SBB CFF FFS

SBB Position on the “squeeze” option for ER-GSM Band

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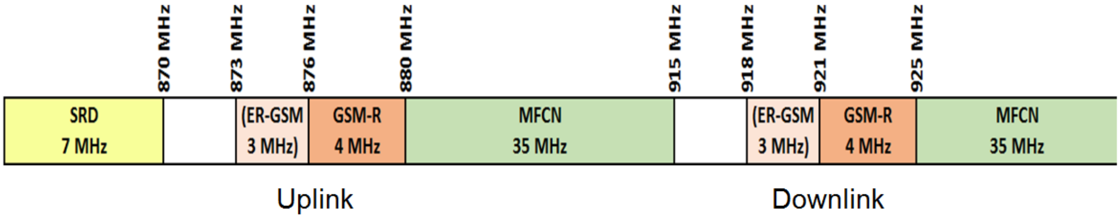
1 Management summary

This report has been created by Swiss Federal Railways SBB, in response to BAKOM's request to clarify the bandwidth demand in the ER-GSM Band.

Radio spectrum has always been a scarce resource, with many potential interested industries. Frequency Authorities will face an even stronger competition with upcoming new technologies. Also the Railway industry is following this development with big concerns related to investments in infrastructure for mobile networks and the outlook of available spectrum in the future.
Following picture presents the current spectrum allocation in the bands relevant for railways:



The GSM-R Band (2x4 MHz) is exclusively reserved for GSM-R across Europe.
The spectrum range of ER-GSM has only been identified for use on a national basis. It does extend the GSM-R band and provide much more flexibility in deploying a GSM-R network.
Several committees, bodies or boards, have been discussing the spectrum need for railway applications and the frequency requirements in the ER-GSM Band in particular.

On June 19th 2017 The European Commission organised a workshop on the efficient use of spectrum in the bands 870-876 MHz and 915-921 MHz by Internet of Things (IoT) and Railways. Passive UHF RFID tags and networked short range devices (SRDs) are also interested in using these bands. The different stakeholders were tasked by the European Commission to further study under which conditions it would be possible to reduce the bandwidth for ER-GSM to 2x1.4 MHz (instead of 2x3 MHz) and thus make some spectrum available for RFID and possibly also for IoT. This so called "squeeze" option aims at achieving a harmonised approach across Europe.
In this context, BAKOM has offered SBB the possibility to elaborate on the required ER-GSM spectrum in Switzerland.

For basic communication purposes the versatile service and application portfolio of a railway company does base on the granted EU harmonized GSM-R frequency band. Despite all opportunities the current GSM-R spectrum share is not sufficient to cover exclusive railway communication requirements according to European Integrated Railway Radio Enhanced Network (EIRENE). Particularly in dense railway networks the number of communication channels exceeds the demand of the available frequency resources.

A mathematical modelling shows that 1.4 MHz resulting in 7 frequencies with 200 kHz spacing is neither sufficient nor reliable for a GSM-R network at highest quality requirements with lowest disruptions at cell level. A GSM-R network requires the repetitive use of the same frequencies at different radio sites. To achieve this, the avoidance of disruptions due to interference is an absolute requirement and is never achievable with such an approach. The practical radio design at SBB shows several areas where the national border does strongly limit the number of permitted frequencies due to multi-national agreements. A reduction of spectrum in the ER-GSM band is not acceptable since cluster sizes for radio network planning providing the number of necessary frequencies for the current traffic demand are strongly limited.

The comparison between Basel, Bellinzona and several other regions within Switzerland results in similar constraints related to available traffic channel capacity already today or in near future.

SBB concludes, that the "squeeze" option is not a feasible way to provide railway critical communication with today available GSM technology, nor it leaves a chance to migrate into a future railway mobile network based on state of the art technologies.
Further studies and analysis on these topics are under investigation and will soon be available.

2 Introduction

With the opening of Gottardo tunnel by mid of June 2016, a big milestone for Switzerland's reliable and safe railways has been achieved. Also for the complete pan European railway traffic it has been a strong sign, to collaborate and strengthen the public transportation sector. Both freight and passengers' trains require mobile communication applications, which have become more and more mission-critical in this sense.

In order to create an interoperable railway market in Europe, the European Commission adopted ETSI's GSM-R based radio systems as the official mandatory train-to-track radio communication technology for services that are considered mission-critical and safety related. These designated services are conventional voice services, e.g. driver-controller and train staff specific point to point calls, railway specific group calls but also emergency calls. Moreover, data services for ERTMS/ETCS signaling systems as data transfer between interlocking systems and railway signal boxes belong to these services. The implementation and use of the current GSM-R system by both SBB and in whole Europe is still expanding. Explicitly, both voice group call services (VGCS according to 3GPP TS 43.068 [9]) but also specific data services for shunting applications are currently introduced based on GSM-R. GSM-R is also the successor technology of the analog shunting communication.

The ECC Decision (02)05 [15] says that all current GSM-R networks in Europe shall use the paired radio blocks 876-880 MHz for the train-to-ground communication link and 921-925 MHz for the ground-to-train communication link. Thus, GSM-R has been granted an EU harmonized frequency band, the so-called UIC frequency band. However, in addition to this, the paired spectrum ranges train to ground direction (873-876 MHz) and ground to mobile equipment (918-921 MHz) has also been identified for GSM-R use on a national basis. New trains but also train platforms being currently updated or renewed, a major number of wireless modems are equipped with radio equipment supporting the ER-GSM band.

However, GSM-R is facing a number of challenges to overcome:

- There is an urgent need to plan the end-of-life of the system with committed vendor support lasting until 2030.
- Mid-term, in shunting yards, stations and other areas, additional capacity for train specific applications will be required supporting the current railway operations for both voice but also data services.
- Parallel operation of GSM-R and its successor technology FRMCS (Future Railway Mobile Communication System) will require additional spectrum for at least the transition period. ER-GSM band nationally harmonized for GSM-R use might be a candidate to facilitate this migration path.

2.1 Scope of the document

The scope of present report is to show the scarce spectrum resources currently available for railway applications, particularly for Basel and Bellinzona area. By introducing the versatile service portfolio required by a railway company, the document does focus on the designated ER-GSM band as a candidate which does provide solutions to overcome the RF-planning issues with its lack of channels.

The limited number of GSM-R frequencies locally permitted for Basel area have to be shared in a mutual agreements between Germany, France and Switzerland. On the short and midterm different GSM-R features have been introduced to mitigate the current situation of missing spectrum.

In the first part, basic GSM-R and GSM features are explained, focusing on the situation of low number of frequencies in theory and in practical usage.

Chapter 9 provides practical radio design insights, explaining the frequency issues, followed by the conclusion in chapter 10.

3 Railway Features and Applications

3.1 Most relevant Railway Applications for focusing areas

3.1.1 GSM-R group calls and correspondent data applications

GSM-R as a main communication system shall provide basic voice and data services for individual railway applications.

In a first instance the introduction of LISA (Light and Integrated Shunting Accessory) covers the need of a real successor of the analogue radio system for all current shunting communication purposes. LISA based on GSM-R specification does support point-to-point voice calls but also voice group calls as well.

While in group receive mode (GRM) status the built-in radio module's firmware does also provide shortest speech interrupt at cell change (cell reselection) by supporting System Information Type 10, 10bis and 10ter which is in full accordance to 3GPP TS 44.018 [4]. The current implementation does prevent the risk of a lost radio signal bearing the link assurance signal during cell change in GRM. Thus, for safety reasons while shunting manoeuvres take place the amount of lost radio speech blocks during cell reselection procedure may be kept extremely low. Hence, LISA does fulfil the outmost exacting working environment of shunters ideally.

Furthermore, data services correspondent to shunting application do support shunters whenever specific shunting routes are requested. For data services based on GPRS bearer, just one single timeslot as a full radio channel can be reserved for requesting of shunting routes since local radio resources are in terms of stated number rarely available.

3.1.2 Point-to-point voice calls

Point-to-point calls may be both mobile originated but also terminated. The call signalling routing is supported by a feature called location based services, which is explained in chapter 3.3.1.

Each call does seize one single timeslot of a GSM-R radio carrier offering up to 6 or even 7 traffic radio channels for radio voice communication in fully dependency of the basic configuration setup of logical channels of the GSM-R TRX.

3.1.3 ETCS Level 2 Application

ETCS Level 2 application does require a 4.8 kBit/s point-to-point data call as a full rate radio channel. The bearer based on circuit switched technique may exchange data between the onboard unit and the associated trackside RBC according to an appropriate special elaborated data exchange protocol. The RBC is a main entity to which freight or passenger trains are connected via the GSM-R network when running in an ETCS Level 2 area.

For each train exchanging ETCS Level 2 data, one radio channel quasi-reserved for this communication application does seize the limited number of channels available maintaining by TRXs per sector of a BTS. The trackside ETCS RBC interfacing with the existing interlocking does also provide central monitoring and does calculate individual movement authorities used by the ETCS onboard unit to enable cab-side signalling capabilities.

3.2 Dual Layer Architecture

The Dual Layer has been conceived to be the main radio network architecture bearing the special ETCS Level 2 application as described above. Dual Layer does provide a full redundancy on the cellular radio network level with a complete duplication of radio access network consisting of BTS and BSC. Moreover, Dual Layer architecture does provide all EIRENE's requirements in terms of optimal radio coverage for both main and redundant layer (Main Layer 1 (ML-1) and Main Layer 2 (ML-2)) and an appropriate Quality of Service, irrespective of free field or tunnel propagation conditions.

Hence, in case of a partly or even a total outage of ML-1, ML-2 as a backup layer is able to take over immediately for service continuity conformity.

Please note, for safety operation reasons Dual Layer architecture does require in full comparison to a single architecture structure always a duplication of network frequency resources.

3.3 GSM-R features critical for railway specific functions and safety

3.3.1 Location dependent addressing

Location dependent addressing does provide automated routing of mobile originated calls to predefined destinations, which are assigned to the responsible train controller area. This enables train driver to easily setup calls by dialling just a short number fully in accordance to the EIRENE-numbering plan.

3.3.2 Priority and pre-emption for both voice and data calls

Due to limited number of available radio channels a higher priority point-to-point call may pre-empt calls with lower prioritization, whenever available radio resources are rare. Prioritization of radio channels is subscription dependent and is an appropriate entry for HLR. ETCS Level 2 data calls may also pre-empt voice calls, if the number of current radio channels available in a certain area are insufficient to setup the data communication. The support of the pre-emption feature (3GPP TS 22.067 [5]) may also be applied to any handover procedure. Whenever a cell change procedure might be failed due to congestion of a target cell, then the timeslot of the target cell is freed immediately in case of a higher prioritized call.

3.3.3 Emergency calls

As already explained GSM-R has to provide different priority levels for individual call handling. Emergency calls are assigned absolute priority. According to EIRENE this includes both point-to-point voice but also group calls as well.

In case of emergency frequency resources shall be immediately freed to notify and warn trains within the control of local or regional administrations and authority. Upon reception of an emergency call for safety reasons all trains' emergency brake application becomes effective, immediately. Drive on is only allowed upon receipt of the overall release sign of the responsible train controller (dispatcher) in the affected area.

Hence, an emergency call must be handled outmost on a mission critical level, thus, lowest-level interfering signal power is an absolute prerequisite to achieve spurious free mobile communication. For GSM-R technology, lowest-level interference requirement can be achieved by considering all co-existing surrounding technologies in the adjacent bands, e.g. LTE (Long Term Evolution) or UMTS (Universal Mobile Telecommunication System).

4 Radio Spectrum Requirements for R-GSM and ER-GSM Band

4.1 R-GSM Band Specifications

The GSM-R network is used to fulfil preferably the requirements of the railway administrations. Particularly, for applications which are safety relevant as mentioned in the chapter 3.3.

As stated in EIRENE SRS 16.0.0 [18]: "For application of railway systems that are relevant to interoperability of the rail systems within the European Community, in particular according to Directive 2008/57/EC [21], the network shall operate in a sub-band, or combination of sub-bands, of the R-GSM band as defined in EN 301 515 [12].

The paired frequency bands 876-880 MHz / 921-925 MHz have been harmonized via the ECC Decision (02)05 [15] by CEPT and have also been assigned to the use for railways operations. In the table below (Table 4-1) specified by 3GPP TS 45.005 [6], also adjacent bands to the UIC frequency band (Mandatory for Interoperability - MI) are listed since GSM-R capable terminals are licensed to get used them on both the extended GSM band (E-GSM, (Mandatory - M)) but also on the primary GSM band (P-GSM, (Mandatory - M)).

	Sub-band - Designation	Frequency (MHz)	
R-GSM band	UIC frequency (GSM-R) band	876-880/921-925	(MI)
	Extended GSM (E-GSM) band	880-915/925-960	(M)
	Primary GSM (P-GSM) band	890-915/935-960	(M)

Table 4-1: UIC-Frequency Bands (extraction of EIRENE SRS)

4.1.1 Number of available radio channels for GSM-R band

The GSM-R band represents in a raster of 200 kHz in total 19 radio channels (ARFCN 955 - 973). However, the number of available channels in border areas is much less.
As an example, the number of frequencies for Basel area is 6. This is in full accordance to the mutual agreement between the Administrations of Austria, Belgium, France, Germany, Luxembourg, the Netherlands, and Switzerland [13].

4.2 ER-GSM band Specifications

The considered paired bands 873-876 MHz / 918-921 MHz for a possible extension for railway operations are just harmonized on national level (see ECC Decision (04)06) [16]).

The ER-GSM band is referenced via EIRENE specification in the "Technical Specifications for Interoperability" (TSI CCS, COMMISSION REGULATION (EU) 2016/919 [20]). Last but not least, the ER-GSM band has been specified in 3GPP TS 45.005 [6].

4.2.1 Number of available radio channels in ER-GSM band

The ER-GSM band represents in a raster of 200 kHz in total 15 additional frequencies.

If 2 neighbouring countries have to share the frequency resources, ARFCN 940 (873.2 MHz (Uplink) and 918.2 MHz (Downlink)) is designated as a guard channel and is therefore not permitted not use, officially [22].

In France, according to ERC report 25 [19], the duplex frequency band 870-876 MHz paired to 915-921 MHz is designated for defense systems.

5 New Approach for the ER-GSM band

5.1 Short Range Devices – current situation

As well known SRD industry is more and more approaching the European Commission while DG CONNECT is asking for harmonization of SRD frequencies, particular for IoT and RFID usage purposes. SRD evolution's does focus on the ER-GSM band which would harm significantly the railway use of this part of this spectrum range.

The European Commission proposed during a workshop on June 19th 2017 a compromise which does foresee a split of the current ER-GSM band to a so-called "squeeze" band for the usage of both SRD but also railway applications. The target shall be to assign just a 1.4 MHz out of 3 MHz band for railway applications.

5.2 Remaining frequency share for Basel area

Therefore, realistically, for Basel area there might be best guess 3 uncoordinated frequencies left for SBB's RF-network planning in the ER-GSM band, which would stipulate the full range of spectrum that may be shared between Germany (DB) and Switzerland (SBB).

6 Spectrum justification for both GSM-R and ER-GSM band

6.1 Spectrum justification for GSM-R networks

For planar networks according to ETSI TR 102 627 [11] the spectrum demand is depicted mathematically in full dependency of cluster size and the overall carrier to interfering C/I situation that is described in 3GPP TS 43.030 [7], 3GPP TS 45.050 [8] and 3GPP TS 45.005 [6].

6.1.1 Number of available channels for GSM-R services and applications

In relation and under consideration of the overall planning aspects, the frequency reuse factor is equal the cluster size. This is also valid for GSM-R's network planning approach.

Therefore, if an averaged cluster size of 5 and a total number of available frequencies of 19 is assumed, then the number of resulting radio channels available per site is 19/5, so about 4. This is in line with ETSI TR 102 627 [11].

However, this id as an ideal approach, best practice is to take into account the overall interference situation as well. Hence, in case of incurrence of an intermodulation impact the number of available channels may be heavily reduced due to less number of channels not impacted reciprocative by 3^{rd}, 5^{th} or even 7^{th} etc., order intermodulation-products.

6.1.2 Number of available GSM-R channels at border area

If the formula above is applied to the borderline area and as stated in chapter 4.1.1, then the amount of available channels does decrease by a factor of 3 to only 1 channel (exactly 1.2).

Under consideration of the current and future railway traffic realistic RF-planning of relevant services will definitively consist of up to 3 TRXs per site in minimum. Thus, the remaining number of TRXs of rounded just 1 for all the relevant GSM-R services and applications is by far not sufficient.

The demand of TRXs is also described in ETSI TR 102 627 [11] where 28 up to 42 radio channels are requested. As a comparison does show in chapters 8 and further, we do strongly confirm the number of carrier frequencies necessarily stringent for RF-planning for both Basel and Bellinzona area.

In the subsequent chapters it is shown what it might mean, if RF-network planners are facing a limited amount of available frequency resources.

6.2 Cluster, frequency reuse pattern – practical aspects of radio planning

As already mentioned to build a GSM-R network, different considerations have to be taken to traffic demand or requirement in a cell – how many subscribers with what services and applications will join the system – and how the geographical distribution of these users will be. Of course, the number of frequencies available with its reuse pattern and the maximum allowed degrade of service are so-called key factors of network planning. Furthermore, the network as such should be designed also for further gradual growth phases, particularly in station areas where more railway services will be expected by trend. Successive demands on traffic growth must be considered when RF-planning work is started.

In order to prevent interference between same frequencies, a so-called reuse pattern called cluster does have to be built up. The reason doing so is to make sure the frequency used in such a cluster is unique, hence, the frequency is used only once in a cluster.

In a few subsequent planning examples underneath, different approaches for frequency reuse patterns as so-called cluster types are shown.

The proposed cluster types analyzed are a 4/12 and a 3/9 in this context. A cluster type 4/12 does consist of 12 frequency groups in 4 sites with 3 sectors each within a given hexagonal cell structure, whereas a 3/9 cluster provides an adequate structure with 9 frequency groups in 3 sites with 3 sectors each.

The amount of available channels in the frequency group for a first approach is the GSM-R band only; in a second approach frequencies offered by the ER-GSM band are considered, additionally.

Frequency Group	A0	B0	C0	D0	A1	B1	C1	D1	A2	B2	C2	D2
Channel	955	956	957	958	959	960	961	962	963	964	965	966
	967	968	969	970	971	972	973					

Table 6-1: Cluster Type 4/12 – consideration of GSM-R band, only

The allowed number of frequencies for the GSM-R band ranges from ARFCN 955 to ARFCN 973. ARFCN 974 is foreseen as a guard channel and is therefore not considered in here.

As the table above with its missed entries shows, this approach which may offer a very low co-channel interference level, however, it is not applicable at all to the amount of channels foreseen for the GSM-R spectrum range. Such a cluster type is not suited for 19 frequencies offered by the GSM-R band.

Frequency Group	A0	B0	C0	D0	A1	B1	C1	D1	A2	B2	C2	D2
Channel	940	941	942	943	944	945	946	947	948	949	950	951
	952	953	954	955	956	957	958	959	960	961	962	963

Table 6-2: Cluster Type 4/12 – consideration of both GSM-R and ER-GSM band

If the cluster type remains, however, the number of available channels is expanded by those offered by the ER-GSM band.

Moreover, if traffic capacity is considered in this context, a site with 3 sectors may have one single TRX configured for pure traffic channels per sector when choosing the cluster type above. In stations areas and shunting yards this might still not be sufficient.

In contrast to the capacity statement above, from spectrum due to modulation's point of view a carrier-spacing of 800 kHz (A0, A1 means 4 x 200 kHz) is sufficient and does therefore fulfill the both conformance requirements of 3GPP TS 45.005 [6] but also ETSI TS 102 933-2 [10]. Terminals with improved receiver performance are not necessarily stringent, if unwanted emissions due to co-site sharing or co-existence within the same geographical area are not to be considered.

Frequency Group	A0 1.sector	B0 2.sector	C0 3.sector	A1 1.sector	B1 2.sector	C1 3.sector	A2 1.sector	B2 2.sector	C2 3.sector
Channel	955	956	957	958	959	960	961	962	963
	964	965	966	967	968	969	970	971	972

Table 6-3: Cluster Type 3/9 – consideration of GSM-R band, only

If the cluster type 3/9 is chosen, the approach in full comparison to what is shown in Table 6-2 is similar. However, the interference situation has to be clearly analyzed since the number of possible unwanted adjacencies is more adverse due to smaller frequency spacing. Please note that spectrum due to modulation requirement might be still sufficient, however, desensitization of terminal's receiver might occur then, if out-of-band emissions from other technologies do impact receiver's performance with unwanted signals, additionally.

From capacity's point of view, there is no change, thus, one single TRX-unit may be installed. As a consequence, only one traffic channel may be allocated for a higher capacity demand. In station areas and shunting yards this might be not sufficient, if channel capacity demand will increase.

Frequency Group	A0	B0	C0	A1	B1	C1	A2	B2	C2
Channel	940	941	942	943	944	945	946	947	948
	949	950	951	952	953	954	955	956	957
	958	959	960	961	962	963	964	965	966

Table 6-4: Cluster Size 3/9 – under consideration of frequencies out of the ER-GSM band

As shown in Table 6-4, the number of traffic channels available for a higher capacity is improved in full comparison to Table 6-3, if ER-GSM band is deployable. As depicted in table above 2 TRXs for pure traffic handling - without any channels reserved for signalling - with 8 channels (TCH) each may be allocated per sector with dynamic channel assignment, if ER-GSM band is available.

Please note that spectrum due to modulation requirement might still be sufficient, however, de-sensitization of terminal's receiver might not occur, unless unwanted and spurious emissions from other technologies, e.g. FRMCS may impact receiver's performance when sharing the ER-GSM band in the future.

6.3 Micro Cell Structure

In a first instance, a micro cell structure applied to a railway network might also provide more available radio channels, especially in hot spot areas where there are stations, shunting yards, etc.

As in many public networks may be shown, the number of available radio channel and traffic distribution is adequate, if an appropriate cluster size for a micro cell structure, e.g. cluster size 7/21 is applied. Moreover, in order to introduce the overall increasing interference level, in public mobile networks downlink power control as a feature may mitigate the increasing interference situation of surrounding cells.

However, a micro cell structure is not appropriate particularly for group calls that are of highest importance for a railway network. A group call has to be set up in the entire group call area. Therefore, the number of channels in a group call area cannot be increased by dividing this area into a certain number of micro cells.

Furthermore, downlink power control cannot be implemented due to voice group calls. In a voice group call several mobile stations in different locations in a group call area are listening to the same radio channel. Downlink power control would adapt the downlink power according to the radio conditions of the so called talker mobile station, which might result in bad radio conditions for some listening mobile stations.

Another aspect is the number of cell changes that might be heavily increased in a network of micro cell structure nature. For connection retainability reasons the number of cell changes has to be strongly limited.

Finally, a 7/21 cluster size is not applicable to a railway network since the number of frequencies getting applied to the necessary spectrum range is missed, definitively.

6.4 Embedded Repeater

If scarce frequency resources do limit nominal cell planning approach, however, a repeater deployment may help out in those areas where frequency resources do run short.

Moreover, the intermodulation requirements given in specifications 3GPP TS 43.030 [7] and 3GPP TS 45.0050 [8] may help to design an adequate RF-network under consideration of repeater units at outmost lowest interference level.

For adequate RF-network planning with optimized carrier-to-interferer-ration (C/I), wide band noise situation has to be considered in the RF-power budgets for both up- but also downlink direction, particularly for group and point-to-point calls whenever EFR for enhanced voice quality performance as a more sensitive codec is deployed.

6.5 Improved Receiver at Terminal Side

As shown in the previous chapters both cluster size and cluster type are decisive key factors for an adequate cellular network design.

At terminal side, improved receiver capability is an important factor to get overcome interference or a blocking situation.

6.6 Frequency Hopping

Frequency hopping is a feature in GSM that may reduce a permanent interfering situation, particularly in areas where co-channel but also adjacent channel interferer are dominant. Depending on differences in path length, destructive or constructive interference may occur.

The interference situation for a mobile station may be strongly dependent on which frequency and timeslot that mobile does happen getting used. Furthermore, frequency hopping may reduce the influence of signal strength variations caused by multipath propagation, significantly. As multipath fading is frequency dependent, fading dips may appear at different locations for different frequencies. Hence, a mobile station using frequency hopping will not remain in a specific fading dip for a longer time than a one single burst. In such a case signal strength variations may be breakable up into pieces of a short duration short enough for the interleaving and coding process correcting errors.

Frequency hopping may also be a mean to enable a small number of given frequencies, if narrow band deployment is the only way getting used of a spectrum share at most optimal level, particularly, if simultaneous operation of a planned migration phase may take place in future evolvement of GSM-R's successor technology. However, synthesizer hopping will enable an efficient frequency hopping gain with reduced overall interference level, if the number of hopping frequencies in the list is large enough.

Moreover, frequency hopping feature enables a protection mechanism for GSM-R system that might be an effective means combating unwanted spurious emissions whenever future technology is to be deployed in migration phase for simultaneous operation.

Due to limited number of frequencies out of the GSM-R band to be allocated frequency hopping as synthesizer hopping is not very efficient.

Furthermore, long time experiences show that even latest GSM-R capable radio modules and terminals do have serious difficulties with frequency hopping features.

Particularly, terminals with group call capabilities are mainly affected. It is a fact that in GRM System Information Type 10ter might be difficult to get overcome. However, System Information Type 10ter is of highest importance when frequency hopping is enabled. As already explained, striving for shortest speech or signal interruption at cell change (cell reselection) is an overall target to get achieved. Therefore, it is an absolute requirement for safety reasons for all shunting manoeuvres.

6.7 GPRS – available GPRS Resources within Circuit-Switched Network

A system designed for circuit-switched traffic may allow a limited number of radio channels per carrier offered in a radio network. By introduction of a GPRS or even EGPRS the efficiency of any available radio channel offering is enhanced due to packet-switched nature of the system itself.

However, the introduction of GPRS or even more EGPRS saving resources for railways' services and applications does come along with significant disadvantages. First of all, wireless modems for the ETCS's on-board unit operation need to be upgraded to provide packet-switched bearer services. Today's installed on-board units are not supporting this function. A rollout all over the Railway Operators will take several years, and a partial rollout will make the demand for radio spectrum even worse, as both technologies need to be supported in parallel.

If EGPRS shall be introduced, which even does provide a boosted throughput with smaller round trip time and a more efficient use of radio channels in full comparison to GPRS, an investment in capital and operational expense required for designated network elements and appropriate features shall not be underestimated.

Moreover, for ETCS over GPRS or EGPRS, for redundancy reasons the packet core network with SGSN and GGSN must be prepared as well. Furthermore, the RBCs' has to be upgraded too, to be able to support packet-switched technology.

Work is underway to lay out the framework for a new standardised railway telecommunications network which will replace GSM-R beginning in 202x. It is not considered economically, to invest in an old technology approach based on GSM technology just for only a few years.

7 Squeeze Option

The workshop held, June 19th 2017 resulted in the proposal to split the current ER-GSM band to a "squeezed" band. The compromise does foresee a simultaneous use of ER-GSM spectrum for SRD and RFID. The target is to assign a share of just 1.4 MHz out of 3 MHz band for railway services and applications.

7.1 Squeeze Option and ER-GSM Band

This option is a significant reduction of the traffic channels in the ER-GSM band to a maximum of 7. In the region around Basel (which is already implemented in the live network), it will result in a different frequency reuse pattern.

A lower frequency reuse pattern for the same technology generates a higher grade of self-interference. GSM-R radio cells with the same frequency and adjacent frequencies will interfere with each other as a negative consequence.

According to 3GPP TS 45.005 [6], 2 major types of system-generated cellular interference do exist:

- Co-channel interference (C/I)
- Adjacent channel interference (C/A).

Furthermore, irrespective of any mathematical modelling, 1.4 MHz for only 7 frequencies left out of the ER-GSM band is neither sufficient nor reliable for a GSM-R network planning at highest quality requirements with lowest disruptions at cell level. A GSM-R network requires the repetitive use of the same frequencies at different radio sites. To achieve this, the avoidance of disruptions due to interference is an absolute requirement.

A heavy degradation of the GSM-R Quality of Service parameters has to be avoided in any case. However, as mentioned above this is not achievable since adjacent channels are always present and dominant, particularly at cell edges.

8 Migration Scenarios – Border Cross Coordination

8.1 Border Cross Coordination

Assuming that LTE will be the bearer technology applied to all FRMCS related services and applications, coordination in border areas has to take place when just one 1.4 MHz carrier is available.

In annex 3 of ECC Decision (08)02 [17], the preferred codes for the UMTS900 system are given. Technically, site identification for LTE is based on a similar technique: For LTE site identification the Physical Cell Identification (PCI) does allow building out of 168 PCIs 3 subgroups for national usage. Therefore, 504 PCIs are available in total for cell identification divided in sets of 84 PCIs each in 6 subgroups A to F at the border between neighbouring countries (for more information, see 3GPP TS 36.101 [1], 3GPP TS 36.211 [3] and annex 5 of ECC Decision (01)01 [14]). Please be aware, annex 5 in [14] does formally refer on public networks since FRMCS bearer based identification on LTE technologies has not yet been specified.

In full dependency of coordinated preferential PCI assignment between neighbouring countries, a coordination of realistic power budgeting in relation to signal strength is also of high importance in order to avoid or to alleviate co-channel interference between neighbouring countries using LTE as a bearer on highest possible level. This does include site-planning data exchange which may take place between all groups of interest bilaterally or trilaterally. This is a prerequisite to use harmonized frequency bands reserved for FRMCS's activities most efficiently.

Border cross coordination does also include PRACH-coordination as well. PRACH-coordination may comprise parametrization of “ghost” PRACHs. “Ghost” PRACH may not reserve resources in the neighboured country's network by increasing the interference level and lowering the performance in the uplink direction heavily.

8.2 Migration Scenario in case of simultaneous FRMCS and GSM-R operation

8.2.1 National Co-existing Planning effects – GSM-R LTE and UMTS

National co-existing planning effects based on new technologies will be worked out by the UIC UGFA-delegation. Therefore, they are not considered in this paper.

8.2.2 Migration between neighbouring countries at border area

A possible migration scenario where particularly at the border area simultaneous operation of GSM-R and FRMCS bearer technology exists, underneath a calculation by approximation shall show the FRMCS bearer's unwanted emissions as an impact on a GSM-R terminal receiver as a victim at border area. FRMCS bearer shall base on LTE technology.

8.2.2.1 Unwanted emission calculation

According to 3GPP TS 36.104 [2] for a FRMCS base station with 43 dBm output power and an assumed antenna gain of 12 dB and 3 dB cable and other losses, the mid frequency of the a 1.4 MHz carrier shall be at 918.8 MHz and a neighboured GSM-R carrier within the same ER-GSM band shall have an offset Δf of 1 MHz. Δf has been chosen appropriately, in order to keep possible co-existence impacts between technologies realistically with modest risk.

Furthermore, according to [2] the unwanted emission of this single carrier shall not exceed the specified level of -7.8 dBm. With 12 dB antenna gain and 3 dB loss, the E.I.R.P. of the unwanted signal is then approximately 1.2 dBm (100 kHz reference bandwidth) and 4.2 dBm at 200 kHz bandwidth at an offset of 1 MHz (band 8 for public is referenced for this calculation in this report since ER-GSM band has not been referenced in the appropriate 3GPP specification yet).

If a line of sight distance of 15 km is proposed to the border line as that is also outlined in [13], the free space attenuation for 15 km is 107 dB; therefore, the unwanted emission does disappear to an acceptable level of approximately -106 dBm (100 kHz) and -103 dBm (200 kHz).

For the use case above the intention was to get a carrier at the band edge of the ER-GSM band placed in order to make sure that the remaining channels are outmost less interfered by the unwanted signal of the FRMCS bearer.

8.2.3 Interference scenario between FRMCS carriers at border area

Additionally, co-channel interference situation between countries due to FRMCS carriers based on LTE technology might be alleviated by smart selection of assigned PCIs reserved for usage in the appropriate country. As already mentioned the maximum allowed E.I.R.P. of the unwanted signal is in full dependency of antenna gain, antenna height over ground, etc.

PCI reservation scenario can be found in [14]. However, this is valid for public operators only.

For the GSM-R's successor technology, the specification has to be expanded appropriately.

9 Reflection for Europe and Switzerland

9.1 Europe

9.1.1 European Rail Freight Corridors

With the projected European Rail Freight Corridors (RFC) the rail freight transportation in Europe will be improved and the modal shift from road to rail encouraged. Two of the corridors (Rhine-Alpine Corridor and North Sea - Mediterranean Corridor) will pass through Switzerland (see Figure 1 and Figure 2).

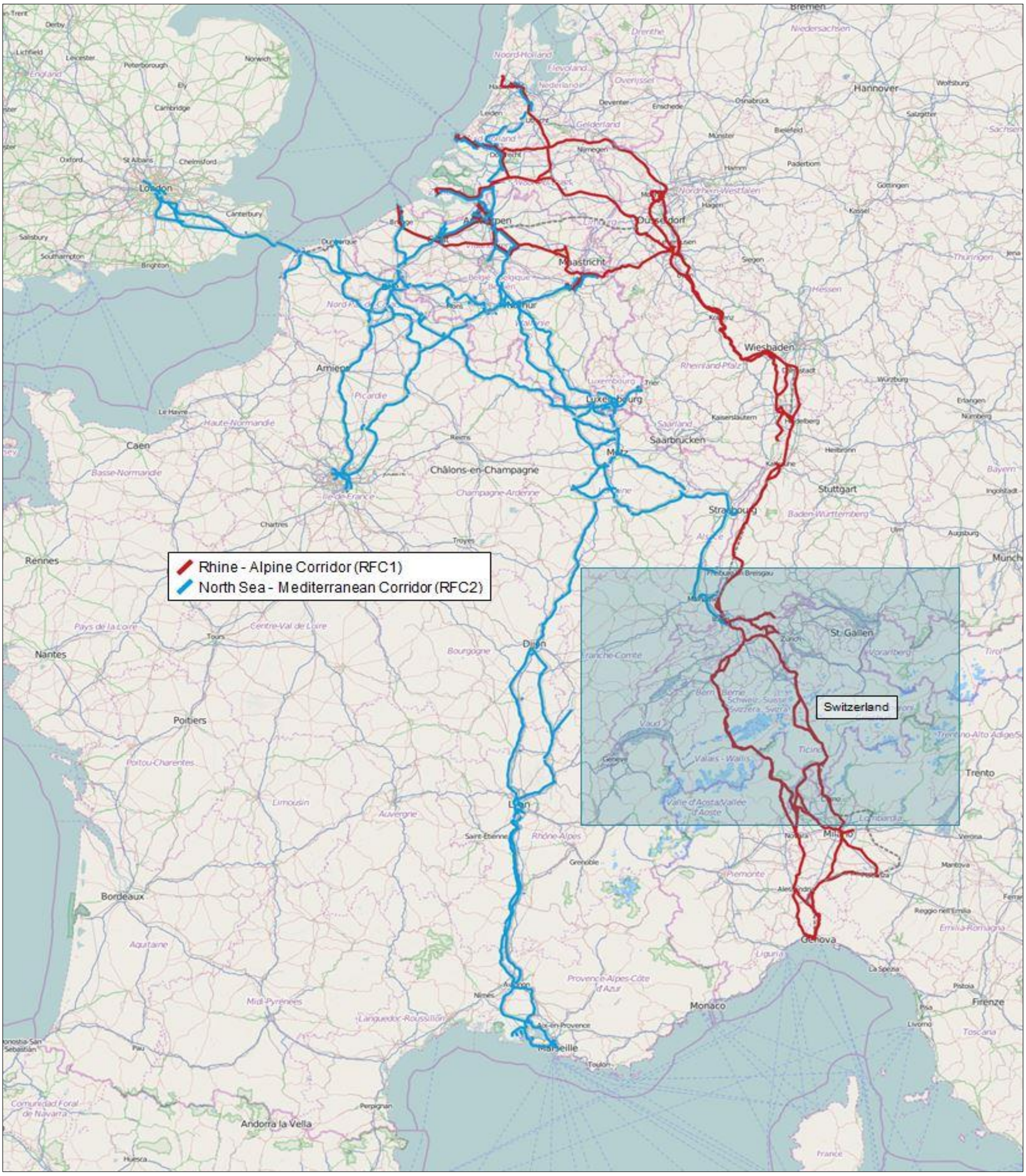


Figure 1: European Rail Freight Corridors (https://cip.rne.eu/apex/f?p=212:24:14921863290810:::::)

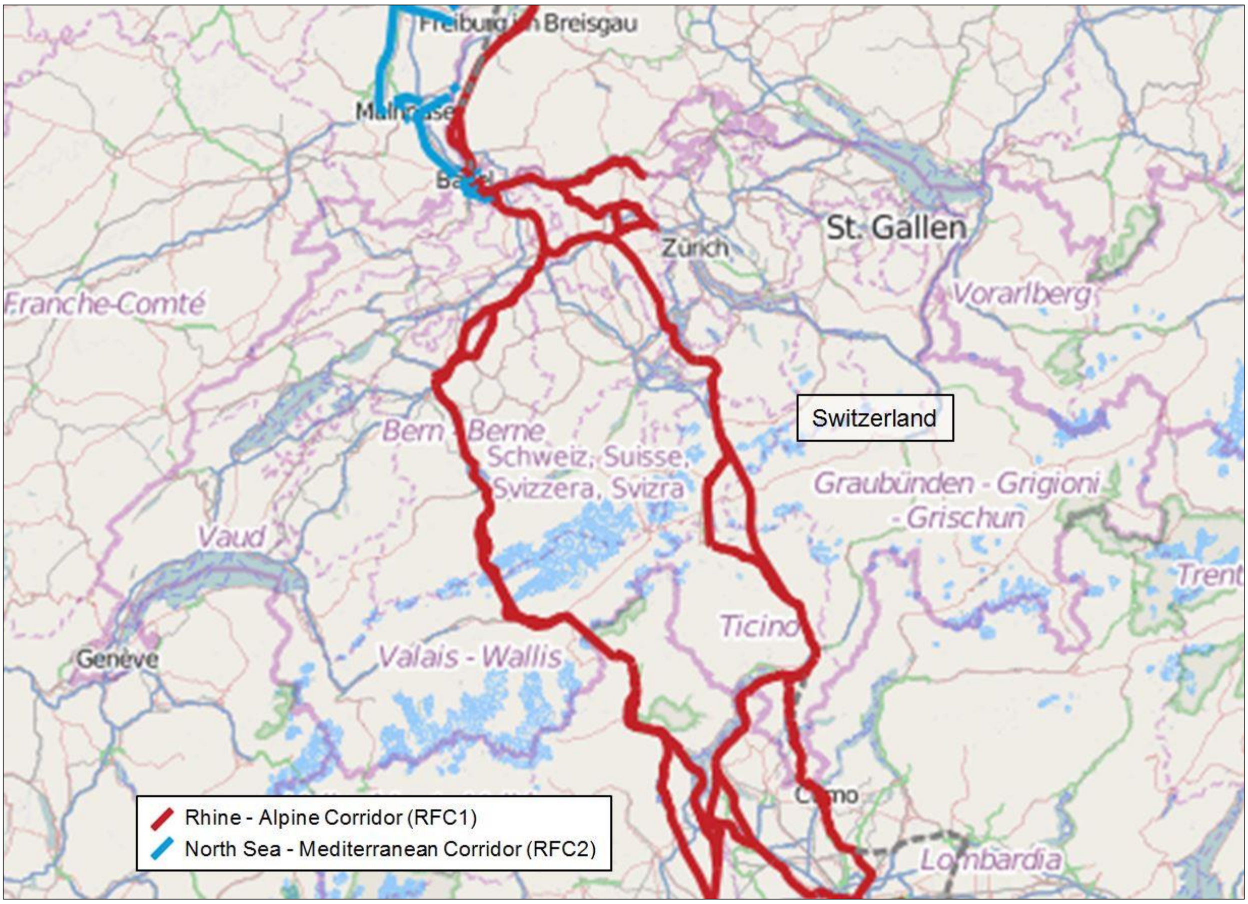


Figure 2: European RFC passing through Switzerland *(https://cip.rne.eu/apex/f?p=212:24:14921863290810:::::)*

9.2 Switzerland

In Switzerland, there are several areas where the available traffic capacity (UIC frequency band) is insufficient to meet the SBB GSM-R network coverage requirements completely.

Basel is the most crucial area in Switzerland, as both in chapter 9.1.1 mentioned Railway Freight Corridors (RFC) will pass through (→ 3 countries, 2 corridors) and numerous shunting areas are located in the region.

The Bellinzona area is very critical too, as over there the traffic capacity requirements are also very high due to shunting activities and ETCS Level 2.

In Geneva, Lausanne, Bern, Olten, Zurich and Chiasso the situation is as challenging as well due to the same reasons as in Bellinzona.

The next Figure 3 and Table 9-1 give an overview of the most critical areas in Switzerland. The situation is not just critical with the current available traffic capacity (UIC frequency band) but also if the ER-GSM Band can be used (independent of whether a 1.4 MHz or a 3 MHz spectrum).

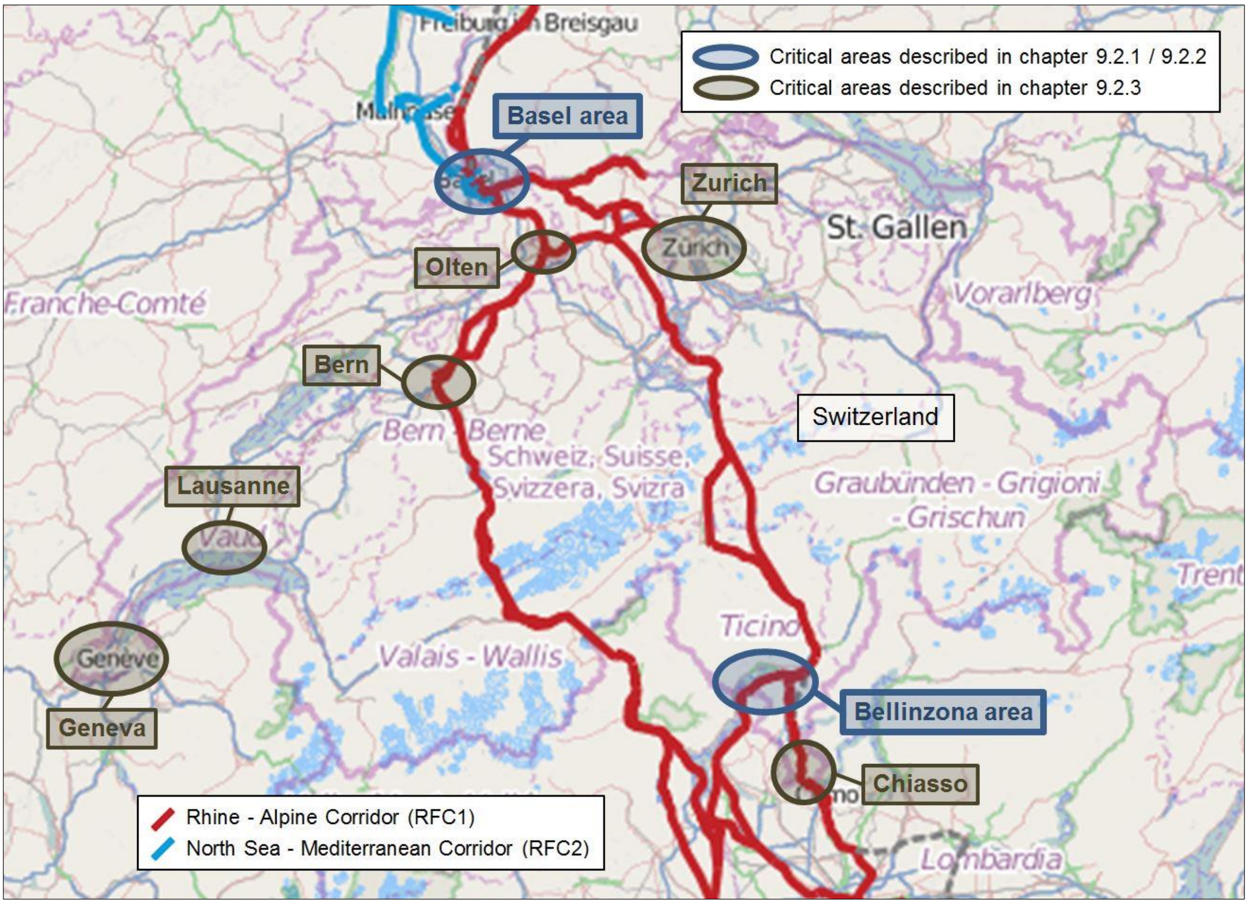


Figure 3: Overview of the most critical areas in Switzerland

Area	Locality within Switzerland	Description in chapter…
Basel	Border area	9.2.1
Bellinzona	Interior	9.2.2
Geneva	Border area	9.2.3
Lausanne	Border area	
Bern	Interior	
Olten	Interior	
Zurich	Interior	
Chiasso	Border area	

Table 9-1: Overview of the most critical areas in Switzerland

9.2.1 Basel area

In relation to spectrum demand, Basel area is indeed one of the most crucial regions in Switzerland: Two ETCS Level 2 trans-European rail freight corridors will pass through a border triangle. The available (limited) frequency spectrum has to be distributed over three countries (see Figure 4 and chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**). A further complication is the fact that several shunting areas in the Basel region are already operated with GSM-R (see Figure 5).

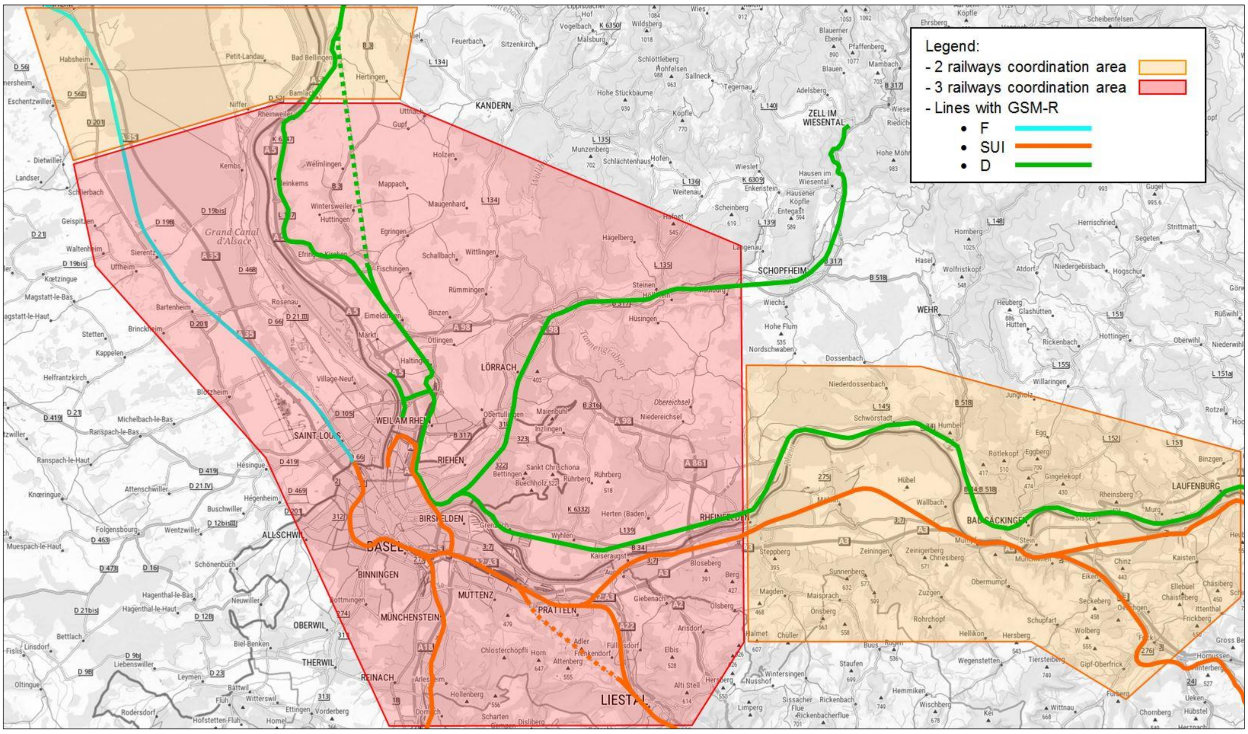


Figure 4: Frequency coordination areas in Basel

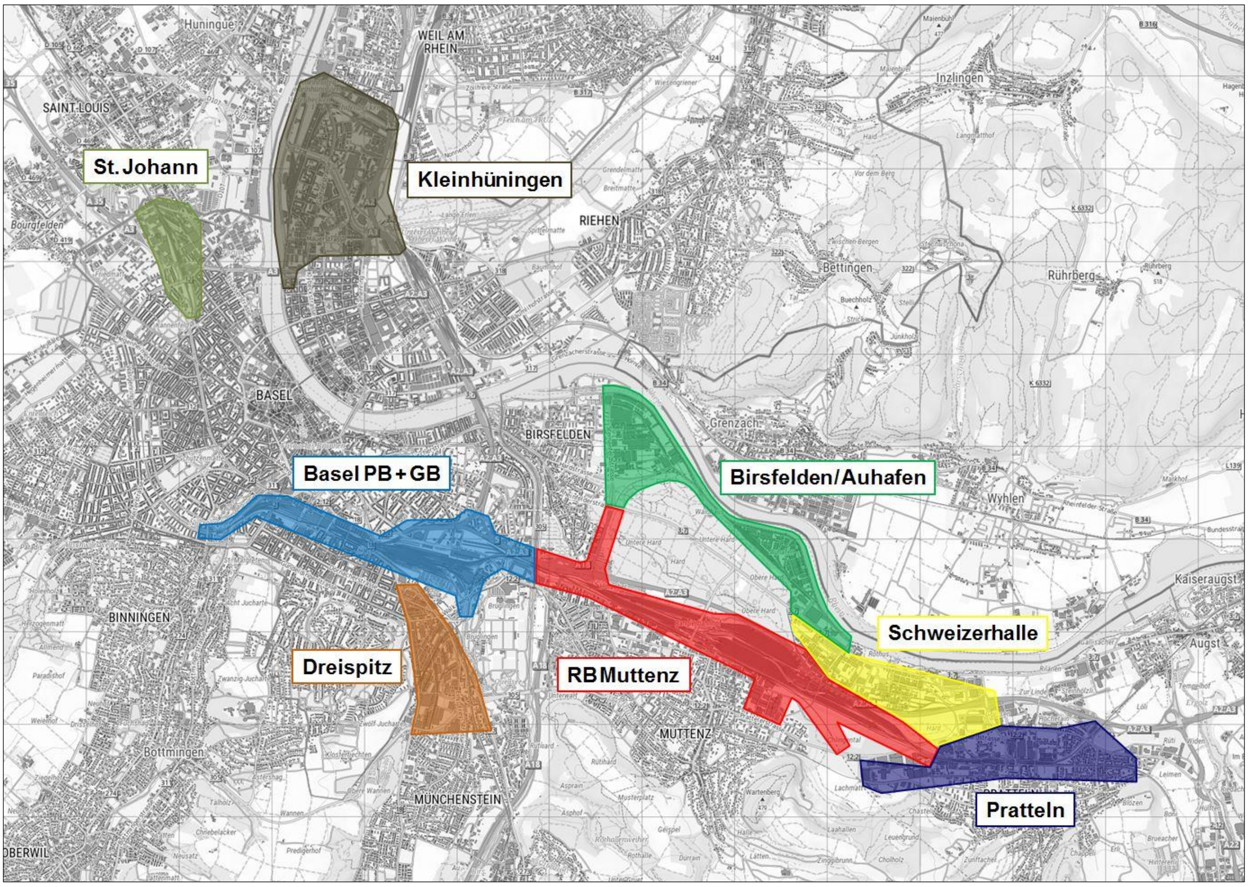


Figure 5: Shunting areas in Basel

In Basel the following traffic capacity is required:

Application	Total No. of required TRXs
Shunting (GSM-R group and P-t-P voice calls)	24
ETCS Level 2 (Railroad line «Basel Hbf - Olten»)	22

Table 9-2: Number of required TRX (Basel area)

As a result of the table above, in order to meet the SBB GSM-R network coverage requirements in the Basel area completely, a total number of around 46 TRXs would have to be installed with 46 single frequencies out of the designated GSM-R band. This is not possible with the available UIC frequency band (876-880 MHz / 921-925 MHz) as the frequency spectrum has to be shared with France and Germany (see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**). In most shunting areas, a traffic capacity of 3 TRXs is required and this cannot be achieved with the currently usable clusters (see chapter 6.2).

Depending on the available frequency spectrum the following applications can be provided:

Application / Spectra	GSM-R group calls (chapter 3.1.1)	P-t-P voice calls (chapter 3.1.2)	ETCS Level 2 (chapter 3.1.3)
GSM-R Band	×	✓	×
GSM-R Band + 1.4 MHz ER-GSM Band	×	✓	×
GSM-R Band + 3 MHz ER-GSM Band	✓ *	✓ *	×

Table 9-3: Provided applications in relation to the available frequency spectrum (Basel area)

* With an additional 1.4 MHz or 3 MHz ER-GSM Band the actual shunting traffic capacity requirements (GSM-R group calls / Point-to-point voice calls) just can be provided if the whole system chain (BSC, BTS, terminals, etc.) supports the mentioned applications in the ER-GSM Band. If only one system element fails, the GSM-R group calls have to be handled over EAC (this means P-t-P voice calls), which would have a significant not yet quantifiable impact to the capacity requirements.

The current application limitations in Basel area are:

- In the shunting area «Basel PB + GB» not all shunting teams will be able to use the new customer device LISA (chapter 3.1.1). Approximately half of the shunting teams cannot be changed over to LISA and therefore still have to continue to use an analogue radio system.
- In the shunting areas «RB Muttenz», «Dreispitz», «Schweizerhalle» and «Pratteln» none of the shunting teams can be changed over to LISA. All shunting teams have to continue to use an analogue radio system until the required shunting traffic capacity is available.
- ETCS Level 2 (Dual Layer Architecture, chapter 0) cannot be provided in the Basel area.

9.2.2 Bellinzona area

In Bellinzona frequency coordination with foreign GSM-R operators is not needed and the full spectrum of the GSM-R Band can be used. But due to very high traffic capacity requirements for shunting and ETCS Level 2, the situation is very challenging as well. In two of the three shunting areas in Bellinzona, a traffic capacity of 3 TRXs is required and this cannot be achieved with the currently usable clusters (see chapter 6.2). Moreover the shunting areas in Bellinzona are quite large and borders on the frequency coordination area with Italy (see Figure 6 and Figure 7).

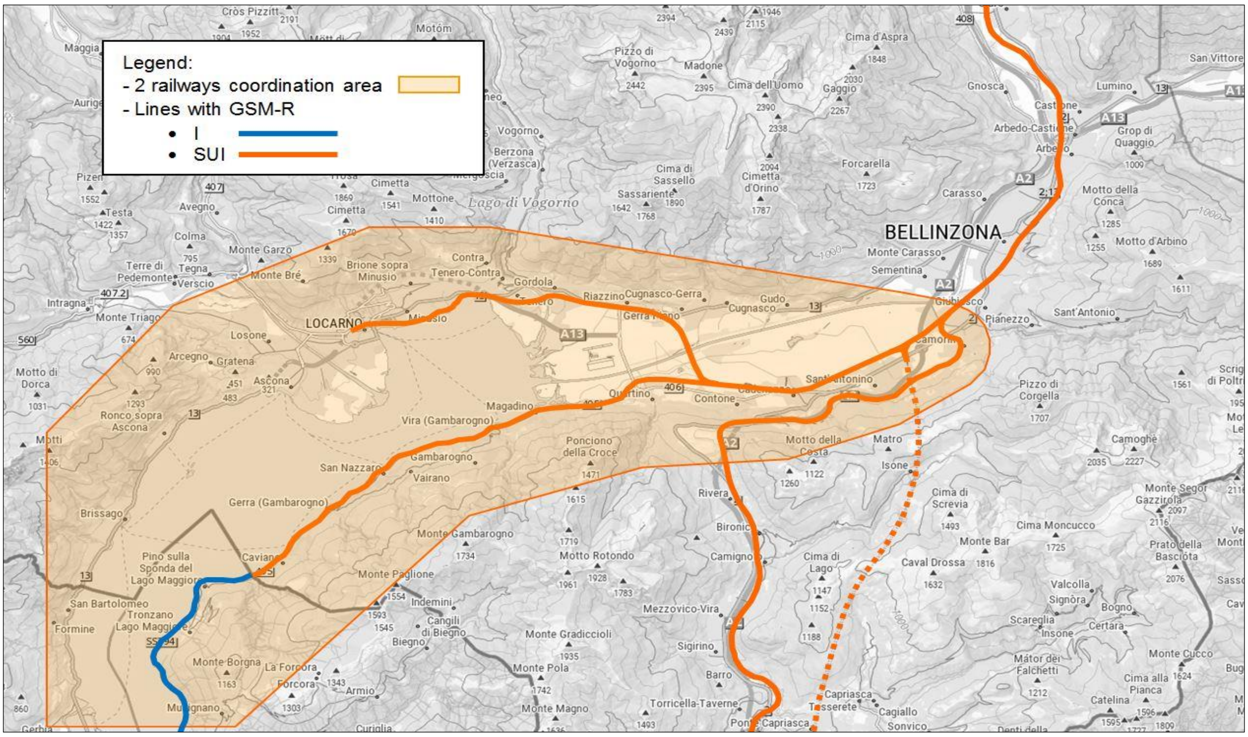


Figure 6: Frequency coordination areas in Bellinzona

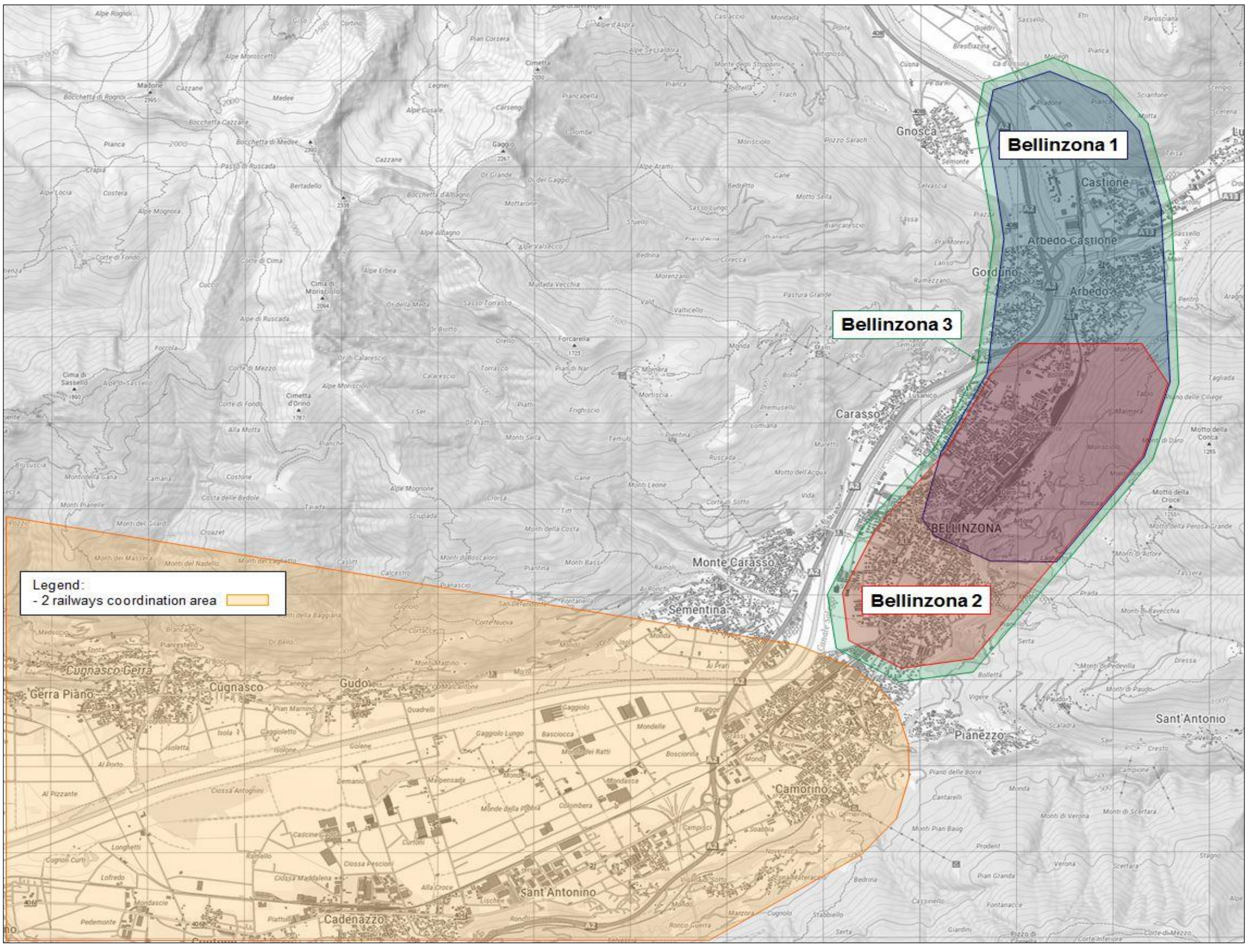


Figure 7: Shunting areas in Bellinzona

In Bellinzona the following traffic capacity is required (area between Bellinzona North and Locarno, between Bellinzona and the border in direction Luino and between Bellinzona and the tunnel portal Ceneri in direction Chiasso):

Application	Total No. of required TRXs
Shunting (GSM-R group and P-t-P voice calls)	8
ETCS Level 2 (Railroad line «Locarno - Bellinzona - Capolago»)	18

Table 9-4: Number of required TRX (Bellinzona area)

As a result of the table above, in order to meet the SBB GSM-R network coverage requirements in the Bellinzona area completely, a total number of 26 TRXs have to be installed with 26 single frequencies out of the designated GSM-R band.

Depending on the available frequency spectrum the following applications can be provided:

Application / Spectra	GSM-R group calls (chapter 3.1.1)	P-t-P voice calls (chapter 3.1.2)	ETCS Level 2 (chapter 3.1.3)
GSM-R Band	×	✓	✓
GSM-R Band + 1.4 MHz ER-GSM Band	×	✓	✓
GSM-R Band + 3 MHz ER-GSM Band	✓ *	✓ *	✓

Table 9-5: Provided applications in relation to the available frequency spectrum (Bellinzona area)

* With an additional 1.4 MHz or 3 MHz ER-GSM Band the actual shunting traffic capacity requirements (GSM-R group calls / Point-to-point voice calls) just can be provided if the whole system chain (BSC, BTS, terminals, etc.) supports the mentioned applications in the ER-GSM Band. If only one system element fails, the GSM-R group calls have to be handled over EAC (this means P-t-P voice calls), which would have a significant not yet quantifiable impact to the capacity requirements.

The current application limitations in Bellinzona area are:

- In the shunting areas «Bellinzona 1/2/3» all shunting teams will be able to use the new customer device LISA (chapter 3.1.1). But due to frequency spectrum limitation reasons just 4 TRXs (not 8 TRXs as required) are in operation (2 TRXs in the center cell, 1 TRX in the outer cells). Therefore a traffic prioritization had to be defined: ETCS Level 2 traffic is more relevant than shunting traffic, which means that the shunting traffic is operating in a «best effort» modus (→only the capacity not used by ETCS Level 2 is available for shunting traffic), which will most probably harm the railway operation.

9.2.3 Other critical areas (Geneva, Lausanne, Bern, Olten, Zurich, Chiasso)

Not just in the Basel and Bellinzona areas the radio coverage situation is very critical, it is also assumed that in Geneva, Lausanne, Bern, Olten, Zurich and Chiasso it will not possible to meet the SBB GSM-R network coverage requirements completely with the UIC frequency band in the short- and medium term.

Depending on the available frequency spectrum the following applications can be provided:

Spectra	Application	GSM-R group calls (chapter 3.1.1)	P-t-P voice calls (chapter 3.1.2)	ETCS Level 2 (chapter 3.1.3)
Zurich, Geneva, Chiasso	GSM-R Band	×	✓	×
	GSM-R Band + 1.4 MHz ER-GSM Band	✓ *	✓ *	×
	GSM-R Band + 3 MHz ER-GSM Band	✓ *	✓ *	×
Bern, Olten	GSM-R Band	×	✓	×
	GSM-R Band + 1.4 MHz ER-GSM Band	✓ *	✓ *	×
	GSM-R Band + 3 MHz ER-GSM Band	✓ *	✓ *	✓
Lausanne	GSM-R Band	×	✓	✓
	GSM-R Band + 1.4 MHz ER-GSM Band	✓ *	✓ *	✓
	GSM-R Band + 3 MHz ER-GSM Band	✓ *	✓ *	✓

Table 9-6: Provided applications in relation to the available frequency spectrum (other critical areas)

* With an additional 1.4 MHz or 3 MHz ER-GSM Band the actual shunting traffic capacity requirements (GSM-R group calls / Point-to-point voice calls) just can be provided if the whole system chain (BSC, BTS, terminals, etc.) supports the mentioned applications in the ER-GSM Band. If only one system element fails, the GSM-R group calls have to be handled over EAC (this means P-t-P voice calls), which would have a significant not yet quantifiable impact to the capacity requirements.

According to current plans ETCS Level 2 will not be operational in Geneva, Bern, Olten, Zurich and Chiasso before 2020.

10 Conclusion

A very important key challenge for the RF-network planning is to design the GSM-R network to re-use the number of available frequencies in such a way that the radio system is able to provide the radio capacity that is required in dedicated areas, whilst ensuring that the Quality of Service level has to remain within acceptable limits according to the requirements for railway services and applications.

The current frequency paired allocation of 2 x 4 MHz (876-880 MHz / 921-925 MHz) exclusively reserved for GSM-R across all Europe is not sufficient to support railway service and application requirements. Additional spectrum for example from ER-GSM is necessary.

In dense railway networks the spectrum allocated seems to be sufficient for traditional point-to-point voice communication needs. However, despite all opportunities the spectrum is insufficient to cover railway communication requirements, e.g. group call traffic for shunting purposes and ETCS Level 2 data communication. As shown, GSM-R sets the base for safety-related communication and control systems.

Moreover, at country border area only the part of the spectrum available depends on the number of countries sharing the frequencies in the GSM-R band. As shown by applying particular cluster sizes for radio planning the number of TRXs providing traffic channels in cells deployed at border area is strongly limited. E.g. only 6 frequencies are at one railway company's disposal due to shared spectrum.

It is evident that railway companies are dependent on a full usage of both parts of ER-GSM and GSM-R bands. For migration and also parallel operation as well as co-existence of technologies at border areas several issues are not yet solved. Ongoing studies will come up with results and recommendations in due time.

Thinking of the fact that particularly in Switzerland many of the railway hubs and shunting yards are very close to the country border (e.g. Basel, Geneva, Lausanne, and Chiasso); it is absolutely required to get the entire ER-GSM band harmonized on a European wide level.

Consequently, **the "squeeze" option which foresees a spectrum of 1.4 MHz for railway services is not a suitable option.** The number of available GSM-R channel resources at lowest interference risk is restricted to a level where RF-planning with appropriate cluster size is not feasible. As shown with a common radio network planning tool modelling of 7 frequencies within 200 kHz spacing**, the "squeeze" option's spectrum range of the ER-GSM band is neither sufficient nor reliable for a GSM-R network at highest quality requirements with lowest disruptions at cell level.**

Basel is in fact a crucial border area; however, for the Bellinzona area seen within the entire context of Ceneri base tunnel, service continuation and their direct impacts on a highest possible service quality is a necessity too. The service quality impact does aim at services with lowest quality degradation, irrespective of bearer technology. **Without full use of ER-GSM spectrum range for railways, SBB does not see a way to achieve the level of quality required for railways.**

Further studies, analysis and simulations among the railway infrastructure as well as the communications industry are still ongoing. SBB expects further details to be available within the coming months.

References

[1] 3GPP TS 36.101
[2] 3GPP TS 36.104
[3] 3GPP TS 36.211
[4] 3GPP TS 44.018, Release 12
[5] 3GPP TS 22.067, Release 12
[6] 3GPP TS 45.005, Release 12
[7] 3GPP TS 43.030, Release 12
[8] 3GPP TS 45.050, Release 12
[9] 3GPP TS 43.068, Release 12
[10] ETSI TS 102 933-2
[11] ETSI TR 102 627
[12] EN 301 515
[13] Agreement between the Administrations of AUT, BEL, F, D, LUX, HOL and SUI (frequency bands 876-880 / 921-925 MHz); Vienna, 25th of June 1999
[14] ECC Decision (01)01
[15] ECC Decision (02)05
[16] ECC Decision (04)06
[17] ECC Decision (08)02
[18] EIRENE SRS, version 16.0.0
[19] ERC report 25
[20] TSI CCS, COMMISSION REGULATION (EU) 2016/919
[21] Directive 2008/57/EC
[22] Agreement between the Administrations of D, LIE, AUT und SUI (frequency bands 918-921 / 873-876 MHz); Berlin, 26th of October 2012

Abbreviation List

3GPP	Third Generation Partnership Project
ARFCN	Absolute Radio Frequency Channel Number
BAKOM	Bundesamt für Kommunikation (Federal Office of Communications (OFCOM))
BSC	Base Station Controller
BTS	Base Transceiver Station
C/A	Adjacent channel interference (Carrier to Interference ratio adjacent channel)
CCS	Control Command and Signalling
CEPT	Conférence Européenne des Postes et des Télécommunications
C/I	Co-channel Interference (Carrier to Interference ratio coherent channel)
DB	Deutsche Bahn
DG CONNECT	Directorate General for Communications Networks, Content and Technology
EAC	Enhanced Automatic Conferencing
EC	European Commission
ECC	European Communication Committee
EFR	Enhanced Full Rate
EGPRS	Enhanced General Packet Radio Service
E-GSM	Extended GSM band
E.I.R.P.	Equivalent Isotopically Emitted Power
EIRENE	European Integrated Railway Radio Enhanced Network
EN	European Normative
ER-GSM	GSM-R Extension Band
ERC	European Radio Committee
ERTMS	European Rail Traffic Management System

ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
EU	European Union
FRMCS	Future Railway Mobile Communication System
FRS	Functional Requirement Specification
GB	Güter Bahnhof
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GRM	Group Receive Mode
GSM	Global System for Mobile Communication
GSM-R / R-GSM	Global System for Mobile Communication - Railway
HLR	Home Location Register
IoT	Internet of Things
M	Mandatory
MI	Mandatory for Interoperability
ML-1	Main Layer 1 (normal operation in Dual Layer network architecture)
ML-2	Main Layer 2 (redundant layer, to be applied in case of outage of ML-1)
LISA	Light and Integrated Shunting Accessory
LTE	Long Term Evolution
PB	Personen Bahnhof
PCI	Physical Cell Identification
P-GSM	Primary GSM band
PRACH	Physical Random Access Channel
P-t-P	Point-to-Point (voice calls)
RB	Rangier Bahnhof
RBC	Radio Block Centre
RF	Radio Frequency
RFC	Rail Freight Corridor (former nomenclature for Rhine - Alpine Corridor and North Sea - Mediterranean Corridor)
RFID	Radio Frequency Identification
SBB	Schweizerische Bundesbahnen
SGSN	Serving GPRS Support Node
SRD	Short Range Devices
SRS	System Requirement Specification
TCH	Traffic Channel
TR	Technical Report
TRX	Transceiver (Transmitter and Receiver)
TS	Technical Specification
TSI	Technical Specification for Interoperability
UGFA	UIC Group for Frequency Aspects
UIC	Union International de Chemin de Fer
UMTS	Universal Mobile Telecommunication System
VGCS	Voice Group Call Service