need to be located at the same radio sites	Both transmitters need to be located at the same radio sites
UL Power Control	To be activated for both GSM-R and FRMCS	To be activated for both GSM-R and FRMCS
3GPP Standard Requirement	Require the use of 3GPP Rel18 by the network and the devices	Require the use of 3GPP Rel17 by the network and the devices
Antennas	Shared or separate antenna between GSM-R and FRMCS	Shared or separate antenna between GSM-R and FRMCS
Multi-vendor Deployment between GSM-R and FRMCS	Independent deployments allowing multi-vendor between GSM-R and FRMCS	Independent deployments allowing multi-vendor between GSM-R and FRMCS
FRMCS EIRP (compared to GSM-R)	To be determined over the course of the 3GPP work	FRMCS EIRP (in 5MHz) must be adjusted to be within 0 to -3dB from the existing GSM-R EIRP (in 200kHz)
RF Boundary	Single RF boundary between GSM-R and FRMCS	Multiple RF boundary between GSM-R and FRMCS
FRMCS Spectrum	Contiguous FRMCS spectrum provided. 5G carrier may be placed at the bottom of the 2x5.6MHz	Requires several non-used GSM-R channels. The 5G NR carrier may be placed at the bottom of the 2x5.6 MHz
Configuration of FRMCS	Network-wide configuration needs to be defined for NR	Configuration of the 5G NR carrier needs to be done as part of the site commissioning

Table 1: Listing of characteristics

3.3 MIGRATION USING THE 1900 MHZ BAND

3.3.1 Introduction

In scenario B the 1900 MHz frequency band may be used to migrate to FRMCS with a low impact[3] on the existing GSM-R spectrum usage. As this band is a TDD band the following specific aspects need to be considered:

- Time – and frame-synchronisation (especially in border areas – see section 4)
- Link budget / site densification relative to existing GSM-R sites
- Co-existence with adjacent systems

Note: these considerations are still valid after the migration phase

3.3.2 Synchronisation

For a TDD based network both time synchronisation as well as frame synchronisation (i.e. downlink and uplink RB allocation) are essential characteristics. Although a fully isolated network could assume any time base and frame structure, RMR networks will need to co-exist (and cooperate) with adjacent networks, notably at national borders. In those cases, synchronisation between the adjacent networks is essential.

Document O-8854 Generic RMR Arrangement process [Ref 9] describes this and defines the process to be followed to accomplish synchronisation between adjacent TDD RMR networks.

3.3.3 Link budget

For GSM-R networks the radio planning has been based on minimum coverage levels related to signal power levels as defined in EIRENE.

For wideband system such as 5G NR a different approach is necessary. In order to determine the radio planning for a specific railway track the following aspects need to be taken in to account:

- transmit power levels of the user devices, i.e. 23dBm or 31dBm EIRP
- impact of the current GSM-R ISDs versus the achievable coverage using the 1900 MHz band; for large ISDs (e.g. 6km) there may be a need for site densification at 1900 MHz, whereas for smaller ISDs (e.g. 2km) that need may not exist
- various technical details that will be provided in the accompanying whitepaper radio network technical aspects O-8868

3.4 MIGRATION USING BOTH 900 MHZ AND 1900 MHZ BANDS.

In migration scenario C, an IM may want to use both the 900 and 1900 MHz bands. Within an IM's radio network cases may exist where at some locations the 900 MHz band may beneficially be used while at other network locations the 1900 MHz band may beneficially be used. Examples of this are

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[3] Although the 1900MHz band in itself has no impact on the existing GSM-R network, some impact might result when using dual band 900 – 1900 MHz antennas

to solve topological difficulties or to isolate areas that use the 1900 MHz band to allow the usage of different TDD frame structures.

The following scenarios using a mix of the 900 MHz and 1900 MHz RMR bands can be distinguished:

- Performance optimization scenario
- Country border scenario
- Coverage limitation scenario
- Large tunnel scenario
- Capacity hotspot scenario

3.4.1 Performance optimization scenario

In this scenario, the FRMCS 900 MHz RAN has been rolled-out either partially or completely across the IM's network but for some parts of the network the IM may decide not to use the FRMCS 900 MHz band.

The reason for this situation, may be a large railway shunting area, a wide and important railway crossing, a dense urban zone or node, or a geographical area with a challenging geomorphology. In all these cases another solution than the FRMCS 900 may beneficially be chosen.

To provide FRMCS coverage in these areas where the FRMCS 900 RAN cells were not foreseen, one or more FRMCS 1900 cells should be used. As a result, the "branches" of railway track served by FRMCS 900 surrounding the FRMCS 1900 zone remain distant enough from each other to limit their mutual interferences and the FRMCS 1900 cells are contained within a central zone.

It is to note that this situation may also occur naturally if the IM has been rolling out the FRMCS 900 on a per line basis (e.g. for ETCS L2 service) and performed already the FRMCS line validations / homologations. If the lines are converging to a common node, then that node is a good candidate for rolling out FRMCS 1900 in the area for the reasons mentioned above so that no significant KPI degradation is experienced.

Figure 3: Performance optimization scenario

3.4.2 Country border scenario

Differences in the FRMCS implementation timelines between bordering countries may lead to complications: one specific country may be ready with its FRMCS 900 and FRMCS 1900 deployment at national level while a border country may still be running GSM-R (with potentially a high number of GSM-R carriers limiting the residual capacity to make rollout of a 900 MHz FRMCS network). Additionally, in some specific cases, GSM-R and FRMCS systems need to continue to operate in parallel during several years in order to respect the Interoperability constraints and the notification period to train’s companies.

For this scenario the FRMCS 900 MHz coverage in country A may be stopped at a certain distance from the border, creating an FRMCS 1900 MHz buffer at the border that protects the Country A FRMCS 900 from interference from country B's GSM-R network (and vice versa). Similarly, a 900 MHz buffer could be created in case the 1900 MHz band is predominantly used by the IMs.

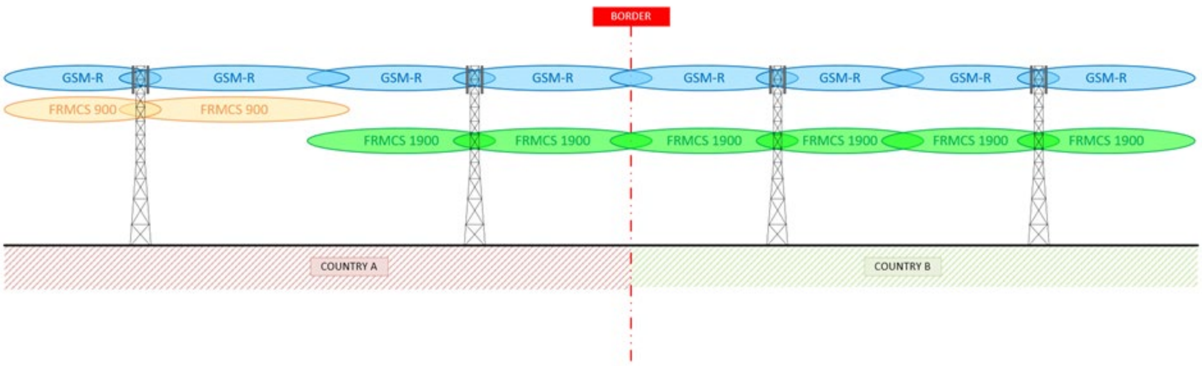

Figure 4: Country border scenario.

Further considerations related to the use of a 900 MHz FDD carrier, or a 1900 MHz TDD carrier are addressed in chapter 4 Cross border considerations.

3.4.3 Coverage limitation scenario

In this scenario, the FRMCS 1900 RAN has been successfully rolled out across the IM's network to minimize the impact of the FRMCS rollout on the GSM-R service.

The FRMCS 1900 RAN allows a near complete and near continuous coverage. There may however be FRMCS 1900 "loss of service" gaps between certain sites in very difficult radio environments, e.g., where no possibility exists to build a new mast. However, when using the 900 MHz band this location could provide adequate performance similar to the GSM-R 900 case. For such gaps the usage of FRMCS 900 cells may provide the necessary continuity of service, thus avoiding site densification.

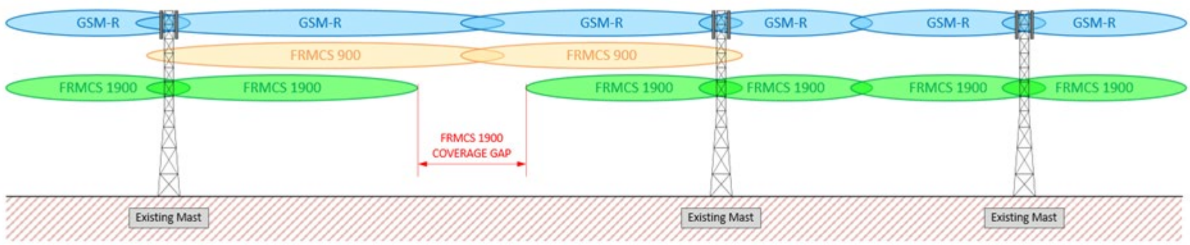

Figure 5: Coverage limitation scenario.

3.4.4 Large tunnel scenario

In this scenario, the FRMCS 1900 RAN has been successfully rolled out across the IM's network to minimize the impact of the FRMCS rollout on the GSM-R service.

The existing GSM-R network may also contain (large) tunnels that are covered by one or more BTS's that use a repeater system (optical or off-air) or a set of Remote Radio Heads.

The IM's analysis of the possibility to reuse the exact same GSM-R injection points in the tunnel for an FRMCS 1900 system may indicate an unacceptable coverage degradation. Note that the compatibility of existing passive components inside the tunnel with the 1900 MHz system may also be a problem, and hence needs to be checked for their suitability.

Like the coverage limitation scenario, the use of FRMCS in the 900 MHz band inside the tunnel may provide the necessary radio performance quality.

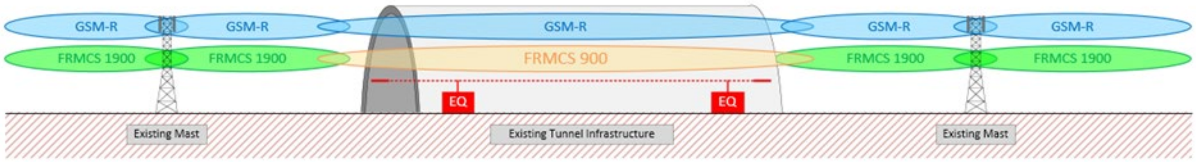

Figure 6: Large tunnel scenario.

Note that in case inside the tunnel the FRMCS 1900 TDD network would be continued it will be necessary to maintain accurate time synchronization with the cells outside of the tunnel. This may restrict the possible implementations to the use of remote radio heads or fibre fed repeaters.

3.4.5 Capacity hotspot scenario

In this scenario, the FRMCS 900 RAN has been successfully rolled out across the IM's network and ensures a complete and continuous coverage by itself. There are no FRMCS 900 "loss of service" gaps to be expected between sites.

In a network localized capacity hotspots may exist, e.g., at large railway stations, indoor coverage spots, shunting areas.

In such case, a localized overlay of one or several FRMCS 1900 cells may provide the capacity upgrade needed for the various services whilst not impacting the FRMCS 900 network used for the main railway track coverage.

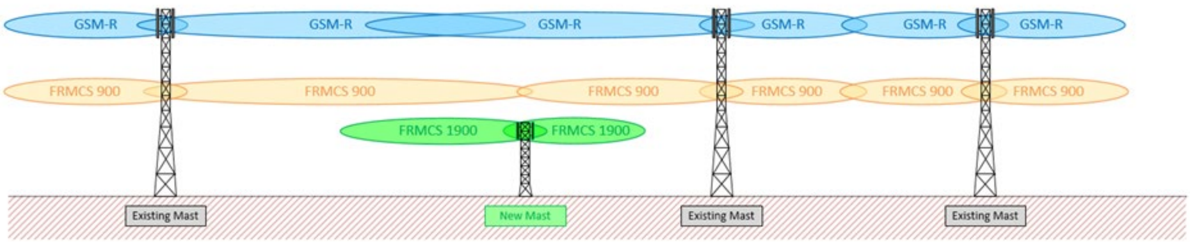

Figure 7: Capacity hotspot scenario.

3.5 MIGRATION USING MNO SERVICES

In scenario D the migration will be based on simultaneous operation of FRMCS based on MNO services, using one or more MNO frequency bands, in parallel with GSM-R. After the migration period the GSM-R network will be switched-off, and the FRMCS system will continue operation using the RMR frequency band(s).

The use of MNO services is FFS, and it is expected that as a minimum the following aspects need to be addressed for this scenario:

- Role of the MNO services:
  - Capacity enhancement for non-critical services
  - Fallback solution for critical services
  - Main layer for critical services
- Which MNO 5G frequency bands to use
- Performance and quality aspects
- Interaction with GSM-R
- Interaction with FRMCS networks that are using RMR spectrum
- Cross-border aspects, if considered
- Roaming aspects
- Cyber security aspects
- Maintenance aspects
- SLA aspects
- Need to change the GSM-R antenna configuration for the migration to FRMCS
- Multi-antenna gains

3.6 MIGRATION USING A HYBRID CONFIGURATION.

In scenario E, a hybrid configuration is created where MNO services are used for complementary or fallback functions combined with FRMCS. Similar to scenario D this scenario is FFS.

3.7 CO-EXISTENCE CONSIDERATIONS.

As with any radio network FRMCS will have to ensure proper coexistence with adjacent spectrum users. The EU Decision 2021/1730 identifies some specific conditions on this for both the FRMCS basestations and for the on-board devices. Due to different usage and deployment scenarios in adjacent frequency bands throughout Europe, the proper co-existence of these adjacent services to the RMR radio bands will not come automatically. Co-existence must be an integral part of the migration strategy on the national level.

Furthermore, due to various space constraints resulting in mutual coupling between antennas on train rooftops additional co-existence issues may result when using other radio systems (e.g. GSM-R and MNO services) simultaneously with FRMCS.

4 CROSS-BORDER CONSIDERATIONS

4.1 INTRODUCTION

For border-crossings between two (or more) countries several scenarios may be distinguished for which different FRMCS network characteristics need to be considered. The following track configuration scenarios may be seen:

- Railway tracks within an area that do not cross the country border
- Railway tracks within an area that do cross the country border but where no service continuity is needed
- Railway tracks within an area that do cross the country border where service continuity is needed. To enable network hand-over and service continuity this scenario will require a coverage overlap into the other country. An example of this is shown in Fig.8 below

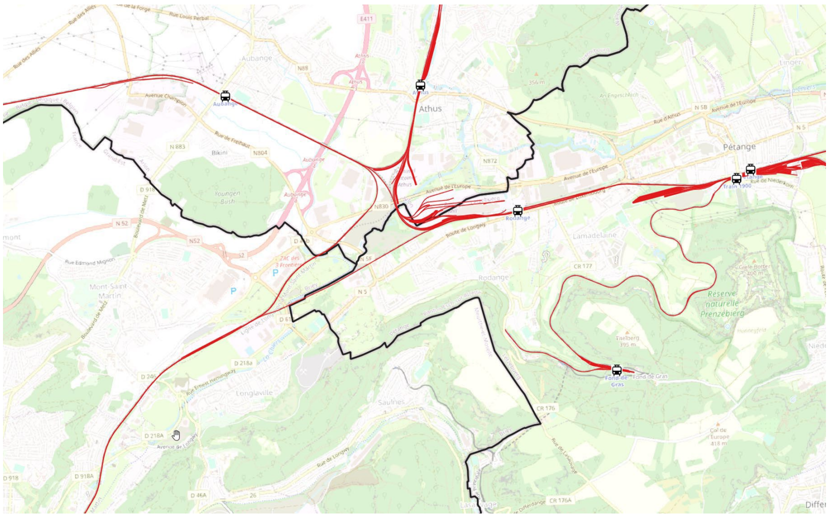

Figure 8: Longwy (FR) | Aubange (BE) | Rodange(LU) area;
Line | Stations, shunting| Stations, shunting.

In addition to this, at country borders there may be different usages of the 900 MHz and the 1900 MHz bands, as well as a mix of GSM-R and FRMCS technologies.

4.2 CROSS-BORDER USING 900 MHZ

For cross-border scenarios where the 900 MHz RMR band is used the necessary regulatory aspects have been covered by the ECC in updates of the existing ECC Recommendations (08)02 [Ref 7] and (05)08 [Ref 8], that now include both GSM-R and FRMCS based networks. In essence the handling of FRMCS based networks in the 900 MHz band is very similar to that currently used for GSM-R networks.

Between IMs the necessary cross-border related details should be handled via jointly agreed Arrangements. Additional information on this is available in the document O-8854-Generic RMR Arrangement process [Ref 9].

The ECC Recommendation (08)02 [Ref 7] contains provisions for cross-border coordination between Railway Mobile Radio (RMR) networks in border areas in the 900 MHz frequency band (n100: 874.4-880 MHz / 919.4-925 MHz), excluding GSM-R vs. GSM-R, based on the use of coordination areas. For a coordination area ECC Recommendation (08)02 defines for RMR wideband systems Field strength (FS) levels of 59 dBµV/m/5MHz at the border line and 41 dBµV/m/5MHz 6km inside the other country when using Preferential Physical Cell IDs (PCIs).

Other examples for cross-border coordination for RMR networks in the 900 MHz frequency band, e.g. options for RMR narrowband vs. wideband in the 900 MHz band, are also described in ECC Recommendation (08)02 [Ref 7]. It should be noted that in some cases this may lead to lower GSM-R field strength levels unless otherwise defined in existing agreement/arrangements between administrations/operators.

4.3 CROSS-BORDER USING 1900 MHZ

For cross-border scenarios where the 1900 MHz RMR band is used the necessary regulatory aspects is covered[4] by the ECC Report 353 [Ref 5] and corresponding ECC Recommendation 23-01 [Ref 6].

As the 1900 MHz RMR band is a TDD band, as opposed to the 900 MHz band being an FDD band, TDD synchronisation aspects need to be addressed in the coordination between IMs. Key elements here are the need for time synchronization as well as frame synchronization between adjacent networks. Specific details on this are provided in the ECC Report [Ref 5], corresponding ECC Recommendation [Ref 6] and in the document O-8854-Generic RMR Arrangement process [Ref 9].

It is anticipated that most RMR operators will be able to jointly develop RMR Arrangements. For the situations where this is not possible, the ECC Report [Ref 5] and ECC Recommendation [Ref 6] enable administrations to leverage a deterministic “safety net” based on a fallback TDD frame structure and field strength level which in that case shall be applied at the border. This should avoid unacceptable interferences between the adjacent networks.

5 ON-BOARD ASPECTS

For an effective migration from GSM-R to FRMCS several on-board aspects[5] must be considered:

- Number of GSM-R and FRMCS rooftop antennae and their configurations, including MIMO configurations
- On-board coexistence of GSM-R and FRMCS: decoupling/isolation to enable simultaneous operation of GSM-R and FRMCS based radio applications (limited space on rooftop)
- On-board coexistence of FRMCS and MNO and other radio applications (limited space on rooftop)
- Dependencies of possible migration scenarios for the rolling stock equipment

[5] The on-board aspects are FFS.

- For example, an RU may decide to keep (cabradio) voice on GSM-R and move ETCS to FRMCS. Then the train needs to support both GSM-R antenna plus FRMCS antenna(s) with the potential for simultaneous operation of both systems.

6 ANTENNA SYSTEMS

For FRMCS both track-side and on-board antenna systems are required, each with their specific characteristics and constraints.

The use of MIMO is a topic with both on-board and infrastructure side aspects. The performance and the capacity of a radio link can be increased by using multiple transmission and receiving antennas to utilize spatial multiplexing and multipath propagation between train- and trackside FRMCS antennas. Simulation results in ETSI TR 103 554-2 [Ref 11] show that railway deployments can benefit from MIMO and receive diversity (RX diversity) gains in both downlink and uplink directions. However, it is still FFS what MIMO configurations should be used as a minimum configuration to ensure adequate FRMCS radio performance.

Another topic for further study is the possible usage of active antenna systems (AAS). As per ECC DEC (20) 02, active antenna systems are not foreseen for FRMCS because of missing co-existence studies with adjacent radio systems. Note that the current CEPT/ECC definitions for AAS and Non-AAS are as follows:

- *Non-AAS (non-active antenna systems) refers to MNO base stations that provide one or more antenna connectors, which are connected to one or more separately designed passive antenna elements to radiate radio waves. The amplitude and phase of the signals to the antenna elements is not continually adjusted in response to short term changes in the radio environment.*

- *AAS (Active Antenna Systems) refers to MNO base stations and antenna systems where the amplitude and/or phase from the various antenna elements is continually adjusted resulting in an antenna pattern that varies in response to short term changes in the radio environment. This is intended to exclude long term beam shaping such as fixed electrical down tilt.*

7 CONCLUSION

The purpose of this document is to support railway Infrastructure Managers (IMs) and Train Operating Companies (TOC or RU) in making their decisions for the migration scenario from their current GSM-R network to a new FRMCS network, focusing specifically on aspects related to the radio network.

To enable this, the document identifies a set of migration scenarios that may be applied by an IM reflecting its specific needs and constraints for one or more railway tracks, areas or regions:

1. Scenario A: Migration using the 900 MHz band
2. Scenario B: Migration using the 1900 MHz band
3. Scenario C: Migration using both 900 MHz and 1900 MHz bands
4. Scenario D: Migration using MNO services
5. Scenario E: Migration using a hybrid configuration

During the development of this document, it was recognized that several more technical subjects need a more exhaustive description or analysis. Some of these subjects have been moved to the accompanying UGFA Report technical aspects FRMCS RAN O-8868.

It is to be noted that the starting point for this document are EC Decision 2021/1730, and the general end-to-end architecture and 5G mechanisms as described in the UIC FRMCS v1 specifications.

The potential usage of FRMCS based on MNO services using one or more MNO frequency bands in scenario's D and E is For Further Study.

As it is expected that over time additional insight and subjects will be developed this document will be a living document.

ANNEX 1: LIST OF REFERENCES

1 EU Implementing Decision 2021/1730

2 ECC Decision (20)02

3 CCS TSI 2023

4 ETSI TC RT document RT(21)082035_Kontron_Final_Whitespace_report

5 ECC Report 353 1900 MHz TDD cross border

6 ECC Recommendation 23-01 - 1900 MHz TDD cross border

7 ECC Recommendation (08)02: Cross-border coordination for Mobile/Fixed Communications Networks (MFCN) in the frequency bands 900 MHz and 1800 MHz excluding GSM vs. GSM and for Railway Mobile Radio (RMR) in the 900 MHz frequency band excluding GSM-R vs. GSM-R

8 ECC Recommendation (05)08: Frequency planning and cross-border coordination between GSM Land Mobile Systems (GSM 900, GSM 1800, and GSM-R)

9 O-8854-Generic RMR Arrangement process

10 O-8786 FRMCS coexistence with GSM-R in the UIC/E-UIC band

11 ETSI TR 103 554-2 V0.4.25 (2020-1203): Next Generation Communication System; Radio performance simulations and evaluations in rail environment; Part 2: New Radio (NR)

12 UIC – O-8868 UGFA Report technical aspects FRMCS RAN (ISBN 978-2-7461-3391-4)

ANNEX 2: MINIMUM REQUIRED GSM-R CAPACITY / RADIO CHANNELS

A2.1 HIGH-LEVEL CONCLUSIONS:

- Some IMs make use of the full set of 19 GSM-R channels in some areas (e.g. high-density, urban) to provide the needed traffic capacity at the desired QoS level while there is no possibility to transfer traffic from GSM-R to FRMCS. In these cases, insufficient spectrum is available to support a 5G NR channel bandwidth smaller than 5 MHz. In this case it is inevitable to migrate by using 1900 MHz band for FRMCS in parallel with GSM-R remaining in the 900 MHz band.
- Some IMs could free up some GSM-R channels, however that would require replanning and adjustment in the field of the existing GSM-R radio network. It is to be noted that the frequency replanning can cause a domino effect to adjacent areas of the radio network to preserve the QoS. For these IMs a migration using both GSM-R plus either a smaller than 5 MHz 5G NR carrier or a 5G NR overlay to GSM-R may be a viable option.
- Some IMs only use a subset of the 19 GSM-R channels and therefore probably have sufficient spectrum to support both their few GSM-R channels plus the 5G NR channel within the 5.6 MHz RMR spectrum. This should allow migrating by using both GSM-R plus either a smaller than 5 MHz 5G NR carrier or a 5G NR overlay to GSM-R.

A2.2 **MINIMUM SET OF SERVICES FOR FULFILLING RAILWAY INTEROPERABILITY**

Typical number of frequencies required for 5 different area types have been gathered as examples from some existing GSM-R networks:

- High Speed Line – Voice only 19 frequencies (example of 2 TRXs/cell, double neighbouring[6] and double or redundant coverage)
- Shunting – At least 1 frequency for voice only
- Hotspot – Voice and GPRS 19 frequencies (example of maximum 3 TRXs/cell and average of 2 TRXs/cell)
- Rural – Voice and GPRS 10 - 12 frequencies (example of maximum 2 TRXs/cell and average of 1 TRXs/cell)
- Standard track – Voice and GPRS 12 – 14 frequencies (example of maximum 2 TRXs/cell and average of 1 TRXs/cell)

When implementing FRMCS in 900 MHz, IMs need to avoid any degradation in service quality or any interruption to their existing GSM-R network.

For 900 MHz co-existing case, there are two possibilities to migrate in the 900 MHz band:

- 5G NR overlay to GSM-R in the 2x5.6 MHz: there is no need to retune frequency in the GSM-R network as the FRMCS system will only be using any free and allowable radio resource.

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[6] Double neighbouring means that on either side of a radio mast both the direct neighbour n plus the following n+1 neighbour is in the cells neighbour list.

This option would be more attractive if it is support by many vendors and if limited GSM-R channels are used simultaneously.

- 5G NR channel bandwidth smaller than 5 MHz: there is a need to retune the existing GSM-R network to free up some radio resource to meet with the required bandwidth of the 5G NR channel bandwidth of <= 3 MHz. To avoid any degradation in service quality and any interruption to the existing GSM-R network, it is mandatory to study a minimum GSM-R traffic requirement.

Example of the current GSM-R network capacity requirements

Country A:

Currently has a nationwide GSM-R network of which about 2% has been constructed with ETCS Level 2. The number of frequencies needs per cell for different area type is:

- Highspeed lines: 2 frequencies per cell and double neighbouring
- ETCS: some lines using 2 frequencies per cell with double neighbours on either side and some lines using 1 frequency per cell with double layer for tunnel coverage
- Dense urban: major stations having 2 frequencies per cell and the rest having 1 frequency per cell
- Urban: 1 frequency per cell
- Rural: 1 frequency per cell

For FRMCS migration, forecasting up to 80% of the GSM-R network can deploy a 5G NR channel bandwidth smaller than 5 MHz or 5G NR overlay to GSM-R in the 2x5.6 MHz with some frequency replanning including areas where GSM-R Service quality will be degraded. The rest of network will not be possible to deploy 5G NR channel bandwidth smaller than 5 MHz or 5G NR overlay to GSM-R in the 2x5.6 MHz.

Country B:

Currently has a nationwide GSM-R network of which about 6.5 % has been constructed with ETCS Level 2. The number of frequencies needs per cell for different area type is:

- Highspeed lines: all high-speed lines are designed to support ETCS L2 2 frequencies per site (2 cells collocated at one site) with double neighbouring
- ETCS: only implemented on some high-speed lines with 2 frequencies per site (2 cells collocated at one site) with double neighbours on either side,
- Dense urban: some limited major stations use 2 frequencies per cell and the other ones use 1 frequency per cell
- Urban: 1 frequency per cell
- Rural: 1 frequency per cell

ANNEX 3: RADIO NETWORK REPLANNING ASPECTS

Standard GSM-R frequency planning will be done using automation tools and/or manually with the traditional 19 GSM-R frequencies. FRMCS with 5G NR channel bandwidth smaller than 5 MHz will probably only allow a reduced number of contiguous GSM-R frequencies (reduced to 14,12 or 10 GSM-R channels).

Case study by DB: Assuming for medium & low-rail traffic railway lines apart of dense and border areas, existing GSM-R deployments providing sufficient spectrum for a potential FRMCS solution with 5G NR channel bandwidth smaller than 5 MHz for the migration period (voice and low bandwidth data services). It is also assumed that FRMCS solutions with 5G NR channel bandwidth smaller than 5 MHz and GSM-R BTS are collocated and share the same mast.

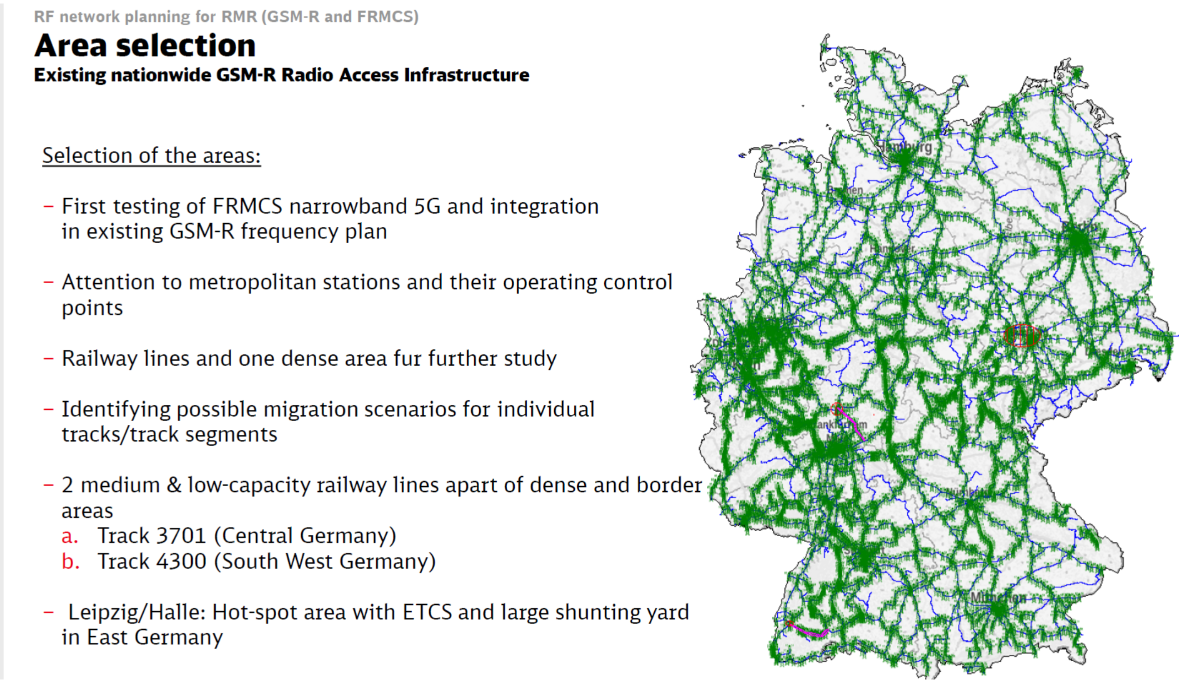

Figure A3.1: Radio network planning.

With regard to mission-critical railway radio communication, this migration scenario in case of simultaneous FRMCS and GSM-R operation will need a maximum of interference-free frequency spectrum. It is not possible to implement an 5G NR carrier with a channel bandwidth smaller than 5 MHz within the R-GSM band without a number of technical mitigating measures, e.g. retuning the existing GSM-R RF plan for all GSM-R radio sites in the intended migration area.

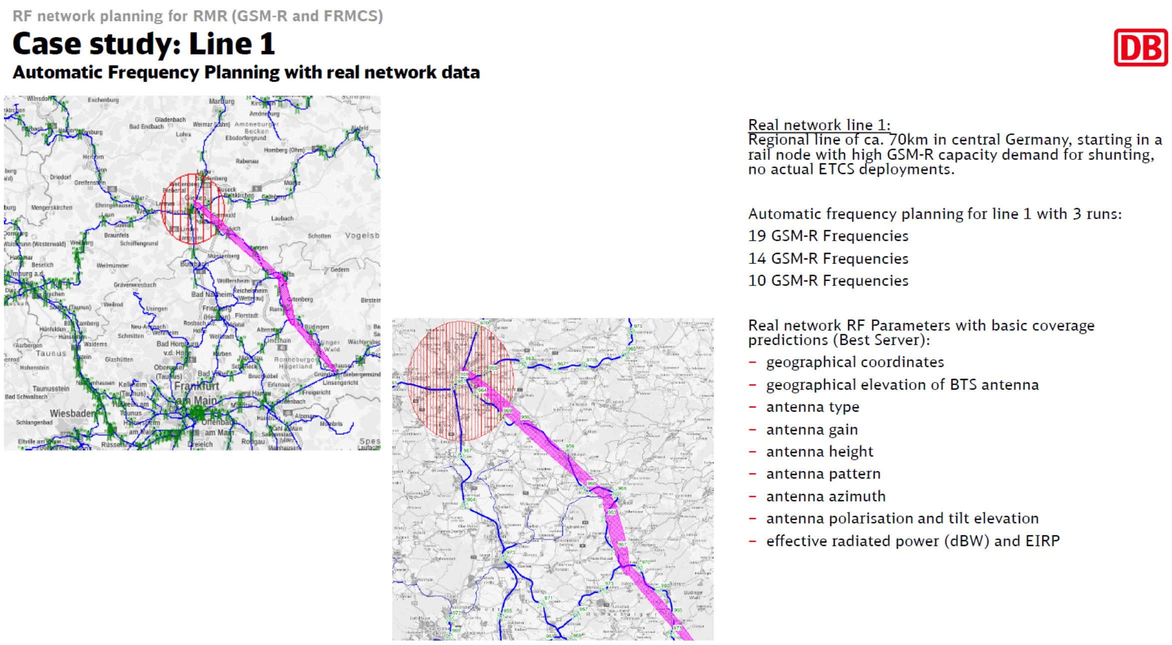

Figure A3.2: Radio network case study.

For medium and high traffic lines, there is insufficient spectrum within the existing R-GSM band to allow the co-existence of 5G NR carrier with a channel bandwidth smaller than 5 MHz and GSM services without some degradation to the GSM-R service. Automatic frequency planning [7] for dedicated lines with 10/14 GSM-R Frequencies shows the necessary measures afterwards in form of manual RF tuning. RF planning with 10 GSM-R Frequencies for existing GSM-R frequency plans only possible in topology with low-capacity demands.

In case of RF retune, there is a need to qualify the GSM-R coverage (by specific measurement campaign and/or other monitoring tools), these activities imply additional cost to be considered for this scenario.

[7] Automatic frequency planning is a feature of DB Netz´radio frequency planning tool

ANNEX 4: RAILWAY UNDERTAKING (RU) CONSIDERATIONS

Today the topic of on-board coexistence (between GSM-R and public mobile broadband) is mostly handled by the train manufacturers and/or RUs and often comes with many kilos of external filtering as the UE-characteristics are not adapted to the interference scenarios on the trains. As new 5G based train communication system FRMCS will have to run in parallel with GSM-R for several years and opens up a lot of challenges to on-board-coexistence. Mainly for business applications on-board trains, RU use cases are also trying to take advantage of the 5G technology but the usage of 4G services of several MNOs are predominant. Regardless of question 4G or 5G, RUs are aware about the topic of insufficient isolation between transmit/receive antennas for RMR and MNO frequency bands on a train roof. The basic question is whether parallel operation of MNO frequency bands adjacent to the RMR radio spectrum can be implemented or not.

Train applications need an extremely high availability of the train to ground communication, if it fails the train can only proceed in a fallback mode, which typically means traveling at much-reduced speeds. Already today a number of measures have to be taken to operate mission critical communication systems as ETCS and GSM-R cab-radios beside MNO radio systems providing broadband services to the passengers on a train.

The estimated effort for the installation of new additional FRMCS antennas on the roof of a single long-distance train is around 2 weeks and includes:

- Add new antenna-sockets and antennas (welding and bonding, removing air-conditioning ducts, isolation, covering)
- Add cabling to antennas and between Cab-radio and FRMCS System (open covering along whole wagon)
- Add filter to GSM-R systems and FRMCS systems
- Add racks to integrate hardware
- Approvals

It was made clear by the RU that vehicle projects (Redesign, ETCS integration, tendering) are long term projects and therefore are asking for FRMCS readiness already today. The missing points to integrate FRMCS antennas as extensive part of FRMCS readiness are:

- Used frequency bands and combinations
- Radio characteristics of the FRMCS UEs, link budgets, coverage levels etc.
- Number of FRMCS UEs necessary e.g. for border crossing

For an effective vehicle migration to FRMCS the on-board coexistence aspects must be taken into account including:

- Specification of the FRMCS UEs (ETSI, 3GPP): Receiver characteristics should be adapted to the train environment
- Migration strategies should be analysed and optimized regarding their impact on on-board coexistence, interference analysis should also be conducted between the different on-board systems that have to be operated in parallel on the train
- Evaluation of other methods (beside 100% RF-coexistence) to meet the availability requirements should be conducted
- Fallback scenarios (to GSM-R (if available)/to public mobile broadband)
- Study further aspects of interference