SECTION 3

SPECTRUM ISSUES

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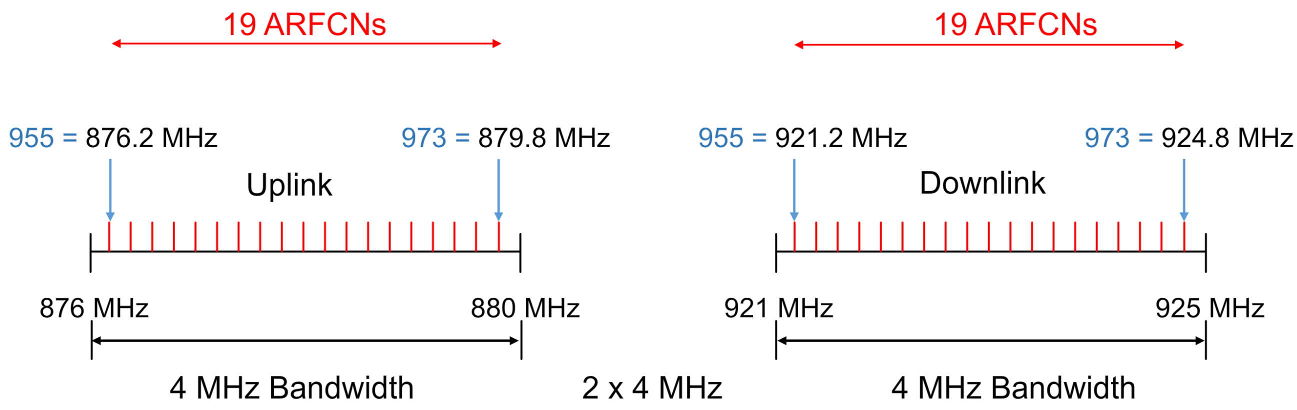


GSM-R Harmonised Spectrum

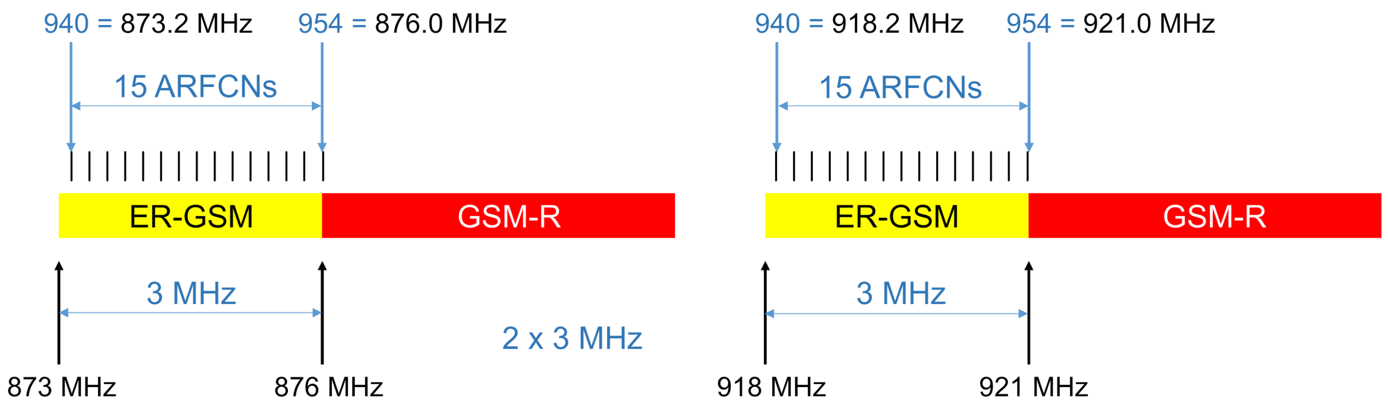
Current GSM-R Spectrum

For the use of GSM-R, Commission Decision 1999/569/EC and ECC Decision (02)05 harmonises the frequency bands 876 – 880 MHz (train to ground) and 921 – 925 MHz (ground to train). This harmonization enables a pan-European communications network for both passenger and freight trains to travel across European borders without the need for multiple radio systems to be installed on trains.

GSM-R networks have been rolled out across Europe covering 96,124 km with plans to increase this to 139,859 km's. It has been estimated 75 000 GSM-R terminals are in use across Europe. GSM-R was initially used for voice communications but is now part of the overall ERTMS strategy of delivering ETCS signalling over GSM-R. Coverage for ERTMS is planned to be complete by 2050. Meanwhile, a replacement for GSM-R has to be found and with it suitable spectrum.

Currently GSM-R uses 2 x 4 MHz block of spectrum. Each 4 MHz block is divided into channels in line with commercial GSM systems. The channel spacing is fixed at 200 kHz. 4 MHz/200 kHz gives 20 channels however a guard band needs to be provided at either end of the spectrum to prevent GSM-R interfering with neighbouring services. So there are 19 usable channels known as Absolute Radio Frequency Channel Numbers (ARFCNs). Indeed the channels are numbered 955 thru 973, corresponding to the uplink frequencies of 876.2 MHz and 879.8 MHz and for the downlink 921.2 thru 924.8 MHz.

This is a limited number of channels which need to be re-used across the rail network. But in busy railway locations this becomes very difficult with such a limited number of channels. More spectrum is needed.



ER-GSM Non-Harmonised Spectrum

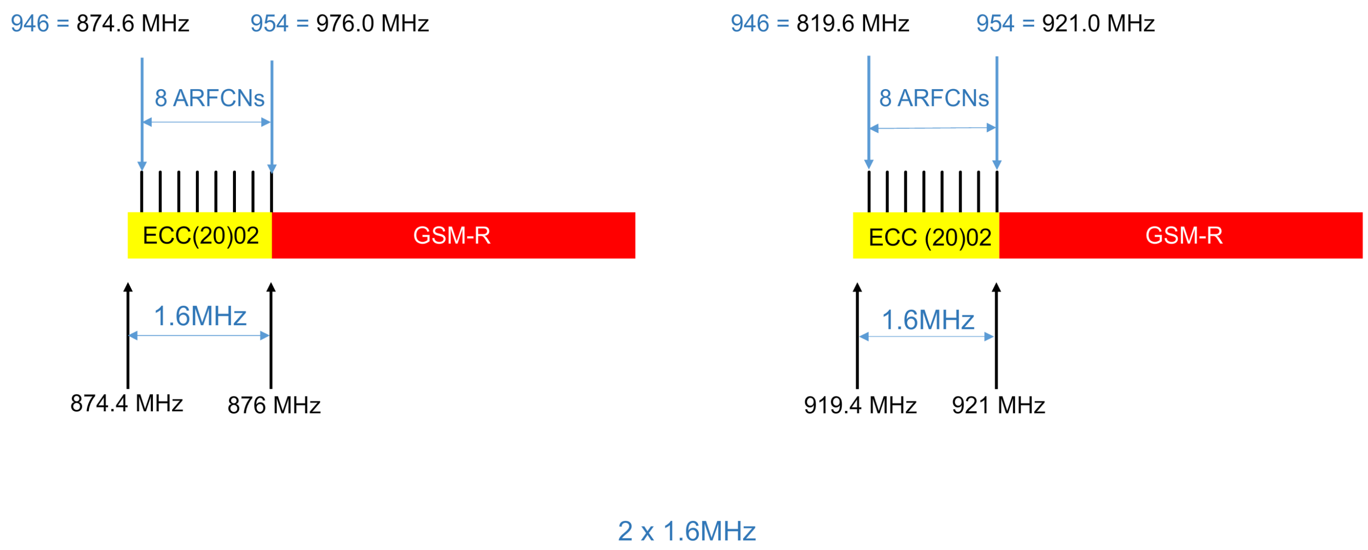
ER-GSM Non-Harmonised Spectrum

There exists an extension to the harmonised spectrum for GSM-R, this is known as the ER-GSM band and is 2 x 3 MHz in total. This extension in the uplink direction is between 873 MHz and 976 MHz and for the downlink 918 to 921 MHz. This provides for a further 15 ARFCNs ranging from 940 to 954. In fact 954 corresponds to an uplink frequency of 976.0 MHz uplink and 921.0 MHz downlink which otherwise would not be available because of the need for a guard band.

Unfortunately this spectrum has not been harmonised for railway use across the whole of Europe. It is available in Germany for example but not in the UK. The reasoning is that part of the spectrum in some European countries has been allocated for military use. The major threat however is from the Short Range Device (SRD) community.

Significant demand for additional UHF spectrum specifically 870 to 876 MHz and 915 to 921 MHz has been demonstrated by the SRD community in the form of a series of ETSI technical reports. These reports addressed nine different SRD applications all requiring spectrum including:

- Generic SRD
- RFID
- Home automation and sub-metering
- Smart meters
- Smart grid
- Metropolitan mesh machine networks
- Surveillance alarms, Fir/smoke alarms, Intruder alarms etc.
- Automotive active safety, automotive diagnostic data exchange, freight protection etc.
- Assistive listening devices

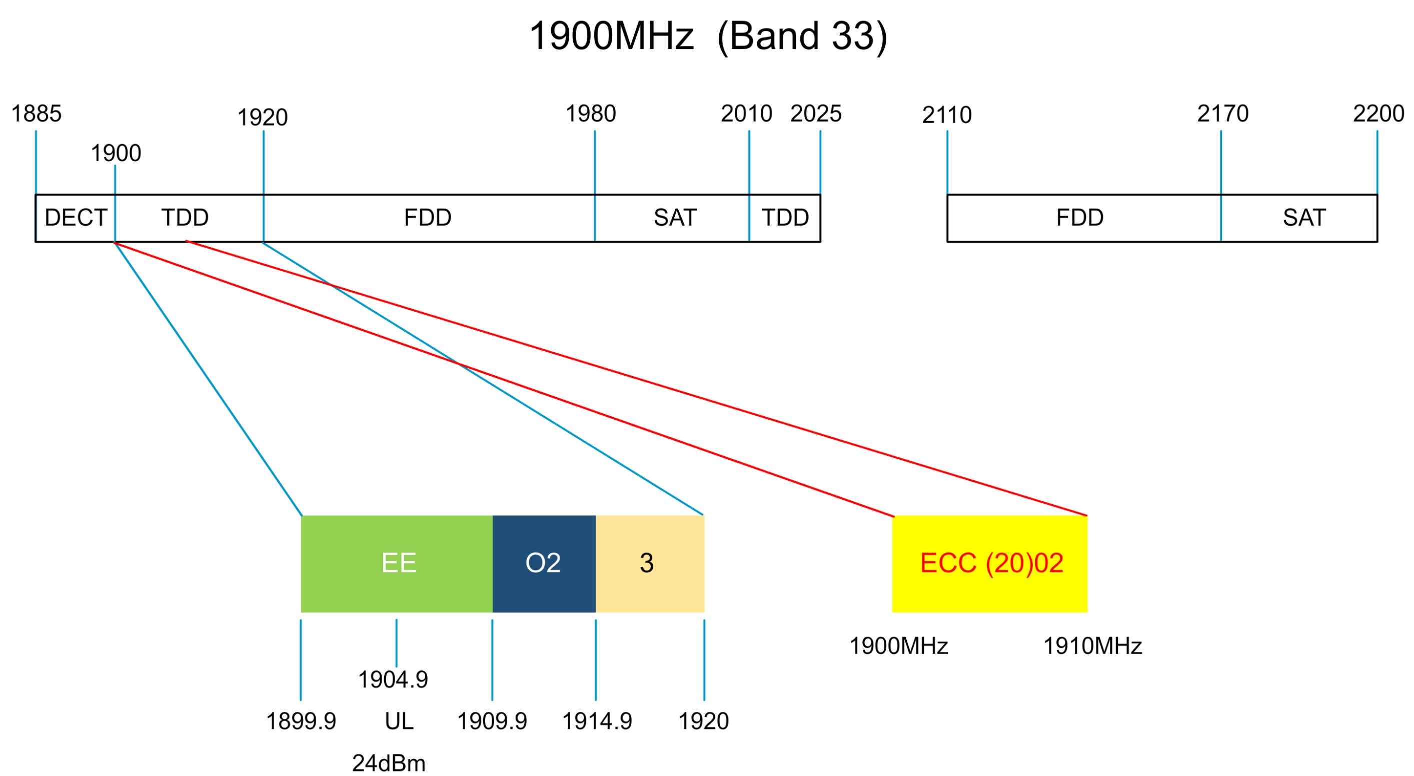


ECC Decision (20)02

ECC (Electronic Communications Commission) Decision (20)02 specifies the harmonised use of the paired frequency bands 874.4 – 880.0 MHz and 919.4 – 925.0 MHz and the use of the unpaired frequency band 1900 – 1910 MHz for Railway Mobile Radio (RMR) and was approved 20 November 2020.

This decision means an additional 3.2 MHz of paired spectrum at 900 MHz and 10 MHz of unpaired spectrum at 1900 which will be harmonised for railway use across Europe. The additional spectrum at 900 MHz will add 1.6 MHz to both the downlink and uplink frequency bands providing a total of 5.6 MHz for use in the downlink and uplink. There are no restrictions about which technology could be deployed in the spectrum, but the additional 1.6 MHz will provide a further 8 ARFCNs as depicted in the diagram.

ECC Decision (20)02 also provides details about transmit power levels that can be used to minimize interference with neighbouring services such as the short range devices. It is interesting to note that uplink power control will be mandatory.

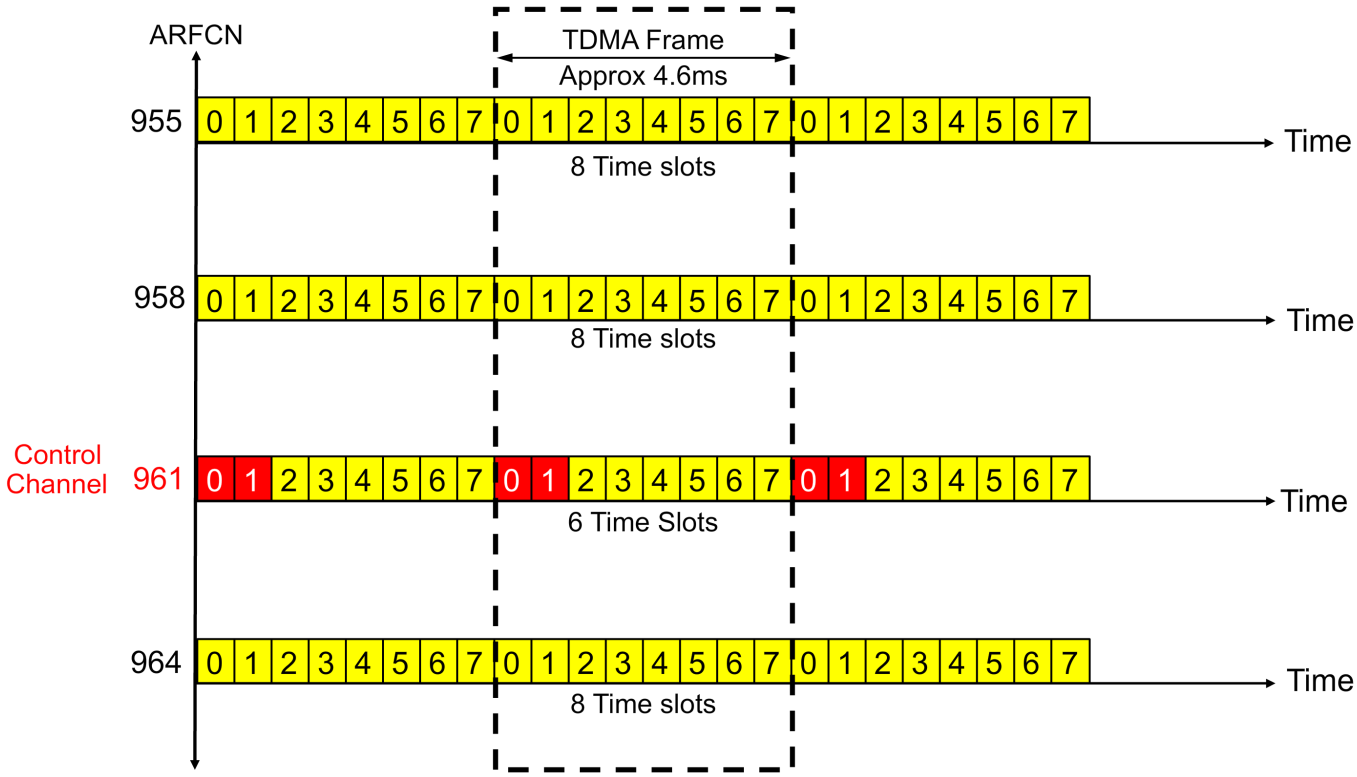


ECC Decision (20)02 (continued)

The second harmonised block of spectrum is between 1900 – 1910 MHz. This is part of the spectrum that was identified for use by 3G technologies. 3G systems in Europe were largely FDD systems which are now being replaced by 4G LTE. There is a small part of the spectrum that was designated for TDD use, namely 1885 – 1920 MHz. The bottom 5 MHz overlaps with the spectrum used by DECT Cordless telephones so cannot be used. This leaves 20 MHz that could be used for mobile telephony. Licences for the use of this spectrum were issued in the UK but operators never deployed TDD. The current UK licence holders are shown in the diagram. The proposed 10 MHz for RMR clashes with the spectrum licensed to EE in the UK. EE are planning to utilize this spectrum to support the Emergency Services Network (ESN).

10 MHz of spectrum could easily a single wideband technology channel such as 4G LTE or a 10 MHz 5G channel, but the range of a cell operating at 1900 MHz will be less than one operating at 900 MHz for two main reasons.

Firstly the propagation loss is greater at 1900 MHz compared to 900 MHz, but the major limiting factor is the maximum power that the mobile device. When using a wideband technology such as 4G LTE or 5G the maximum power a mobile device can use will be 31 dBm. This is 1.25 Watts whereas a GSM-R cab radio can transmit 8 Watts using GSM-R. Other RMR terminals will be limited to 23 dBm or 0.2 Watts when using 4G LTE or 5G.



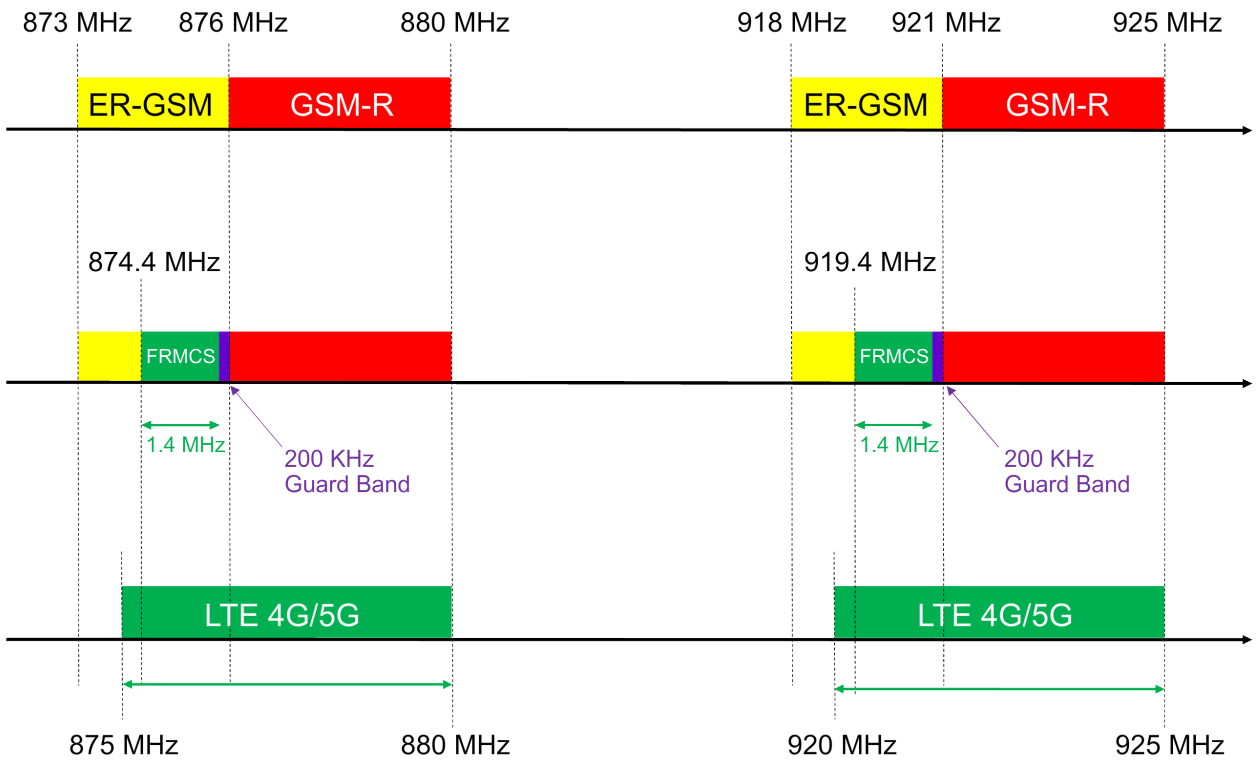
GSM-R Air Interface

GSM-R is a digital radio system meaning that voice has to be digitized before being superimposed (modulated) onto a radio channel. Voice is digitized at 12.2 kbps. Circuit switched data is already in a digital format with a maximum bit rate of 9.6 kbps. Packet switched data can be handled at various bit rates from 9 kbps through to 22 kbps. Video would also need to be digitized, but the bit rate far exceeds what can be carried on a GSM radio channel, hence the need for FRMCS. Digital voice and data can be easily multiplexed onto a single radio channel. The multiplexing technique is known as Time Division Multiplexing and 8 circuits can be multiplexed onto a TDMA (Time Division Multiple Access) frame. This frame structure has a duration of approximately 4.6 ms and the 8 circuits are carried in 8 timeslots numbered 0 to 7. A voice call would be carried using one timeslot, for example TS2 and every 4.2 ms TS2 will repeat delivering another 'burst' of digital speech.

A GSM base station can support a maximum of 16 ARFCNs (by definition) but railway networks do not need to carry huge amounts of traffic so most base stations will be equipped with one or two radio channels. In busy locations however there may be a need for more capacity so additional radios can be equipped in the base station. The diagram shows a base station equipped with 4 radios using ARFCNs 955, 958, 961 and 964. Each channel carries a succession of TDMA frames of 8 timeslots. However, one radio channel is required to carry GSM control signalling which will be found in two timeslots on one of the radio channels, in this example 961.

Timeslot 1 is used by the base station to broadcast paging messages to alert trains about an incoming voice call. This timeslot is also used to notify trains about group calls. Timeslot 0 is also used to answer calls from trains. Timeslot 2 is then used to exchange call set up signalling between the train and the network. Therefore these two timeslots are reserved and cannot carry traffic leaving just 6 timeslots on this radio channel.

Determining the capacity on the GSM air interface is simply counting available timeslots and the number of radio channels. The same perhaps, cannot be said for LTE or 5G.



Migrating to FRMCS

It will not be possible to simply switch off GSM-R and switch on its successor overnight. GSM-R networks are still being rolled out across Europe and it will take time to roll out FRMCS, test and validate its performance before railways commit. So a migration process has been proposed where the original GSM-R spectrum remains in place and FRMCS is rolled out in the ER-GSM spectrum. It has been suggested that a 1.4 MHz LTE channel could be deployed at the upper edge of the ER-GSM spectrum thus allowing SRD devices to continue to use the remaining spectrum. A 200 kHz guard channel may be necessary to separate the LTE carrier from the GSM channels.

If the non-harmonised spectrum is not available there is the possibility of re-farming the 4 MHz GSM-R spectrum, taking 1.4 MHz for LTE and the remaining spectrum for GSM-R.

Over time it may then be possible to re-farm the 4 MHz GSM-R spectrum and use 1 MHz of ER-GSM to provide a useful 5 MHz LTE channel of 5G channel. Whether 5 MHz will be sufficient in the long term remains to be seen.

Configuration	Uplink throughput
Maximum current data throughput available on SNCF R 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 carrier of 1.4 MHz in 900 MHz range and in railway environment	200 kbps /site (LS Telecom study) 300 kbps / site (preliminary estimation done by ETSI/TCRT)

Is 1.4 MHz of FRMCS Spectrum Viable?

A CEPT ECC document FM56(18)047 produced in June 2018 reports on the possibility of using 2 x 1.4 MHz of FRMCS spectrum at 900 MHz. This spectrum would be used in parallel with GSM-R spectrum to provide a migratory path for the rollout of FRMCS.

The cited example in the document references SNCF-RESEAU (SNCF-R) GSM-R network which uses the 19 ARFCNs in the existing harmonised spectrum. The current site configuration uses just one channel per site on their normal rail lines and a double layer coverage on high speed lines. The double coverage in France has been chosen to increase availability and capacity.

On a single layer site 6 Traffic Channels (TCH) are available with two timeslots used for GSM signalling. On a double layer site two independent channels are used each configured with two timeslots for GSM signalling and therefore only 12 TCHs.

The calculated Circuit Switched Data (CSD) capacity is 4.8 kbps x 6TCH = 28.8 kbps on a single layer site and therefore approximately 60 kbps on a dual layer site.

At the time the document was published SNCF-R were studying GPRS as a means of increasing capacity in support of ETCS Level 2 operations. The maximum expected data throughput with GPRS is in the region of 150 kbps for a dual layer site. This estimation is based on 4 timeslots on each radio channel to be dedicated to GPRS and assuming Coding Scheme two (CS2) was being used. CS2 carries user data at approximately 12 kbps. Therefore 8 TS x 12 kbps = 96 kbps. The remaining 4 TS carry 4 x 4.8 kbps = 19.2 kbps so in total 150 kbps per site is quoted.

Studies performed by LS Telecom on behalf of ERA suggest 1.4 MHz of LTE spectrum could carry 200 kbps at the cell edge. ETSI studies suggest 300 kbps could be carried in 1.4 MHz of LTE spectrum at 900 MHz. SNCF-R calculations suggest 1.4 MHz is a workable bandwidth.

Type of Traffic	Uplink throughput
Maximum current data throughput available on GSM-R radio site. 4 TRX in the harmonised 2x4 MHz Voice applications: train radio, shunting radio, operational radio; data applications	24×12,2 kbps (voice) + 6×9.6 kbps (data) + 8 kbps (signalling) **circa. 360 kbp**
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)	24×12.2 kbps (voice) + 6×9.6 kbps (data) + 8 kbps (signalling) + 4×4 kbps ETCS PS-mode + 4×4,8 kbps ETCS CS-mode **circa. 400 kbps**
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 to 400 kbps / site (ETSI TR 103 554 V1.1.1)

A Second Case Study

DB Netz AG is the railway infrastructure manager of Deutsche Bahn AG and are using both the GSM-R spectrum and the ER-GSM spectrum. Current GSM-R sites typically use one or two channels but in dense areas up to 4 channels are required.

The four channels provide 32 timeslots of which 2 are used for GSM control channels. 24 are used to carry 12.2 kbps speech which totals 292.8 kbps. 6 timeslots are used for circuit switched data at 9.6 kbps totalling 57.6 kbps. The uplink throughput also identifies 8 kbps signalling. The total uplink throughput is approximately 360 kbps.

Deploying ETCS will require more capacity so the plan is to deploy an extra radio channel providing a total of 40 timeslots. Two (presumably) timeslots for GSM signalling. Six timeslots for circuit switched data. One timeslot for Packet Switched ETCS data multiplexing four trains and four Circuit Switched timeslots also for ETCS traffic. The table suggests approximately 400 kbps of uplink traffic will be generated at this site which a 1.4 MHz LTE channel cannot support adequately.

In the two case studies the traffic that has been considered is that which will be found on a GSM-R network. It does not include any of the additional services which FRMCS is envisaged to provide. Consideration must be given to the traffic levels that FRMCS will bring.

Critical Application	Applicable to Migration?
Operational voice	Yes
Shunting voice	No
Emergency call (112)	Yes
Alert from public	No
Alert to public	No
ETCS	Yes
ATO	Yes
Remote control of engine	Yes
Train integrity	No
Advisory messaging	No
On-board telemetry	No
Critical sensing/video	Yes

List of Critical Applications

ECC Report 294 suggests that the spectrum requirements need to be evaluated during the migration from GSM-R to FRMCS and finally one the migration is complete. To do this two Packages have been defined.

Package Number 1 which must be supported during the migration phase includes:

- The current GSM-R critical applications such as group calls, point to point calls, REC and ETCS Level 2
- Train positioning but not based on Cell ID, but GPS or similar.
- ATO up to GoA2
- Remote control of engines
- On-board intelligence sensing to support ATO such as object or person detection systems.
- Critical video for remote control in shunting yards

Package Number 2 must be supported after migration to a full FRMCS system and includes:

- Everything in Package Number 1
- ETCS Level 3
- ATO up to GoA4
- Virtual coupling
- Everything else deemed as necessary.

The table shows those applications that will be required during the migration phase.

Traffic Density and speed	DL Traffic per train Mbps	UL Traffic per train Mbps	Number of Trains per km	Cell size Km	DL Traffic per cell Mbps	UL Traffic per cell Mbps
Low	0.2	0.19	0.33	8	0.53	0.51
High			0.67		1.08	1.04
High speed			0.5		0.8	0.77

Throughput Required by Critical Applications During the Migration Phase Excluding Video

The amount of spectrum required for FRMCS depends on the supported applications and associated traffic volumes. Additionally the number of trains in the area and the characteristics of the radio technology GSM-R versus LTE. To determine the spectrum requirements the critical railway applications have been considered. Additionally three types of railway environment are considered including:

- Low density rail segment
- High density rail segment
- High speed rail segment

A reference train was used which includes on train staff and on-board systems. The railway stations at which trains stop will impact on the levels of traffic but are not included here.

The calculations assume an Inter Site Distance (ISD) of 8 km which is typical of GSM-R operating at 900 MHz. The table above shows the calculated traffic volumes assuming no critical video applications are being used. In all three scenarios the uplink and downlink data volumes are symmetrical and approximately 1 Mbps which would not be supported in a 1.4 MHz LTE channel.

Traffic Density and speed	DL Traffic per train Mbps	UL Traffic per train Mbps	Number of Trains per km	Cell size Km	DL Traffic per cell Mbps	UL Traffic per cell Mbps
Low	3.5	3.49	0.33	8	**9.24**	**9.22**
High			0.67		**18.77**	**18.73**
High speed			0.5		**14.0**	**13.97**

Throughput Required by Critical Applications During the Migration Phase Including Video

Adding critical video shows the impact of introducing autonomous trains over the next 15 years. Video transmission in both uplink and downlink directions becomes a major requirement of FRMCS

Excluding Video

Traffic Density and speed	DL Traffic per train Mbps	UL Traffic per train Mbps	Number of Trains per km	Cell size Km	DL Traffic per cell Mbps	UL Traffic per cell Mbps
Low	0.42	3.46	0.33	8	1.1	9.15
High			0.67		2.22	18.57
High speed			0.5		1.66	13.86

Including Video

Traffic Density and speed	DL Traffic per train Mbps	UL Traffic per train Mbps	Number of Trains per km	Cell size Km	DL Traffic per cell Mbps	UL Traffic per cell Mbps
Low	**4.38**	**7.42**	0.33	8	**11.55**	**19.6**
High			0.67		**23.45**	**39.79**
High speed			0.5		**17.5**	**29.7**

Traffic Levels After Migration

After migration and assuming Package Number 2 has been included the traffic levels increase further, but video is the most bandwidth hungry. Clearly more spectrum will be required both during and after migration.

Two options which have been suggested is the use of other frequency bands including the 1900 MHz and 2300 MHz bands. Getting access to this spectrum may prove difficult because it is already licensed to the commercial cellular operators. Co-existence studies have been performed and reported in CEPT/ECC FM56. The frequencies specified includes 10 MHz of spectrum between 1900 and 1910 MHz. In the UK this is licensed to BT/EE for LTE support of the Emergency Services Network (ESN) which is a public safety network. Parts of the 2300 MHz network is also licensed to Telefonica O2 in the UK for LTE operation.

If those frequency bands became an option for FRMCS. The substantial increase in propagation loss would require site densification and considerable cost for the railways. Additionally, the on-board equipment may then need to be capable of operating on different frequency bands, assuming LTE was used at 900 MHz as well. Switching completely to 1900 MHz or 2300 MHz would require a complete rebuild of the radio network and refitting the rolling stock.

Otherwise, 1900 MHz or 2300 MHz could be used for hotspot coverage at railway stations and shunting yards, but again at cost.

Sharing Railway Communications with other Networks

- License conditions
- Service level agreements
- What to share
- Reason for sharing
- With whom to share

Access to Other Networks

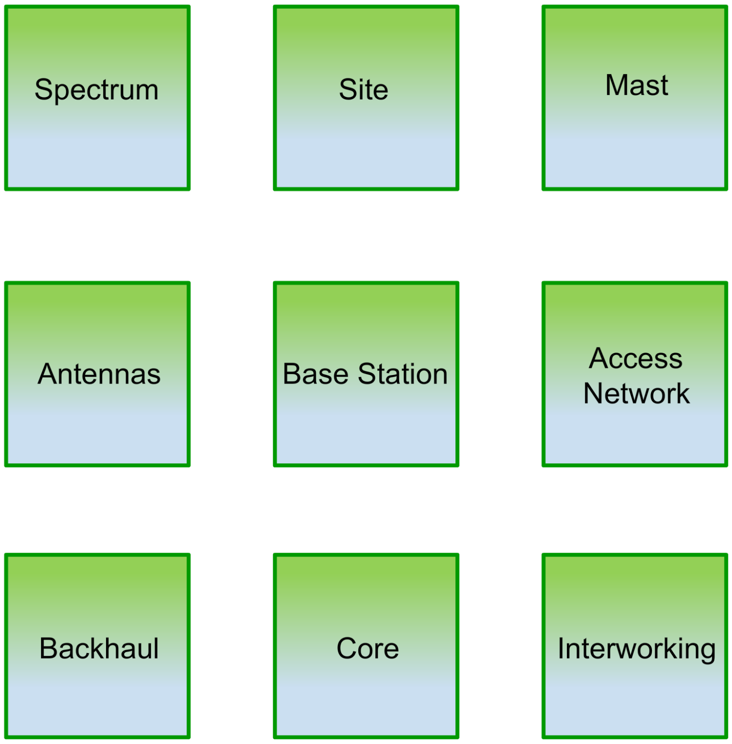
If spectrum becomes an issue there may be other ways of implementing FRMCS. Railway communications could be shared with existing radio networks including commercial cellular and Professional Mobile Radio (PMR) networks. However, before any decision can be made a number of factors need to be carefully considered. Firstly, the terms of the license issued by the regulatory body may impose restrictions on the use of that spectrum making it unsuitable for sharing. Additionally without any restrictions service level agreements need to be organized so that the shared network meets the requirements of the railway network. Is the organization prepared to accept the legal obligations and liabilities imposed upon it by the railway community?

There are many parts to a communications network and it may only be necessary to share parts such as base stations and the radio spectrum. It is possible to share the entire communications network freeing the railway operator of the onerous task of building and maintaining a network.

It may be desirable to enter a sharing agreement to support the exiting system. The FRMCS network supporting the critical applications such as emergency communications, ETCS, ATO etc. Performance applications could be carried on the partner network. Business applications could also be supported by a separate network offering wireless internet connectivity for passengers.

Railway communications could be shared with commercial Mobile Network Operators (MNOs). Commercial operators have access to large amounts of spectrum but they would need to be willing to accept the legal responsibilities of carrying railway communications. How can the MNO separate commercial traffic from railway traffic? Is it possible to prioritize railway traffic over commercial traffic. Would a commercial operator be will to invest in the additional sites needed to cover the railways to the level imposed by the EIRENE specifications? In the European setting how will trains move across boarders? Will these need interconnects to other FRMCS networks?

There are commercial PMR network that could be useful partners. They may not have extensive geographical coverage but they may be useful partners for providing communications at railway stations and shunting yards



What to Share

There are many parts of a commercial cellular network that may be shared. In fact many MNOs already share parts of their networks to reduce both Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).

In theory the radio spectrum itself could be shared, but MNOs have probably paid a lot in auction fees are very guarded about this vital commodity. Even if sharing took place it would take careful frequency planning to minimize the interference between the two networks.

Sites are commonly shared between MNOs to minimize build costs, share site rental and control interference. Because the target coverage for a railway network along the lines is not in alignment with wide area coverage of MNOs, there may be limited opportunity for site sharing.

Sharing masts is akin to site sharing. Commonly done by commercial MNOs but there will be limited opportunities in the railway environment.

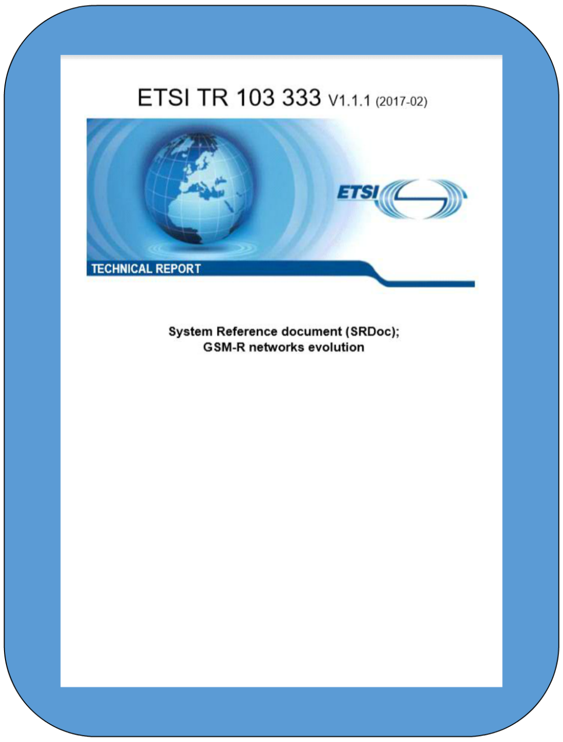
Antenna sharing is in theory possible but not commonly done by commercial MNOs. The reasoning is isolation between equipment to minimize the problems of interference. Additionally shared antenna will restrict the coverage and optimization opportunities for the operators. Another consideration is the frequency band. GSM-R operates at 900 MHz and a specific portion of that band. This may not tie in with the frequency band of the MNO.

There is a distinct possibility of sharing base stations. Today base station design utilizes Software Defined Radios (SDR) where a single base station can support multiple frequency bands and different radio technologies (GSM, UMTS, LTE etc.) simultaneously.

The access network would include the Base Station Controller (BSC). This is still present in GSM-R networks but has been removed in LTE and 5G systems.

Certainly the backhaul transport can be shared back to the core network. Sharing the core network is also possible providing there are mechanisms to hand traffic with different priority levels and possibly including VPN (Virtual Private Networks).

The interworking may prove a challenge. If railway networks are to be co-ordinated then some means of interworking across international boarders needs to be considered.


ETSI TR 103 333 V1.1.1 (2017-02)

TECHNICAL REPORT

System Reference document (SRDoc);
GSM-R networks evolution

- Railways need 2 x 7MHz of spectrum
- Performance & business applications use shared network
- 900 MHz is the preferred band
- ER-GSM band needs harmonising
- Spectrum needs identifying by 2020
- Spectrum made available by 2022 for trials
- Spectrum made available for deployment by 2023

Conclusion

ETSI TR 103 333 was developed by ETSI TC RT NG2R to support the cooperation between ETSI and ECC of CEPT. It was intended to describe the spectrum requirements for a European system for operational railway communications based on 4G or 5G technologies operating in the harmonised and non-harmonised 900 MHz spectrum. Based on the investigations that were carried out to produce this document a number of conclusions were drawn.

Railways will need 2 x 7 MHz of dedicated spectrum to accommodate the current GSM-R systems and future critical communications and applications for decades to come. This will involve GSM-R operating in parallel with FRMCS during the migration from GSM-R to the successor technology whether it be 4G or 5G,

For the additional railways applications including performance and business, other options such as sharing with commercial MNOs and Public Safety Communications operators is anticipated.

From economic reasons, using the 900 MHz band is preferred, based on reuse of the existing GSM-R radio sites. Usage of the 700 MHz or 400 MHz ranges would lead to less reuse and/or re-location of existing sites. However the 700 MHz and 400 MHz range is unlikely to be made available to railways.

Usage of the 2 x 4 MHz spectrum for railways in 876 – 880 MHz paired with 921 – 925 MHz is not sufficient. Use of the 2 x 3 MHz in the 873 – 876 MHz and 918 – 921 MHz band, has already been requested for railways in the ETSI TR 102 627. The introduction of FRMCS requires the harmonisation of the 873 – 876 MHz / 918 – 921 MHz band.

This spectrum needs to be identified by 2020, made available for trials per 2022, and available for operational deployment as of 2023.