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FRMCS - ETCS Baseline 3 (non-)compatibility / Technical Report

Analysis on behalf of the CTO-Council of the potential technical solutions/scenarios and proposed actions regarding FRMCS – ETCS Baseline 3 (non-)compatibility.

April 2024

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1 Management summary

The solution stream has analysed the solution space identified in the CTO working group report [1] in more detail and came to the conclusion, that the proposed baseline light and adapter solutions span indeed the available solution space as alternative to onboard BL4 SV3.0.

Baseline light design principles and focus could be agreed upon quickly. A solution proposal document was elaborated, released on March 28, 2024 [2] and submitted to ERA. Baseline light is a low-risk solution with limited operational and trackside impact for which industry support can be expected. It is an intermediate step to SV3.y. To what extent costs and migration time can be reduced, will – among other factors – depend on the future certification regime for this solution which unlike BL4 SV3.0 does not affect the SIL4 core of ETCS.

The detailed change requests for baseline light have not yet been written. First the regulatory framework must be agreed with ERA. However, the concept document provides a comprehensive basis for detailed change requests.

The adapter topic was ridden with considerable complexity in terms of a wide solution (sub-)space and multiple challenges and risks. From 7 identified (sub-)solutions one solution (D) suitable for SV2.1 vehicles and a second solution (A) for SV2.0 vehicles could be identified, and the basic way of working described.

Adapter solutions are associated with higher technical risks than baseline light (especially variant A) and an uncertain supplier ecosystem, as a complete separate development would be needed to realise the adapter, most likely specific to each relevant vendor combination of ETCS onboard and telecom onboard equipment. Further risk mitigation would need prototyping activities that exceeds the original remit of the working group.

This technical report of the CTO working group solution stream covers the following aspects:

- Compatibility aspects (generic and specific to the proposed solutions).
- Overall migration aspects including FRMCS radio coverage.
- Summary of baseline light including assessment.
- Description of the adapter solution space, advantages and disadvantages of the different variants, going into detail on selected topics like addressing and bearer choise for the preferred variants and outlining what topics would have to be further studied if the adapters would have to be considered alongside or instead of baseline light.

2 Introduction

2.1 First report of the Working Group

The first report of the working group was the basis on which the solution stream developed solution concepts to allow for ETCS BL3 onboard compatibility with FRMCS [1].

2.2 Remit regarding Solution Details, Technological Feasibility and Standardization needs

- Clearly describe the solutions and the delta between them and BL4 (SV3.0) on functional level, e.g. which change requests are included.
- Analyse the potential limits of the solutions with respect to support of further digitalization, e.g. support for ATO, DAC, etc.
- Analyse further measures to improve the solutions in terms of cost, timeline and risk.
- Identify key technical complexity and risks and paths to address those.
- Based on the outcome detail required changes to current standardization.

2.3 Preparation of the document

This report was composed by a technical working group, with following participants:

Organization	Name	Position
Deutsche Bahn	Morten Schläger	Senior Referent Telecomunication
Deutsche Bahn	Jenny Dang	Expert FRMCS Migration
Nederlandse Spoorwegen	Edwin Bottelier	GSM-R/FRMCS specialist
Nederlandse Spoorwegen	Maarten Burghout	GSM-R/FRMCS specialist
SBB	Alex Brand (Coordinator of solution stream and report editor)	ERTMS / FRMCS Portfolio Management
SBB (Emch & Berger)	Alfonso Gonzalez	ERTMS expert
Siemens (Unisig)	Frank Kaiser	ERTMS expert
Kontron (Unitel)	Michael Mikulandra	Head of Products
Funkwerk (Unitel)	Alexander Ende	Team Lead Product Management
ERTMS User Group (EUG)	Rob Dijkman	Technical Director
ERTMS User Group (EUG)	Simon Lambert	Lead Engineer
Thales (Unisig)	Stefan Fritzsche	ERTMS expert

3 Solution Space and Basic Principles

In [1] two solution concepts were proposed for the problem of baseline 3 (non-)compatibility with FRMCS, namely “Baseline Light” and the “Hack Solution” which in the following will be named “Adapter Solution”. In the first meeting of the solution stream members the solution space was reconsidered, and it was found that these solutions cover the available solution space.

Regarding the “Baseline Light” solution it was also decided that such a solution should limit itself to the existing ETCS functionality of BL3 SV 2.0 and SV 2.1 vehicles, that is no change requests other than what is required to introduce FRMCS should be considered. Furthermore, the introduction of FRMCS should be possible in such a manner that SS-026 (the core ETCS application) is not affected.

Regarding the “Adapter Solutions”, apart from the TOBA variant 1b considered in 2019, further adapter variations were identified that would have to be assessed for suitability.

If the BL3 vehicle that is FRMCS-enabled via BL Light or Adapter is an SV 2.1 vehicle, it shall still be able to use GSM-R PS/GPRS (if supported by trackside) for ETCS when there is no FRMCS coverage.

The solution concepts should have as little impact on trackside (FRMCS, fixed network, RBC) as possible. However, introducing BL3 SV 2.0 and SV 2.1 onboard compatibility with FRMCS means that the RBC cannot be upgraded from SV 2.3 to SV 3.Y even after completion of the initial FRMCS vehicle migration. Upgrades will only be possible once all SV 2.Y vehicles made FRMCS compatible are out of service or migrated to SV 3.Y.

Changes to FRMCS specification have to be avoided in order not to jeopardize the already tight FRMCS timeline.

4 ETCS Onboard Architecture according TSI 2016 and 2023

The following drawing of SS-037 v 3.2.0 (TSI 2016) [6] shows the telecom onboard architecture of an SV 2.1 onboard supporting GSM-R circuit-switched communications and GSM-R packet-switched communications (GPRS).

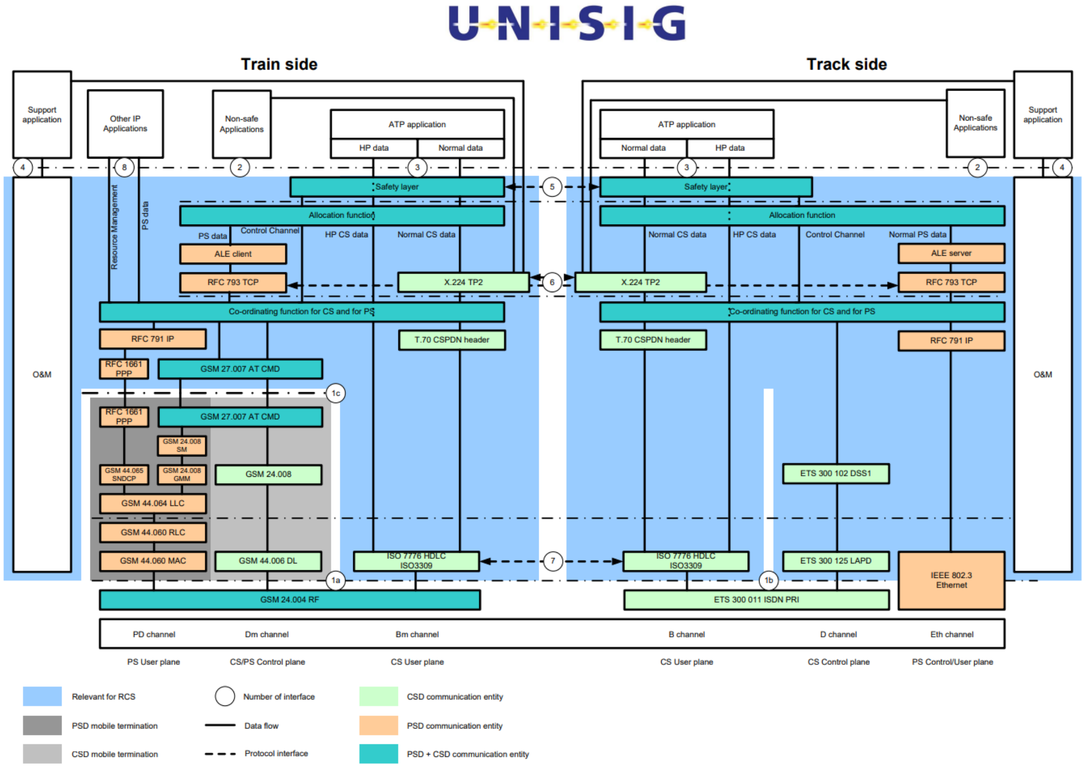

Fig. 4-1: Telecom Reference Architecture according to SS-037 V. 3.2.0 (SV 2.1 Onboard).

The addition of FRMCS leads to the following changes according to SS-037-1 V 4.0.0 (TSI 23) [7]:

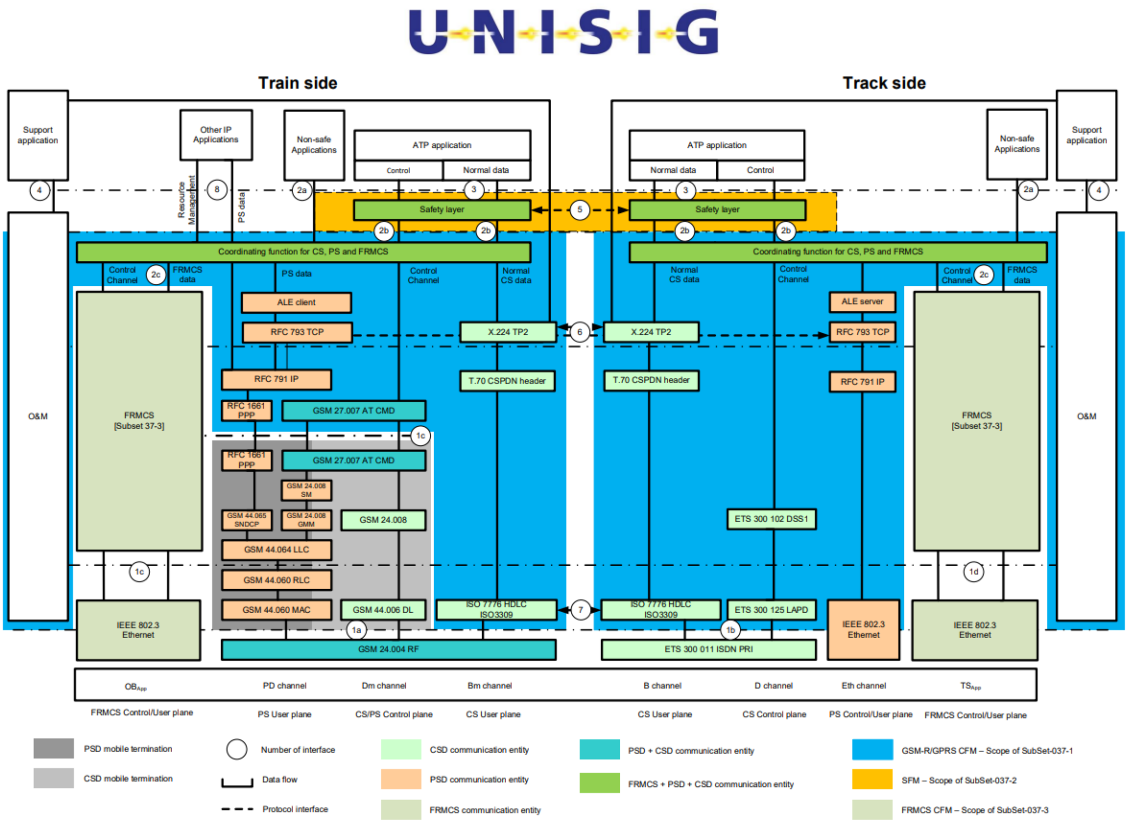

Fig. 4-2: Telecom Reference Architecture according to SS-037-1 V. 4.0.0 (SV 3.0 Onboard).

The protocol stacks relevant for FRMCS onboard and trackside are shown in Fig. 1 of SS-037-3 V 4.0.0 [8]:

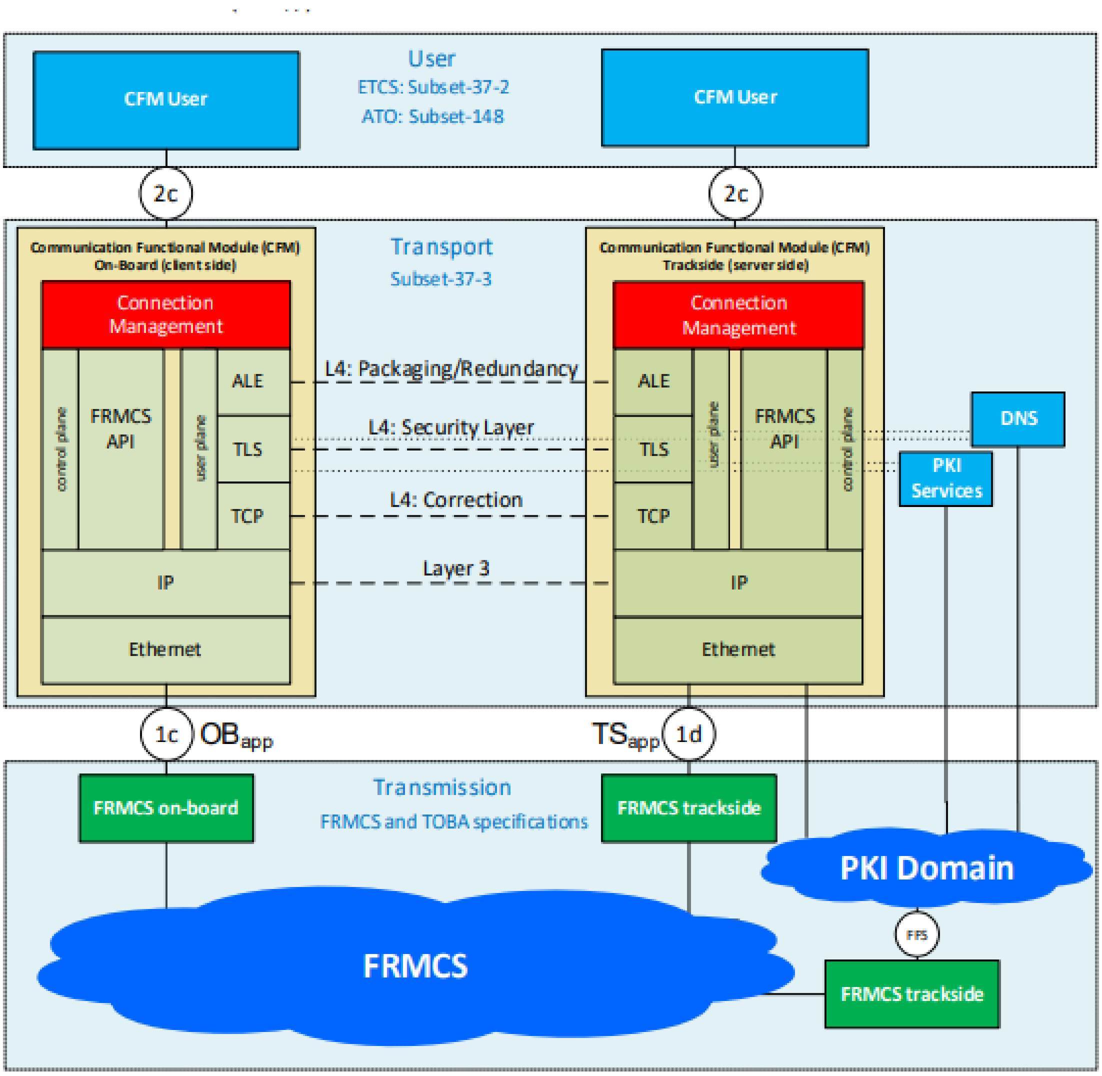

Fig. 4-3: Reference Architecture of Euroradio according to SS-037-3 V. 4.0.0

5 Migration and Compatibility Aspects

5.1 Supported Radio Bearers, Compatibility Matrix and Use Cases

In table 5-1, a compatibility matrix mapping trackside and onboard versions for ETCS is shown for the current TSI CCS 23, the baseline light solution and the adapter solution (both limited to BL3 vehicles). It must be noted that there is no strict mapping between system version and communication means for ETCS. Regarding onboard, the following statements can be made:

- An onboard < SV 2.1 will not be able to use GSM-R PS (packet switched, also known as GPRS) for ETCS, even though the onboard radio modem might support GPRS (which could then be used for other services like online monitoring etc.). For ETCS, only GSM-R CS (circuit-switched) will be used.
- Onboards with SV 2.1, 2.2 or 3.0 will typically support GSM-R PS, but in theory could have only GSM-R CS implemented for ETCS, if the IM has not requested GSM-R PS according to the conditions outlined in the TSI CCS.
- According to TSI 23, for ETCS over FRMCS to be possible the onboard must have at least SV 3.0 implemented. However, this does not mean that an onboard SV 3.0 must always have FRMCS implemented, even though this is expected to be the normal case (due to IMs notifying end of GSM-R service from 2030 onwards with a five-year notice period as outlined in TSI 2023).

Table 5-1 therefore shows the typically supported communication means for the different onboard solutions, while in practice there could be some deviation from what is shown.

On the trackside, there is no clear mapping between system version and communication means at all. The permitted communication means are rather determined by
- the available trackside (RBC) interfaces (CS, PS, FRMCS),
- the existence of a trackside GSM-R network and its features (CS only or CS + PS capable),
- the existence of a trackside FRMCS network, and
- the existence and configuration of other trackside entities such as an ETCS DNS and specific balise information.

Therefore, with one exception table 5-1 does not show communication means for trackside. For baseline light and adapter solutions table 5-1 is derived taking into account that with these two solutions ETCS functionality will either be based on SV 2.0 or SV 2.1. The exception regarding trackside communication is an “SV 2.3 FRMCS only mode” shown in the table. Depending on the migration strategy, it could for example also be an “SV 2.1 FRMCS only mode”, in theory even an “SV 1.1 FRMCS only mode”. This “FRMCS-only mode” is to illustrate the situation where GSM-R is taken out of service (following the conditions and lead-times outlined in the relevant TSI). The result being that those vehicles not supporting FRMCS, irrespective of system version, will no longer be compatible with such a track.

Standard TSI (2023 + Amendment)

				Trackside				
				B3		B4		
				SV2.0	SV 2.1	SV 2.2	SV 2.3	SV 3.0
Onboard	B3	SV 2.0	GSM-R (CS)	Yes	Yes	Yes	Yes	No
		SV 2.1	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No
	B4	SV 2.1	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No
		SV 2.2	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No
		SV 3.0	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes

Baseline Light

				Trackside					
				B3		B4			
				SV2.0	SV 2.1	SV 2.2	SV 2.3 Dual Mode	SV 2.3 FRMCS only (Note 1)	SV 3.0
Onboard	B3	SV 2.0	GSM-R (CS)	Yes	Yes	Yes	Yes	No	No
		SV 2.1	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 2.0 BL	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	No
		SV 2.1 BL	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	No
	B4	SV 2.1	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 2.2	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 3.0	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	Yes

Adapter

				Trackside					
				B3		B4			
				SV2.0	SV 2.1	SV 2.2	SV 2.3 Dual Mode	SV 2.3 FRMCS only (Note 1)	SV 3.0
Onboard	B3	SV 2.0	GSM-R (CS)	Yes	Yes	Yes	Yes	No	No
		SV 2.1	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 2.0 AD	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	No
		SV 2.1 AD	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	No
	B4	SV 2.1	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 2.2	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 3.0	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	Yes

Note 1: An FRMCS-only mode for trackside (SV 2.3 is shown as an example, it could also be another system version) is required to be able to decommission all GSM-R/GPRS infrastructure when obsolete. The consequence is that in this situation an SV 2.0 or 2.1 vehicle without Baseline Light or FRMCS adapter will no longer be able to run on this track.

Table 5-1: Compatibility Matrix Onboard to Trackside according to TSI 2023 (top), with Baseline Light (middle) and Adapter (bottom).

Even though the remit of the group is to consider only BL3 vehicles, there was some discussion on whether the "Baseline Light" solution could also be considered for BL4 SV 2.1 and BL4 SV 2.2 vehicles. In theory, it should not make a difference whether "Baseline Light" is applied to a BL3 SV2.1 or a BL4 SV2.1 vehicle. Including also BL4 SV2.1, the compatibility matrix would look like this:

Baseline Light if also applicable to B4 SV2.1 vehicles

				Trackside					
				B3		B4			
				SV2.0	SV 2.1	SV 2.2	SV 2.3 Dual Mode	SV 2.3 FRMCS only (Note 1)	SV 3.0
Onboard	B3	SV 2.0	GSM-R (CS)	Yes	Yes	Yes	Yes	No	No
		SV 2.1	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 2.0 BL	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	No
		SV 2.1 BL	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	No
	B4	SV 2.1	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 2.1 BL	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	No
		SV 2.2	GSM-R (CS+PS)	Yes	Yes	Yes	Yes	No	No
		SV 3.0	GSM-R (CS+PS) + FRMCS	Yes	Yes	Yes	Yes	Yes	Yes

Note 1: Same as Table 5-1.

Table 5-2: Compatibility Matrix Onboard to Trackside, when Baseline Light is also applied to B4 SV2.1 vehicles.

Application of “Baseline Light” for BL4 SV2.2 vehicles is not further considered.

Installing a trackside RBC with SV 2.1, 2.2 or 2.3 does not mean that the communications network must support ETCS over GSM-R PS/GPRS. If an IM does not require ETCS over GPRS for spectrum efficiency reasons, it is possible to only use GPRS for online key management purposes (or other non-ETCS services/applications like monitoring, telemetry, etc.). In such an IM’s network, where the DNS would not signal availability for ETCS over GPRS, SV 2.1 vehicles that support GPRS and online key management would use circuit-switched GSM-R for ETCS communications, and GPRS for e.g. exchange of key-related information. On the mobile network side it is also possible to migrate directly from GSM-R circuit-switched communications to FRMCS without having to support GPRS at all. In this case, however, some services like online key management could only be introduced once FRMCS is available.

The following table shows the “Use Cases” for “baseline light” or “adapter” vehicles in terms of combinations of onboard and trackside system versions and desired functionality. The choice of use cases is not comprehensive, other functionality may be possible, but these are considered the relevant use cases that have an impact when defining possible FRMCS solutions:

Use Case	Vehicle	Infrastructure	Desired Functionality
1	SV 2.0	SV 2.0 to SV 2.3	ETCS functionality limited to SV 2.0. SV 2.3 only to provide FRMCS.
2	SV 2.1	SV 2.0 to SV 2.3	ETCS functionality limited to SV 2.0. No GPRS. SV 2.3 only to provide FRMCS.
3	SV 2.1	SV 2.1 to SV 2.3	ETCS functionality limited to SV 2.0. ETCS over GPRS only for spectrum efficiency. SV 2.3 only to provide FRMCS.
4	SV 2.1	SV 2.1 to SV 2.3	ETCS functionality according to SV 2.1 including online key management. SV 2.3 only to provide same functionality with FRMCS.

Table 5-3: “Use Cases” in terms of combinations of onboard and trackside system versions and desired functionality.

5.2 Introduction of FRMCS Radio Coverage and Decommissioning of GSM-R

A typical FRMCS roll-out in a GSM-R network from the point of view of the ETCS service will look as follows:

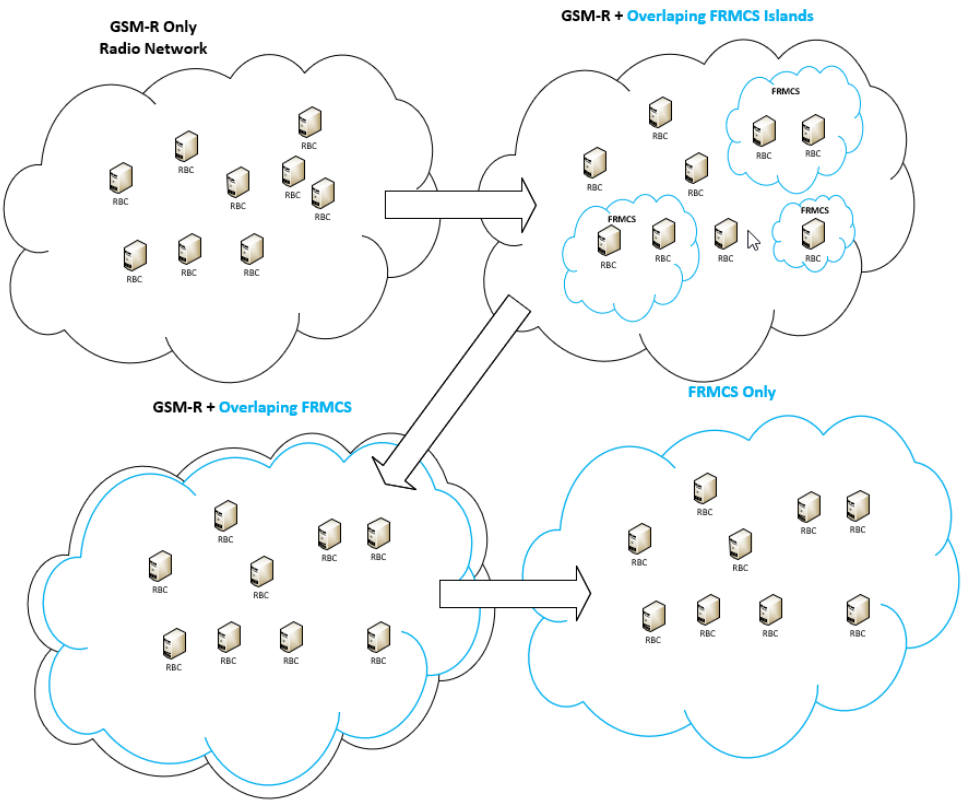

Fig. 5-1: Typical Roll-Out sequence of FRMCS in a GSM-R network in terms of "RBC coverage areas" (from left to right and top to bottom).

Before ETCS over FRMCS can be put into service for a given RBC coverage area, the FRMCS radio rollout must make sure that the whole area is covered with FRMCS radio coverage at the required Quality of Service (QoS). While this is feasible (top-right drawing in Fig. 5-1), it is generally not feasible to limit the FRMCS radio coverage to exactly that RBC coverage area because of radio propagation effects. Coverage may "spill over" to neighboring tracks, over lakes, etc. Therefore, for an onboard unit to base itself just on whether there is FRMCS radio coverage at a given time and place to decide whether to use FRMCS for ETCS or not is generally not sufficient. In TSI 23, two redundant means are used to establish whether an RBC is FRMCS-enabled or not: a new balise message (packet 245) that will be read by SV 3.Y onboards (but ignored by earlier onboard system versions) and a background check in the radio coordinating function to check whether the RBC responds to a control plane request via FRMCS. This is shown in the radio coordinating function algorithm (Fig. 19 from SS 037-1 V 4.0.0 [7]) with three different "T-Connect.Request" entry points on the top based on the content of balise packet 245:

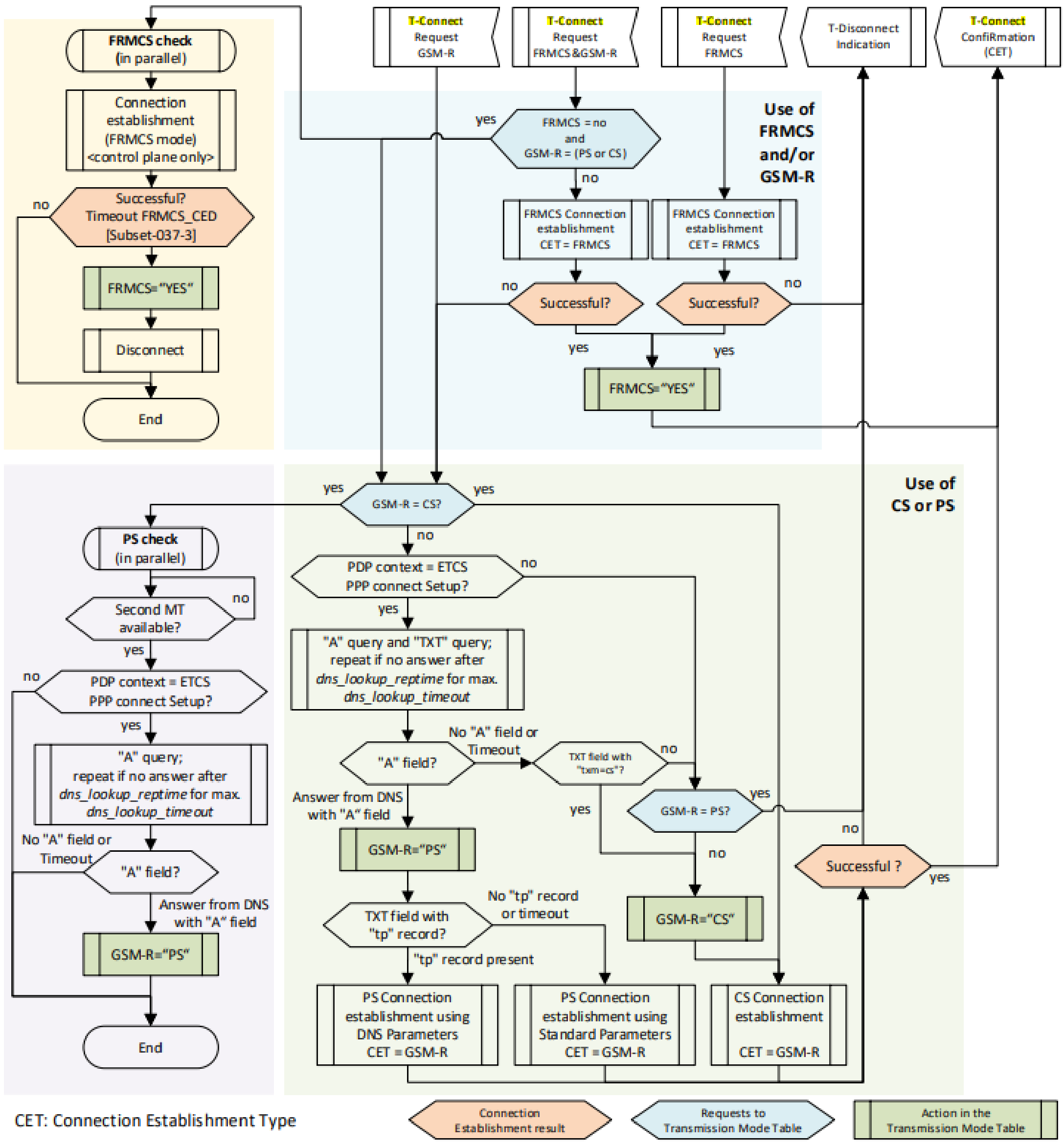

Fig. 5-2: Selection of GSM-R CS, GSM-R PS and FRMCS by the coordinating function in TSI 23 (Subset 037-1 V 4.0.0).

The solution concepts proposed in the following will not make use of P245, instead they will rely only on the background check.

Note that in Fig. 5-1 a case is shown where GSM-R is switched off on the whole network once FRMCS coverage is ubiquitous and all vehicles and RBCs support FRMCS. It may also be possible to switch GSM-R off RBC per RBC coverage area, taking the progress of the FRMCS rollout, the RBC upgrades and the fleet migration into account.

5.3 Migrating the RBCs to Enable FRMCS and to introduce New Trackside Functionality

In this section only RBC migration is considered and thus from a radio bearer perspective only the ETCS radio bearer.

5.3.1 Approach based on TSI23

With TSI23, the standard approach for FRMCS RBC migration would be as follows (assuming no BL2 SV1.0/1.1 vehicles need to be supported):

1. When FRMCS coverage preconditions according to the previous subsection are met, an RBC can be upgraded to B4 SV2.3 (including deployment of balises with packet 245).
    - B4 SV3.0 vehicles will now use FRMCS as radio bearer for ETCS and use the functions for which the RBC is configured up to the full envelope of functionalities provided by SV 2.3 (e.g. ATO).
    - B3/4 SV2.Y vehicles will continue to use GSM-R as a radio bearer for ETCS (PS if SV 2.1 or 2.2 onboard with GPRS installed and the RBC is configured to support ETCS over GPRS, otherwise CS) and use the functions for which the RBC is configured and which are supported by the vehicle (e.g. even if trackside supports ATO, an SV2.0 or SV2.1 onboard will not support ATO).

2. As soon as FRMCS vehicle migration for a given track is completed (i.e. all vehicles are SV3.0 or higher), the RBC can be upgraded to B4 SV 3.Y, the GSM-R interfaces (PS and CS) can be decommissioned and new functionality (e.g. DAC, improved ATO as defined by future TSI versions) can be introduced.
    - FRMCS will now be used as bearer for ETCS.
    - The available end-to-end functionality for a given vehicle will depend on the exact RBC system version and configuration as well as the exact vehicle system versions as defined in future TSI versions.

Note that it is possible to upgrade an RBC to FRMCS without supporting the full SV2.3 ETCS functionality by providing the required FRMCS interface and deploying balises with packet 245. Like this, also BLS2 SV1.Y vehicles can be supported on a dual-mode GSM-R/FRMCS track.

5.3.2 Impact of "Baseline Light" and Adapter Solutions

If "baseline light" or "adapter" vehicles must be supported on a track, the situation would be as follows (again ignoring BL2 SV 1.0/1.1 vehicles):

1. When FRMCS coverage preconditions according to the previous subsection are met, an RBC can be upgraded to B4 SV2.3 (including deployment of balises with packet 245).
    - B4 SV3.0 vehicles will now use FRMCS as radio bearer for ETCS and use the functions for which the RBC is configured up to the full envelope of functionalities provided by SV 2.3 (e.g. ATO).
    - B3/4 SV2.Y vehicles will continue to use GSM-R as a radio bearer for ETCS (PS if SV 2.1 or 2.2 onboard with GPRS installed and the RBC is configured to support ETCS over GPRS, otherwise CS) and use the functions for which the RBC is configured and which are supported by the vehicle (e.g. even if trackside supports ATO, an SV2.0 or SV2.1 onboard will not support ATO).
    - B3/4 SV2.Y (Y<2) vehicles with adapter or baseline light will use FRMCS as a radio bearer for ETCS and use the functions for which the RBC is configured and which are supported by the vehicle (e.g. even if trackside supports ATO, an SV2.0 or SV2.1 onboard with adapter or baseline light will not support ATO).

2. As soon as FRMCS vehicle migration for a given track is completed (i.e. all vehicles are equipped with SV3.0 or higher, baseline light or the adapter), the RBC can be upgraded to B4 SV 2.3 "FRMCS only" and the GSM-R interfaces (PS and CS) can be decommissioned

   - FRMCS will now be used as a communication bearer for ETCS by all vehicles.
   - The supported functionality does not change due to the decommissioning of GSM-R but if ATO is to be used, an SV 2.2 vehicle must be upgraded to BL4 SV3.0 since no adapter or Baseline Light solution is envisaged for SV 2.2.
3. Only when all adapter and baseline light vehicles are retired or upgraded to B4 SV3.Y, the RBC can be upgrade to B4 SV 3.Y and new functionality (e.g. DAC, improved ATO as defined by future TSI versions) can be introduced.
   - The available end-to-end functionality for a given vehicle will depend on the exact RBC system version and configuration as well as the exact vehicle system versions as defined in future TSI versions.

6 Baseline Light

6.1 Basic Design Principles and Limitations

Basic design principles:

1. Architecture to introduce FRMCS will add functionality to the non-safety-relevant part of Euroradio, adopting as much as possible the principles of SS-037-1 and SS 037-3in TSI 23 according to Fig. 4-2.
2. Vehicle upgrade is limited to what is strictly necessary for FRMCS.
3. ETCS functionality is limited to functionality of the existing BL3 SV 2.0 or SV 2.1 vehicles, with BL4 SV 2.1 as an option for further study.
4. Introduction of FRMCS shall be possible without affecting SS-026 (the core ETCS application), thus the solution adopted for CR1359 in TSI 23 will have to be revised, as described in [2].
5. Towards the trackside, the solutions must look like a fully compliant ETCS/FRMCS onboard system, hence there is no or minimal trackside impact.

Functional limitations:

- No new functionality of BL4 SV 2.1, 2.2 or 3.0 other than FRMCS support, for instance no SV 2.2 ATO support.
- No online key management for BL3 SV 2.0 “baseline light” trains (because there is no online key managgement also without baseline light).

6.2 Consequence of Avoiding Changes to SS-026 for FRMCS Introduction

Baseline light is a pure onboard solution. Baseline light vehicles will not be able to read balise packet 245 of e.g. TS SV2.3. Baseline light is designed in such a way that this is not a problem. Furthermore, no DMI changes will be made that were originally envisaged with CR1359.
The operational consequences are outlined in detail in [2], chapters 3 and 4. The findings are summarised here.

The following two tables copied from [2] show the DMI differences between baseline light and SV 3.0 vehicles.

In the scenario shown in table 6-1, the only difference on the DMI between an SV 3.0 on board and a baseline light onboard is that SV 3.0 shows whether an FRMCS or GSM-R registration has failed while baseline light will generically show that the registration has failed. This is in accordance with the basic FRMCS design principle that application and telecoms should be separated.

The scenario shown in table 6-2 is similar with one exception: there is one use case where instead of “registration failed” a “radio connection failure”-symbol will appear, when the RBC is only reachable by GSM-R and the GSM-R registration failed but the FRMCS registration succeeded. However, this indication is due to a more generic problem of interaction between onboard and mobile network independent of the baseline light solution and has thus no operational consequence specific to baseline light.

Situation	implemented radio network		RBC	B3 on-board	B Light on-board		SV 3.0 on-board		
	GSM-R	FRMCS		GSM-R	FRMCS + GSM-R	FRMCS	GSM-R	FRMCS + GSM-R	FRMCS
SoM with valid position on a line where RBC is reachable by GSM-R and FRMCS	yes	no [3]	GSM-R + FRMCS	NA [2]	NA [2]	NA [2]	NA [2]	NA [2]	NA [2]
	yes	yes	GSM-R + FRMCS						
	yes	failed	GSM-R + FRMCS			Registration failed			FRMCS registration failed
	failed	no	GSM-R + FRMCS	NA [2]	NA [2]	NA [2]	NA [2]	NA [2]	NA [2]
	failed	yes	GSM-R + FRMCS	Registration failed			GSM-R registration failed		
	failed	failed	GSM-R + FRMCS	Registration failed	Registration failed	Registration failed	GSM-R registration failed	GSM-R registration failed FRMCS registration failed	FRMCS registration failed
	no	yes	GSM-R + FRMCS	NA [1]			NA [1]		
	no	failed	GSM-R + FRMCS	NA [1]	Registration failed	Registration failed	NA [1]	FRMCS registration failed	FRMCS registration failed

Table 6-1: DMI comparison. Start of Mission with valid position, RBC reachable by GSM-R and FRMCS.

Situation	implemented radio network		RBC	B3 on-board	B Light on-board		SV 3.0 on-board		
	GSM-R	FRMCS		GSM-R	FRMCS + GSM-R	FRMCS	GSM-R	FRMCS + GSM-R	FRMCS
SoM with valid position on a line where RBC is reachable by GSM-R only	yes	no	GSM-R			NA [1]			NA [1]
	yes	yes	GSM-R			NA [1]			NA [1]
	yes	failed	GSM-R			NA [1]			NA [1]
	failed	no	GSM-R	Registration failed	Registration failed	NA [1]	GSM-R registration failed	GSM-R registration failed	NA [1]
	failed	yes	GSM-R	Registration failed		NA [1]	GSM-R registration failed	GSM-R registration failed	NA [1]
	failed	failed	GSM-R	Registration failed	Registration failed	NA [1]	GSM-R registration failed	GSM-R registration failed FRMCS registration failed	NA [1]

Table 6-2: DMI comparison. Start of Mission with valid position, RBC reachable by GSM-R only.

In terms of driver input, there is one situation where certain data entry possibilities to contact an RBC only relevant for GSM-R would be blanked out when FRMCS is to be used on an SV 3.0 vehicle. In baseline light these would not be blanked out. The driver can consult the rulebook to see which options are available and which data needs to be entered. If he fails to do this and choses the "short number" option (for the moment not available under FRMCS) to contact an RBC, he will receive a connection failure indication (see clauses 3.3.3.3 and 3.3.3.4 in [2]).

When entering level 2, in certain cases there might be alterations to announcements as explained in clauses 3.4.1.7 and 4.4.1.1 in [2]. The operational consequence for the level transition is only relevant for an entry scenario to a mixed level line with level 2 overlay on top of level 1 or level NTC, if the level transition order is engineered before the radio network registration order.

Finally, when changing from GSM-R to FRMCS, there might be cases where the registration to the right network takes too much time so that the first connection attempt will fail. However, in this case the second connection attempt will succeed without any real operational consequences, as outlined in clauses 3.2.1.11 and 3.5.2.3 in [2].

6.3 Trackside Impact

Once all vehicles support FRMCS (either with baseline light or SV 3.Y), the "GSM-R part" of the trackside (in particular the ISDN interfaces) can be eliminated, however, balise packet 45 that orders GSM-R registration has to remain as outlined in clause 3.4.2 in [2].
No upgrade to SV 3.Y RBCs is possible as long as there are SV 2.Y Baseline Light trains having to use the respective tracks.

6.4 Assessment of Baseline Light and Standardisation Needs

Given general constraints during dual mode operation of GSM-R and FRMCS, the minor deviations in behaviour of a baseline light vehicle on an SV 2.3 track as compared to an SV 3.Y vehicle on an SV 2.3 track can be considered acceptable, as long as an IM does not require new onboard functionality offered by SV 2.2 or does not introduce TS SV 3.Y to provide new functionality.

Baseline light has no impact on ongoing FRMCS standardisation.

On the ETCS onboards side, there is very limited extra development required. Baseline light combines essentially existing subsets of different baselines:

- SV 2.0 vehicles: set of specifications 2 combined with the Euroradio subsets of ETCS B4R1.
- SV 2.1 vehicles: set of specifications 3 combined with the Euroradio subsets of ETCS B4R1.

In both cases, two small alterations are required to SS-037-1 V 4.0.0, namely

1) a modified bearer selection algorithm that works without the information in balise packet 245 as starting point; and
2) faking a GSM-R registration towards the ETCS application, based on balise packet 45 information once GSM-R is decommissioned.

In terms of standardisation needs, once it is decided how the baseline light solution is to be documented for SV 2.0 and SV 2.1 vehicles, an amendment to CR1359 has to be written based on the content of [2].

If, from a migration, certification and cost perspective baseline light is deemed to be advantageous compared to an upgrade to SV 3.0 for FRMCS migration, this appears to be an attractive low-risk solution.

7 Adapter Solutions

7.1 Basic Design Principles and Issues

Basis Design Principles:

1. Towards the ETCS onboard / Euroradio the Adapter acts as an EDOR emulator, no change to Euroradio.
2. Towards TOBA/FRMCS Onboard Gateway the Adapter acts as "TSI23 + amendment compatible" Euroradio with OBapp support, thus full use of FRMCS service and transport stratum with FRMCS QoS and transport security.
3. Towards trackside, the solutions must look like a fully compliant ETCS/FRMCS onboard system, hence no or minimal trackside impact.
4. Needs bearer selection algorithm and look-up table for address conversion outside of ETCS onboard.
5. To train driver it looks essentially like ETCS over GSM-R.

The principle is shown in Fig.1 of TOBA 7540 [3], we propose a slightly extended version of this logical architecture:

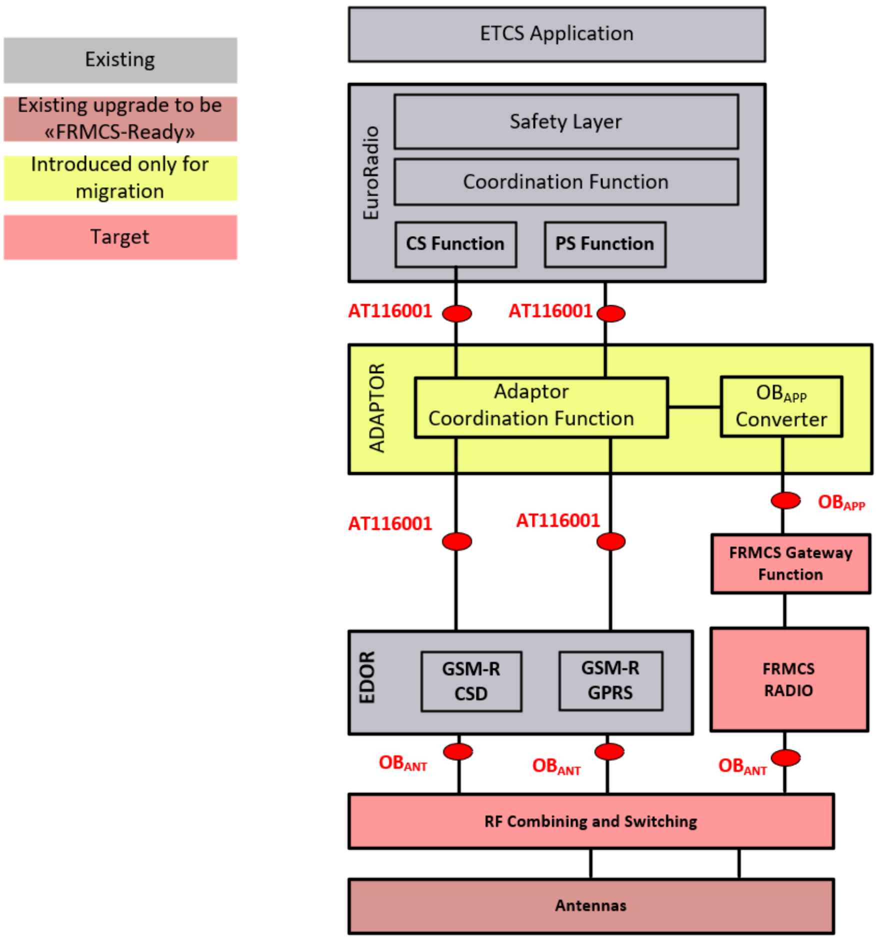

Fig. 7-1: Existing ETCS OBU with PS/CS Conversion/Bypass

Issues identified in the variant assessment from Unitel in 2019 related to the support of ETCS that remain to be solved, irrespective of the sub-solution described below:

- Euroradio protocol timing risks (timing and race conditions).
- Euroradio stack supplier specifics and behavior variations will likely lead to significant integration risks end efforts.
- Implementation of cybersecurity measures.
- Look-Up table or algorithm needed to determine the correct communications path, might need trackside over the air provisioning capability to ensure maintainability.

Additional issues that need to be considered, raised by ERA and the group:

- Scope of solution: for which baselines, where is the coordinatiing function, what solution is intended for trackside?
    - As far as not already covered in chapter 5, this will be covered in the remaining part of this chapter.
- Coexistence of different trackside / onboard scenario (e.g. adapter to run on TS SV 3.0 or only TS SV 2.Y, transition between lines with TS SV 2.Y and TS SV 3.0 and how to manage onboard alternance of GSM-R and FRMCS RBCs)
    - See chapter 5, for third issue also remaining part of this chapter.
- Several questions to details of the solution like addressing, conversion from AT commands to OBapp interface, indication of "communication network ready" to ETCS onboard, triggering of "external switch", handover from FRMCS to GSM-R.
    - These matters will be clarified in the remaining part of this section.
- Handling of start of mission after cold movement, transition from GSM-R in one country to FRMCS in another country.
    - See section 7.11 for further information.
- Operational impact, activation of the switch, handover from GSM-R RBC1 to FRMCS RBC2, train driver does not see FRMCS issues and most likely cannot select FRMCS manually (e.g. cold start in FRMCS only area).
    - See section 7.11 for further information.
- How to handle several versions of the solution by different suppliers.

7.2 Solution Space for Adapter Solutions

The following sub-solutions were identified:

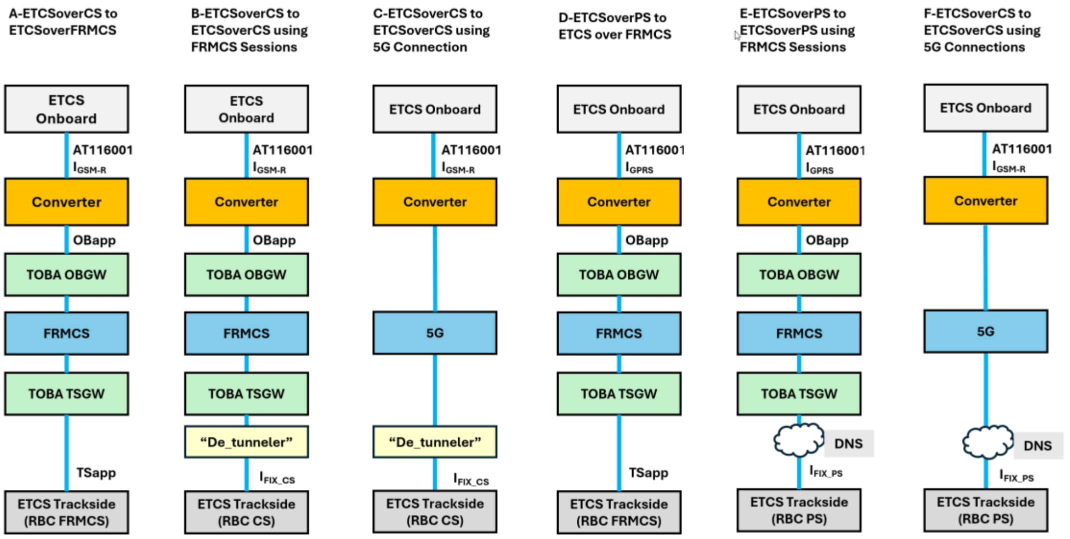

Fig. 7-2: Solution Space for Adapter Solutions

In the following, a rough description is provided as a basis for a first round of prioritisation. The remaining solutions will be further detailed in the following subsections.

7.2.1 Solution A (CS Converter)

- Solution with an onboard converter from ETCSoverCS to ETCSoverFRMCS;
- Corresponds to TOBA1b.
- Satisfies the basic design principles in section 7.1.
- No limitations for BL3 SV 2.0 vehicles (i.e. existing SV 2.0 functionality expected to work over FRMCS in the same manner as over GSM-R CS).
- Use of GPRS under GSM-R coverage for BL3 SV 2.1 as per more detailed solution description further below.

7.2.2 Solution B (CS Tunnelling using FRMCS)

- Solution delivers an ETCSoverCS data stream via an FRMCS tunnel to a trackside "De-Tunneler" which in turn delivers the ETCSoverCS data stream via the existing RBC CS (ISDN) interface to the RBC.
- Does not satisfy design principle 3 in section 7.1, i.e. significant trackside impact as described further below.

7.2.3 Solution C (CS Tunnelling using Vanilla 5G)

- Solution delivers an ETCSoverCS data stream via a vanilla 5G bearer to a trackside "De-Tunneler" which in turn delivers the ETCSoverCS data stream via the existing RBC CS (ISDN) interface to the RBC.
- Does not satisfy design principles 2 (no FRMCS QoS and transport security support) and 3 in section 7.1.

7.2.4 Solution D (PS Converter)

- Solution with an onboard converter from ETCSoverPS to ETCSoverFRMCS.
- Corresponds to the PS variant of TOBA1b.
- Satisfies the basic design principles in section 7.1.
- As a standalone solution not suitable for BL3 SV 2.0 vehicles (would need a joint A+D solution to be applicable for BL3 SV 2.0 vehicles).

7.2.5 Solution E (PS "Tunnelling" over FRMCS)

- This solution tunnels ETCS over PS sessions between onboard and RBC using FRMCS transport.
- Two subvariants have been identified as described further below.
- Does not satisfy design principle 3 in section 7.1, trackside impact is described further below.

7.2.6 Solution F (PS "Tunnelling" using Vanilla 5G)

- Solution delivers an ETCSoverPS data stream via a vanilla 5G bearer to a PS-capable RBC using GPRS addressing principles and session.
- Does not satisfy design principles 2 (no FRMCS QoS and transport security support) and 3 in section 7.1.

7.3 Rationale for Eliminating Solutions C and F

Solutions C and F were eliminated because of the following reasons:

- Will only be best effort service as no control over vanilla 5G and no FRMCS QoS mechanisms.
- No transport security (TLS) as provided by FRMCS.
- Additional trackside components like de-tunneller required, in case of solution C also ISDN infrastructure and ISDN interface at RBC need to be kept in operation after switch-off of GSM-R.
- Need to provide target information to the de-tunneller for the RBC CS connection.
- TOBA box / FRMCS implementation anyway required for ground-train voice communications.
- Direct access to 5G modems required, so either providing dedicated (additional) 5G modems on board or share 5G modems with TOBA OBGW, which means the FRMCS OBrad interface would have to be enhanced.

Note that the IM will anyway have to provide FRMCS services to cater for SV 3.0 onboards with FRMCS, so FRMCS QoS and security mechanisms should be used by all FRMCS onboards.

7.4 Rationale for Putting Solution B on Standby

Solution B has the following advantages compared to solution A:

- Tunnelling (en-/decapsulation of frames, e.g. HLDC over TCP/IP) instead of protocol conversion reduces onboard complexity.
- Adapter B vehicles could use FRMCS to connect to existing RBCs without having to upgrade them with an FRMCS interface.

However, solution B has the following impact on trackside:

- At least two redundant (de-)tunnellers that have to be provided with the target RBC MSISDN numbers to set up the connection between (de-)tunnelling entities and RBCs.
- ISDN links have to be maintained for these connections providing redundant paths from each (de-)tunneller to each RBC.
- The ISDN interfaces at the RBCs would have to be kept in operation.
- Careful dimensioning of the ISDN network needed during FRMCS/GSM-R parallel operation to cater both for the existing traffic from GSM-R to the RBCs as well as the additional traffic generated between the (de-)tunnellers and the RBCs.

- Additional security measures on the ISDN between (de-)tunnelling entities and the RBCs to meet the security level afforded by FRMCS with SV3.0 vehicles.

It is difficult to argue that we need BL3 compatible FRMCS solutions to provide faster and cheaper FRMCS vehicle migration so that we can cater for GSM-R/ISDN obsolescence and then define solutions that will result in having to maintain ISDN legacy infrastructure well beyond that date. Therefore, solution B will not be further dealt with in the following.

7.5 "Addressing" in GSM-R, GPRS and FRMCS

7.5.1 "Addressing" in GSM-R Circuit-Switched Data

According to SS-037, V 3.1.0 [5], for GSM-R:

5.2.1.5 The Network address contains the network address of the called SaS user. This parameter is composed of sub-fields, e.g. the length of the called number, the type of number, the numbering plan, and the number itself.

5.2.1.6 The Mobile Network ID identifies the mobile network. The Mobile Network ID shall consist of the Mobile Country Code and the Mobile Network Code according to [ITU-T E.212].

5.2.1.7 In the case of mobile originated calls, the connection request should contain the subparameter Mobile Network ID, to request the appropriate network associated with the called SaS-user.

The RBC ETCS ID is contained in packet 42 and 131, it encodes the NID_C (10 bits, country or region identity number) and NID_RBC (14 bits, RBC identity) fields according to Susbset 026-7, clause 7.4.2.10.

The called number (of the RBC) is contained in packet 42 and 131 in the NID_Radio field (64 bits, encoded as at most 16 Binary Encoded Decimals). It may contain a country code CC, e.g. 41 for Switzerland or 49 for Germany.

The Mobile Network Identity (consisting of the 3-digit mobile country code and the 2-digit mobile network code) is contained in balise packet 45 in the NID_MN field (24 bits).

The country code CC in the called number of the RBC (packet 42) is not the same as the Mobile Country Code (MCC) in the NID_MN field of packet 45, e.g. 228 for Switzerland or 262 for Germany.

In GSM-R, the Euroradio will register the EDOR to the network(s) as requested by the application. The network(s) will be determined by the stored last network information, by packet 45 received from trackside (RBC or balise) or by network selection dialog by the driver. After registration, Euroradio will request connection(s) to RBCs using AT commands triggered by the application (stored last RBC, packet 42, driver dialog). For each RBC connection a new call will be set up, using again AT commands between Euroradio and the EDOR.

7.5.2 "Addressing" in GSM-R Packet-Switched Data (GPRS)

The needed address information for GPRS is in general the same as for CS service, but in PS the ETCS ID will be used to determine the network address of the RBC. According to Subset 037, V 3.2.0 [6], for GPRS, the following fully qualified domain name (FQDN) shall be used for the request to the trackside DNS to obtain an IP address for the destination RBC:

8.3.2.3.5 The format of the string (host name) sent to the DNS shall be: "id.ty.etcs", using lowercase hexadecimal ASCII character representation of the <ETCS ID> and <ETCS-ID Type> . Example: If the ETCS id type is RBC and the ETCS ID is '1001 0011 1100 0000 1111 0101, the formatted string will be 'id93c0f5.ty01.etcs'.

The ETCS ID is contained in balise packet 42/131.

In GPRS, as, in GSM-R, the Euroradio will register the EDOR to the network(s) as requested by the application. The network(s) will be determined by the stored last network information, by packet 45 received from trackside (RBC or balise) or by network selection dialog by the driver. After registration, the GPRS attach and the PDP context activation will be ordered by Euroradio via AT commands. Based on information in packet 42/131 (conveyed from ETCS Onboard to Euroradio via interface 3 in Figs. 4-1 and 4-2), it will start a DNS request to obtain the target/destination RBC IP address which will be used to deliver packets to this RBC.

The PDP context may remain active also when no "ETCS session" is ongoing. To connect to a new RBC, triggered by packet 42, a new DNS request based on the new target RBCs ETCS ID is performed which, unlike in GSM-R CS, is not directly visible on the AT-interface between Euroradio and EDOR.

7.5.3 "Addressing" in FRMCS

According to Subset 037-3, V 4.0.0 [8], the following fully qualified domain name (FQDN) shall be used towards the onboard FRMCS client that will communicate with the trackside MCX server (which will provide the target RBC IP address to the FRMCS client):

6.4.3.2.3 The remote address in "Session start" is:
"id<ETCS-ID>.ty<ETCS ID type>.cc<NID_C>.ertms"
formatted as
ETCS-ID: 6-digit lowercase hex ASCII string
ETCS-ID type: 2-digit lowercase hex ASCII string
NID_C: 3-digit lowercase hex ASCII string
Example: id031123.ty08.cc00c.ertms

Compared to GPRS, the FQDN contains the additional "country code" field based on the NID_C value (which is not the same as the country code in a called number with GSM-R CS and also not the same as the Mobile Country Code in the NID_MN field). This NID_C value is contained in the ETCS_ID (packet 42/131). The FQDN of FRMCS can thus be constructed from the FQDN of GPRS by decoding the ETCS_ID into its component parts: NID_C (first 10 bits) and NID_RBC (remaining 14 bits).

Instead of the FRCMS FQDN, functional aliases may also be used for session start requests from the FRMCS client towards the MCX, but this is not yet specified in detail in TSI23 and the ETCS application will most likely still only use the FRMCS FQDN over OBapp towards the FRMCS client.

While, according to Fig. 4-2, there is still an interface numbered 1c in FRMCS, this is now the Ethernet-based OBapp interface instead of the serial interface using AT commands.

7.6 Solution A Details

In the following, the solutions will be described in more detail focusing on applicability to vehicle system versions, addressing and bearer selection. A more in-depth analysis on behavior during start of mission would have to be carried out in a separate document similar to [2] if needed.

7.6.1 Solution A only applicable for SV 2.0 vehicles

The following picture shows a possible implementation of solution A for an SV 2.0 vehicle. As an SV 2.0 vehicle does not support GPRS / packet switching (PS) for ETCS and no online key management via GPRS, only GSM circuit-switched data will have to be converted to FRMCS.

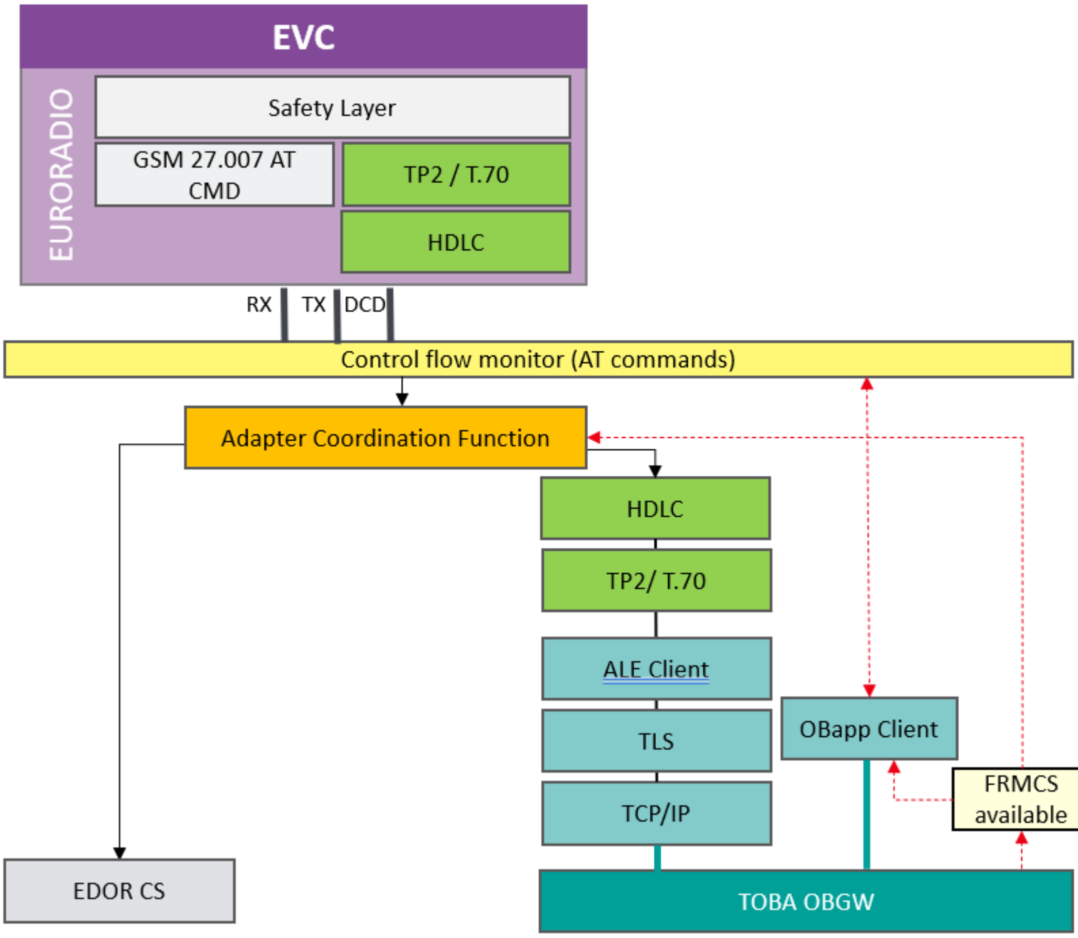

Fig. 7-3: Possible Implementation of Adapter Solution A for an SV 2.0 vehicle (no PS support).

For this solution the main challenge is the decoding/encoding/conversion of the X.225/T.70/HDLC protocol layers into IP packets and back.

The solution would use the loose-coupled principles known from ETCS over FRMCS, i.e. the adapter would behave like a loose-coupled application with local binding. OBapp would be needed to set up the FRMCS sessions.

As regards addressing, according to section 7.5.3 an FQDN in the following format is needed: “id<ETCS-ID>.ty<ETCS ID type>.cc<NID_C>.ertms”.
There appear to be two options for the adapter to obtain the required data to construct this URI/FQDN:

a. Provide an onboard lookup-table that maps MSISDN to the FQDN (given that the MSISDN is provided to the adapter with the AT command)
b. Use the MSISDN (again provided via AT command) as functional alias that will be resolved by the trackside MCX server

Solution a needs some provisioning (preferably over the air). It should work since there is generally a one-to-one mapping from MSISDN to ETCS ID.

For solution b the FQDN format is not yet specified in FRMCS V1 ([8] does not mention it and the FRMCS SRS only provides examples not related to ETCS) but may be included in later FRMCS versions. So, it is yet to be confirmed whether the MSISDN can be used in the URI to find the right RBC based on standard FRMCS principles (i.e. without impact on FRMCS specifications and undue trackside impact).
A third approach would be analyzing the payload to catch ETCS ID, ETCS ID type and NID_C, but since the payload is only sent after connection establishment, this approach will not work.

Regarding the choice of bearer (FRMCS or GMS-R CS), with option a above, if the onboard lookup table contains an entry for a given MSISDN, then FRMCS will be used to connect to the RBC (i.e. the data flow is first converted and then delivered via the FRMCS onboard gateway / FRMCS transport to trackside), otherwise GSM-R.

With option b, an adapter coordinating function needs to be introduced in the adapter that populates a "Transmission Mode Table" (TMT). An adapter vehicle cannot read packet 245 but it can apply the same background mechanism described in section 5.2 as an SV 3.0 vehicle using the MSISDN as functional alias to check whether an RBC is FRMCS-enabled and if so update the TMT for this MSISDN. When an RBC session is initiated and an AT command with the number to be dialled is delivered from Euroradio to the adapter, depending on the TMT entry for this RBC the EDOR sets up a GSM-R call (TMT: FRMCS = no) or the data flow is first converted and then delivered via the FRMCS onboard gateway / FRMCS transport to trackside (TMT: FRMCS = yes).

With both options, in normal operation the same bearer (GSM-R of FRMCS) will be used for the whole duration of a connection with a given RBC, thus it is sufficient to perform bearer selection only when receiving an AT command with a new number to be dialled.

7.6.2 Solution A applicable for SV 2.0 and SV 2.1 vehicles but only on SV 2.0 infrastructure (no ETCS over GPRS)

The question arises how SV 2.1 vehicles can be supported. When the trackside is SV 2.0 / does not support GPRS, a possible solution would look like Fig. 7-4 (Euroradio would never try to set up a session using PS data and the PS EDOR would not be used).

From an adapter point of view, it would be the same solution A as in the previous picture. If the GSM-R network does not support GPRS, a PDP context activation is not possible hence PS will not come into play. Even if GPRS is available and a DNS for GPRS is implemented, if no RBC IP address is delivered Euroradio will not attempt to use PS for ETCS but continue to use or fall back to CS. If GPRS is enabled for other services like online monitoring (independent of an RBC not supporting GPRS), the EDOR can use GPRS for these services, as a separate access point name with independent DNS will be used for such services. However, once GPRS is decommissioned, alternative solutions would have to be implemented to migrate these services to FRMCS, which is however outside the scope of this document.

If many IMs will directly migrate from GSM-R CS to FRMCS for ETCS without using GPRS for ETCS as an intermediate step then the number of vehicles that could benefit from such a solution will increase significantly, as also a share of SV 2.1 vehicles (that in theory support GPRS but never use it because they do not run on infrastructure enabled for ETCS over GPRS) are now in scope.

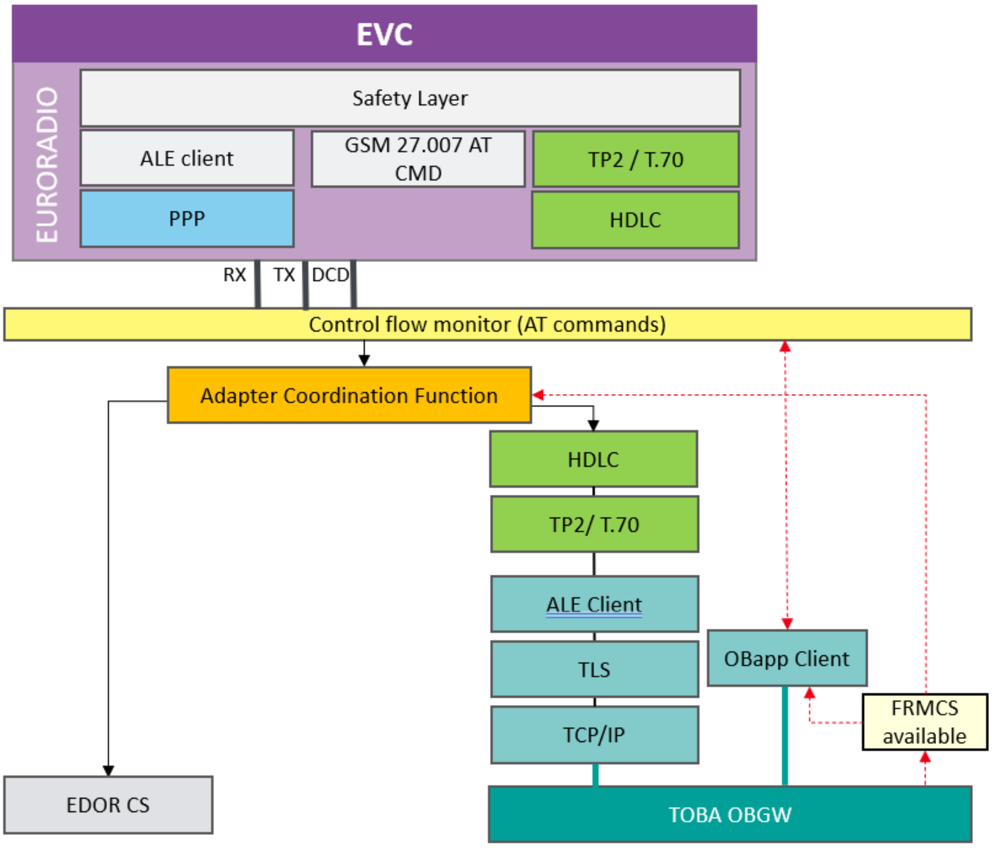

Fig. 7-4: Possible Implementation of Adapter Solution A for SV 2.0 and 2.1 vehicles on tracks with no PS support.

7.6.3 Solution A applicable for SV 2.0 and SV 2.1 vehicles, allowing to use ETCS over GPRS for SV 2.1 vehicles on a PS-enabled infrastructure (but no PS support for FRMCS)

When trackside is e.g. SV 2.1 or SV 2.2. and an onboard SV 2.1 is required to use GPRS because of spectrum efficiency reasons where there is no FRMCS coverage[1], the question is whether an A-only adapter solution similar to Fig. 7-4 could be developed that forces Euroradio to request a GSM-R CS connection when FRMCS is available (FRMCS RBC and FRMCS coverage) but will request GPRS in case of no FRMCS coverage yet.

Such a solution with CS fallback for FRMCS would potentially be applicable to all SV 2.0 and SV 2.1 vehicles to be migrated to FRMCS, if no other considerations like required additional ETCS functions and long remaining vehicle lifecycle requiring a future-proofed solution come into play. Such a solution will have to make use of elements of a packet-switched adapter. Therefore, first solutions D, E1 and E2 are described in more detail.

7.7 Solution D Details

The following picture shows a possible implementation of solution D for an SV 2.1 vehicle. As with solution A, this solution would use the loose-coupled principles known from ETCS over FRMCS, i.e. the adapter would behave like a loose-coupled application with local binding etc. Obapp would be needed to set up the FRMCS sessions.

[1] Note that while GSM-R PS (GPRS) uses 2G spectrum more efficiently than GSM-R CS, when the data is delivered over FRMCS, the spectrum efficiency is very similar (differences mainly result due to different protocol overheads between CS and PS).

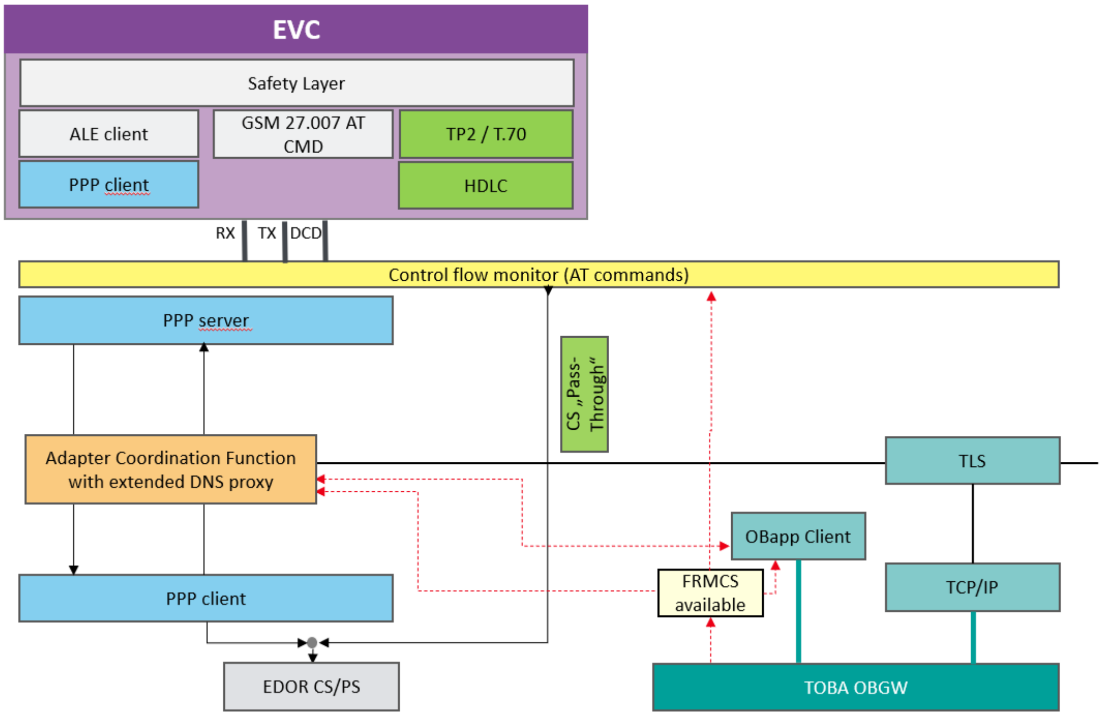

Fig. 7-5: Possible Implementation of Adapter Solution D for SV 2.1 vehicles.

On a track where GSM-R CS is used exclusively for ETCS, this solution would pass the CS data from Euroradio directly to EDOR without manipulation ("CS Pass-Through Box").
On a track with a GPRS-enabled mobile network, it would check via DNS request whether GPRS is to be used for ETCS and if so, pass the PS data via adapter coordinating function to the PS EDOR, otherwise pass the CS data to the CS EDOR.
On an FRMCS-enabled SV 2.Y track (RBC is FRMCS-enabled, FRMCS coverage available), first it needs to be made sure that the adapter receives PS data and not CS data. The PS data would then be forwarded by the adapter coordinating function via the TLS entity to the TOBA / FRMCS onboard gateway.

The main questions to be solved are:

a. How does the adapter know when to use FRMCS and when GPRS for ETCS?
b. How does the adapter obtain the target/destination addresses for the RBC in these two cases? (Note that there will be separate IP addresses for FRMCS and GPRS in an RBC that supports FRMCS.)
c. What protocols need to be used / converted? Is PPP relevant for FRMCS? How can a TLS layer be introduced for FRMCS?
d. How is it made sure that Euroradio delivers PS data to the adapter when trackside is migrated directly from GSM-R CS to FRMCS (i.e. no ETCSoverPS support with corresponding ETCS DNS) or a new RBC is put into service not yet known to the onboard?

Regarding questions a and b, in the circuit-switched domain (solution A) every new ETCS session is initiated with the setup of a new call using AT commands and thus the adapter has a clear trigger for bearer selection. In the PS domain, by contrast, once one or more PDP contexts are activated via AT commands, there are no triggers on the AT interface to let the adapter know when it has to check whether to use GPRS or FRMCS because a new RBC area is entered. Instead, DNS requests would have to be intercepted, which could be achieved by deep packet inspection. Furthermore, DNS responses would have to be manipulated. This would introduce significant complexity into the solution. A more elegant approach was identified, namely the introduction of a DNS proxy with some extended functionality in the adapter. Since the IP address of the DNS to be used can be configured in the Euroradio, it can be configured to use such a local DNS proxy. Like this, rather than having to use deep packet inspection over the whole media flow to capture DNS requests, all DNS requests can be dealt with by the proxy as appropriate.

7.7.1 "DNS extended proxy" functions

It is assumed that the "adapter coordinating function" as describe below tells the proxy when to use FRMCS or GPRS. The following function are executed by this proxy:

- When GPRS is to be used ("FRMCS = no" in the adapter TMT) forward the DNS request to the remote (ETCS GPRS) DNS server and forward the answer to Euroradio. Subsequently the user PS data will be delivered to the PS EDOR by the adapter coordinating function.

- When FRMCS is to be used ("FRMCS = yes" in the adapter TMT):
  - Expand GPRS FQDN to FRMCS FQDN.
  - Send request to remote (trackside) MCX server via FRMCS gateway to obtain target RBC IP address.
  - Create «txt field» if necessary («txt field should not be necessary since PS will be used).
  - Provide IP address in A field to Euroradio.

  Subsequently the adapter coordinating function forwards the user data flow to the TLS entity.

Note that the GPRS FQDN can be expanded unambiguously to the FRMS FQDN, as the required information is contained in the ETCS ID. Once the IP address is obtained, data can be delivered to the RBC via FRMCS/TOBA onboard gateway (see protocol conversion requirements below). Note also that not only the destination IP addresses will be different for the GPRS and the FRMCS path, but also the source IP addresses so that information on the return path can be sent using the right communication bearers.

As an additional function, once the GPRS network is no longer available, the extended proxy will need to provide fake responses to the GPRS attach and PDP context activation requests for Euroradio as explained below.

7.7.2 Adapter coordinating function and Adapter Transmission Mode Table (TMT)

The coordinating function will be informed by the FRMCS onboard gateway whether it is registered in an FRMCS network. Additionally, it needs to implement the «FRMCS background check» in the same manner as this would be done in the coordinating function (subset 037-1) of an SV 3.0 or baseline light vehicle, hence set up a "control plane only call". The correct IP address is obtained per "DNS extended proxy function" as described above. No TLS is required for this background check, as the protocol level is not started for such a "control plane only call".

This function will maintain an "Adapter Transmission Mode Table" that will store whether an RBC is FRMCS-enabled if the background check was successful. FRMCS will be used for an ETCS session if both the TMT in the Euroradio Coordinating Function has "PS" stored and the Adapter TMT "FRMCS" stored for the RBC to be used.

7.7.3 Protocol Conversion Requirements

PPP is only used as a local protocol between Euroradio and EDOR, thus will be terminated locally and does not need to be converted.
The adapter has to implement TLS according to subset 146, but this should be straightforward using the same mechanisms and infrastructure that will anyway be in place for FRMCS.
The ALE protocol is the same for GPRS and FRMCS.

In conclusion, apart from setting up TLS no further protocol manipulation or conversion is required.

7.7.4 Making Sure Euroradio delivers PS Data to the Adapter when FRMCS Transport is to be Used

As long as GSM-R (CS or PS) transport is used, the traffic between Euroradio and EDOR will not be influenced but monitored (direct for CS, via DNS proxy for PS RBCs).

Independent of the availability of a GPRS mobile network, the adapter needs to emulate such a network in terms of GPRSattach and PDP context activation. Without this Euroradio will never switch to PS as it is necessary for the FRMCS connections.

If after decommissioning of GSM-R a connection attempt to an unknown RBC or an RBC previously connected to via GSM-R CS will be made by Euroradio via CS (Fig. 33 in [6]):

- First connection setup attempt:
  1. The CS connection setup attempt will fail.
  2. In parallel, using a different EDOR, a PS connection attempt will be made, if necessary first performing GPRS attach and PDP context activation that must be faked as successful by the extended DNS proxy if the GPRS network is no longer available, then followed by the DNS request from which the ETCS ID / FQDN can be determined.
  3. The adapter will now perform a background check using this FQDN to obtain first a target RBC IP address for FRMCS and then setting up the control plane "call" to the RBC. If the RBC responds, then "FRMCS = yes" is written in the adapter TMT for this ETCS ID / FQDN.
  4. If the DNS request has not yet timed out, the target IP address is delivered to Euroradio, which will store "PS" in its transmission mode table, otherwise this attempt will be terminated without updating the Euroradio TMT:
- Second connection attempt (with "FRMCS = yes" for this RBC in the adapter TMT):
  5. If PS is stored in the Euroradio TMT for this RBC, the DNS proxy will forward the DNS request via FRMCS client / gateway to the MCX and receive an IP address. The connection is established in PS mode and the ETCS data transfer via FRMCS begins.
  6. If the previous DNS request timed out and PS is not yet stored in the Euroradio TMT for this RBC, then steps 1 of 2 of the first attempt will be repeated, but the DNS request will immediately be processed via FRMCS, so that an IP address can be provided to Euroradio to ensure that the Euroradio TMT stores PS for this RBC. In this case a third connection attempt would be required to successfully start the ETCS session via FRMCS.

If after decommissioning of GSM-R a connection attempt to an unknown RBC will be made by Euroradio via PS (Figs. 31 or 32 in [6]):

1. A PS connection attempt will be made, if necessary first performing GPRS attach and PDP context activation that must be faked as successful by the extended DNS proxy if the GPRS network is no longer available, then followed by the DNS request from which the ETCS ID / FQDN can be determined.
2. The adapter will now perform a background check using this FQDN to obtain first a target RBC IP address for FRMCS and then setting up the control plane "call" to the RBC. If the RBC responds, then "FRMCS = yes" is written in the adapter TMT for this ETCS ID / FQDN.
3. If the DNS request has not yet timed out, the target IP address is delivered to Euroradio, the connection is established in PS mode and the ETCS data transfer via FRMCS begins.
4. If the DNS request has timed out, a second connection attempt is required, this time the DNS request is immediately processed via FRMCS (since "FRMCS = yes" in the adapter TMT for this RBC) and the IP address provided in time so that the ETCS session can start successfully via FRMCS.

7.7.5 Supporting and "converting" multiple PDP contexts (e.g. for key management or other services)

If multiple PDP contexts need to be supported because services other than ETCS use GPRS and are multiplexed on a GPRS bearer, multiple PPP and DNS proxy instances need to be supported by the adapter.

7.8 Solution E Details

Initially it was thought that solution D would be too complex because of the required packet inspection and modification before the alternative with the DNS proxy was identified. A solution E tunneling ETCS over PS sessions between onboard and RBC using FRMCS transport was first considered to be less complex at the expense of some trackside impact. The two subvariants E1 and E2 that were identified will be described all the same for documentation purposes, even though solution D is now preferred.

7.8.1 Solution E1

The following picture shows a possible implementation of solution E1 for an SV 2.1 vehicle:

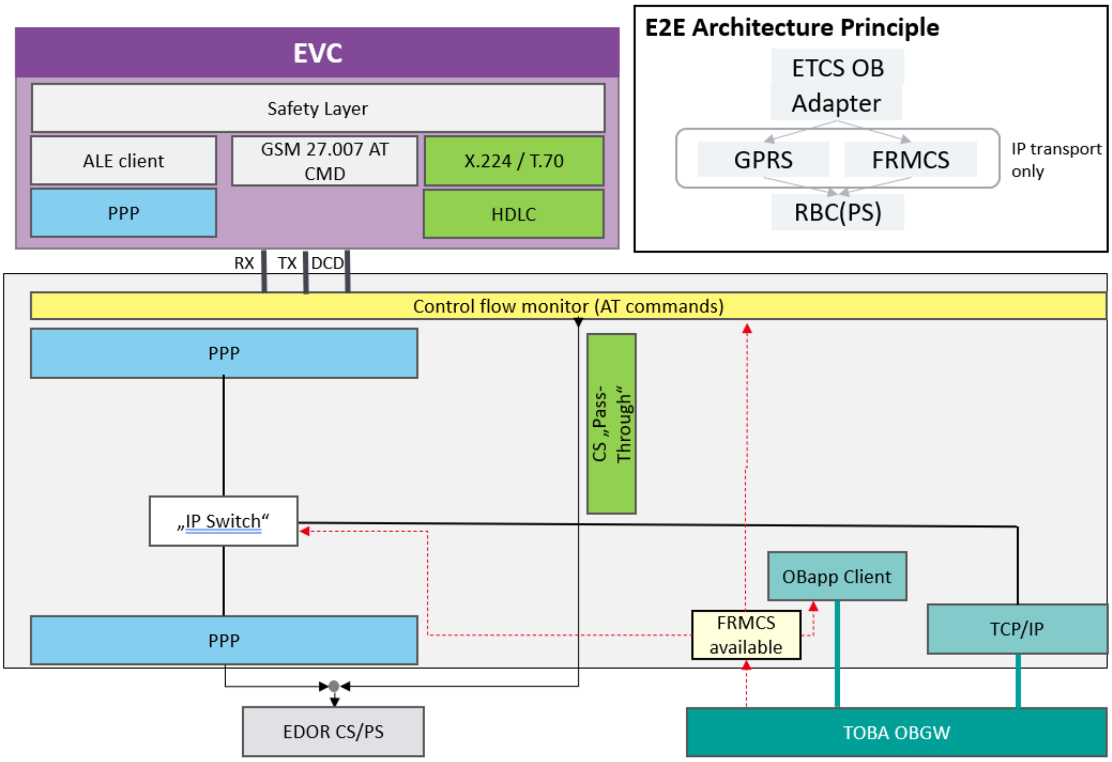

Fig. 7-6: Possible Implementation of Adapter Solution E1 for SV 2.1 vehicles.

With this solution, when under FRMCS coverage, the PS media flow will be directed via FRMCS transport using the same target / destination IP address and the same RBC PS (GPRS) interface as when using GPRS. As a consequence, the use of FRMCS transport does not necessitate the upgrade of the RBC with an FRMCS interface, a GPRS-enabled RBC will do. Even though the destination address is the same, the source IP address would be different for GPRS and FRMCS transport so that the right communication bearer is used on the return path. It is expected that this will not cause problems with RBCs but would have to be checked in detail.

As with adapter solution D provisions would be needed that Euroradio switches to PS for an RBC that is not yet known or could previously be reached with GSM-R CS connections.

7.8.1.1 "FRMCS available" function and Adapter Transmission Mode Table (TMT)

To ensure a consistent behavior and to avoid packet loss due to unwanted switching between FRMCS and GPRS, a mechanism to choose correctly between FRMCS or GPRS for the whole RBC session must be in place. As with solution D, the "FRMCS available" function will know from the FRMCS onboard gateway whether it is registered in an FRMCS network. However, establishing whether the whole RBC service area is covered sufficiently by FRMCS and thus FRMCS can be used for an ETCS session cannot be achieved with the "FRMCS background check" from solution D because the dedicated FRMCS interface at the RBC may not be available or not be reached (separate IP address for the FRMCS interface). Instead, an Adapter TMT must either be provisioned separately (e.g. over the air) and some packet inspection would be required to figure out when a new RBC area is entered (maybe GPS-based geofencing would also suffice) or the DNS proxy from solution D would have to be introduced also in solution E to perform an "FRMCS background check" addressing the FRMCS port of an RBC (which would obviously only work with an RBC featuring a dedicated FRMCS port) and to trigger the bearer selection when changing an RBC service area.

7.8.1.2 Cybersecurity Issues

TLS could not be used in the adapter, as this would not be compliant with ETCSoverGRPS and the RBC(PS) on trackside. It would have to be checked if the omission of TLS is acceptable, given that 5G radio used by FRMCS is quite secure and so far, no attacks are known similar to the ones for GSM-R, but 5G radio covers only the air gap. Between TOBA onboard gateway (OBGW) and trackside gateway (TSGW) MCdata service is used. At one point in time the possibility to add more features, e.g encryption, in the onboard/trackside gateways on top of Mcdata was discussed. This would help to have a secure connection between OBGW and TSGW. Between TSGW and RBC(PS) we have what is available in ETCSoverGPRS. One could add TLS or Ipsec in the adapter but would need in consequence a TLS or Ipsec function in front of the RBC(PS), which can be seen as security tunnel. This requires a new network node on trackside.

7.8.1.3 Assessment of Solution E1

From the above description one can deduce that the desired onboard complexity reduction compared to solution D cannot be achieved. On top of that, this solution implies that the RBC must feature a PS (GPRS) interface (i.e. a second Ethernet interface with associated protocol stacks alongside the FRMCS interface) during the whole lifetime of adapter E vehicles and the ETCS DNS must be kept in operation. For IM that have ETCS over GPRS in operation and thus have an ETCS DNS infrastructure and PS interfaces in place, the impact of not being able to decommission them as long as adapter E vehicles are in operation may be considered moderate (unlike ISDN links from solution B we are dealing here with technologies with no imminent obsolescence). However, IM that plan to migrate directly from GSM-R CS to FRMCS would have to introduce an ETCS DNS and additional RBC interfaces only because of adapter type E vehicles.

7.8.2 Solution E2

In order to avoid the problems associated with bearer selection in solution E1, the following solution E2 was proposed:

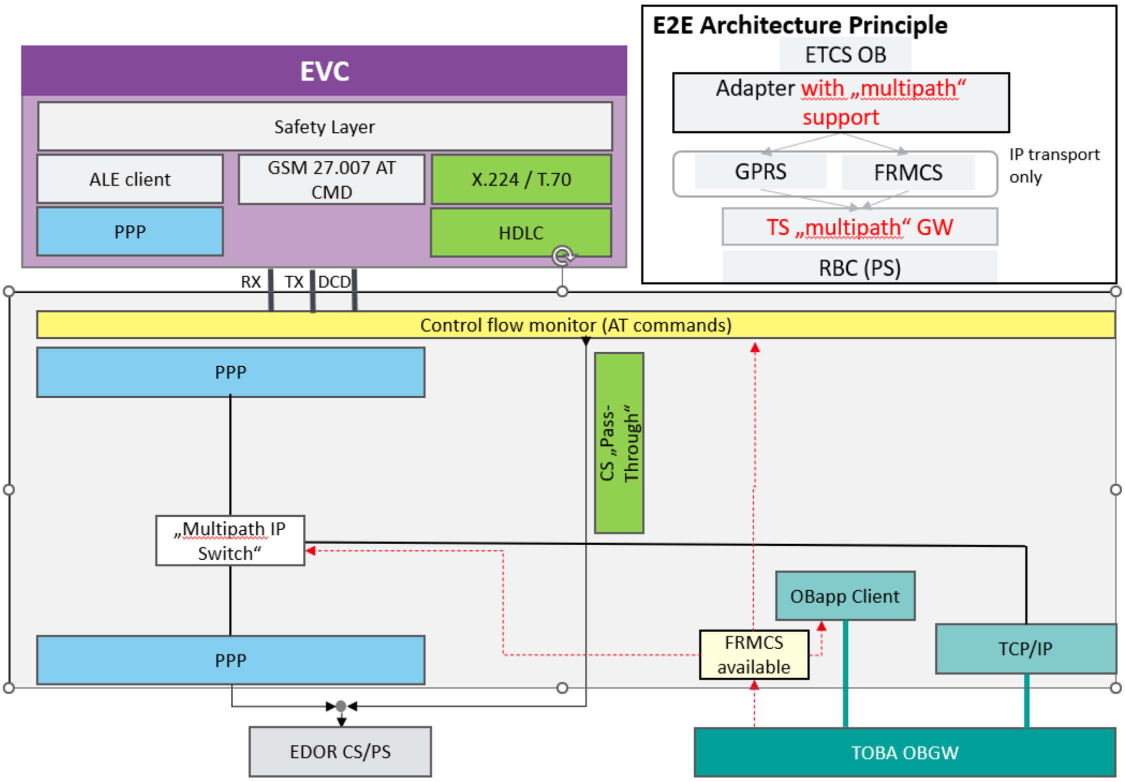

Fig. 7-7: Possible Implementation of Adapter Solution E2 for SV 2.1 vehicles.

In this solution, the "IP switch" includes packet duplication so that packets can be delivered both via GPRS or FRMCS transport. In essence, this is similar to the optional "multipath solution" defined for FRMCS (even though the FRMCS multipath solution does not support GPRS bearers). It would need a trackside "multipath" gateway as a counterpart to the onboard multipath switch, so that duplicated packets can be filtered out and only one consistent data stream is forwarded to the RBCs (and vice versa on the onboard "multipath IP switch").

Pushing packets via FRMCS transport would require a pre-established link to the FRMCS trackside gateway, for which a "host to network" (H2N) addressing solution could be used. While H2N is expected to be part of the FRMCS specifications, the specific requirements of ETCS over FRMCS sessions (like QoS and support of visited network destinations) may need enhancements to the FRMCS specifications specific to solution E2.

The advantage of this solution as compared to solution E1 is that no separate mechanism is required to assess whether an entire RBC service area is covered by FRMCS since unwanted loss or duplication of packets because of uncontrolled switching between GPRS and FRMCS will not occur owing to the multipath feature. "FRMCS available" is limited to indication of FRMCS network registration and availability of FRMCS radio coverage.

In addition to the trackside impact of solution E1, solution E2 would force IM to deploy GPRS-enabled trackside multipath gateways.

7.9 Solution A with CS Fallback under FRMCS for SV 2.1 Vehicles

In subsection 7.6.3 a solution A with "CS Fallback under FRMCS" was proposed to cater for SV 2.0 and SV 2.1 vehicles, allowing SV 2.1 vehicles the use of ETCS over GPRS on an SV 2.1, 2.2 or 2.3

infrastructure (but no PS support for FRMCS, i.e. when Euroradio orders set-up of a GPRS session, this cannot be translated to FRMCS).

In order to allow FRMCS in a GPRS area (FRMCS is available), whenever ETCS over FRMCS is to be used, Euroradio would have to be forced to fall back to CS. This can be achieved if a DNS request is responded by special text field with content "txm = cs". To avoid trackside impact and complicated configuration, this is best achieved by an extended DNS proxy known from solution D which would however not respond with the target IP address of the RBC but rather with the text field. Euroradio will then switch back to CS and the session setup is performed as with solution A described in section 7.6.

One issue is how to support online key management on an infrastructure supporting this feature. While it is possible to limit the use of FRMCS and the CS fallback only to ETCS and tell the adapter to use GPRS for online key management (since it is a separate PDP context and separate APN), there are two problems:

- On trackside systems that support both GPRS and FRMCS this would result in simultaneous use of GPRS and FRMCS which might need to be avoided because of cross-system-interference / antenna isolation requirements or requires frequency coordination putting additional constraints on already challenging radio planning during parallel operation of GSM-R and FRMCS.
- On an infrastructure supporting FRMCS, once GSM-R is switched off and thus GPRS is not available anymore, the PS interface of the EDOR will no longer be used. Presumably this will mean that there is no longer a way to exchange online key management related information.

Given these issues and given that we need anyway some elements from solution D for the CS fallback to work, the conclusion is that rather than using A with CS fallback, for SV 2.1 vehicles only solution D should be considered.

7.10 Assessment of Remaining Adapter Solutions and Recommendation

The following tables compare a few relevant aspects of the solutions:

Solution	„Who" chooses FRMCS?	How is FRMCS chosen?	Issues specific to bearer choice
SV 3.0	Coordinating function in SS-037-1	P245 **and** control plane „check"	One TMT in coordinating function
BL Light	Coordinating function in SS-037-1	Control plane „check"	One TMT in coordinating function. Coordinating function needs to fake GSM-R registration to ETCS application after GSM-R decommissioning.
Adapter A	Adapter coordination	Control plane „check" or look-up table	One TMT or look-up table in adapter (SV 2.0 vehicles). Adapter needs to fake GSM-R registration to Euroradio /ETCS application after GSM-R decommissioning.
Adapter A, CS fallback	Adapter coordination	Control plane „check" or look-up table	TMT (CS or PS) in coordinating function. TMT (FRMCS) in adapter. Needs modified DNS proxy of adapter D to force CS fallback in coord. function under FRMCS. Fake GSM-R registration as in adapter A.
Adapter D	Adapter coordination	Control plane „check"	TMT (CS or PS) in coordinating function. TMT (FRMCS) in adapter. Needs onboard DNS proxy (alternative to be avoided: deep packet inspection and packet modification). Adapter needs to fake GPRS attach and PDP context activation after GSM-R decommissioning.

Adapter E1	Adapter coordination	Database entry or control plane „check"	TMT (CS or PS) in coordinating function. TMT (FRMCS) in adapter. Needs packet inspection and provisioning of database or onboard DNS proxy as in solution D. GPRS faking as in solution D.
Adapter E2	Adapter coordination/ switch	Based on FRMCS radio coverage availability	Multipath solution onboard and trackside required to guarantee consistent QoS because of potential ping-ponging between bearers in an RBC coverage area. GPRS faking as in solution D.

Table 7-1: Bearer selection process of the different solutions (including SV 3.0 and baseline light).

Solution	Trackside Impact
BL Light	Only new "FRMCS-only" mode for RBC (balise with P45 ordering GSM-R registration must remain).
A	New "FRMCS-only" mode for RBC (balise with P45 ordering GSM-R registration must remain), provisioning of functional aliases in trackside MCX depending on solution details.
D	Only new "FRMCS-only" mode for RBC (balise with P45 ordering GSM-R registration must remain).
E1	• For IMs with RBCs enabled for ETCS over GSM-R PS and corresponding DNS infrastructure: DNS needs to be maintained, GSM-R PS interface at RBCs needs to be kept (may be separate physical Ethernet interface or separate logical interface with separate software stack on same physical interface) -> this is a rather minor impact, as technology with no imminent obsolescence and potentially moderate operational expenses • For IMs that plan to migrate to FRMCS without intermediate step ETCS over GPRS: DNS and GSM-R PS interface at RBCs need to be introduced only for a few E1 adapter vehicles. Would all IMs have to do so if a single EVU somewhere in Europe plans to deploy E1 vehicles?
E2	Same as E1. • Additionally: the special onboard "adapter multipath entity" needs a trackside counterpart. • (Note that the **optional** FRMCS multipath contained in FRMCS V1 is a similar concept, albeit not envisaged to be used with GSM-R PS) • Again the question: would all European countries have to live with this trackside impact as soon as vehicles with an E2 adapter are certified in one country?

Table 7-2: Trackside impact of the solutions.

Use Case	Vehicle	Infrastructure	Desired Functionality	Possible Adapter Solutions
1	SV 2.0	SV 2.0 to SV 2.3	ETCS functionality limited to SV 2.0. SV 2.3 only to provide FRMCS.	A
2	SV 2.1	SV 2.0 to SV 2.3	ETCS functionality limited to SV 2.0. No GPRS. SV 2.3 only to provide FRMCS.	A, D, E1 or E2
3	SV 2.1	SV 2.1 to SV 2.3	ETCS functionality limited to SV 2.0. ETCS over GPRS only for spectrum efficiency. SV 2.3 only to provide FRMCS.	A with CS fallback, D, E1 or E2
4	SV 2.1	SV 2.1 to SV 2.3	ETCS functionality according to SV 2.1 including online key management. SV 2.3 only to provide same functionality with FRMCS.	D, E1 or E2 extended / duplicated to handle independent ETCS and Key Management Sessions A with CS fallback if adapter only to be used for ETCS over FRMCS, while other data sessions like key management are separately upgraded to use FRMCS with the Obapp interface according to Baseline Light or SV 3.0 (if certification much easier than for ETCS)

Table 7-3: Applicability of the solutions to the use cases from table 5-3

If SV 2.0 vehicles are to be fitted with an adapter, given that solution B was eliminated already earlier because of trackside impact, only solution A remains.

Regarding SV 2.1 vehicles, as mentioned in subsection 7.8, solution E1 does not reduce onboard complexity compared to solution D. Solution E2 may reduce the onboard complexity slightly, but at the expense of an unacceptable trackside impact. Furthermore, there are cybersecurity limitations with these solutions. Therefore, solutions E1 and E2 can be eliminated. Solution A with CS fallback has functional limitations compared to solution D and combines "the worst" of solutions A and D, namely the need for protocol conversion as in solution A and that of a DNS proxy as in solution D. Therefore, the recommendation for SV 2.1 vehicles is to consider only solution D unless GPRS is not planned to be used, then solution A could also be an option.

If only one solution is to be considered, given that solution D appears to be less complex than solution A since protocol conversion can be avoided, the recommendation would be to focus only on solution D.

Looking at the issues raised in section 7.1 related to the adapter solutions, with the description of the solutions in the previous subsections, a significant number of these issues has been covered and solution D looks viable, whilst in solution A no risk mitigation measures could be found regarding the complexity of the required protocol conversion. However, the following main issues or risks from the Unitel assessment back in 2019 remain open:

- Euroradio protocol timing risks (timing and race conditions),
- Euroradio stack supplier specifics and behavior variations will likely lead to significant integration risks end efforts.

Note that the first risk, at least regarding timing issues, should not pose a major blocking point for a solution D that is packet-based and where the FRMCS radio bearer is expected to be more responsive than GPRS. However, a final assessment of both risks can only be made in the context of a specific project looking at implementation of a solution for a specific combination of suppliers. A further unresolved issue going hand in hand with the second issue above is that of the willingness of suppliers to implement adapter solutions. It is not clear whether the necessary supplier ecosystem will be available.

Further issues listed in section 7.1, mostly raised by ERA, have also been covered in this section except some detailed operational cases like start of mission after cold movement, transition from GSM-R in one country to FRMCS in another country and detailed operational impacts. These would have to be dealt with as described in section 7.11 below. The last ERA question how to handle several versions of the solution by different suppliers covers similar areas as the "supplier specifics" above. It is up to the migration stream to determine whether a limited number of variants would cover a large enough fleet to contain this issue.

7.11 Further Topics to be Considered for Proposed Adapter Solutions

If, for whatever reason, baseline light is not considered to be a viable approach for reducing costs and duration of FRMCS vehicle migration, then the proposed adapter solutions would have to be studied in more detail and a concept document along the lines of the baseline light concept document [2] would have to be written. For Adapter D a very first draft was written [4], taking the baseline light concept document [2] as a basis and indicating those parts, where the adapter solution differs from baseline light and further studies would be required. This document would then cover (among other topics) the following:

- DMI issues related to FRMCS
- Behavior of solution after decommissioning of GSM-R (including DMI behavior)
- Behavior during start of mission, in particular after cold movement
- Behaviour during registration

- Behaviour when moving from an FRMCS coverage area to a GSM-R CS or GPRS coverage area including border crossing and roaming.

In addition, the following topics would also need to be considered further for an adapter solution:

- The trackside radio infrastructure and the ETRMS monitoring equipment cannot/ should not detect the usage of the adapter onboard. The railway undertakers will have to think about appropriate diagnosing tools in case of adapter malfunctions, will have to fix them and report this to the IM.
- Euroradio needs to know whether it has two or one EDOR available for resource management and which mobile is connected to which network for key management or for handovers into other countries. It must be made sure that this information is still available after the introduction of the adapter between Euroradio and EDORs.

8 References

[1] FRMCS - ETCS Baseline 3 (non-)compatibility, Analysis on behalf of the CTO-Council of the issue, business impact, potential solutions/scenarios and proposed actions regarding FRMCS – ETCS Baseline 3 (non-)compatibility, October 2023.

[2] ETCS FRMCS Baseline Light concept, Joint EUG UNISIG Proposal, March 28th, 2024.

[3] FRMCS Telecom On-Board System ‐ Architecture Migration Scenarios, UIC TOBA-7540, V 1.0.0, April 15th, 2020.

[4] ETCS FRMCS Adapter D concept, CTO Extended Group Indicative Draft Proposal, April 26th, 2024.

[5] EuroRadio FIS, Subset 037, UNISIG, V 3.1.0, May 9th, 2014.

[6] EuroRadio FIS, Subset 037, UNISIG, V 3.2.0, December 17th, 2015.

[7] EuroRadio FIS, GSM-R CS/PS Communication Functional Module and Coordinating Function FRMCS/GSM-R, Subset 037-1, UNISIG, V 4.0.0, July 5th, 2023.

[8] EuroRadio FIS, FRMCS Communication Functional Module, Subset 037-3, UNISIG, V 4.0.0, July 5th, 2023.

9 Abbreviations

AT	AT commands / interface, the commands to control a modem (e.g. set up a communication link)
CS(D)	Circuit-switched (data or domain)
DMI	Driver Machine Interface
DNS	Domain Name Server
EDOR	ETCS Data Only Radio
ETCS	European Train Control System
ETCSoverCS	ETCS session over GSM-R circuit-switched data links
ETCSoverPS	ETCS session over GSM-R packet-switched data links
FQDN	Fully Qualified Domain Name
FRMCS	Future Rail Mobile Communications System
GPRS	General Packet Radio Service (of GSM-R)
GSM-R	Global System for Mobile Communications – Rail
IM	Infrastructure Manager
MCX	Mission Critical Server (part of FRMCS service stratum)
OBant	Interface from OBGW to antenna
OBapp	Interface from OBGW to application
OBGW	Onboard Gateway
OBrad	Interface from OBGW to radio modules (an additional, currently optional OB interface)
PDP	Packet Data Protocol
PS(D)	Packet-switched (Data or Domain)
QoS	Quality of Service
RBC	Radio Block Center
RF	Radio Frequency
TLS	Transport Layer Security
TMT	Transmission Mode Table
TOBA	Telecom Onboard Architecture
TSGW	Trackside Gateway
URI	Universal Resource Identifier