CONNECTING EUROPE FACILITY (CEF)

Activity 12

ETCS over GPRS/Edge capacity study in station environment (ERTMS objective 1 & 2)
O-3300 v1.0.0

Call identifier: CEF 2014-EU-TM-0279-S

ACCESS: x Public ☐Restricted ☐Confidential

	NAME	DATE	VISA
Author	CEF Activity 12	15 February 2016	P. Tane
Review	UIC, LEONARDO, KAPSCH, NOKIA	23 March 2018	
Approval	ERTMS/GSM-R ERIG KAPSCH	29 March 2018	R. Sarfati O. Eudes

MODIFICATION HISTORY

VERSION / ISSUE	DATE	DESCRIPTION OF CHANGES	AUTHOR
0.0.1 TO 0.0.8	**15/02/2016**	**DRAFT EVOLUTION**	**UIC, NOKIA, KAPSCH, LEONARDO**
0.0.9	**23/03/2018**	**FINAL DRAFT FOR REVIEW**	
1.0.0	**29/03/2018**	**FINAL VERSION**	

Executive Summary

The proposed ETCS over GPRS/Edge capacity study in Station environment encompasses the Connecting Europe Facilities (CEF) Activity 12. It aims to identify solutions in order to facilitate and speed up the ERTMS deployment in corridors, primarily in stations, where complex situations exist and for which the capacity constraints need to be addressed in an efficient manner from a frequency perspective. In particular, this study will consider the possibilities offered by the use of Packet-Switched Data in parallel to Circuit Switched Data CSD to carry ETCS Level 2 data.

The study results will allow faster ERTMS deployment in corridors, primarily in stations, where complex situations exist. It highlights the ability of the solution to overcome capacity issues at hot spots and allows increasing GSM-R efficiency in the near future by using packet data (PSD, i.e. GPRS/E-GPRS) as part of GSM-R in parallel to Circuit Switched Data CSD to carry ETCS Level 2 data.

The study demonstrates the ability of the GSM-R network to handle mixed traffic of both CSD and PSD trains in high radio traffic areas and includes the validation of priority mechanisms, which guarantee resource allocation to ETCS Level 2 in CSD and PSD mode, while fulfilling the performance requirements of GSM-R for voice and other PSD non-ETCS end users.

Finally, based on the promising results of this theoretical study, the contributors of the document consider that the establishment of a pilot project, equipped with Commercial Off-the-shelf equipment, would allow the confirmation of the end-to-end solution in a real environment to be demonstrated.

A pilot would be an opportunity to further demonstrate the benefits outlined in the present study, potentially including automated in-station ETCS Start of Mission, developing the general awareness of IP services, and reducing the impact of the frequency constraints. It would also pave the way towards Future Rail Mobile Communication System (FRMCS).

Table of Contents

1. Scope of the study

The station environment, and hotspots in general, present challenges for the GSM-R system due to the capacity requirements which result from their operational use, be it related to the concentration of GSM-R Users (both rolling stock and train personnel) or to the nature of the traffic they attract (converging tracks, variable speed profiles). The introduction or development of ETCS-enabled trains further increases the capacity demands on the system while frequencies available remain a scarce resource, especially in dense urban areas.

The present study identifies solutions in order to facilitate and speed up the ERTMS deployment in corridors, primarily in stations, where complex situations exist and for which the capacity constraints need to be addressed in an efficient manner from a frequency perspective. In particular, this study considers the possibilities offered by the use of Packet-Switched Data in parallel with Circuit Switched Data CSD to carry ETCS Level 2 data.

The study aims to demonstrate that GSM-R network performance can handle mixed traffic with both CSD and PSD trains in high radio traffic areas. This includes validating priority mechanisms which guarantee resource allocation of ETCS Level 2 in CSD and PSD mode while fulfilling the performance requirements of GSM-R for voice and PSD non-ETCS users.

The study takes into account different use cases typical of the station environment:

1. Station scenario, taking into consideration in-station ETCS L2 departure and low speed profiles,
2. Passing Station scenario, with ETCS L2 under conventional/low speed profiles,
3. Perturbed scenario, such as traffic disruption and restoration

The particular case of RBC Hand Over areas, which can result in traffic hotspots, have not been investigated as part of the present study.

2. References and abbreviations

2.1. Reference documents

Reference	Document
[R01]	“Traffic Model for RBC – Train Communication”, issue 1.0.7, UNISIG
[R02]	A 11 T 6001 13.0.0, “Radio Transmission FFFIS for EuroRadio”, UIC
[FRS08]	EIRENE Functional Requirements Specification v8.0.0, UIC
[SRS16]	EIRENE System Requirements Specification v16.0.0, UIC
[FFFIS_EuR]	Radio Transmission FFFIS for EuroRadio v13.0.0, UIC
[O8662]	O-8662_v1.0_EoG_Phase_1_report_v040.pdf, “ETCS over GPRS Phase 1 Report”, UIC
[O8657]	O-8657 v1.0 GSM-R – PSD RAN and CORE network feature evaluation, UIC
[O8664]	O-8864 v1.0 “ETCS in PS-mode GPRS/EGPRS Guideline”, UIC
[50.159]	TS 50159 2012-01 “Railway Applications - Communication, Signalling and Processing Systems – Safety-Related Communication in Transmission Systems”, IEC

2.2. Abbreviations

8PSK	8 Phase Shift Keying
ARP	Allocation Retention Priority
C/I	Carrier to Interference ratio
CS-[number]	Coding Scheme –Channel Coding (GPRS)
CSD	Circuit Switched Data
EDGE	Enhanced Data Rates for GSM Evolution
EDOR	ETCS Data Only Radio
E-GPRS	Enhanced GPRS
eMLPP	enhanced Multi-Level Precedence and Pre-emption Service
EoM	End of Mission
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETCSoCS	ETCS over CSD
ETCSoPS	ETCS over PSD
ETSI	European Telecommunications Standards Institute
FRMCS	Future Rail Mobile Communication System
GBR	Guaranteed Bit Rate
GERAN	GSM EDGE Radio Access Network

GMSK	Gaussian Minimum-Shift Keying
GPRS	General Packet Radio Service
GSM-MT	GSM Mobile Termination
GSM-R	Global System for Mobile Communication – Railway
IETF	Internet Engineering Task Force
IP	Internet Protocol
MA	Movement Authority
MCS-[number]	Modulation and Coding Scheme (EDGE)
MPTCP	Multipath TCP
M2M	Machine-to-Machine
OBU	OnBoard Unit
PDTCH	Packet Data Traffic Channel
PFC	Packet Flow Control
PSD	Packet Switched Data
RBC	Radio Block Center
SoM	Start of Mission
SRD	Short Range Device
TBF	Temporary Block Flow
TCH	Traffic Channel
TCP	Transport Control Protocol
TEN-T	Trans-European Transport Networks
TRX	Transmitter
UIC	Union Internationale des Chemins de Fer (International Union of Railways)
UNISIG	UNion Industry of SIGnalling
USF	Uplink State Flag

3. Inputs and assumptions

3.1. Introduction to the questionnaire

Selected UIC members were asked for their input through a questionnaire (see attachment "Annex 1"). The following UIC members provided responses to the questionnaire (Annex 1):

- Deutsche Bahn (Germany),
- Infrabel (Belgium),
- Network Rail (United Kingdom),
- ProRail (Netherlands),
- RFI (Italy),
- SNCF (France),
- SBB (Switzerland).

The questionnaire was essentially intended to gather information regarding operational hotspots (stations, shunting yards):

1. Inputs with regards to the number of trains present, the number of trains that might be passing through the station and the number of voice users;
2. Inputs with regards to the forecasted adoption by the respondents of trains equipped for ETCS in general and for ETCS over GPRS in particular between today (2017) and 2025;
3. Inputs on forecasts for GPRS traffic not related to ETCS (especially non-critical traffic),
4. Inputs on current setup of the GSM-R sites (number of TRX, allocation of TCH vs PDTCH, etc…)

The following subsections analyse the information provided by the respondents (Annex 2) and provide context on how the information can be used.

3.2. Use cases

The questionnaire envisioned two major scenarios (Large Station, Passing Station) and enquired about a Safety Margin parameter.

The Large Station scenario refers to locations where typically a large number of platforms are present with trains at standstill. This scenario is of particular interests when considering the feasibility of proceeding with the ETCS Start of Mission from the station itself as compared to proceeding with ETCS away from the station. Especially in the case of ETCS over CSD, the ETCS Start of Mission from the station itself is very challenging when it comes to frequency planning, as will be studied in a later section (see 4.6 and 4.7). From a traffic handling perspective, this scenario presents a large number of stationary users that may require radio resources and therefore cause fluctuations in the volume of traffic which is likely to result in a significant variation between peak hours vs non-peak-hours when compared with train movements in and out.

The Passing Station scenario considers locations where there are typically a lower number of platforms than in the Large Station scenario, but where parallel tracks offer the ability for trains to transit through the cell at moderate to high speed. From a traffic handling perspective, this scenario places more demands on the flexibility of the radio resource management as the volume of traffic fluctuates with trains coming in and going out of the cell.

The purpose of the Safety Margin, sometimes called Perturbation Factor, is to identify the impact of operational perturbations either in or outside the hotspot area resulting from pure railway operational causes. This can include telecommunications reasons or some other causes. The cell occupancy at the hotspot may differ significantly and potentially be greater than the planned cell occupancy during normal / nominal operation. This Safety Margin can also be interpreted as a measure of expected over-dimensioning of the telecommunications system in order to prevent disruption to railway operation. It will be seen that ETCS over GPRS offers more flexibility than ETCS over CSD to address perturbations to the traffic (see notably 4.9).

For each of the aforementioned scenarios:

1. Scenario 1: Large Station scenario,
2. Scenario 2: Passing Station scenario,
3. Scenario 3: Perturbed scenario,

Different traffic type mixtures were considered:

a. ETCS over PSD in combination with Voice traffic
b. ETCS over PSD in combination with Voice traffic and ETCS over CSD
c. ETCS over PSD in combination with Voice traffic, ETCS over CSD and other packet-switched-based applications

3.3. Traffic Model for RBC-Train Communication

For the purpose of this study, the UNISIG Traffic Model [R01] is used.

A 4 kbps Guaranteed Bit Rate (uplink and downlink) is recommended (see notably Table 2-2 in [R02]) for ETCS over GPRS traffic. Answers to the questionnaire, which sought to identify the "typical" bandwidth for ETCS over GPRS, varied between 1 kbps for ProRail and 4.8 kbps for Deutsche Bahn and Infrabel in Large Stations.

Values in the 4kbps range are more conservative and are in practice more aligned with the CSD bearer of 4.8 kbps used for ETCS over CSD. These values would in practice ensure (if enforced by the Packet Flow Context feature[1], see section 4.2.3 for feature description) a high level of protection for trains already engaged in an ETCS over GPRS session, but could limit the adaptability of the system to spikes in ETCS over GPRS traffic, as trains could be rejected by the GPRS system (subject to policy). In contrast, if the system were to be configured with a default GBR of 1 kbps, i.e. aligned with the "typical" value provided by ProRail, conflicts for bandwidth could result in a less deterministic Time to Transfer delay for some ETCS users in case of congestion of the ETCS over GPRS session. However, as can be seen later in the document, due to the packet scheduler in combination with Packet Flow Context feature, the Nominal obtained bit rate per ETCS over GPRS will be at least 1.8kbit/s in the case of CS-2 single slot operation. In multi-slot operation the nominal bit rate will increase.

Moreover, the Guaranteed Bit Rate [GBR] of 4 kbps, applicable to Uplink and Downlink, required by EIRENE FFFIS for EURORADIO v13, chosen in accordance with the common ETCS traffic model, can be considered as the reference value required by each train in ETCS over PSD. This value is aligned to the current ETCS over CSD value of 4.8 kbps (transparent CS bearer) used by the majority of railway operators. But, referring to Prorail's response to the questionnaire, even if the GBR required by EIRENE is 4 kbps, the average bitrate is much lower, estimated at 1 kbps. This

[1] Please note that Packet Flow Context is mandatory only when mixing ETCS over GPRS traffic with other, non-critical, GPRS applications.

value is also dependent on the configuration of the ETCS system, but it could have a large impact on the maximum number of supported trains.

In conclusion, even if 4 kbps (symmetric UL and DL) was used as the upper limit, due to the statistical multiplexing of the PSD technology, a lower value than 4 kbps symmetric for each train could be a reasonable value for network dimensioning. A good approach could be dimensioning for 4kbps symmetric, without taking into account the estimated increase in traffic in degraded mode.

3.4. *Volume of train traffic*

The table below summarizes the information provided by the respondents in the Large Station and Passing Station scenarios.

Operator	Scenario	Trains at standstill	Trains in transit	Trains in approach
Deutsche Bahn	Large Station	27	1	2
Network Rail	Large Station	10	0	2
ProRail	Large Station	6	6	2
Infrabel	Large Station	11	1	4
RFI	Large Station	16	0	2
SNCF	Large Station	16	0	0
Deutsche Bahn	Passing Station	7	1	2
Network Rail	Passing Station	2	2	9
ProRail	Passing Station	1	2	0
Infrabel	Passing Station	4	0	1
RFI	Passing Station	5	2	2

3.5. *Applications and types of traffic*

3.5.1. *Types of traffic*

Within the context of this study, three major sources of traffic impacting the radio resources were considered:

- Circuit-Switched Traffic, some of which may be considered critical (REC calls, ETCS over CSD);
- Critical Packet-Switched Data Traffic (i.e. ETCS over PSD in this study);
- Non-Critical Packet-Switched Data Traffic (such as Passenger Information, etc…).

These three sources of traffic may conflict for radio resources, and pre-emption mechanisms are available to help with the arbitration as documented in 4.1.5. Please note that the Packet Flow Context feature (see section 4.2.3) is mandatory only when mixing ETCS over GPRS traffic with other, non-critical, GPRS applications.

3.5.2. Forecasts for GPRS/EDGE usage amongst respondents

From the responses to the Questionnaire, one may derive the following information regarding the usage of GPRS (ETCS excepted).

Timeframe	Observation
2017	Only ProRail is currently using GPRS as part of its operation (for non-critical purposes), with a significant user base in Large Stations (150, which includes Passenger Information panels) and a moderate traffic (2kbps average, 4kbps peak)
2020	SNCF plans to introduce GPRS in this timeframe with a medium user base in Large Stations (15) but with a more aggressive data profile (5kbps average, 10 kbps peak)
2025	Deutsche Bahn, Network Rail and Infrabel would introduce GPRS services in this timeframe for a small user base, both in Large and Passing Stations, with a data profile increased as compared to the SNCF 2020 profile (10 kbps average, 15 kbps peak).

Note: no data available in the survey response from RFI regarding that piece of information.

When it comes to ETCS, with the notable exception of SNCF, which foresees PSD-capable on-board equipment for 50% of the ETCS trains (in Large Stations), most of the respondents foresee the availability of PSD-capable on-board equipment in the 2025 timeframe (with large variations from 5% to 100%).

	2017	2020	2025
ETCS equipment in-train penetration	Negligible	0-20%	20-100%
… % of which are ETCS over PSD capable	Negligible	0-50%	5-100%

Finally, it should be noted that availability of EDGE capable devices for onboard systems is anticipated from 2019 onwards.

According to the National Implementation Plans, the use of Level 2 is not homogeneous. While some countries have declared their intention to use Level 2 in their complete network (Austria, Czech Republic, Netherlands, Norway, Portugal and Slovakia), others intent to use Level 1 or 2 depending on the existing type of signaling or depending on the type of lines. Finland has the intention to use only Level 1. [2]With respects to the current implementation of Level 2 and the different baselines, some valuable information can be found in the maps provided by UNISIG[3], where there is an outlook of the ETCS baselines contracted for each track section, and information coming from contracts on the number of vehicles to be fitted with ETCS, including the baseline. So far, there is no indication of the number of vehicles that may be fitted with ETCS Baseline 3 Release 2 (with Packet Switching) in the near future, other than trains planning to run in Denmark.

[2] EC Report on National Implementation Plans, as of 31st December 2017: "Synthesis Report on NIP" v1.1 https://ec.europa.eu/transport/modes/rail/interoperability/interoperability/ccs-tsi_en

[3] http://www.ertms.net/?page_id=55#

This is also shown in the details from the projects that have received funds from the European Commission during the last year, via the Connecting Europe Facility (CEF) programme.[4]

3.5.3. The ETCS application in a GPRS/EDGE context

Document O-8664 "ETCS in PS-mode GPRS/EGPRS Guideline" [O8864] provides guidance regarding the mandatory GSM-R PS-mode network extensions, system features, necessary planning tasks and the parameters dedicated to GPRS/EGPRS when used as a bearer for ETCS.

It identifies notable features in "Table 2-11" reproduced below as Table 1 which provides a summary of typical ETCS messages used and their size in octets and relative frequency of occurrence.

	OBU to RBC	RBC to OBU	SaPDU size	Message Frequency (seconds)			Total packet size + header Uplink	Total packet size + header Downlink
ETCS Message	Uplink	Downlink	(octets)	min	max	typical	[octets]	[octets]
Authentication Message 1, AU1	X		13	1	1		73	0
Authentication Message 2, AU2		X	21	1	1		0	81
Authentication Message 3, AU3	X		9	1	1		69	0
Authentication Response, AR		X	9	1	1		0	69
Disconnect, DI	X		9	1	1		69	0
Initiation of a Communication Session	X		19	1	1		79	0
Configuration Determination,		X	20	1	1		0	80
Session Established, (only max packet size)	X		43	1	1		103	0
Validated Train Data,	X		60	1	1		120	0
Ack. of Train Data,		X	23	1	1		0	83
General Message + extra packet(s), entry		X	50	2	2		0	110
General Message + extra packet(s), Full Supervision		X	19	3	40		0	79
General Message + extra packet(s), exit		X	23	1	1		0	83
Acknowledgement of GM	X		23	3	40		83	0
Movement Authority + extra packets (100-500 octets)		X	500	6	120	20	0	560
Request to shorten MA + options	X		40	1	1		100	0
Acknowledgement of MA	X		23	6	120	20	83	0
Train Position Report	X		33	3	120		93	0
Termination of Communication Session	X		19	1	1		79	0
Ack. of Termination,		X	19	1	1		0	79
MA Request, 20-60 octets	X		60	6	120		120	0
TCP acknowledgement	X		20	10	10		80	0
TCP acknowledgement		X	20	10	10		0	80

Table 1: characteristics of typical ETCS messages (Source: O-8664)

As indicated in 3.3, the recommended GBR value is 4 kbps per train.

From Table 1, one can infer that the largest message in the downlink direction is the Movement Authority which can reach up to 560 octets with header. In the uplink, the largest message reaches up to 120 octets which indicates that the downlink is the dominant factor when it comes to capacity constraints.

[4] https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/projects-by-transport-mode/rail

4. Solutions and general considerations

The following options are available for consideration within the operator's toolbox to address the capacity needs in a station environment:

- Network side:
  - Usage of Packet-Switched Data, and additionally consideration of EDGE vs. GPRS modulation and coding schemes together with the associated coverage implications (C/I, …),
  - Usage of priority mechanisms: pre-emption, guaranteed bandwidth, etc…
  - For ETCS over PSD, usage of the features endorsed by the TEN-T testing (see 4.2)
- Onboard side
  - Usage of EDOR compliant to (MI) and (M) requirements of Eirene 8/16 (see 4.3)
  - Impact of power constraints (8W in GMSK vs 2W in 8-PSK)
- Others
  - Focus on ETCS over PSD where the major resource bottleneck occurs (the station surroundings) and transition to ETCS over CSD where and when it becomes manageable from a radio resource perspective,
  - Etc.

Besides the aforementioned areas of consideration, the special case of the migration between ETCS over CSD to ETCS over PSD is also considered in the present study.

4.1. General considerations on GPRS and EDGE

The majority of the European GSM-R networks were initially planned for CS application (voice and data) in combination with low packet switched demands served over GPRS using CS-1 and CS-2. A number of networks were planned to achieve the minimum coverage requirement as specified in EIRENE, whereas others were planned from the outset with enhanced coverage requirements, foreseeing the introduction of higher coding schemes (CS-3/CS-4 or MCS-3+) to cope with future higher packet switched demands.

4.1.1. Offered data throughput for GPRS and EDGE coding schemes

The following table summarizes the modulation and the theoretical maximum offered data rate per time slot for the GPRS and EDGE coding schemes, excluding the RLC/MAC overhead. The exclusion of the RLC/MAC overhead provides more "user-oriented" figures in terms of data rate.

Coding scheme	Bitrate excluding RLC/MAC overhead (kbps/slot)	Modulation
GPRS CS-1	8.0	GMSK
GPRS CS-2	12.0	GMSK
GPRS CS-3	14.4	GMSK
GPRS CS-4	20.0	GMSK
EDGE MCS-1	8.0	GMSK

EDGE MCS-2	10.4	GMSK
EDGE MCS-3	14.8	GMSK
EDGE MCS-4	16.8	GMSK
EDGE MCS-5	21.6	8-PSK
EDGE MCS-6	28.8	8-PSK
EDGE MCS-7	44.0	8-PSK
EDGE MCS-8	53.6	8-PSK
EDGE MCS-9	58.4	8-PSK

It should be noted that:

- these theoretical maximum data rates per timeslots require radio conditions that surpass those defined by the EIRENE recommendations,
- the Tx power of a Mobile Station using 8-PSK modulation is specified as being 6 dB lower than when using GMSK modulation. As a consequence, a Mobile Station (such as a Cab Radio) specified to emit at up to 8W in GMSK will be limited to 2W in 8-PSK.

4.1.2. Comparative robustness of GPRS and EDGE

GPRS

GPRS uses the same GMSK modulation as the GSM voice service.

The following figure provides the GPRS comparative error correction for the codecs CS-1 to CS-4:

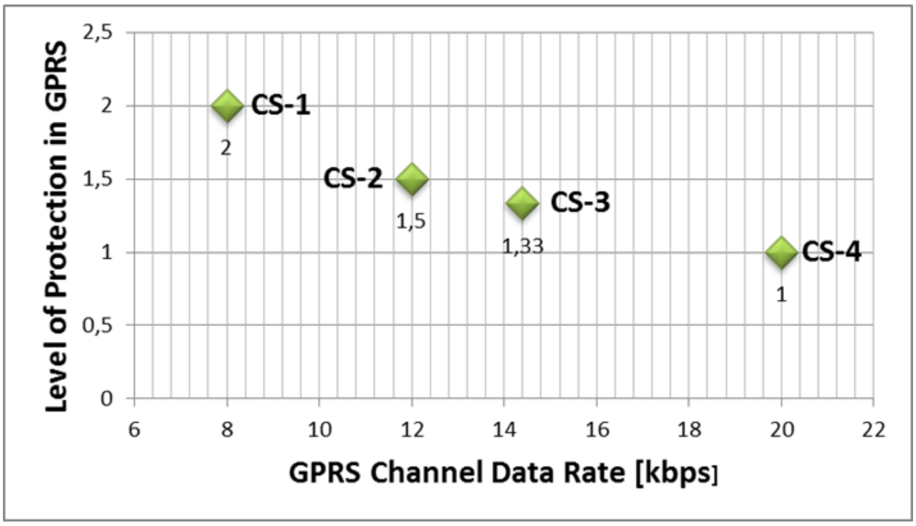


Figure 1 - Level of protection in GPRS

EDGE

EDGE is an enhancement of GPRS and introduces new Modulation and Coding Schemes (MCS1-9). Like GPRS, the coding schemes MCS-1 up to MCS-4 use GMSK modulation. EDGE introduces 8-PSK modulation for MCS-5 to MCS-9.

The following tables provide the EDGE comparative error correction:

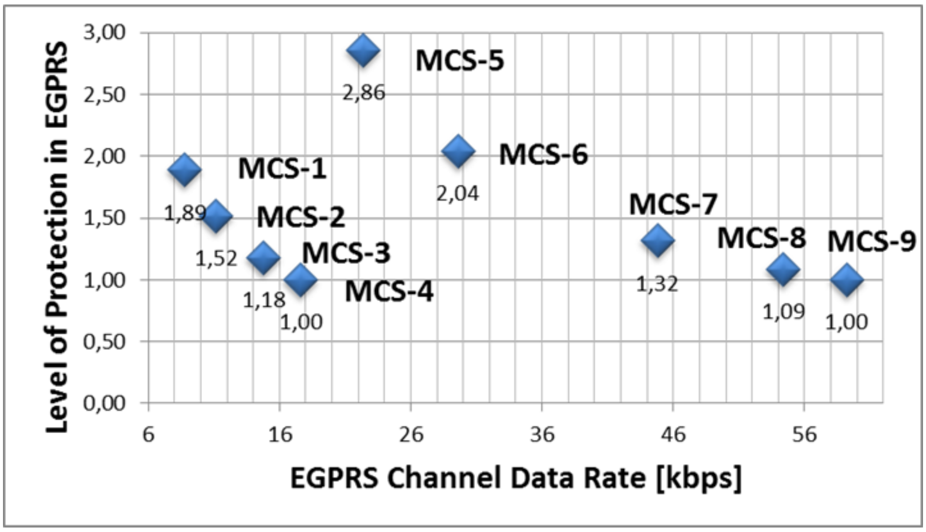


Figure 2 - Level of protection in EDGE (EGPRS)

It should be noted from this figure that MCS-5 provides the highest Forward Error Correction (FEC) of all the EDGE codecs.

For the ETCS Level 2 application, the utilisation of the most robust MCS is advised for the macro-GSM-R cells, typically covering the tracks between large stations.

For High packet switched capacity demanding areas, such as large stations, the utilisation of the highest coding schemes, with less robustness, could be considered, potentially by making use of microcells within the station. The microcells would provide locally high levels coverage in combination with high C/I, reducing the data errors in the radio transmission.

4.1.3. Cell selection and cell reselection in GPRS/EDGE

In ETCS over CSD implementations, the mobility is under the control of the network, as it is for voice services. The system behaviour will be different for ETCS over PSD as mobility is essentially left to the mobiles themselves in GPRS.

In practice, in GPRS implementations based on the NC0 network control mode, GPRS/EDGE mobiles will read the system information broadcast on BCCH and only use the C1/C2 criteria for cell selection and reselection. This means that mobiles will autonomously decide on the cell selection and reselection based on the cell that appears to offer the best coverage, regardless of the availability of the GPRS service in the cell.

Hence, if the GPRS service is not available in a given cell, be it due to the GPRS not being configured for the cell, or any other reason, the GPRS-enabled mobile could still stay in the cell and consequently fail to establish a GPRS connection, regardless of the availability of the GPRS service on a neighbour cell, even if it had adequate coverage for the mobile GPRS needs. This also includes the case of double coverage areas.

A potential solution to this handling of mobility in GPRS/EDGE calls is to pay particular attention to the coverage levels of neighbouring cells on lines where GPRS/EDGE is expected to be used and, additionally, to consider providing the GPRS/EDGE service in those neighbouring cells where there is a risk of reselection by the mobile.

4.1.4. Impact of the use of various coding schemes

Based on EIRENE SRS specification version 16.0.0 [SRS16] as well as in previous versions, GSM-R lines have to be planned for a minimum coverage level, at the antenna (0dBi) on the roof of a train, of;

- coverage probability of 95% based on a coverage level of -98 dBm for voice and non-safety critical data;
- coverage probability of 95% based on a coverage level of -95 dBm on lines with ETCS levels 2/3 for speeds lower than or equal to 220km/h;
- coverage probability of 95% based on a coverage level between -95 dBm and –92 dBm on lines with ETCS levels 2/3 for speeds above 220km/h and lower than or equal to 280km/h;
- coverage probability of 95% based on a coverage level of -92 dBm on lines with ETCS levels 2/3 for speeds above 280km/h.

The above coverage requirements are based on the MS reference sensitivity level as specified in 3GPP TS 45.005, namely -104 dBm. These are used in current GSM-R networks with some designs experiencing better coverage in particular environments and it should be further noted that the above applies to ETCS lines using the CSD bearer.

When it comes to GPRS/EDGE coverage levels in general, and ETCS over GPRS/EDGE in particular, there are currently no coverage levels specified. Target levels will depend on multiple factors, such as whether the intended purpose includes critical applications such as GPRS. In addition consideration will need to be given to potential new sources of interferences such as the SRD devices that could be deployed in parts of the ER-GSM extension band. It is important to acknowledge that PSD throughput drops quickly as interference increases. As a result a more robust radio network should be planned, taking into account C/I requirements higher than 12dB stipulated within EIRENE 8/16.

In practice, for the provision of ETCS over GPRS, it may be useful to proceed with further real-life testing of ETCS over GPRS in conditions representative of the future operational use and also to take into consideration the recommendations ETSI TC-RT will be producing with regard to QoS characteristics to be applied to PSD services in a railways environment.

At this stage, one may consider that the EIRENE coverage requirements specified in EIRENE SRS specification version 16.0.0 for ETCS shall in most cases allow ETCS over PS operation under coding scheme CS1-CS2. The use of higher coding schemes would certainly provide a gain with higher throughput and reduced latency, but their use should be considered with an associated adequate radio study to ensure optimal performance and this may result in potential alterations to the design (including densification and/or the use of microcells where appropriate).

4.1.5. Pre-emption capabilities

The scarcity of the spectrum resources available to railways, and the different levels of criticality between operational uses leads to the need to enforce, on the one hand, pre-emption capabilities to allow higher priority applications to get hold of radio resources at the expense of less critical applications and, on the other hand, to ensure adequate protection of critical uses against pre-emption where required.

In a nutshell, in the application of the GSM/GPRS standards to railways, the criticality of respective critical services (such as REC calls using voice resources as well as ETCS which may use circuit-switched and packet-switched mode) needs to be taken into account regardless of the use of the domain (i.e. GSM or GPRS).

In practice, this means that the GSM-R system needs to support arbitration:

- between users of the circuit-switched mode (pure GSM-R, intra-domain),
- between users of the packet-switched mode (GPRS/EDGE, intra-domain),
- between a user of the circuit-switched mode and a user of packet-switched mode (inter-domains).

The GSM/GPRS standard does offer pre-emption capabilities intra-domain but not inter-domain. This means care is needed when it comes to arbitration between the circuit and packet domains, especially when it comes to the provision of an ETCS bearer.

Within the packet domain, as outlined in 4.2.3, the Packet Flow Context feature offers the ability to give priorities to sessions deemed more critical (such as ETCS) over less critical sessions. This is mandatory when mixing different traffic types.

Within the circuit domain, eMLPP mechanisms offer pre-emption capabilities to timeslots available for TCH usage, for example to pre-empt a voice TCH and grant it to an ETCS over CSD call. The side effect of this is that where timeslots are shared between TCH and PDTCH usage, they may then be subject to pre-emption by ETCS over CSD users; in the case of large stations, if a high level of multiplexing can be achieved on a PDTCH, this puts the ETCS over PSD users at risk if their PDTCH is pre-empted. As a consequence, although this is an engineering matter, due care should be given to preserving adequate timeslot resources for exclusive PDTCH usage free from pre-emption.

Further, consideration should be given to the relative variations between ETCS over CSD and ETCS over GPRS during the day and whether smart timeslot reservations would be appropriate. In particular, if the peaks of expected ETCS over GPRS vs ETCS over CSD are not happening at the same time (for example as a result of different train operating companies equipped with different EDOR generations), sharing timeslots between TCH and PDTCH usage could lead to a more optimal usage of timeslots. See 4.9 for further details.

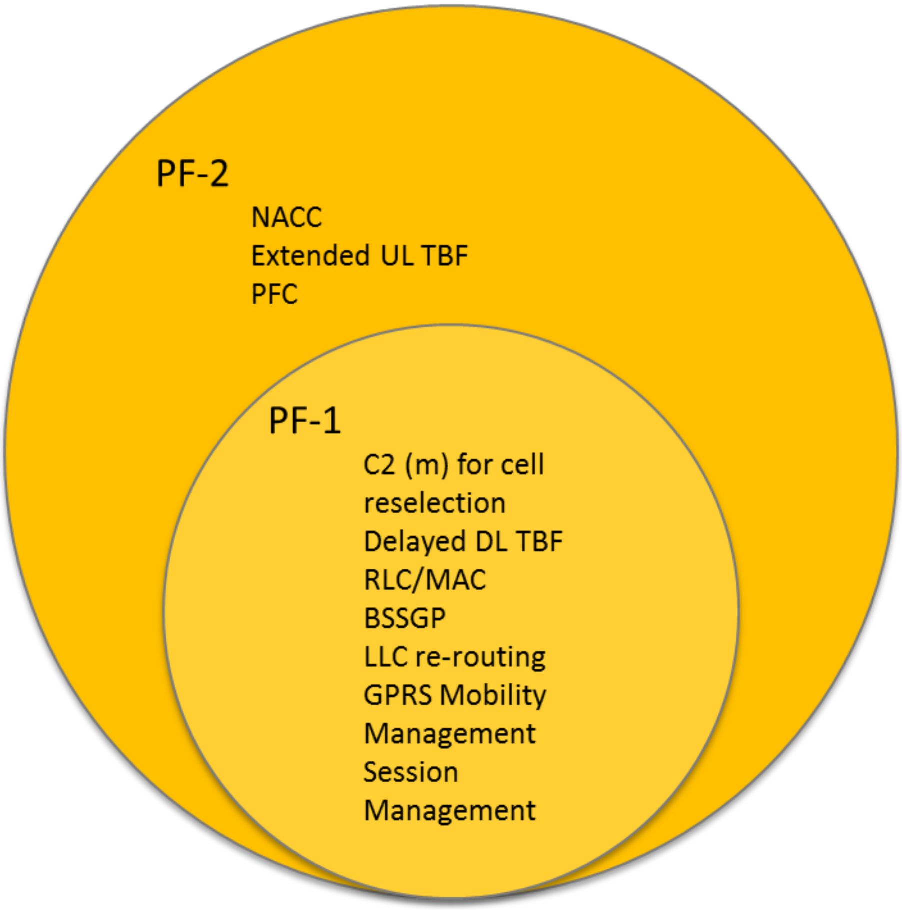
4.1.6. Abis capacity impact

The utilization of higher (E)GPRS coding schemes, for example MCS-7,8 and 9 is not only dependant on coverage level and C/I, but also requires sufficient capacity on the Abis interface. In large stations, where the higher coding schemes would allow more throughput and eventually more users on the cell, the Abis capacity has to be planned accordingly.

4.2. TEN-T findings: enabling features for ETCS over GPRS/EDGE

The document “ETCS over GPRS Phase 1 Report” ([O-8662]) details the results of the work performed on ETCS over GPRS Phase 1 “Bearer service optimisation”, the achieved End-to-End IP layer performance. The report identifies the minimum conditions to be fulfilled by the GPRS/EGPRS bearer service.

It notably identifies several features as essential to the delivery of the ETCS application over GPRS (and EDGE). In [O8662], two incremental sets of features are considered, summarized in the picture below.



The PF-2 feature set brings notable benefits, outlined in the following sections, for a more efficient ETCS over GPRS service.

4.2.1. Extended Uplink TBF

Principles of operation

The extended uplink TBF mode, defined in 3GPP TS 44.060, when supported by both the network and the mobile station, allows the network to keep the uplink Temporary Block Flow open upon explicit request from the mobile station that pre-allocation is required. This allows the possibility to pre-allocate a TBF before actual data is ready for transmission and introduces a significant reduction in Time Transfer Delay.

Benefits in ETCS over GPRS

As indicated in [O8662] and investigated in [O8657], the following 3GPP features have been evaluated as essential to lower the impact of frequent allocation/de-allocation of a GPRS/EGPRS transmission resource:

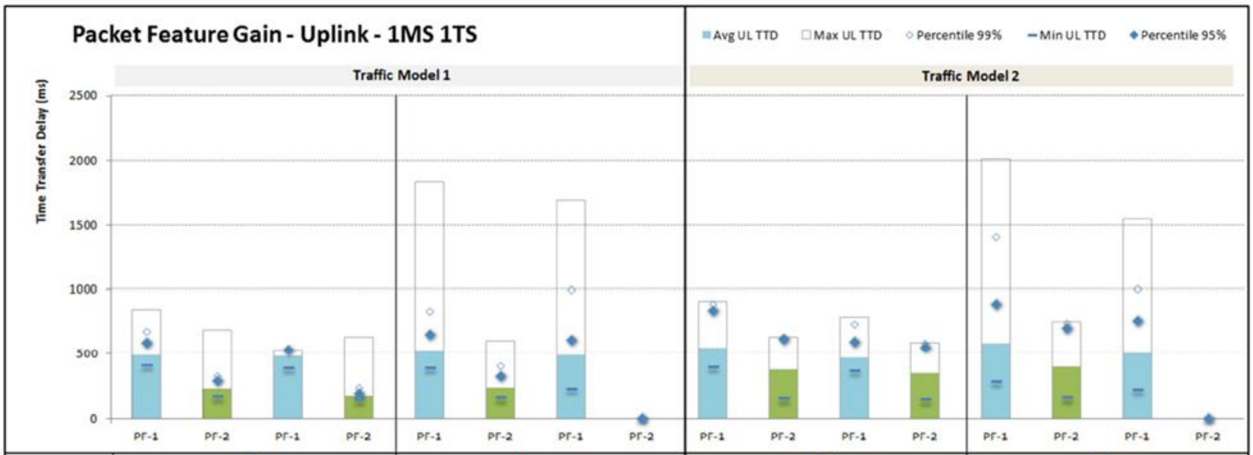
- Extended Uplink TBF feature (PF-2),
- Delayed Downlink TBF feature (PF-1).

[O8662] indicates:

> *In static conditions (cell change inactive), PF-2, and in particular Extended UL-TBF feature, decreases significantly the TTD. It's particularly noticeable taking into account more frequent ETCS application data exchange as considered by TM-1. Under less frequent ETCS message exchange (TM-2) conditions, the feature gain is also visible but smaller, due to an implementation of the Extended UL-TBF feature following 3GPP recommendation (restriction on extended uplink timer = 5 seconds that does cover some TM2 frequency message request).*

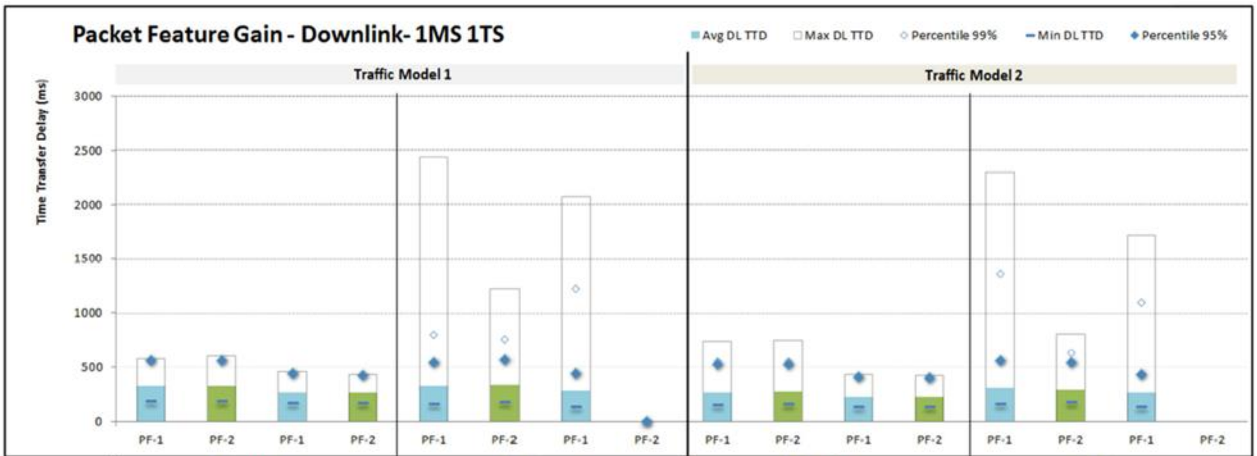
It should be noted that the Extended UL-TBF feature gains are solely in the Uplink case (as can be expected from the nature of the feature). Please refer to Figure 3 and Figure 4 for related results in CS-1 and CS-2.

Further, it should be noted that the Extended UL-TBF feature (which can be set on a per cell basis) introduces longer TBF retention which could be perceived as detrimental to efficient radio resources utilization for ETCS over GPRS as radio resources are retained longer by ETCS and other (E)GPRS users. To alleviate this, [O8662] notes that the usage of higher coding schemes, i.e. MCS-5 and up, would allow "*another TBF allocation strategy than in CS-1/CS-2 or MCS-1/MCS-2/MCS-3*", and by leveraging the higher bandwidth, could compensate partly to the delay caused by the radio transport resource allocation. This would allow the release of the TBF upon completion of the ETCS message transmission and free the radio resources for subsequent use by other applications or ETCS sessions.



TTD (ms)	No Cell Change						Cell Change						No Cell Change						Cell Change					
	CS1			CS2			CS1			CS2			CS1			CS2			CS1			CS2		
	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain
Avg UL TTD	491 ms	222 ms	55%	480 ms	165 ms	66%	524 ms	229 ms	56%	490 ms	-	-	545 ms	373 ms	32%	468 ms	344 ms	26%	583 ms	394 ms	33%	506 ms	-	-
Min UL TTD	404 ms	162 ms	60%	383 ms	146 ms	62%	383 ms	159 ms	58%	223 ms	-	-	396 ms	151 ms	62%	362 ms	143 ms	60%	278 ms	159 ms	43%	215 ms	-	-
Max UL TTD	845 ms	683 ms	19%	527 ms	628 ms	-19%	1832 ms	600 ms	67%	1694 ms	-	-	907 ms	627 ms	31%	786 ms	583 ms	26%	2010 ms	748 ms	63%	1550 ms	-	-
Percentile 95%	586 ms	284 ms	52%	525 ms	189 ms	64%	652 ms	319 ms	51%	609 ms	-	-	837 ms	616 ms	26%	594 ms	553 ms	7%	884 ms	699 ms	21%	758 ms	-	-
Percentile 99%	670 ms	323 ms	52%	526 ms	229 ms	56%	826 ms	400 ms	52%	994 ms	-	-	886 ms	625 ms	29%	730 ms	581 ms	20%	1409 ms	738 ms	48%	1001 ms	-	-
Packet loss	0	0	0%	0	0	0%	0	0	0%	0	-	-	0	0	0%	0	0	0%	0	0	0%	0	-	-
Re-sequencing	0	0	0%	0	0	0%	0	0	0%	0	-	-	0	0	0%	0	0	0%	0	0	0%	0	-	-
Duplication	0	0	0%	0	0	0%	0	0	0%	0	-	-	0	0	0%	0	0	0%	0	0	0%	0	-	-

Figure 3 - PF2 feature gain in Uplink (Source: [O8662])



	No Cell Change						Cell Change						No Cell Change						Cell Change					
	CS1			CS2			CS1			CS2			CS1			CS2			CS1			CS2		
	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain	PF-1	PF-2	Gain
Avg DL TTD	323 ms	323 ms	0%	269 ms	265 ms	2%	326 ms	336 ms	-3%	281 ms	-	-	267 ms	272 ms	-2%	226 ms	223 ms	1%	311 ms	292 ms	6%	266 ms	-	-
Min DL TTD	184 ms	182 ms	1%	166 ms	169 ms	-2%	158 ms	181 ms	-15%	133 ms	-	-	155 ms	158 ms	-2%	135 ms	133 ms	1%	156 ms	173 ms	-11%	135 ms	-	-
Max DL TTD	575 ms	602 ms	-5%	457 ms	435 ms	5%	2438 ms	1222 ms	50%	2076 ms	-	-	738 ms	748 ms	-1%	435 ms	420 ms	3%	2291 ms	802 ms	65%	1714 ms	-	-
Percentile 95%	556 ms	558 ms	0%	440 ms	421 ms	4%	540 ms	565 ms	-5%	438 ms	-	-	529 ms	528 ms	0%	409 ms	400 ms	2%	557 ms	546 ms	2%	432 ms	-	-
Percentile 99%	567 ms	571 ms	-1%	449 ms	434 ms	3%	799 ms	754 ms	6%	1226 ms	-	-	553 ms	552 ms	0%	425 ms	412 ms	3%	1360 ms	631 ms	54%	1096 ms	-	-
Packet loss	0	0	0%	0	0	0%	0	0	0%	0	-	-	0	0	0%	0	0	0%	0	0	0%	0	-	-
Re-sequencing	0	0	0%	0	0	0%	0	0	0%	0	-	-	0	0	0%	0	0	0%	0	0	0%	0	-	-
Duplication	0	0	0%	0	0	0%	0	0	0%	0	-	-	0	0	0%	0	0	0%	0	0	0%	0	-	-

Figure 4 - PF2 feature gain in Downlink (Source: [O8662])

4.2.2. *Network-Assisted Cell Change / RAN Information Management*

<u>Principles of operation</u>

The original purpose of the GPRS service is to offer a packet mode bearer services on a "Best Effort" basis. A consequence of this is that standard cell reselection is controlled by the Mobile only and this may cause user data exchange interruption of up to several seconds, which would be detrimental to the ETCS over GPRS service operation.

The Network Assisted Cell Change (NACC) feature has been specified in 3GPP Release 4 with the aim of reducing cell reselection time duration in intra BSC/PCU to less than 1 second. This involves the network in the cell reselection process by providing adjacent cell system information required for initial access after the cell change.

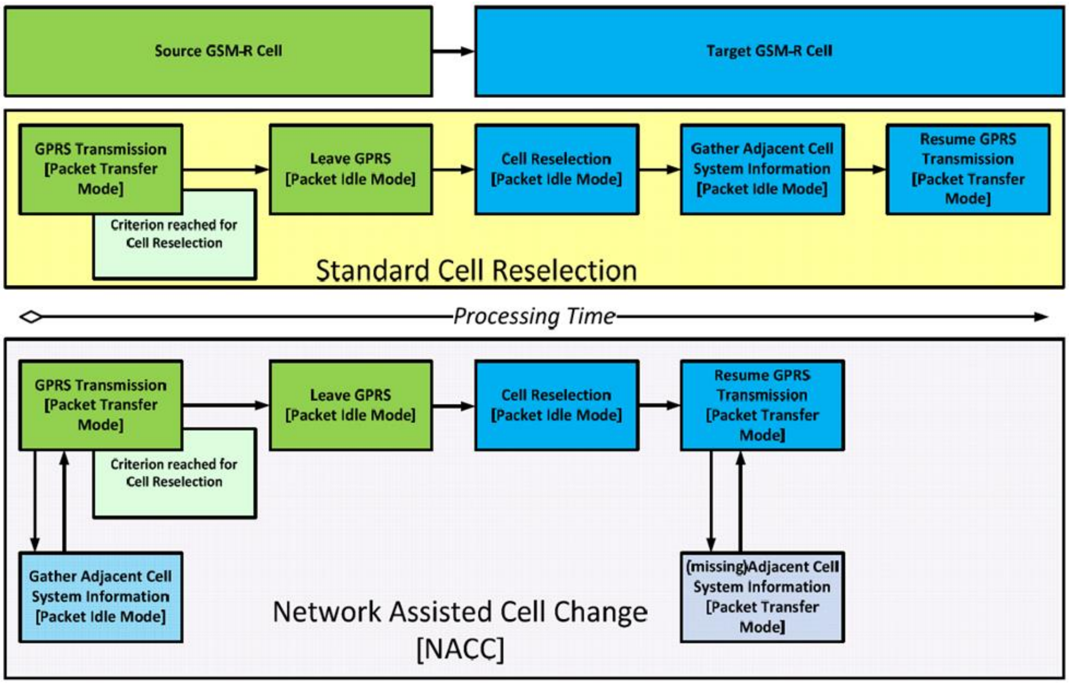


Figure 5 - Network Assisted Cell Change process (Source: [O8662])

<u>Benefits in ETCS over GPRS</u>

Document [O8662] assesses the benefits of the NACC feature when considered in combination with the other features of the PF2 parameter feature set. Building on the tests identified in Figure 3 and Figure 4 for CS-1 and CS-2, document [O8662] indicates that:

> *[In Uplink], In addition to the feature gain noticed under static conditions, PF-2 and in particular NACC feature brings a gain by decreasing the TTD during the cell change process. It is particularly noticeable on the maximum TTD values.*

And

> *[In Downlink], In dynamic conditions (cell change active), PF-2 and in particular NACC feature decreases the packet transfer delay during the cell change process. It is particularly noticeable on the maximum TTD values, which are exclusively related to packets sent during the cell change process.*

The overall performance of the Network Assisted Cell Change is therefore perceived as essential to ensure the efficient operation of the ETCS over GPRS service in mobility.

4.2.3. Packet Flow Context

Principles of operation

As noted in [O8662]:

> *ETCS application has a typical interactive characteristic. The train in ETCS Level 2 provides periodic reports about train speed, train position etc. and the RBC processes the information and determines the "Movement Authority" assigned to the train (spatial extent, speed, and relevant trackside details, per each track section). Taking into account the ETCS safety aspect, the application needs to have a time stringent processing within the radio access network compared to other applications at the same time. Based on the aforementioned assumption it has been decided to assign the ETCS application into the "Real Time" traffic class group, consisting of Conversational and Streaming traffic class to satisfy the stringent time requirement and to be able to guarantee the needed bit rate in case of ETCS and non-ETCS traffic at the same time.*

As mentioned in the previous section, the GPRS service was originally designed (3GPP Release 97) to offer a packet mode bearer services on a "Best Effort" basis. 3GPP Release 99 specified enhanced QoS control functions through the introduction of the Packet Flow Context (PFC) feature specified in 3GPP TS 44.060.

During the Packet Flow Context establishment process control plane functions are responsible for:

- admission control of the data connections,
- selection of appropriate transmission modes (acknowledged/unacknowledged),
- selection of forward error protection (degree of convolutional coding),
- and allocation of radio resources.

The feature's QoS awareness allows for a predictable service delivery for types of traffic deemed more critical, such as the ETCS over GPRS service, with a guaranteed bit rate (GBR).

Benefits in ETCS over GPRS

In case of concurrent ETCS and non-ETCS traffic, the QoS of ETCS users is guaranteed by assigning guaranteed bandwidth to the ETCS user(s).

4.2.4. Summary of TEN-T findings

> *The results […] manifest the gain of the selected features (in particular [Extended Uplink TBF] and NACC) to improve the IP-performance in terms of packet latency. Also a transition from a "Best Effort" to an "Application Dependent Resource Allocation" system, taking into account PFC feature, is feasible when other non-ETCS applications are operational at the same time.* [O8662]

It is therefore recommended, in addition to PF-1, that the following three features are deployed in order to improve the resilience and / or quality of the ETCS service:

- Extended Uplink TBF,
- Network Assisted Cell Change ,
- And Packet Flow Context,

4.3. EDOR Reference Requirements

The reference EDOR configuration considered in the following analysis is based on the standard configuration with two GSM-MT modules (see [SRS16] Chapter 16, MI), as is required to guarantee that two simultaneous ETCS connections can be made, regardless of whether these connections are established in CS or PS mode ([SRS16], section 16.3.3).

The GSM-R PS-mode requires support of GPRS and EGPRS bearer services including all available (Modulation) Coding Schemes (MI) (16.3.3i). The GPRS/EGPRS bearer service are operated in Mobile Class B only (class B devices operate in either packet mode or voice / data mode, but only one at a time). Mobile Class A terminals are not commercially available at the time of writing (class A terminals can manage both packet data and voice simultaneously).

To allow for the concurrent operation of different data communication flows, with different APNs, such as ETCS, KMS, ATO and other applications, the ETCS data only radio shall support at least "4" primary PDP contexts (M) ([SRS16], 16.3.3ix Req.). Considering that the reference EDOR includes two GSM-MT, this requirement is fulfilled with GSM-MT supporting two simultaneous PDP contexts, which is a currently available feature.

The reference ETCS data only radio in PS-mode is assumed to support the parameters of the QoS profile "ETCS application" according to [FFFIS for Euroradio] (MI) (Req. 16.3.3vii), where the QoS Profile "ETCS application", with a Guaranteed Bitrate is assigned only to the APN used for ETCS, and complies with the profile specification in [FFFIS for Euroradio] (M) (10.8.5.2 Req.).

The QoS Profiles "Non-ETCS application" with a non-Guaranteed Bitrate is assigned to any APN except the APN used for ETCS. (O) (10.8.5.1), with parameter listed in [SRS16] "Table 10-2 : non-ETCS application QoS Profile".

The reference EDOR, with the features listed above, is capable of supporting scenarios, applications and types of traffic indicated by operators with piece of equipment.

4.4. General capacity considerations

Starting with the EDOR and Network (MI) requirements, some general consideration about capacity could be derived. These considerations should be carefully analysed as, in EIRENE 8/16, from the network side, GPRS & EDGE are both Optional bearer services (SRS 16 2.3.1). As only CS switched operation is mandatory, ETCS L2/3 capacity would be based on one train per timeslot.

Network configuration and performance are therefore key elements to ensure capacity improvements in the station environment.

In a typical mainline scenario, where a cell occupancy of more than 4 trains in ETCS L2 are uncommon, standard BTS configurations with 2 TRX providing 14 timeslots for traffic, and therefore up to 14 simultaneous connections in ETCS over CSD would be sufficient.

Problems arise in station environments where a large number of trains are stopped on platforms or are moving slowly (< 50 km/h), and where radio resources are limited, considering that the whole area is usually covered by one or two BTS with a maximum of 3 or 4 TRX. This could be seen in the answers to the questionnaire. In this scenario, where the infrastructure operator needs to consider the use of ETCS L2 on a large percentage of trains to improve station capacity, the CS mode of operation will probably not be adequate, as voice calls also increase in parallel with the higher density of trains and mobile users.

As an example, the large station scenario presented by Italian Railway for Florence SMN in 2025, with a 100% penetration of ETCS L2 and a minimum of 16 simultaneous trains at standstill and two trains approaching at a slow speed in the station area, would be challenging to implement in CS mode. The scenarios for High Density operation in the key nodes of Rome and Milan, not included in the questionnaire, are even worse. Therefore, the only strategy to fulfil the radio resource requirements with the existing GSM-R system is to use PSD as a bearer for ETCS.

Based on the EDOR reference requirements outlined in section 4.3, with the GSM-R PS-mode supporting the GPRS and EGPRS bearer services including all available (Modulation) Coding Schemes, the obtainable bandwidth will be directly related to the available and / or negotiated coding scheme.

Assuming a GBR of 4 kbps per ETCS train (see 3.3), the table below summarizes the number of simultaneous users that could be multiplexed onto one timeslot per coding scheme under optimal conditions. CSD is included as a reference.

Codec	Theoretical Bitrate (kbps)	ETCS users per timeslot
CSD	4,8	1
CS-2	12	3
MCS-3	14,4	3
MCS-5	21,6	5
MCS-6	28,8	7
MCS-7	44	7

Table 2: ETCS users multiplexing per coding scheme under optimal conditions (assuming 4 kbps GBR)

Note: the multiplexing is limited to 7 users per (group of) timeslot(s) due to limitations associated with the Uplink State Flag (USF).

4.5. Capacity consideration on the network side

4.5.1. General network capacity considerations

As ETCS level 2 has been introduced already in a number of countries on a limited number of tracks, a number of trains equipped with EDOR's are establishing ETCS Level 2 connections over CS. These trains will be in use for some years, and the network capacity planning needs to take account of this CS data. From the responses to the questionnaire, it is clear that this assumption will largely remain valid till 2025 in many counties. For those ETCS Level 2 connections over CS, one timeslot per connection has to be taken into account.

Besides the utilisation of data services, being CSD or PSD, the radio network has to cope with voice users. With the high concentration of trains inside a large station, usage of voice tends to increase along with the CS voice traffic it creates. The operational procedures in the stations can have a high influence on the required capacity for CS voice calls in the stations. Although the questionnaire does not provide a good indication of voice traffic for the large stations, it can be seen that the number of VGCS/VBS calls is mostly one, expect for Deutsche Bahn where up to 5 parallel group calls can be ongoing (which may be explained by the presence of a nearby shunting yard).

4.5.2. Network capacity impact of mixing GPRS and EGPRS users

Based on the responses to the questionnaire, a high degree of variation exists between the different GSM-R networks in terms of other PSD users in the large stations, namely varying from none to up to 150 (ProRail). In the latter case (ProRail), existing users, amongst which a large proportion are information panels and M2M traffic oriented devices, rely on GPRS (i.e. not EDGE-capable) modules. As a result the network capacity dimensioning will have to cope with mixed PSD data traffic, using GPRS and eventually EDGE for ETCS Level 2 over GPRS. This is further explored in section 4.10.

4.5.3. TBF adaptability and (GSM) signalling considerations

The TBF retention time is a key parameter in (E)GPRS engineering.

The Extended Uplink TBF parameter extends the time period before an uplink TBF is released.

A delayed release of the downlink TBF is when the release of the downlink TBF is delayed following the transmission of a final data block, rather than instantly releasing the TBF.

In the case of low density areas (such as high speed lines), longer TBF retention shall in most cases be favoured as this reduces the data transmission latency that would be caused by re-establishing TBF for the train.

In case of high density areas, such as large stations, longer TBF retention may actually have an adverse effect on the PDTCH capacity that can be achieved from a given radio resource as the quality of the radio link and the slower mobility could enable a faster transmission of the data and, at the same time, more concurrent users are trying to get access to the shared resource.

The TBF retention time not only impacts the TBF used for ETCS Level 2, but on all TBF's used in the cell, which could be in use by different applications, being on the train or at a static location. The impact of the TBF retention timer needs to be considered for the network capacity dimensioning, especially in large stations.

A consequence of having the flexibility to adapt the TBF retention times based on individual cells is that it allows the system engineering to match the requirements of each environment, i.e. low latency and a more “static” resource allocation at high speeds, more flexibility in capacity allocation at the expense of (slightly) higher latency at lower speeds.

In general, for large stations, a balance will need to be found to optimize the cell capacity between signalling and PDTCH load as both can become a limiting factor for the TTD required for ETCS Level 2, especially with other applications in use in parallel (such as the ProRail case with up to 150 other non-critical data GPRS users).

4.5.4. Densification

To support more users with the same amount of radio resources, higher coding schemes, such as MCS5+ based on 8-PSK modulation, can be used to increase the multiplexing of users per PDTCH (keeping in mind the maximum number of 7 simultaneous users due to the USF limitation).

That being said, the usage of higher coding schemes comes at the trade-off of ensuring adequate signal quality to truly benefit from them, requiring the EDORs to support them and reviewing the link budget considering that the 3GPP specs foresee no more than 2W output in GSM900 for modulations other than GMSK.

Assuming these obstacles can be overcome, within the generally confined space of large terminal stations, and subject to adequate radio engineering, a microcell serving the trains idle at platforms and departing trains could be envisaged.

4.5.5. Pre-emption mechanisms / timeslot allocation

Within the packet domain, as outlined in 4.2.3, the Packet Flow Context feature offers the ability to give priorities to sessions deemed more critical (such as ETCS) over less critical sessions, and is even mandatory when mixing those types of traffic.

But, the GSM/GPRS standard does not offer pre-emption capabilities inter-domain, that is between the circuit and packet domains. In the context of acting as a bearer for ETCS, this has several implications for the GSM-R/GPRS network.

The first one to note, not PSD related, is that ETCS over CSD can use eMLPP mechanisms to pre-empt timeslots available for TCH usage. The side effect of that aspect is that timeslots that may be shared between TCH and PDTCH usage may then be subject to pre-emption by ETCS over CSD users; in the case of large stations, if a high level of multiplexing can be achieved on a PDTCH, this puts the ETCS over PSD users at risk as their PDTCH could be pre-empted. As a consequence, although this is an engineering matter, due care must be taken to preserve timeslot resources for exclusive PDTCH usage, safe from pre-emption.

The second aspect to consider is that the relative variations between ETCS over CSD and ETCS over GPRS during the day implies that smart timeslot reservations could be appropriate. In particular, if the peaks of expected ETCS over GPRS vs ETCS over CSD are not happening at the same time (for example as a result of being different train operating companies equipped with different EDOR generations), sharing timeslots between TCH and PDTCH usage could lead to a more optimal usage of timeslots.

4.6. Use Case 1: facilitating in-station ETCS Start of Mission, solutions at the station level

4.6.1. Description of the scenario

In order to allow train movement to start for a train in ETCS, the driver has to perform the procedure Start of Mission (SoM). This procedure can be triggered by the driver in the following cases, according to the planned operative modes and the ERTMS/ETCS level:

a. Once the train is awake, OR
b. Once shunting movements are finished, OR
c. Once a mission is ended, OR
d. Once a slave engine becomes a leading engine

The procedure may be automated or, for example, could follow a voice conversation between the train driver and the dispatcher. The table below provides indicative figures (extracted from a joint presentation from UK's Rail Delivery Group / Digital Railway from August 2017) for data entry times from Start of Mission onwards.

Action	Duration (s)	Comment
Open cab and boot up	57	(Can be longer as it depends on the cab)
Start of Mission (SoM)	1	
Driver ID	2	
Change level	35	(Only required from cold start)
Connection to RBC	20	
Train data entry	30	
Select start	4	
Total (cold start)	**149**	**2'29" total** **1'32" from SoM** **54" from RBC connection initiation**
Total (not from cold start)	**114**	**1'54" total** **0'57" from SoM** **54" from RBC connection initiation**

Figure 6 - ETCS Level 2 data entry duration (Source of the data: RDG/Digital Railway Education Day, August 2017)

In practice, performing the ETCS Start of Mission in-station presents a certain number of challenges when it comes to the radio infrastructure.

In large stations, a large number of trains may be at standstill and preparing for departure: these trains, depending on the operational approach being taken, will start using radio resources, at the very least, a minute before actually starting their movement;

When operating in circuit-switched mode, each ETCS train will occupy one TS, essentially like a continuous voice call, and two TS during the RBC handover procedure.

The combination of these two aspects can lead to an engineering constraint on radio timeslots and associated supporting frequencies for an operator looking to perform ETCS Start of Mission in-station.

4.6.2. Dimensioning factors

The contribution to the radio dimensioning of the specific case of the ETCS Start of Mission in-station is driven by the following aspects:

- The number of trains at a standstill in platform which have established a connection to the RBC;
- The number of trains on tracks outside the station but covered by the station cell and the number of trains in transit through the station;
- The number of trains on the approach to, or departing from the station;
- The "Safety Margin" assumption catering to degraded conditions.

The number of trains at standstill having established a connection provide a baseline for the radio resource requirements while the trains in movement (either in transit or approaching/departing) contribute a fluctuation in the traffic that needs to be supported, which may be more or less fleeting depending on the speed of movement.

The following table captures the range of the parameters based on the answers to the questionnaire (see section 3).

Parameter	Large Station	Passing Station
Trains at standstill	6 (ProRail) to… 27 (Deutsche Bahn)	1 (ProRail) to… 7 (Deutsche Bahn)
Trains in transit	0 (terminus stations) to… 6 (ProRail)	Up to 2
Average speed of transit train (kph)	60 (Deutsche Bahn) to… 100 (ProRail, Infrabel)	80 (Deutsche Bahn) to… 160 (Network Rail)
Trains in approach or departing	2 to 4	2 (typical) to… 9 Network Rail
Average speed of approaching train (kph)	40 (typical) to… 80 (Network Rail)	40 (typical) to… 100 (Network Rail)
Safety Margin	25-30% to 50%	25-30% to 100%

Table 3 - questionnaire inputs relevant to the in-station ETCS SoM

A train in transit through a station cell (footprint ~2 km) would stay in the cell for a duration of 120 seconds at 60 kph and 72 seconds at 100 kph. A train approaching at 40 kph would take approximatively 90-120 seconds to travel across half a 2 km cell.

4.6.3. Theoretical application

Notwithstanding the resources required for voice, the following diagrams summarize respectively the timeslots and frequency required solely for supporting a certain number of ETCS Users at 4kbps GBR at a given point in time.

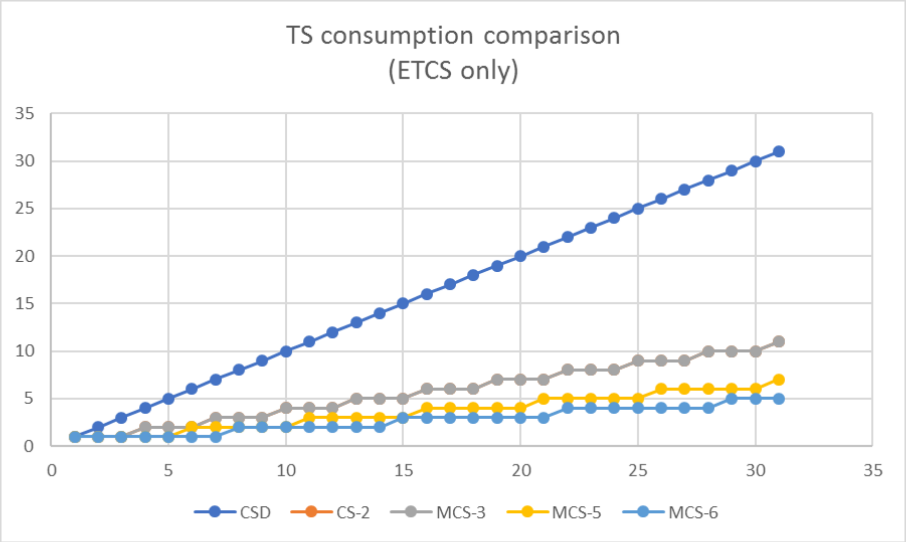


Figure 7: timeslot consumption comparison (ETCS only, 4kbps GBR)

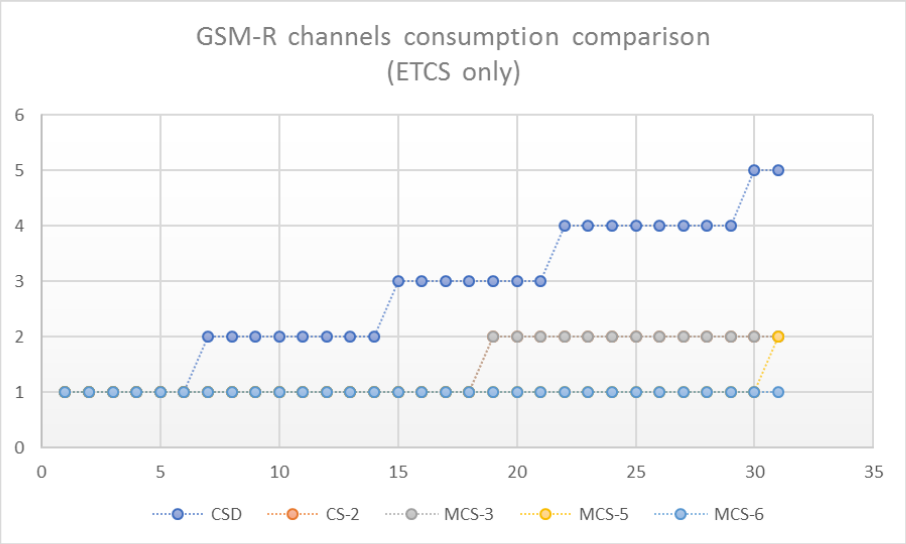


Figure 8:GSM-R channels consumption comparison (ETCS only, 4kbps GBR)

Applying the worst case data from the questionnaire, i.e. trains at standstill with simultaneous presence in the station cell of trains in transit and in approach, the frequency requirements and the spare timeslots capacity can be derived. This is shown in Table 4 and Table 5 below.

Two basic models are considered:

- “pure”; where the given transport scheme (i.e. CSD, MCS-3, MCS-5 and MCS-6) provide transport for all ETCS trains (regardless as to whether they could be inferred to be CSD or PSD capable for ETCS),
- “mixed”; where the CSD trains consume 1 timeslot per train and PSD trains consume timeslots as per Figure 8.

The calculations are performed on the “nominal” case, i.e. without the “Safety Margin”, and on the “degraded case”, i.e. with the “Safety Margin”.

“Spare timeslots capacity” or “Max free TS” refers to the number of timeslots remaining for other services, such as voice or other non-critical PSD usage once the BCCH timeslot, the SDCCH timeslot(s) and the timeslots used for ETCS (CSD and PSD) have been removed from the “raw” capacity. For example a single GSM-R channel offers eight “raw” timeslots, of which six can be used for traffic; if ETCS traffic requires 2 timeslots, the “spare timeslots capacity” is four.

Please note that the figures would be identical for CS-2 and MCS-3 under optimal conditions hence the tables only feature MCS-3.

			Trains			ETCS (nominal)			ETCS (degraded)			Minimum frequencies used for ETCS (nominal) - pure				Minimum frequencies used for ETCS (degraded) - pure				M f
Operator	Scenario	Year	Standstill	Transit	Approach	total	CSD	PSD	total	CSD	PSD	CSD	MCS-3	MCS-5	MCS-6	CSD	MCS-3	MCS-5	MCS-6	C
Deutsche Bahn	Large Station	2025	27	1	2	6	5	1	8	7	1	1	1	1	1	2	1	1	1	
Deutsche Bahn	Passing station	2025	7	1	2	2	1	1	3	2	1	1	1	1	1	1	1	1	1	
Network Rail	Large Station	2025	10	0	2	12	0	12	18	0	18	2	1	1	1	3	1	1	1	
Network Rail	Passing station	2025	2	2	9	13	0	13	26	0	26	2	1	1	1	4	2	1	1	
ProRail	Large Station	2025	6	6	2	14	1	13	21	2	19	2	1	1	1	3	2	1	1	
ProRail	Passing station	2025	1	2	0	3	0	3	5	0	5	1	1	1	1	1	1	1	1	
Infrabel	Large Station	2025	11	1	4	16	8	8	21	10	11	3	1	1	1	3	2	1	1	
Infrabel	Passing station	2025	4	0	1	5	2	3	7	3	4	1	1	1	1	2	1	1	1	
RFI	Large Station	2025	16	0	2	18	0	18	23	0	23	3	1	1	1	4	2	1	1	
RFI	Passing station	2025	5	2	2	9	0	9	12	0	12	2	1	1	1	2	1	1	1	
SNCF	Large Station	2025	16	0	0	15	0	15	18	0	18	3	1	1	1	3	1	1	1	

Table 4: minimum frequency requirements for ETCS SoM in station

			Trains			ETCS (nominal)			ETCS (degraded)			Max free TS (nominal) - pure				Max free TS (degraded) - pure				Max free TS (nominal) - mixed				Max free TS (degraded) - mixed			
Operator	Scenario	Year	Standstill	Transit	Approach	total	CSD	PSD	total	CSD	PSD	CSD	MCS-3	MCS-5	MCS-6	CSD	MCS-3	MCS-5	MCS-6	CSD	MCS-3	MCS-5	MCS-6	CSD	MCS-3	MCS-5	MCS-6
Deutsche Bahn	Large Station	2025	27	1	2	6	5	1	8	7	1	0	4	4	5	6	3	4	4		0	0	0		6	6	6
Deutsche Bahn	Passing station	2025	7	1	2	2	1	1	3	2	1	3	5	5	5	1	1	1	1		4	4	4		3	3	3
Network Rail	Large Station	2025	10	0	2	12	0	12	18	0	18	3	0	2	3	2	1	1	1		2	3	4		0	2	3
Network Rail	Passing station	2025	2	2	9	13	0	13	26	0	26	3	5	0	2	2	1	1	1		1	3	4		5	0	2
ProRail	Large Station	2025	6	6	2	14	1	13	21	2	19	0	7	1	3	2	1	1	1		0	2	3		5	0	1
ProRail	Passing station	2025	1	2	0	3	0	3	5	0	5	1	4	5	5	1	1	1	1		5	5	5		4	5	5
Infrabel	Large Station	2025	11	1	4	16	8	8	21	10	11	0	7	1	3	3	2	2	2		3	4	4		0	1	2
Infrabel	Passing station	2025	4	0	1	5	2	3	7	3	4	7	3	4	5	1	1	1	1		3	3	3		1	2	2
RFI	Large Station	2025	16	0	2	18	0	18	23	0	23	6	6	1	2	3	1	1	1		0	2	3		6	1	2
RFI	Passing station	2025	5	2	2	9	0	9	12	0	12	2	2	3	4	2	1	1	1		3	4	4		2	3	4
SNCF	Large Station	2025	16	0	0	15	0	15	18	0	18	3	0	2	3	3	1	1	1		1	3	3		0	2	3

Table 5: spare timeslot capacity for other services (such as voice)

4.6.3.1. CSD considerations

By its very nature, the CSD bearer exhibits a linear relationship between the number of ETCS users and the number of radio timeslots required as it establishes circuit-switched data to the RBC and maintains it throughout the mission.

From a frequency use perspective, distinct thresholds appear in Figure 8, yet one can clearly infer that by 2025 in all Large Station scenarios, excluding ProRail and Deutsche Bahn, the unrestrained use of ETCS over CSD in stations will be challenging to implement, as the number of trains at standstill together with transitory traffic (trains in transit and in approach) would require 3 GSM-R channels or more, without taking into account the safety margin. In the case of ProRail's Large Station scenario, in addition to the 6 trains at standstill, there are 6 trains in transit and 2 in approach, which would result in similar challenges to the Large Station scenario with 10-16 trains at standstill.

The use of the term "unrestrained use" in the previous paragraph refers to a theoretical approach whereby trains at standstill, regardless of their relative readiness to depart, would open a connection to the RBC and hence clog the radio resources. In practice, current ETCS over CSD implementations undertake a more pragmatic approach, whereby the establishment of the connection to the RBC is made shortly before the train is ready to depart (one or two minutes being sufficient if one considers the data from Figure 6), for example by the placing of a direct call from the dispatcher to the train driver to alert of departure.

In the Passing Station scenarios, based on questionnaire data, the unrestrained use of ETCS over CSD presents a less severe challenge when looking solely at trains at standstill, even though the Deutsche Bahn (7), RFI (5) and Infrabel (4) would quickly lead to the use of at least 2 GSM-R channels under nominal conditions. This would definitely be the case when considering trains in transit and trains in approach.

Other aspects to consider when using CSD as a bearer for ETCS relate to performance in degraded traffic conditions and during RBC handovers.

In degraded conditions, in addition to the nominal traffic, Table 3 indicates that Large Station scenarios foresee between 25% to 50% additional traffic, with an even larger variation in the Passing Station scenarios where the additional traffic ranges from 25% to 100%. In most instances, in the 2025 timeframe, the added contingency for traffic would lead to the requirement for one, and sometimes two, GSM-R channel(s) to cater for the extra traffic, further complicating the implementation of the GSM-R frequency plan.

Finally, in the case of RBC handovers, the use of ETCS over CSD requires the establishment of a separate dedicated CSD connection towards the target RBC. In the unlikely case that the RBC handover would happen inside the station cell, this would increase the timeslot consumption for the duration of RBC connection establishment (~20 seconds) and the performance of the RBC handover procedure itself.

4.6.3.2. PSD considerations

When using GPRS or EDGE, the situation changes significantly. Looking at Figure 7 and Figure 8, one can see that the TS consumption curves are much flatter, thanks to the multiplexing of users allowed by GPRS or EDGE, and that the thresholding effect is much less visible.

In particular, it can be derived from Figure 8, that if we consider ETCS users only, at 4kbps GBR each under optimal radio conditions, it takes 19 users or more before an additional GSM-R channel is required in CS-2/MCS-3 and 31 users or more in MCS-5.

In practice, looking at Table 4 and Table 5, one can see that the frequency requirements in “pure” mode are essentially reduced to a maximum of two frequencies with a “spare timeslots capacity” that is generally three or more spare timeslots, allowing resources for operational voice communication without requiring an additional channel. The other thing to note is that when considering ETCS traffic only, the application of the “Safety Margin” to the number of ETCS users does not necessarily imply the requirement for additional channels: the multiplexing enabled by GPRS/EDGE essentially dampens the effect of the perturbation on the number of timeslots required.

If we take into consideration the results in “mixed” mode, one can see from Table 4 and Table 5 that scenarios where ETCS over CSD constitutes the majority of the traffic, such as Deutsche Bahn’s or Infrabel’s Large Station scenarios, the effect of the perturbation may lead to the requirement for an additional channel due to the contribution from the CSD resource requirements. In the scenarios where ETCS over PSD prevails, the additional traffic associated with the Safety Margin may be absorbed due to the spare timeslots capacity available as a result of the nominal traffic, and hence there would be no need for an additional channel. Considering that hotspots such as station environments may themselves be surrounded by areas already dense in GSM-R channel usage, such optimization may help with relaxing some constraints on the GSM-R frequency planning.

4.7. Use Case 2: starting from the station with ETCS over PSD and transitioning to ETCS over CSD, solutions in the vicinity of stations

4.7.1. Description of the scenario

In a number of European countries, ETCS over CSD is already either in operation, under construction or contracted. Migrating the operation of such lines in their entirety to ETCS over PSD may be impractical and / or uneconomical due to the changes required on the RBC and on-board equipment, most probably implying a new certification.

In a majority of those cases, the ETCS Level 2 Start of Mission takes place outside the stations themselves, in areas less dense in traffic. Extending the ETCS Level 2 area towards the station on these lines, operating or planning to operate ETCS over CSD, will have the following impacts:

- move of the start and end of mission towards the station, resulting in the station being in the use case 4.6 as described above.
- one or more new RBC's for the station area and access railway line up to the existing ETCS Level 2 area. The new RBC could use ETCS over CSD or ETCS over PSD. However as described under 4.6, especially for large stations, the preference will be for a solution based on ETCS over PSD.

Although an ETCS over PSD solution is the preference for the large station, trains which were already operational under ETCS over CSD will continue their use of ETCS over CSD in the station area. As a result, in the station itself, a mixture of ETCS over CSD and ETCS over PSD will exist. This use case is described under 4.9.

Due to the newly introduced RBC(s), an RBC handover will happen in the vicinity of the station. This RBC handover can be of the type ETCSoCS towards ETCSoCS or ETCSoPS or vice versa.

4.7.2. Theoretical application

The questionnaire data collected as part of the present study does not directly provide input for the present use case, however the following situations may be envisaged near the initial RBC announcement balise, depending on the capabilities of the EDORs installed in the train:

- ETCSoCS towards ETCSoPS RBC handover, and vice versa
- ETCSoCS towards ETCSoCS,

Every RBC handover requires two EDORs to be simultaneously connected, one to each of the RBC's involved in the RBC handover process.

The situation ETCSoCS to/from ETCS/PS requires simultaneous CS and PS connections from the train, while a ETCSoCS to/from ETCSoCS requires two simultaneous CS connections. The simultaneous CS/PS connection is less demanding in capacity terms as one PS TS can handle up to seven trains simultaneously (subject to radio conditions and available coding scheme).

As the original ETCS level 2 area did not include the large stations, mainly driven by capacity limitations, one can assume that the initial RBC announcement balise was not under the coverage of the station macro cell. Where the RBC handover takes place further away from the station, one can consider that the macro cell is covering one or two railway lines, and has 2 TRX providing 14 timeslots for traffic, and should be capable of handling the additional traffic required for RBC handover.

On the other hand, if the RBC Handover were to take place under the coverage of the station macro cell, or in a dense rail area (several parallel tracks, with simultaneous trains in busy hour), an adaptation of the radio network in that area would be recommended, to isolate the area from the station cell or macro cell covering the wider railway, with the aim of keeping the connection times in the cell of the RBC handover small.

4.8. Use Case 3: implementing critical traffic on a pre-existing GPRS/EDGE non-critical deployment

4.8.1. Description of the scenario

As indicated in the questionnaire responses, some railway organizations have already implemented or plan to implement GPRS for non-critical applications in the large stations.

Operator	Timeframe	Number of users	Average Throughput	Peak Throughput
ProRail	Already operational	150	2 kbit/s	4 kbit/s
SNCF	From 2020 on-wards	15 growing to 30	5 kbit/s	10 kbit/s

Table 6: Operational or planned non-critical GPRS users

Deutsche Bahn also indicated the usage of non-critical GPRS/EDGE from 2025 onwards, but the number of users specified was negligible, and as such this has not been taken into consideration in this use case.

This GPRS/EDGE traffic is in addition to the ETCS over PS or CS traffic described in the use case under paragraph 4.6.

A number of network features considered for ETCS over PSD will have an impact on those existing non-critical applications, such as;

- TBF timers, which are common for all PSD data users
- PSD priority mechanism based on PFC and ARP

Increasing the TBF timer to avoid TBF attach in between successive ETCS over PSD messages will also increase the occupation of the radio capacity by non-critical users, and as such increase the required capacity of the radio cell serving the large station. On the other hand, depending on the type of non-critical application, an increase of the TBF timer could reduce the signaling load associated with the non-critical users in the cell.

Further ETCS over PSD application will have priority over the non-critical applications and as a result the transfer delay for the non-critical applications may increase and even fall below the requirement for the non-critical application. Where no further capacity increase is possible on the GSM-R cell, the non-critical application should be offloaded towards other wireless networks, such as a public radio network or Wi-Fi.

4.8.2. Dimensioning factor

The dimensioning factors are the same as for the ETCS Start of Mission described in paragraph 4.6.2, with additional traffic estimates provided via the questionnaire for non-critical GPRS traffic.

As multiplexing occurs within the GPRS domain, the dimensioning is based on the average throughput provided.

For this case it has been assumed that the non-critical GPRS users are only capable of operating under GPRS coding schemes i.e. no CSD fallback.

For the degraded mode only an increase in ETCS traffic is taken into account.

4.8.3. Theoretical application

One basic model is considered, whereby the CSD trains consume 1 timeslot per train and PSD trains consume timeslots as per Figure 8. On top of the timeslots for ETCS, the required timeslots for non-critical PS application is added.

The calculations are performed in the “nominal” case, i.e. without the “Safety Margin”, and in the “degraded case”, i.e. with the “Safety Margin” applied to the ETCS traffic only.

“Spare timeslots capacity” or “Max free TS” refers to the number of timeslots remaining for other services (such as voice) once the BCCH timeslot, the SDCCH timeslot(s) and the timeslots used for ETCS (CSD and PSD) have been removed from the “raw” capacity.

Looking at Table 7 and Table 8, one can see that the frequency requirements in nominal and degraded mode for an additional 150 users on top of the ETCS traffic remains relatively low, namely four TRX, with a typical “spare timeslots capacity” of one or more spare timeslots providing resources for operational voice communication whilst not requiring an additional channel.

			Gprs users other than ETCS			Trains			ETCS (nominal)			ETCS (degraded)		
Operator	Scenario	Year	n° of users	Avg troughput	req. Through-put	Standstill	Transit	Approach	total	CSD	PSD	total	CSD	PSD
ProRail	Large Station	2025	150	2	300	6	6	2	14	0	14	21	0	21
ProRail	Passing station	2025	3	2	6	1	2	0	3	0	3	5	0	5
SNCF	Large Station	2025	30	5	150	16	0	0	15	0	15	18	0	18

			Minimum TS used for ETCS (nominal)				Minimum TS used for ETCS (degraded)				TS other GPRS users				Minimum frequencies used nominal				Minimum frequencies used degraded			
Operator	Scenario	Year	CSD	MCS-3	MCS-5	MCS-6	CSD	MCS-3	MCS-5	MCS-6	CS-4	MCS-5	MCS-6	MCS-7	CSD	MCS-3	MCS-5	MCS-6	CS-4	MCS-5	MCS-6	MCS-7
ProRail	Large Station	2025	0	4	3	2	0	6	4	3	22	22	22	22	4	4	4	4	4	4	4	4
ProRail	Passing station	2025	0	1	1	1	0	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SNCF	Large Station	2025	0	5	3	3	0	6	4	3	8	7	6	5	2	2	2	2	2	2	2	2

Table 7:minimum frequency requirements for ETCS SoM in station in combination with non-critical PS application

			Gprs users other than ETCS			Trains			Max free TS (nominal)			Max free TS (degraded)		
Operator	Scenario	Year	n° of users	Avg troughput	req. Through-put	Standstill	Transit	Approach	MCS-3	MCS-5	MCS-6	MCS-3	MCS-5	MCS-6
ProRail	Large Station	2025	150	2	300	6	6	2	3	4	5	1	3	4
ProRail	Passing station	2025	3	2	6	1	2	0	4	4	4	3	4	4
SNCF	Large Station	2025	30	5	150	16	0	0	1	3	3	0	2	3

Table 8: spare timeslot capacity for other services (such as voice)

4.9. *Use Case 4: mixing ETCS over CSD and ETCS over PSD, solutions to dynamic mixture of traffic*

4.9.1. Description of the scenario

Fleets of train typically vary in their level of equipment and this also applies to ETCS over GPRS readiness. Similarly, for a given set of routes leaving a particular station, due to a franchising scheme or for historical reasons, the rolling stock on the respective routes may differ.

This aspect may be beneficial in terms of radio resource optimization if the peak hours of the different services (one being more prevalent in terms of ETCS over CSD equipped rolling stock as compared to the other) do not happen at the same time. This could for example result from one service being a regional commuter train line, with pronounced peak hours at the beginning and the end of the work day, with the other being a long distance train line with more infrequent departure schedules.

For the purpose of this use case, the questionnaire data collected as part of the present study cannot be directly used for the sake of demonstration, as the use case depends on the respective fluctuation over the course of the day of ETCS over CSD and ETCS over PSD. The approach taken compares two theoretical distributions of ETCS over CSD and ETCS over PSD users, one being uniform and the other exhibiting appropriate characteristics.

4.9.2. Theoretical application

The following distributions follow the same Safety Margin, i.e. 50%.

The uniform distribution foresees a maximum of 18 ETCS trains at peak hour in degraded mode, of which 5 are ETCS over PSD and 13 are ETCS over CSD. Under this scheme, 3 channels are required to cater for the traffic combination of CSD and MCS-3.

The time-variant ETCS/CSD vs ETCS/PSD distribution foresees an absolute maximum of 20 ETCS trains in degraded mode between 7am and 10am and between 5pm and 8pm, of which 10 are ETCS over PSD and 10 are ETCS over CSD. It also foresees an absolute ETCS over CSD maximum of 13 trains in degraded mode between 12pm and 3pm, with an associated maximum of 3 ETCS over PSD trains during that same time period (between 12pm and 3pm), giving a total of 16 trains. Under this scheme, despite potential higher peaks of traffic in terms of total number of ETCS trains connected, a maximum of two channels are required to cater to that traffic at a combination of CSD and MCS-3.

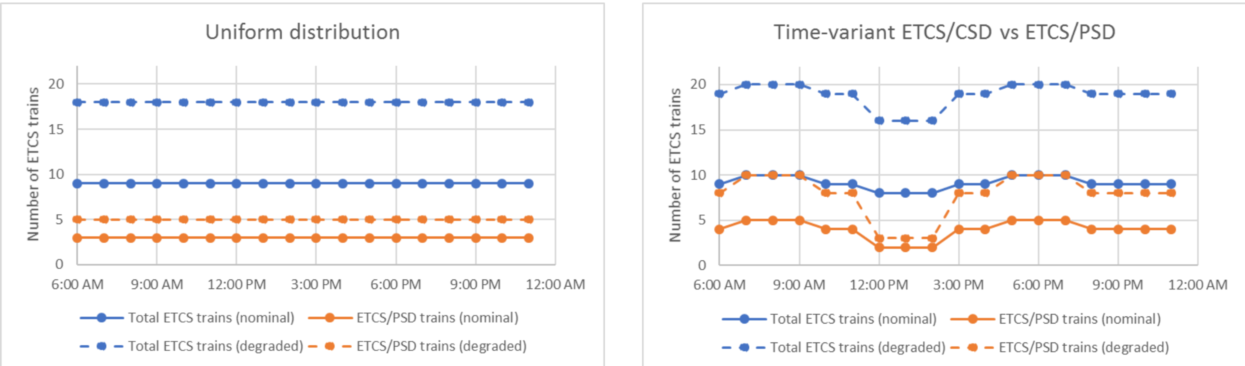


Figure 9: benefits of GPRS/EDGE in dynamic traffic mix (example)

Although a contrived example, as the calculation accounts for ETCS traffic only under theoretical optimal radio conditions, GPRS/EDGE, thanks to multiplexing and the ability to implement timeslots usable either as TCH or PDTCH, offers interesting optimization characteristics which may allow for a relaxation of the GSM-R frequency planning constraints in hotspots featuring variations over time in the mix between ETCS over CSD and ETCS over PSD rolling stocks.

It should be noted that although providing flexibility, the use of timeslots as either TCH or PDTCH is probably not appropriate in the railway environment as this can become challenging when inter- and intra-domain pre-emption (see 4.1.5) comes into play. A more pragmatic and conservative approach would be to define sufficient non-pre-emptible dedicated PDTCH timeslots required to support peak ETCS over GPRS/EDGE usage in nominal traffic conditions: under such scheme, nominal traffic would be "cleanly" handled for both nominal ETCS over CSD and nominal ETCS over PSD users while allowing dynamic usage of shared TCH/PDTCH timeslots to cope with relative perturbations affecting either population of users.

4.10. Use Case 5: mixing GPRS and EDGE users, handling evolutions on the mobile side

Situations may occur in which trains are using GPRS modulation for non-critical applications, while in the same radio cell, EDORs may use EDGE modulation for the ETCS over PSD. The same may be applicable with fixed trackside equipment making use of GPRS only devices. In such situations a non-ideal distribution of the TBF will occur over the PSD TS, as GPRS and EDGE can't be mixed simultaneously in the same TS. As non-edge capable mobiles can't detect their TFI if it is transmitted in the EDGE modulation, in the worst case scenario, with only one GPRS only capable mobile in the radio cell, this would occupy a full Timeslot.

4.11. Use Case 6: the transition to FRMCS

Based on the use cases described in the previous sections, the use of GPRS/EDGE can be seen to bring benefits in facilitating ETCS scenarios that would be challenging to address with the use of CSD, notably by providing flexibility in traffic handling through multiplexing, dampening the effects of traffic spikes and fluctuations. Overall, this means that the use of GPRS/EDGE will help railway operators coping with increased traffic in hotspots whilst relaxing constraints on the GSM-R frequency planning.

In addition to the short term benefits for today's operations and planning, more efficient use of GSM-R frequencies will also be an essential tool in preparing today's GSM-R networks for the transition to FRMCS, the successor to GSM-R. In essence, although the spectrum resources available to railways are still under discussion, the favoured option would see FRMCS introduced in parts of the extension band (873-876/918-921 MHz), just below the core GSM-R band (876-880/921-925 MHz). Subject to finalization of the frequency band and technology choices, GPRS/EDGE is expected to help reduce the spectrum requirements of existing GSM-R users in order to make spectrum resources available for FRMCS users as time goes on. These aspects are explored in more details in section 5.2.

Another key benefit to the railways of the introduction of GPRS/EDGE lies in the greater familiarity that railways operations personnel will gain with the use of wireless IP-based services. IP-enabled services and applications are key items within FRMCS, notably as an enabler of one of the cornerstones of its objective represented by the bearer independence of railway applications. Whether through critical (such as ETCS) or non-critical applications, the use of wireless IP-based services over GPRS/EDGE, with its inherent trade-offs and challenges in latency, capacity, usage multiplexing will allow railway personnel to further their hands on experience in preparation of the full move to IP envisioned by FRMCS.

5. Going beyond the GSM-R/GPRS/EDGE bearer

The above analysis of ETCS capacity in high density environments and migration from CS to PS domain suggest also a strategy for evolution or integration of GSM-R with new technologies and, ultimately, the migration to FRMCS.

The TEN-T studies and test campaigns were related to the feasibility analysis of using the PS domain in place of the CS for signaling and also for optimizations techniques to be introduced in GSM-R to fulfill the required QoS, as those reported in section 4.2.4, and also to increase capacity (see EDGE).

To reach the objectives, two key steps were achieved:

1. EIRENE as well as UNISIG Subset 093 update and related test specifications (O-2475) update. In particular, PS related QoS parameters are bearer independent, so they are potentially applicable to any IP bearer.
2. TCP/IP, selected as the transport protocol for ETCS, is the main Internet protocol used for reliable data transfer between IP nodes.

These key steps open the way to bearer independency of IP over ETCS, where PS GSM-R is only one of a set of potential bearers and where all IP bearers fulfilling capacity and QoS requirements are potential candidates.

The clear advantage of GSM-R is that it is the existing communication system defined for European interoperability so, with rather limited upgrades and re-engineering of existing networks and on-board systems, it is possible to improve train capacity, as described in the document, to satisfy the future increase of train density planned by European Railway Operators.

In brief, the introduction of ETCS over GPRS&EDGE is the fastest and cheapest way to fulfil new capacity requirements maximising existing investments and maintaining full interoperability at least as long as GSM-R will be maintained.

The existing ETCS on board architecture, shown below, is the same for CS and PS mode, assuming that EVC and EDOR are updated to support new standards, and the Euroradio serial interface supports the extended AT command set required for PS. On the land side, the RBC shall additionally support the packet switched traffic coming from the GGSN/SGSN, as in the standard GPRS network architecture.

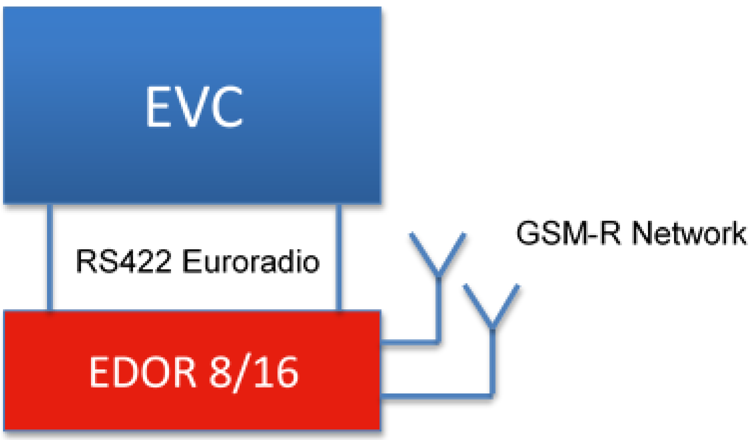


Figure 10: the standard on-board system

The TCP/IP protocol is reliable as it re-transmits packets until the message is delivered correctly.

In the case where the available bandwidth is lower than that required, the traffic shows a congestion phenomenon, where the channel is saturated by retransmission and the roundtrip delay greatly increases. Whilst the message is delivered without errors, the T_NVCONTACT timer is likely to expire if the RTD exceeds the configured value.

As an example, even if the GSM-R network is correctly dimensioned for signalling traffic, when all connections have the same (highest) priority, in case of radio disturbance affecting the achievable throughput momentarily, several trains in the area may have to stop due to the expiration of their respective T_NVCONTACT timers. This impacts (rail) service availability and procedures will need to be considered to allow for trains to restart, as the risk of random radio interferences in dense urban areas cannot be excluded, especially with the anticipated deployment of SRD devices in the lower part of the ER-GSM band.

The straightforward strategy to avoid congestion is to move existing PS services not related to (ETCS) signalling, for example information to passengers, to public operators or unlicensed access network (WiFi, …). Under this scheme, safety and operational critical services, like signalling, remain managed by the dedicated GSM-R network but other innovative ideas could be considered.

5.1. The Sardinia Trial

An interesting idea to increase the available bandwidth and reliability is to add radio system diversity with seamless transitions. Considering that the signalling protocol is TCP/IP, the perfect candidate for this is the MPTCP protocol, an IETF standard, that is end-to-end compatible with TCP/IP, so no changes in the signalling application would be required. It allows path diversity and aggregation with very fast transition, as different paths are simultaneously used in case of congestion on the main one. This protocol was successfully tested in the ESA 3inSat Sardinia Trial, where configured bearers were public 3G operators and the satellite provider was Inmarsat. Also PS Tetra data was used as an ERTMS bearer, in single or multipath configuration. In the Sardinia Trial the main reason for using MPTCP was related to the lack of the GSM-R coverage and the site was a candidate to test alternative solutions, not requiring a dedicated network for railway, but guaranteeing anyway an adequate level of reliability and quality of service using already existing public networks.

In the typical high density urban scenario additional available bearers include public 4G operators and private Wi-Fi local coverage. In this context the evolution of the on-board system could be the proposal shown in Figure 10, with a standard on-board system, maintained to keep compatibility, is complemented with an MPTCP router connected to the EVC via an additional IP Ethernet interface. This interface is foreseen also in new EVCs, so it should be already available in most standard ETCS system.

The use of an Ethernet interface will provide an alternative to serial links to the EDOR in PS mode.

The MPTCP router includes a proxy MPTCP function, which is required at the border of the MPTCP island to allow standard TCP/IP streams to be processed in the multipath. A symmetric one is located at the land side. In brief, the MPTCP proxies allow interoperability of TCP/IP while passing MPTCP islands.

In this application the MPTCP router, on entering high density areas, establish all available radio links, with GSM-R as the default one, considering that the GSM-R is the private network with guaranteed QoS. This is also the only one used when all the traffic is delivered without congestion, while the others are monitored in terms of RTD with very low bitrate. As soon as the GSM-R link is close to saturation, which is detected by MPTCP via the congestion window of the stream, packets start to be delivered on other available paths, - LTE and Wi-Fi in this hypothesis, - dynamically increasing the available throughput.

A plot of the MPTCP behaviour is shown in Figure 11

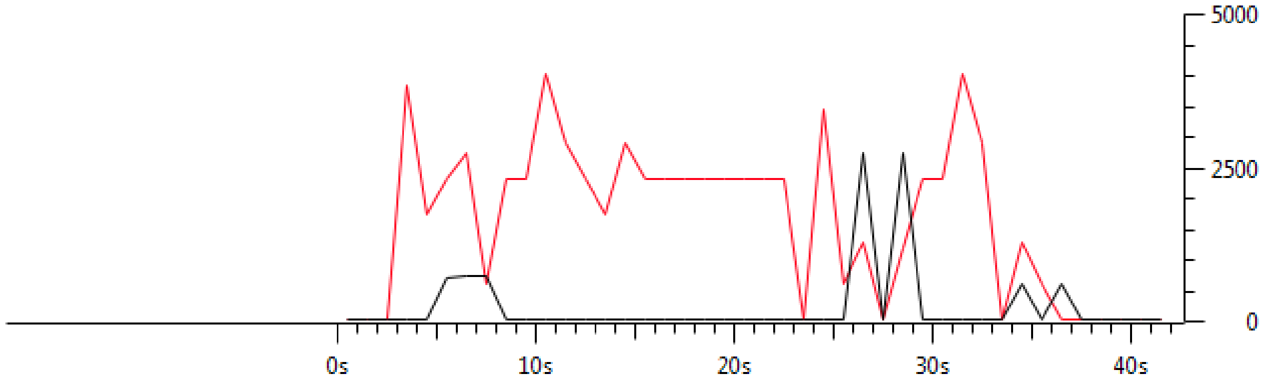


Figure 11: Manual switching between 3G & SAT

As it easy to see from the graph, the transition between bearers is seamless and transmission on the other bearers starts as soon as the other one fades. More interesting is the case where both paths are available but are affected by a large Bit Error Rate. In this case transmission is done simultaneously on both paths and the first arriving good packet is delivered to the receiver.

It is clear that this architecture offer great reliability at minimum cost, as it's unlikely that all links are down simultaneously, considering that the GSM-R is primarily used in normal conditions.

In the perspective of future evolutions, this architecture supports all IP bearers, with or without GSM-R, and also signalling over heterogeneous bearer - with signalling grade QoS, which was the main scope for selection of MPTCP in the Sardinia Trial. In this application the dedicated railway system is not available at all, so the global coverage and the required availability is guaranteed by multiple radio bearers with the main condition of radio overlaps among them. The satellite is used in areas where other networks offer poor service. The MPTCP protocol continuously engages new "better" bearer when the serving one offer poor quality or is congested. Of course other protocols could fulfil QoS targets, but the MPTCP is available now, it is an IETF standard and also field proven for railway signalling applications.

One important point to note is that individual IP connections must correctly transmit the Option 30 field of the TCP/IP header, to ensure correct operation of the MPTCP protocol. This field informs the system that the TCP/IP stream is one of the multipath MPTCP link. The Sardinia Trial revealed that some public operators remove these fields, thus excluding the link from the pool. In this case the operator shall guarantee its support in verifying the proper network configuration, especially of routers insisting on the complete path. Otherwise an additional tunnelling (as GRE, IPsec for example) would be needed on links not transmitting the Option 30 field unaltered, introducing some additional complexity, but also additional security, when required.

In Figure 12, the complete radio architecture is shown, including the land side, required for re-combination of TCP/IP streams. As it is possible to see, the Railway operator will become a "Virtual Railway Operator", managing both private and public networks, with the responsibility to ensure the required global Level of Service.

This is an interesting service model that could be a prelude to a different role for the Railway Operator in the future.

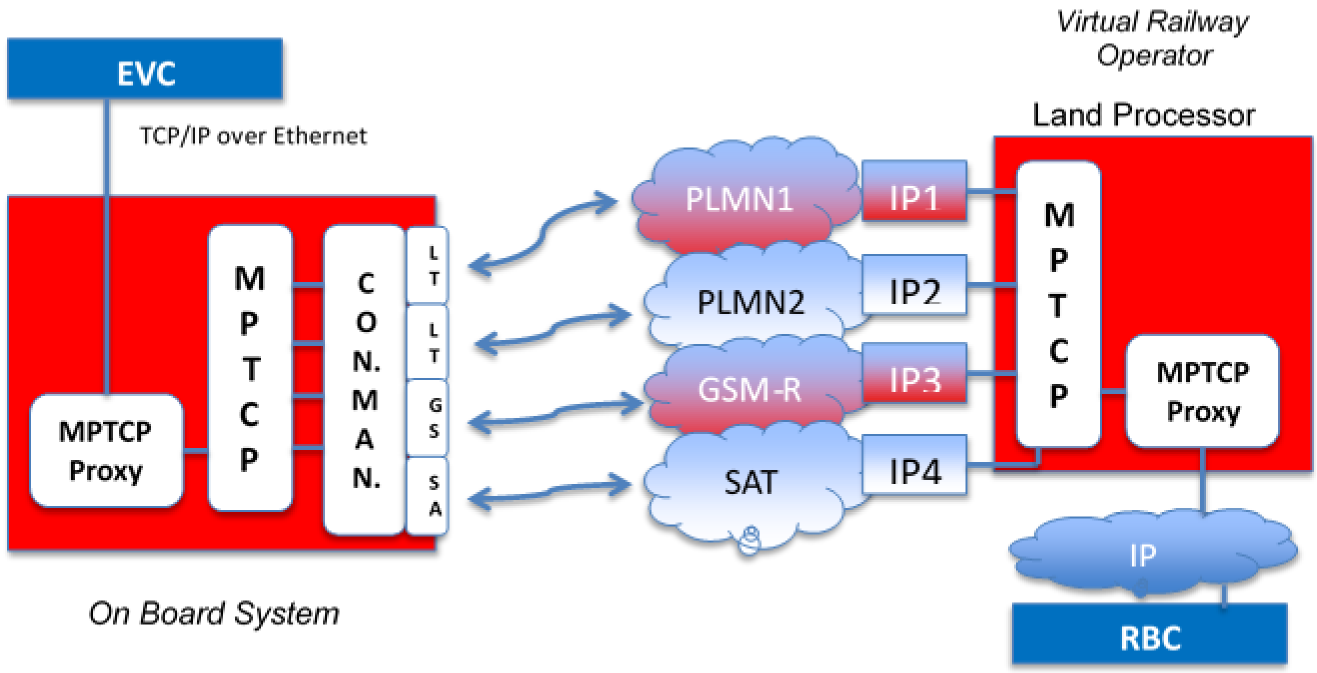


Figure 12: One possible on-board evolution with the MPTCP protocol

5.2. FRMCS: current trends

The Future Railway Mobile Communications System (FRMCS) project was setup by the UIC in 2012 to collect user requirements and identify technical preconditions for the successor to GSM-R.

Its objectives encompass the following aspects:

- Offer bearer-independence for railway applications
- Support multiple Radio Access Technologies for flexible deployments
- Provide high availability and high robustness
- Be interoperable for cross-border operation and GSM-R coexistence
- Be flexible and allow deployment options to implementers

As part of that vision, the bearer independence is embodied by the forecasted reliance on IP-based applications to facilitate the use of the multiple Radio Access Technologies (RATs) available to the FRMCS User, notably through the evolution of the Cab Radio and EDORs towards a Mobile Communication Gateway.

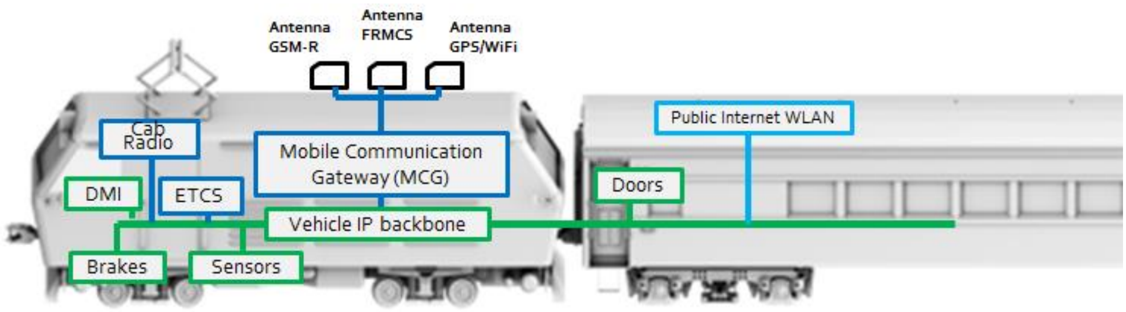


Figure 13: the Mobile Communication Gateway

In that regard, the move to a PSD bearer for ETCS, along with the generalization of a GPRS/EDGE-enabled IP bearer for non-critical applications, as considered in the present study, present a logical stepping stone to foster IP awareness amongst railway personnel as well as to facilitate the introduction or the deployment on a larger basis of IP-based applications. Naturally, the profile of the applications will remain limited by the capacity offered by the GPRS/EDGE technology capabilities, but a large number of low bandwidth applications relevant to railways could be implemented.

Another area where GPRS/EDGE introduction may be of use is the "compression" of the usage of GSM-R frequencies in the UIC band to provide additional resources for the FRMCS system. In the current discussions at European level, parts of the ER-GSM band (873-876/918-921 MHz) may be allocated to Short Range Devices, where permitted, the remainder of the extension band could be used by railways for the introduction of FRMCS. A commonly discussed scenario at the time of writing would see the FRMCS being deployed initially in the band 874.4-876/919.4-918 MHz with the underlying assumption of a wideband carrier of a bandwidth compatible with a LTE 1.4 MHz carrier (the use of the word compatible is of importance here as 5G is also amongst the candidate technologies for FRMCS).

Under such a scenario, assuming the width of the FRMCS channel would follow the same discrete progression of currently known LTE channel widths, i.e. 1.4 MHz → 3 MHz → 5 MHz, the transition from a 1.4 MHz channel to a 3 MHz channel would require from the railway operator to save 8 GSM-R frequencies out of the 19 at its disposal in the UIC band (876-880/921-925 MHz). Such an optimization of frequency usage would certainly require a varied set of measures considering that the overall railway traffic would in the meantime be expected to grow. However, the usage of GPRS/EDGE as investigated in the present study would certainly play a role in mitigating the impact of a widespread usage of ETCS by multiplexing users on a lower number of GSM-R timeslots than permitted by the usage of a CSD bearer.

5.3. Considerations on security aspects

ERTMS, as a whole, is a signaling system which, according to the Standards EN50126, EN50128 and EN50129, has security requirements at level 4 (SIL 4), which is the highest in that it provides a THR (Tolerable Hazard Rate per hour and per function) including between 10^{-9} and 10^{-8}.

The GSM-R radio system is one of the components of the ETCS system <u>but GSM-R in itself has no security requirement</u>. The basis for this assertion is that it is classified as a Category 3 transmission system, according to EN50159 norm "*Railway applications - Communication, signaling and processing systems - Safety-related communication in transmission systems" [50.159]*.

According to the standard, Category 3 systems are: ***Open transmission systems where there is opportunity for malicious attack, and cryptographic defense measures are required.***

In the norm there is also a table, adding some example:

Category	**Main characteristics**	**Example transmission systems**
Category 3	Properties are unknown, partially unknown or variable during the lifetime of the system. Unknown multiple users groups. Significant opportunity for unauthorized access.	Packet switched data in public telephone network. Internet. Circuit switched data radio (e.g. GSM-R). Packet switched data radio (e.g. GPRS). Short range broadcast radio (e.g. Wi-Fi). Radio transmission systems without restrictions.

The interesting aspect is that GSM-R (CS or PS) is considered the same as Wi-Fi and the Internet or a Public Network for safety. Even if this could seem a disadvantage, in a future and current perspective it enables all radio system to be a candidate for a signaling bearer: note that Wi-Fi is widely used as bearer for CBTC system in metro applications.

In a Cat.3 system strong countermeasures are required for following threats:

- Repetition
- Deletion
- Insertion
- Re-sequence
- Corruption
- Delay
- Masquerade

When safety related computers have to communicate over open transmission systems, as in the case of EVC and RBC, separate protection layers are needed.

In the specific case of GSM-R CS signaling data, this protection layer is provided by the EURORADIO protocol, adding safety-related transmission function to EVC-RBC communications. In this specific case the Safe Functional Module (SFM) provides safe services. The safety services provide safe connection set-up, and safe data transfer during the connection lifetime. The safe data transfer provides data integrity and data authenticity. The SFM reports the errors that occur in the safety layer and transfers error indications from the lower layers.

In conclusion, radio systems used for signaling, including GSM-R, are considered open transmission system without safety requirements. In this case, to interface safety related applications, separate protection layers are needed, and in GSM-R CS this is the EURORADIO protocol. This concept is valid in general, so, for the future, the use of any radio system, including public, is suitable for signaling.

The SIL 4 level of ERTMS is reached at a system level. This means that disruptions including hacking of the GSM-R service will normally produce a train stop event, not an accident, but this means that the global availability of the transportation system is directly related to the availability of the radio bearer.

6. Conclusion

The present study identifies several paths for which the implementation of GPRS or EDGE in a station environment contributes to enabling or simplifying operations. It should be further noted that the present study has been performed with a telecom perspective on the railway needs and that, in particular, the findings identified regarding the suitability of GPRS/EDGE to the ETCS application may benefit from being cross-examined from a signalling perspective in order to draw more complete conclusions.

Amongst other things, consideration for migrating as early as possible towards ERTMS Baseline 3 Release 2 should be taken as this would enable common certification for both network and on-board side of CSD and PSD.

Subject to increasingly demanding radio conditions when using higher modulation and coding schemes, the usage of GPRS/EDGE as a bearer for ETCS in a station context offers gains ranging from three to seven more trains per timeslots as compared to ETCS over CSD, which is by nature limited to 1 ETCS train per timeslot. This efficiency in terms of timeslots consumption can then be used to enable other, non-critical, IP-based applications or a more widespread use of ETCS in station (including ETCS Start of Mission). The actual benefits for a real station remain dependent upon an adequate study taking into account the particular service profiles at that station.

Besides the capacity gains identified, the implementation of GPRS/EDGE may also prove beneficial with regard to the simplification of the GSM-R frequency planning and, as such, may provide a useful stepping stone towards the migration to FRMCS.

It should also be noted that the implementation of ETCS over GPRS/EDGE also offers a stepping stone towards ATO (GoA 1 and 2), online KMS as well as enabling the usage of ETCS level 2 in station areas for more efficient train operation.

The gain in operation performance and efficiency shall ultimately yield a greater track capacity with related benefits for passengers and operators. It would also facilitate the deployment of railway applications, notably in station, by leveraging the usage of GSM-R spectrum.

Finally, the contributors of the document consider that the establishment of a pilot project equipped with Commercial Off-the-shelf equipment would allow the testing of an end-to-end solution. It would be an opportunity to further demonstrate the benefits outlined in the present study, be it on the facilitation of performing automated in-station ETCS Start of Mission, on developing the general awareness of IP services, on benefiting from some relaxation of the frequency constraints and would pave the way towards FRMCS.

7. Annexes

7.1. Questionnaire

The following questionnaire sent to UIC Infrastructure Managers members of ERIG and answers were received from:

- Deutsche Bahn (Germany),
- Infrabel (Belgium),
- Network Rail (United Kingdom),
- ProRail (Netherlands),
- RFI (Italy),
- SNCF (France),
- SBB (Switzerland).

These input data represent a significant sample which allowed the study to be conducted in confidence.

questionnaire on
CEF Call Activity 12

7.2. Summary Input data

Based on individual answers received, a summary document was established gathering the input data. This document, after several updates including UIC member's answers, is given below:

Answers summary
to questionnaire