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STUDY ON THE ARCHITECTURE OF ON-BOARD RADIO COMMUNICATION EQUIPMENT

FINAL REPORT

ERA 2017 31 OP

STUDY ON THE ARCHITECTURE OF ON-BOARD RADIO COMMUNICATION EQUIPMENT

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The opinions expressed in this study are those of the authors and do not necessarily reflect the views of the European Union Agency for Railways (ERA).

EXECUTIVE SUMMARY

This is the Executive Summary of a report on the evolution of on-board communication system. It provides input to the European Union Agency for Railways (ERA) in order to assist them in updating the relevant portions of the mandatory standards for which ERA is responsible.

The main objective of the study is to provide information and conclusions on the most suitable options for on-board communication system architecture concepts so as to provide sufficient flexibility to support current and future user needs, and to allow for changes related to other radio technologies, radio frequencies and applications during its lifetime (roughly between 2020 and 2040) at low cost for updating activities. The study addresses both software architecture and hardware architecture, with a focus on the radio applications which are currently mandatory in ERA's *CCS TSI* standards document.

As a secondary objective, the report provides background information and analysis of relevant requirements, standards, operational, technical and economic impact, certification and authorisation, and ongoing research activities.

This study is part of a sequence of studies conducted on behalf of ERA in order to ensure the future of European operational rail communications by planning for a successor to the current system, *GSM-R*. GSM-R addresses most of the current needs, but is expected to become uneconomic to maintain due to obsolescence of the underlying 2G mobile technology, and does not address all future needs.

1 THE EVOLVING ARCHITECTURE OF FRMCS: PROGRESS AND GAPS

The requirements for the *Future Railway Mobile Communication System (FRMCS)* go beyond those of GSM-R, irrespective of how the system will ultimately be implemented. These requirements drive the standards development process.

Three major technological threads interact, actually or potentially, with the standardisation process. First, there is *Mission-Critical Push-To-Talk* (*MCPTT)*, the approach of the *3GPP* standards group to mission-critical functionality. Second, there is the case of 4G voice over IP, referred to as *Voice over LTE (VoLTE)*. Third, there is the potential use of *Over-the-Top (OTT)* solutions that are fully decoupled from the underlying network.

1.1 REQUIREMENTS FOR THE FUTURE RAILWAY MOBILE COMMUNICATION SYSTEM (FRMCS)

The *International Union of Railways (UIC)* launched the *FRMCS* project in 2012 in order to lay the groundwork for the introduction of a successor of GSM-R. This process has generated a *User Requirements Specification (URS)*, which is now in its third release. The URS documents requirements worldwide, not just for Europe, and including Urban Rail.

The URS deals with six classes of applications (of which this report provides detailed analysis only of a selection of the most critical):

- Critical communication applications (e.g. emergency communications, Automatic Train Control, shunting …)
- Performance communication applications (e.g. lineside telephony, public address …)
- Business communication applications (e.g. wireless internet on-train for passengers …)
- Critical support applications (e.g. role management and presence, multi user talker control…)
- Performance support applications (for further study)

- Business support applications (e.g. billing information …)

A range of *Functional and System Principles Use Cases* have been elaborated to clarify requirements for these classes of applications. A series of functional and system principles have been developed that should be fulfilled in satisfying the use case needs.

1.2 VOICE OVER LTE (VOLTE)

Voice over LTE (VoLTE) technology is widely recognised as the emerging standard for voice communications over 4G, and also as the expected approach for 5G as well. Interworking with traditional circuit-switched voice has also been addressed (which would likely be essential for interworking with GSM-R).

VoLTE requires QoS assurance by means of a Guaranteed Bit Rate (GBR) transmission path (bearer); however, the bandwidth needed is low in comparison with LTE capabilities.

1.3 THE 3GPP APPROACH TO MISSION-CRITICAL COMMUNICATIONS

Work on mission-critical communications has been ongoing within the 3GPP standards group for many years, primarily in response to the needs of the *Public Protection and Disaster Relief (PPDR)* community. Notably, *Mission Critical Push To Talk (MCPTT)* provides an arbitrated method to support voice communications between several users (group call), where each user has the ability to gain access to permission to talk. Data and video requirements have subsequently been accommodated. 3GPP has now confirmed that this work will be supported not only for current 4G LTE networks, but also for emerging 5G mobile networks.

The PPDR community has requested interworking capabilities between these new MCPTT capabilities and older systems such as TETRA and P25. Solutions have been committed for 3GPP Release 15. To date, no specifications support interoperability between MCPTT and VoLTE calls.

Operational rail communications requirements are similar to those of PPDR mission-critical communications, but they differ in many details. 3GPP has accepted many operational rail requirements, but normative work is still ongoing.

1.4 FULLY OVER-THE-TOP (OTT) SOLUTIONS

One could instead contemplate a solution that is fully *Over-the-Top (OTT)* and *bearer independent* (i.e. fully decoupled from the underlying network). Numerous studies over the years have seen merit in a non-3GPP fully bearer independent solution as a future solution to operational rail communication needs.[1] Full bearer independence would tend to simplify integration of new applications and new transmission media (such as satellite and Wi-Fi), and would likewise simplify future migration of the operational rail communications network.

We refer to bearer independent solutions in this study as *over-the-top (OTT)* to connote that they run over the top of existing IP-based communication systems.

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[1] See Lovan Pushparatnam, Guillaume Gach, J. Scott Marcus, Catherine Maton (2017), "Study on Implications of the bearer independent communication concept"; J. Scott Marcus and Frédéric Pujol (2015), "Evolution of GSM-R"; and David Taylor, Nils Lofmark, Maria McKavanagh (2014), "Survey on operational communications (study for the evolution of the railway communications system)", all of which were conducted on behalf of ERA.

Despite these substantial advantages, the sector has apparently not been motivated to do concrete work to plan for a migration to this comprehensive form of bearer independence. In order to enable meaningful comparison, the authors have sketched out in rough form a possible OTT design. Its system architecture is presented in the report.

OTT solutions for voice services

The proof-of-concept design for operational rail voice services that we use to promote discussion is based on the *Session Initiation Protocol (SIP)*. For many reasons, this seems to be an obvious choice. Consider for example:

- SIP is a successful and widely implemented protocol – there is substantial experience with it, and the experience is generally good.
- There is a substantial base of existing software technology and tools, including a popular open source server implementation, Freeswitch.
- SIP is the basis of the *IMS*, which is at the core of VoLTE, VoWi-Fi, MCPTT and future carrier services such as eCall. Much of the work already being done to design and implement FRMCS on a 3GPP basis could perhaps be re-purposed to an OTT solution on this basis.

So far as we can see, all GSM-R functionality would be amenable to implementation on this basis. In fact, the implementation of voice functionality would likely be similar to that which would be needed for an IMS MCPTT implementation.

OTT solutions for location support services: example of location

A new approach to determination of the location of the train would be needed in order to support (1) *Location Dependent Addressing (LDA)*, which ensures that calls originated by the train driver are automatically routed to the most appropriate controller, and (2) *Railway Emergency Call (REC)*, which initiates an urgent, pre-emptive call to the responsible controller and to potentially impacted trains.

In practice, the ID of the mobile cell serving the train's UE is routinely used today to locate the train. This is inappropriate in a fully bearer independent system, and probably impossible over satellite or Wi-Fi. Aside from that, it represents only a very imprecise estimate of the train's location.

In the most obvious solution, external servers would keep track of the train's location, which would then be mapped against the boundaries of responsibility of the controllers (similar to what is already done in some implementations of *enhanced Location Dependent Addressing (eLDA)* function.)

The 3GPP-based design presumably has similar requirements, but a solution has not been designed. A fully over-the-top solution to location identification might well make sense for 3GPP-based solutions, and would also be useful in the event of an eventual migration to full bearer independence.

Common principles for OTT solutions

Quality of Service (QoS) would require careful attention, particularly if there is a desire to support satellite or Wi-Fi. Whether OTT or not, future operational rail communications will not be running over a random mix of transmission facilities, but rather over a small number of bearers whose performance characteristics have been carefully chosen with QoS requirements in mind.

We have studied interworking issues between an OTT solution and GSM-R, and consider them to be manageable. The same goes for interworking between an OTT solution and an MCPTT solution. If it is necessary to provide full interworking among three distinct solutions (GSM-R, MCPTT-based solutions, and OTT solutions), things get more complex.

2 ON-BOARD SYSTEMS: THE CURRENT SITUATION, FUTURE DEVELOPMENTS

Our focus here is on the key findings of the report, not on details of implementation.

2.1 THE CURRENT SITUATION

The report provides extensive detail on (1) on-board hardware and software, including the cab radio and the ETCS Data Only Radio (EDOR); (2) installation and upgrade mechanisms available for on-board hardware and software; (3) maintainability considerations; (4) certification mechanisms for on-board hardware and software; and (5) observations based on the previous migration from analogue operational rail communications to GSM-R.

Key findings relevant to the migration to a successor to GSM-R are:

- The evolution of voice and (ETCS) data in separate silos, both in terms of architecture and implementation, results in needless cost for on-board equipment.
- Proprietary interfaces increase the complexity of on-board systems, and contribute to vendor lock-in.
- Lack of harmonisation in country-specific de facto requirements imposes additional costs on suppliers of on-board equipment and on Railway Undertakings (RUs). There is a need to conform to multiple requirements, since the train must be able to roam from one country to another.
- The on-board antenna system poses special challenges. Space on the roof of the train is limited, making it challenging to simultaneously satisfy all requirements (including redundancy).
- Specificities of the transmission system and the ERTMS security system are managed as part of ETCS. This fragmentation of the architecture contributes to complexity and thus to cost of on-board systems.
- There is a need to modernise the security architecture.
- The duration and complexity of recertification and readmission of trains and on-board equipment can be substantial.
- Even for non-critical on-board functionality, the duration for readmission can be substantial.
- The specification of transmission parameters is insufficiently tight, meaning that full interoperability cannot be guaranteed for trains that roam from one country to another.

2.2 LIKELY DEVELOPMENTS GOING FORWARD

We assess likely relevant developments going forward as regards (1) on-board operational rail functionality; (2) radio technology; (3) spectrum management; (4) migration scenarios; (5) antennas; (6) hardware limitations, especially as regards chipsets; (7) Software-Defined Radio (SDR); (8) ongoing and potential future research projects; and (9) network and information security.

Key findings relative to these developments are:

- The relative sequencing of migration to 4G and/or 5G is not altogether clear. This has implications for migration of on-board equipment to FRMCS, and even more so for on-board equipment than for trackside due to the likely sequencing of the migration.
- Despite strong interest over the years in fully OTT solutions, the sector is on a trajectory where MCX-based solutions are likely to appear before fully OTT solutions (if fully OTT solutions emerge at all).
- The limited number of vendors who are prepared to create MCX-capable modems implies a risk of vendor lock-in.

- The current approach of the European rail sector is embodied in having UIC specify requirements to the 3GPP standards development process.
- There is significant risk of delay in the 3GPP standards process, largely due to the perceived complexity of the functionality that has been requested in conjunction with limited resources to work on the standards.
- Allocation of frequency bands in support of eventual FRMCS migration needs careful study and planning.
- Antenna system design is a significant risk area that requires attention, especially during the migration period.
- Power requirements for GSM-R are greater than those typical for 4G LTE today. If this were to be the case for FRMCS, concerns over health effects might possibly arise. Careful study and planning of these aspects is called for.
- There appears to be an insufficient number of rail experts engaged in the normative work.
- Cybersecurity aspects of the Train Communication Network (TCN) have received little attention to date.

3 THE WAY FORWARD

In light of the findings developed, we put forward the following recommendations. They can be broken down into three broad categories: (1) recommendations that are generally relevant to the overall implementation of future operational rail communications systems; (2) recommendations that are specific to the implementation of on-board elements of future operational rail communications systems; and (3) procedural recommendations that suggest steps that ERA may wish to take in order to facilitate a clean transition to the next generation of operational rail communications systems.

Recommendations that are generally relevant to the overall implementation of future operational rail communications systems

- Fallback to GSM-R must be maintained.
- In terms both of standardisation and of implementation, strong separation of critical versus non-critical applications should be practised. Recertification of non-critical functions should be as lightweight as possible, consistent with reliability and safety requirements.
- Greater harmonisation of national requirements is called for.
- An overall re-thinking of the approach to QoS is called for.
- In the interest of avoiding needless complexity and associated cost for the rail community, consideration should be given to not carrying GSM-R capabilities that are not used or very rarely used over without change into 3GPP FRMCS standards. Detailed analysis of real needs from an operational perspective is required.
- In designing train location capabilities for FRMCS, consideration should be given to possible implementation of these capabilities on a purely OTT basis, which is to say entirely outside of the network. This potentially simplifies interworking with GSM-R, and also simplifies any future migration.

Recommendations that are specific to the implementation of on-board elements of future operational rail communications systems

- Standardised interfaces should be used wherever possible.
- Single points of failure (SPoFs) should be avoided.
- Software should be designed to be configurable / parameterisable where feasible, with due concern for reliability and safety.
- The use of over-the-air update should be considered where feasible, with due concern for reliability and safety.

Procedural recommendations addressed to ERA

- ERA and the sector should keep an eye on research trends that may provide solutions that can profitably be applied to operational rail communications.
- ERA should explore and carefully consider the incentives of the supplier community.
- In terms of the frequency bands and technologies to be used, careful migration planning at national level will need to be complemented by coordination at European level.
- ERA and the rail community should consider as part of the FRMCS migration the adoption of a modernised and integrated security architecture that addresses both voice and data / ETCS services in an integrated way.
- ERA should seek to revise the CCS TSI and other standards that are relevant to recertification as infrequently as practical.
- ERA should monitor the progress of UIC and 3GPP on FRMCS standards.
- ERA should use this report as an opportunity to explore the openness of the sector to OTT solutions, together with the feasibility and practicality of OTT solutions.
- If there were a decision to commence work in earnest on the standardisation of OTT solutions, it would likely be necessary to identify and engage with a suitable standards body. We consider it unlikely that 3GPP would be willing to undertake standardisation of a fully OTT solution, and they are possibly not the most appropriate standards body in any case.

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LIST OF RECOMMENDATIONS

ABBREVIATIONS

API	Application Programming Interface
2G	Second generation of wireless mobile telecommunications technology
3G	Third generation of wireless mobile telecommunications technology
3GPP	3rd Generation Partnership Project
4G	Fourth generation of wireless mobile telecommunications technology
5G	Fifth generation of wireless mobile telecommunications technology
3iBS	intelligent, innovative, integrated Bus Systems
ADL	Architecture Description Language
ANSSI	Agence nationale de la sécurité des systèmes d'information
AP	Access Point
APCO	Association of Public-Safety Communications Officials
ASCI	Advanced Speech Call Items
ATC	Automatic Train Control
BEREC	Body of European Regulators for Electronic Communications
BIC	Bearer Independent Communication
BSS	Base Station Subsystem
CAPEX	Capital Expenditure
CCS TSI	Technical Specifications for Interoperability relating to the Control-Command and Signalling subsystems of the trans-European rail system
CEPT	European Conference of Postal and Telecommunications Administrations
CER	Community of European Railway and Infrastructure Companies
CIM	Common Information Model
CMIP	Common Management Information Protocol
CS	Circuit-Switched
CSFB	Circuit-Switched Fall-Back
DMR	Digital Mobile Radio
dPMR	Digital Private Mobile Radio
DSD	Driver Safety Device
CSP	Communications Service Provider (including MNO, satellite and all kind of content and applications service providers)
DSRC	Dedicated Short Range Communications
E2E	End-to-End
EBSF	European Bus System of the Future
ECC	Electronic Communications Committee
ECO	European Communications Office
ECS	Electronic Communication Services
EDOR	ETCS Data Only Radio
EIM	European rail Infrastructure manager
ENISA	European Union Agency for Network and Information Security
EPC	Evolved Packed Core
ERA	European Union Agency for Railways
ER-GSM	Extended GSM-R
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
eTOM	enhanced Telecom Operations Map
ETSI	European Telecommunications Standards Institute
EU	European Union
FCAPS	Fault, Configuration, Accounting, Performance and Security
FDD	Frequency Division Duplex
FRMCS	Future Railway Mobile Communication System
FQDN	Fully Qualified Domain Name

FTS	Fixed Terminal System (dispatcher system)
GSM	Global System for Mobile Communications (refer to 2G)
GSM-R	Global System for Mobile Communications-Rail
IC	Interoperability Constituent
HPUE	High Power User Equipment
HTTP	HyperText Transfer Protocol
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMS	IP Multimedia Subsystem
IM	Infrastructure manager
IOP	Interoperability
IP	Internet Protocol
ISO	International Organization for Standardization
IT	Information Technology
ITIL	Information Technology Infrastructure Library
ITS	Intelligent Transport System
ITU	International Telecommunication Union
ITU-R	ITU's Radiocommunication sector
ITxPT	Information Technology for Public Transport
KMS	Key Management System
KPI	Key Performance Indicators
LMR	Land Mobile Radio
LPWAN	Low-Power Wide-Area Network
LTE	Long Term Evolution
LTE-A	LTE Advanced (refer to 4G)
LTE-A Pro	LTE Advanced Pro
M2M	Machine-to-Machine
M(V)NO	Commercial Mobile (Virtual) Network Operator
MCG	Mobile Communication Gateway
MCX	Mission Critical Applications (i.e. MCPTT, MCVideo and MCData)
MCPTT	Mission Critical Push-to-talk voice
MCVideo	Mission Critical real-time video
MCData	Mission Critical real-time data
MHz	MegaHertz
MiMO	Multiple Input Multiple Output (Multiple antenna)
MIP	Mobile IP
MNO	Mobile Network Operator
MS	Member State
MSISDN	Mobile Station International Subscriber Directory Number
MTTR	Mean-Time-To-Repair
NEMO	Network Mobility
NG	Next Generation
NG2R	Next Generation Radio for Rail
NGTC	Next Generation Train Control
NMC	Network Management Center
NOC	Network Operations Center
NRA	National Regulatory Authorities
NSS	Network SubSystem
NXDN	Next Generation Digital Narrowband
OSI	Open Systems Interconnection
OMTS	On-board Multimedia and Telematic Subsystems
OTT	Over-The-Top
OWA	Open Wireless Architecture

P25	Project 25 (Refer to APCO)
PDT	Professional Digital Trunking
PMR	Private Mobile Radio - Professional Mobile Radio
PPDR	Public Protection and Disaster Relief
PRIME	Platform of Rail Infrastructure Managers in Europe
PS	Packet-Switched
PSCE	Public Safety Communication Europe
PT	Public Transport
PTToC	Push-To-Talk over Cellular
QCI	QoS Class Identifier
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RCS	Rich-Communication Suite
S2R	Shift2Rail
RAM	Reliability, Availability, and Maintainability
RAMS	Reliability, Availability, Maintainability and Safety
RED	Radio Equipment Directive
RINF	Register of INFrastructure
RU	Railway Undertaking
SATCOM	Satellite Communications
SALUS	Security And InteroperabiLity in Next Generation PPDR CommUnication Infrastructure
SDR	Software Defined Radio
SIP	Session Initiation Protocol
TDD	Time Division Duplex
TETRA	Terrestrial trunked Radio
SLA	Service Level Agreement
SMI	Structure of Management Information
SNMP	Simple Network Management Protocol
SOA	Service Oriented Architecture
SPOF	Single Point of Failure
TCMS	Train Control and Monitoring System
TCN	Train Communication Network
TMN	Telecommunications Managed Network
TOM	Telecom Operations Map
UIC	International Union of Railways
UMTS	Universal Mobile Telecommunications System
UNISIG	Union industry of signalling
ViLTE	Video over LTE
VoIP	Voice over IP
VoLTE	Voice over LTE
VoWiFi	Voice over Wi-Fi
WAPECS	Wireless Access Policy for Electronic Communications Services
WebRTC	Web Real-Time Communications

APPLICABLE DOCUMENTS

References.	Document Title
1.	SPECIFIC CONTRACT ERA 2017 31 OP “Study on the architecture of on-board radio communication equipment”
2.	Terms of reference ERA 2017 31 OP “Study on the architecture of on-board radio communication equipment

1. INTRODUCTION

This is the Final Report of a "Study on the architecture of on-board radio communication equipment" (ERA 2017 31 OP) conducted by Systra on behalf of the European Railway Agency.

This Final Report consolidates and integrates the content, findings and recommendations that were developed under Interim Report #1 and Interim Report #2 of this study. The first of these focused on the overall end-to-end communication architecture, while the second covered on-board architecture options.

This study is one out of a sequence of studies performed or contracted by the ERA that collectively seek to ensure the future of European operational rail communications by planning for a successor to the current system, GSM-R. GSM-R does a reasonably good job of addressing current needs, but is expected to become uneconomic to maintain by roughly 2030 due to obsolescence of the underlying 2G mobile technology.

1.1 Purpose and objectives

This study has a focus on the evolution of on-board communication. It provides input to the ERA in order to assist them in updating the relevant portions of the mandatory standards in the CCS TSI.

As noted in the Terms of Reference issued by ERA, the main objective of the study is to provide information and conclusions on the most suitable options for on-board communication system architecture concepts so as to provide sufficient flexibility to support the current and future user needs, to allow changes related to other radio technologies, radio frequencies and applications during its lifetime (roughly between 2020 and 2040) at low cost for updating activities. The study addresses both software architecture and hardware architecture, with a focus on the radio applications which are currently mandatory in the CCS TSI.

As a secondary objective, the report provides background information and analysis of relevant requirements, standards, operational, technical and economic impact, certification and authorisation, and ongoing research activities.

1.2 Alternative approaches to a successor to GSM-R

UIC, ETSI and the Railway industry are currently leading the identification of railway requirements and the introduction of them in 3GPP further releases. This study aims to provide clarity of what is feasible for both options and what are the main risks, by providing a clear analysis of potential compliancy (3GPP gap analysis and OTT feasibility).

Many of the previous studies identified a strong interest on the part of the sector in the development of a *bearer-independent* successor to GSM-R that would fully de-couple operational rail communications from the underlying network. The standards development work done to date by the sector is not, however, fully bear-independent. Our terms of reference call on us to re-visit this issue and to assess the potential for fully bearer-independent *over-the-top (OTT)* solutions.

With that in mind, the first part of this report assesses two competing communication architecture approaches. One approach is based on 3GPP standards and specifications, and on services similar to those offered today by commercial Mobile Network Operators (MNOs). The other is based on Over-the-Top (OTT) services using IETF and 3GPP standards. Given that the industry has done little concrete work on fully bearer-independent OTT designs, we based our assessment of potential OTT approaches on a proof-of-concept design that we developed ourselves. Both designs seek to expand the set of bearers to include Wi-Fi and satellite. In the second part of the study, we analyse the impact of these options on the overall on-board architecture

Compared to the time this study was initiated, more and more attention is paid now to the on-board part of the overall architecture, where in the period before the focus was on network/trackside only. In particular ETSI and at S2R consider onboard as essential part of the technical architecture/concept of FRMCS. As their activities and developments are still ongoing, this report can only provide a snapshot of the current situation.

1.3 Questions to be answered

The study seeks to answer three over-arching generic questions:

- What could be the criteria to be taken into account when defining or selecting the architecture of the on-board (radio) communication
- What could be the options for this architecture
- Which architecture options are considered as the most promising ones

Within this general framework, the Terms of Reference call on us to answer a range of specific questions:

- General questions
    - Which existing and/or future requirement specifications for functions, performance, architecture, and interfaces can be considered as relevant for this study?
    - Is it possible to make railway specific applications (in particular the mission critical voice and ETCS data applications) fully independent of the bearer services, i.e. not requiring specific features in the IP based transport services (e.g. an "Over The Top" approach)?
        - can these applications provide compliant solutions?
        - what are pros and cons
    - When not or not fully, what (3GPP) features will be necessary to create compliancy?
        - Are these features already included in current or defined releases, or are additional features needed?
        - Are these features expected to be supported by user/terminal equipment and by public networks, or are specific agreements with suppliers and network operators/service providers required
    - Could the concept as used in the public domain smartphones (apps/android or similar) be applied in a critical communication environment (on-board, trackside, other user equipment) and what are the conditions for success. What are the possibilities, processes and constraints to develop, certify, distribute and maintain apps?
- On-board related questions
    - Taking into account the general questions, what could be options for on-board radio communication system architecture
    - What architecture options can create sufficient flexibility to cope with future developments, such as upgrading and maintaining on-board equipment (for both hardware and software), and taking into account the economic and operational impact of upgrade activities
    - How to prevent or minimise impact on the existing vehicle (train) certificates when updating/changing the onboard equipment
    - What is the (technical, economic) impact on the architecture when, additional to current 3GPP technologies, other technologies (such as Wi-Fi, satellite communication) have to be supported?
    - What standards could be applicable on (elements of) the on-board communication ecosystem
- ETCS specific question
    - What kind of changes of - or additions to - the current ETCS on-board equipment (EVC) would be needed to achieve that introducing the successor(s) of GSM-R can be done without impact on this updated ETCS equipment

1.4 Methodology

As previously noted, the study was conducted in two phases, the first addressing general architectural considerations for both trackside and on-board, the second drilling down specifically in on-board system issues.

Each reflected a standard project methodology based on desk research, interviews, and assessment of the results in order to develop findings and conclusions.

The key documents reviewed for the first and second phase of the project appear in annex 9 and annex 10, respectively. The questionnaires provides to stakeholders for the first and second phase of the project appear in annex 9.2.2 and annex 10.1, respectively. The list of interviewees for the first and second phase of the project appear in annex 9.3.3 and annex 10.2, respectively.

1.5 Structure of this document

This Final Report begins in Chapter 2 by reviewing the requirement that the UIC has identified for the Future Rail Mobile Communications System (FRMCS). The next three chapters review the characteristics (Chapter 3), assess the gaps that remain to be addressed (Chapter 4), and provide an overall assessment (Chapter 5) of 3GPP-based FRMCS approaches, using a proof-of-concept OTT design for comparison. Chapter 6 reviews the current situation as regards on-board equipment, while Chapter 7 assesses likely future developments regarding on-board systems. Our Findings and Recommendations appear in Chapter 8, as well as suggestions as regards “low-hanging fruit” where implementation might potentially begin even before the standards work is complete. We close with an Annex providing background material, including the list of interviewees for the study and the questionnaires that we used for the interviews.

2. REQUIREMENTS FOR THE FUTURE RAILWAY MOBILE COMMUNICATION SYSTEM

2.1 User Requirement Specifications

UIC started the Future Railway Mobile Communication System (FRMCS) project in 2012 to prepare the necessary steps towards the introduction of a successor of GSM-R. These first steps ended with the delivery of the first User Requirements Specification (URS) which is a gathering of all railway operational needs and not limited to the European Railways.

A second release was publicly available in June 2016 on the UIC website, and a third release by the end of January 2018.

The capture of railway needs is made through the Functional Working Group, which is one of the two working groups under the steering committee of the UIC FRMCS project. Members of this group are UIC members, and mostly European Railway users, part of the UIC FRMCS project. It has to be noted that more than 99% of the railway requirements come from European members. Chinese and Korea Railways showed interest in joining UIC FRMCS project, but no members are currently joining and attending UIC FRMCS project meetings.

The URS is a collection of existing and future needs for railway operations including six categories of applications (application is the name used to describe an operational scenario) based on the level of criticality for railway operations:

1. Critical communication applications (e.g. emergency communications, Automatic train Control, shunting…)
2. Performance communication applications (e.g. lineside telephony, public address…)
3. Business communication applications (e.g. wireless internet on-train for passengers…)
4. Critical support applications (e.g. role management and presence, multi user talker control…)
5. Performance support applications (for further study)
6. Business support applications (e.g. Billing information…)

It has to be noted that a subset of the applications will be candidate for the status of "mandatory for interoperability" in the EU legal framework (CCS TSI); this is subject to further analysis which is outside the scope of this report.

We agreed with the Agency (ERA) to focus our study on a subset of the URS applications to conduct our gap analysis between Railway requirements and both options, 3GPP based evolution and OTT evolution, in a timely manner and efficient way. This subset is the following (and will be the basis for section 4 on compliance analysis):

- Voice communication applications
    - On-train voice communication between the driver and the controller(s) of the train (URS FU-7100 sections 5.1 and 5.2)
    - Multi-train voice communication for drivers including ground user(s) (URS FU-7100 section 5.3)
    - Shunting voice communication (URS FU-7100 section 5.6)
    - Railway emergency communication (URS FU-7100 section 5.15)
- Data communication applications
    - Automatic train control (ATC) communication (URS FU-7100 section 5.9)
    - Automatic train operation (ATO) communication (URS FU-7100 section 5.10)
- Supporting applications
    - Secured voice communication (URS FU-7100 section 8.1)

- Multi user talker control (URS FU-7100 section 8.2)
- Role management and presence (URS FU-7100 section 8.3)
- Location services (URS FU-7100 section 8.4)
- Authorisation of voice and data communications (URS FU-7100 sections 8.5 and 8.6)
- Authorisation of application (URS FU-7100 section 8.7)
- Prioritisation or QoS class negotiation (URS FU-7100 section 8.8)
- Inviting-a-user messaging (URS FU-7100 section 8.11)
- Arbitration (URS FU-7100 section 8.12)

The URS also describes eight (8) fundamental principles to serve as a guidance for the development of the successor of GSM-R:

1. The FRMCS shall satisfy the needs of the operational railway.
2. The FRMCS shall support the automatic transition between bearer services or networks whilst continuing to support the voice and data applications that facilitate the operation of the railway.
3. The FRMCS shall place the human being at the centre of the design.
4. The FRMCS shall support the application of the harmonised operational rules and principles where available. For EU countries, these are defined in the technical specification for interoperability relating to the operation and traffic management [OPE TSI].
5. The FRMCS shall support machine to machine (M2M) communication.
6. The FRMCS shall mitigate the risk of miscommunication.
7. The re-use of installed base, for example GSM-R, shall be considered for FRMCS.
8. The FRMCS shall provide precautionary measures to prevent unauthorised access.

The URS is considered to be the reference document for railways to define their needs.

2.2 Functional Use Cases

The URS has then been translated into two other working documents to feed the 3GPP gap analysis: one to describe the functional use cases (UIC document FU-7110), and the other to describe the system principles use cases (UIC document AT-2504). 3GPP needs use cases to work on new requirements.

The Functional Use Cases, one for each the URS application, are intended to make the railway operational needs understandable by 3GPP. Functional use cases describe how to initiate, leave or terminate different kinds of communication applications and how the different use cases are linked to each other. These functional use cases are different from an operational point of view (e.g. different users with different roles are involved depending on the type of communication), but very similar in terms of communication aspects.

It is to be noted that no priority order has been established for the functional use cases. The Functional Working Group considers that all functional use cases are of the same level of priority and must be exhaustively included in the future system.

2.3 System Principle Use Cases

The Architecture and Technology Working Group of the UIC FRMCS project is in charge of developing the System Principles Use Cases, derived from the URS, to make the railway needs understandable as communication requirements.

UIC document FW-AT 2504 (System Principles Use Cases) is a working document, not publicly available, describing current set of eight system principles to be applied to FRMCS.

The current set of system principles is the following:

1. On-/Off-net Communication: a kind of direct link between handsets/on-board equipment for voice and data communications without any network assistance
2. End-to-End Network slicing for FRMCS: providing optimised resources by a commercial MNO for a gold member such as railways. It is not clear yet for the authors of the study why this “solution” is considered as a system principle.
3. Bearer Flexibility: as different qualities of service (QoS) are required for every single application, flexibility to adapt applications to available bearers based on QoS need is required. This concept shall allow ease of migration from 4G to 5G (if 4G is chosen as the first bearer to support FRMCS).
   Bearer independence is not used in the UIC document because UIC considered the concept inappropriate (e.g. ETCS could not be considered over Wi-Fi)
4. QoS in a Railway Environment: resource management with guaranteed bit rate. Latencies, packet error loss rates, session establishment delays and session loss rates are Key Performance indicators provided for each type of application. It is to be noted that some of the KPI are more stringent than with the GSM-R system. The explanation on such figures are not yet understood by the authors of the study (use cases are not clearly mentioned in this document to understand why such stringent figures are required).
5. Interworking between GSM-R (circuit-switched and packet-switched communications) and FRMCS
6. Interworking to External Networks (IP and non-IP networks such as PSTN)
7. FRMCS System Security Framework including requirements on confidentiality, privacy, integrity, availability and non-reputation.
8. Positioning Accuracy: figures for 2D positioning systems.

The following system principles will be introduced in a later stage:
1. Satellite: adaptation of application to bearer quality of service. Satellite access could play a role in 5G connectivity for the Railway community as already stated in 3GPP technical specifications TS 22.261 Service requirements for next generation new services and markets; Stage 1 recognizing the added value that satellite coverage brings, as part of the mix of access technologies for 5G, especially for mission critical and industrial applications where ubiquitous coverage is crucial.
2. Roaming between FRMCS systems.
3. Third-party information: interfaces between FRMCS system and external systems such as train tracking systems.
4. Availability and maintainability: fault-tolerant mechanisms.
5. Service awareness: exchange mechanisms between Application and Transport layers.

A few performance characteristics are still missing in those documents. We can mention the following:
- Capacity: what is the maximum/mean number of railway users in a multi-user communication or group call? This important figure has a direct impact on spectrum requirements and is required per cell.
- Coverage: mainlines, regional lines, high-speed lines, tunnels, railway stations, railway depots, shunting yards require different coverage levels depending on the applications to be delivered in those areas. For example, ATP requires more stringent coverage level than wireless internet on-train for passengers.
- Voice quality: this is a major performance indicator to provide quality report and compare OTT with VoLTE communications (please refer to GSA[2] report providing results and comparison of OTT versus VoLTE voice quality).

[2] https://gsacom.com/paper/volte-ott-voice-quality-report/

3. OVERALL ARCHITECTURAL HIGH-LEVEL PRINCIPLES

The architecture approaches shall provide different solutions to cover the Railway needs. As discussed in previous section, Railway needs encompass voice and data communication services considered either as generic communication services such as business as usual voice, SMS and data or as railway specific communication voice services and some supporting applications. Most of the data applications are not railway specific and we will focus on voice services and more precisely on voice over IP later in the document.

LTE networks are now largely deployed worldwide. With this large-scale deployment, Voice over IP (VoIP) solutions based on the Packet-Switched (PS) domain are gradually replacing legacy Circuit-Switched (CS) solutions (2G and 3G) to become the major mobile voice communication solution.

VoIP solutions include 3GPP based evolutions and Over-The-Top solutions:

- GPP based evolutions, with different solutions to support VoIP:
  - Voice over Long-Term Evolution (VoLTE), which is an IP voice services delivered over an LTE network,
  - Mission Critical applications, which are generic communication applications with mission-critical characteristics,
  - A combined architecture approach based on VoLTE and Mission Critical applications, and
- Internet-based voice applications also called Over-The-Top (OTT) voice applications such as Skype and WeChat (China).

The following sub-section 3.1.1 is focusing on VoLTE service, while the subsequent sub-section 3.1.2 deals with Mission Critical applications and combined VoLTE/Mission Critical approach. Following that, Section 3.2 focusses on OTT approaches to the problem, which is to say on approaches that do not depend on the capabilities of a particular mobile network, and the latest Section 3.3 focusses on IP addressing common issue.

3.1 3GPP-Based Evolution

3.1.1 Voice over LTE (VoLTE)

3.1.1.1 Description

Voice calls over LTE are recognised as the industry-agreed progression of voice services across mobile networks, deploying LTE radio access and IMS technologies, and becoming the new de facto standard to deliver voice services by biggest telecom operators[3].

VoLTE is in accordance with 3GPP specifications (starting from Release 8, the first release supporting LTE), IETF Internet standards (mainly Request For Comments (RFC) about UDP, TCP, SIP, RTP/RTCP and tel URI) and additional profiling is defined within GSMA Permanent Reference Documents, mainly GSMA PRD IR.92 – IMS profile for voice and SMS which is relevant for this study. This IMS profile identifies a **minimum mandatory set of features** defined in 3GPP specifications that a User Equipment (UE) and network are required to implement in order to guarantee an interoperable, high quality IMS-based telephony service over LTE.

Therefore, VoLTE is a GSMA profile of the 3GPP standard for the delivery of services currently provided via CS networks - mainly voice and SMS - over the PS-only network of LTE, leveraging the

[3] https://www.gsma.com/futurenetworks/volte-2-2/

core network IP Multimedia Sub-System (IMS). When mobile networks deploy LTE radio access technology, conformity to the VoLTE profile provides telecom operators with assurance of interworking between their LTE network and the devices that connect to it, as well as providing for the expected user experience of voice Multi-Media Telephony service and SMS. In combination with Policy Control, IMS provides for the required QoS appropriate for voice service using LTE radio access technology, thereby providing the user experience of voice calls that subscribers expect.

We noted during our interviews that global feeling is that VoLTE will be more and deployed and will continue in 5G.

3.1.1.2 Functions

The following functions are supported by a UE and a LTE network which are VoLTE-capable or VoLTE-compliant[4]:

- Incoming and outgoing conversational voice calls (audio calls) with high definition (HD voice)
- Public emergency call (112 in Europe) in the IMS domain (also known as IMS emergency call based on SIP, 3GPP and IETF specifications)
- Messaging service (SMS over IP or SMS over IMS)
- Supplementary Services as defined in 3GPP MMTel Technical Specifications 24.173:
  - Originating Identification Presentation (OIP) and Originating Identification Restriction (OIR)
  - Terminating Identification Presentation (TIP) and Terminating Identification Restriction (TIR)
  - Communication Diversion (CDIV): communication Forwarding Unconditional, on not logged in, on busy, on not reachable, and on no reply
  - Communication Hold (HOLD)
  - Anonymous Communication Rejection (ACR) and Communication Barring (CB) of incoming and outgoing calls
  - Message Waiting Indication (MWI)
  - Communication Waiting (CW)
  - Ad-hoc multi-party Conference (CONF)
- Interworking with other LTE-networks (PS) from other telecom operators, non-SIP networks (CS networks such as 2/3G networks and PSTN) and SIP PBX. This feature enables voice communications between User Equipment located in different networks (PS and CS domains). This feature is supported thanks to the EPC and the IMS.

It is important to note that an IMS multimedia telephony communication service could support more media capabilities such as real-time video, real-time text and data, transfer of fax but also more supplementary services as provided by GSM-R as CS speech supplementary services such as Closed User Groups (CUG) or Unstructured Supplementary Service Data (USSD).

3.1.1.3 Architecture

The VoLTE logical architecture is based on the 3GPP defined architecture and principles for VoLTE UE (User Equipment), radio access network (E-UTRAN), Evolved Packet Core network (EPC), and the IMS Core Network.

[4] https://www.gsma.com/newsroom/wp-content/uploads//IR.92-v12.0.pdf

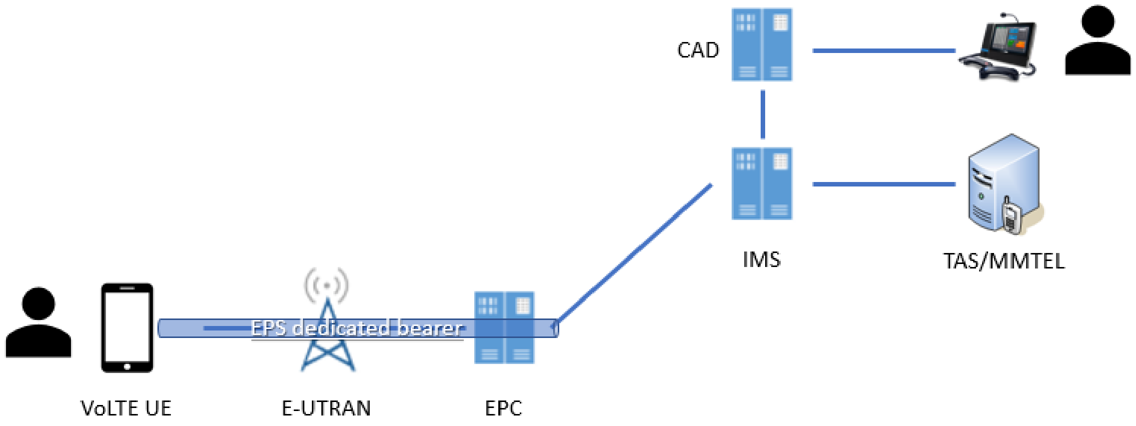

Figure 1. 3GPP/VoLTE block diagram

[1] Network resources are allocated by the network. The UE must deliver traffic in a GBR manner (buffers) in line with 3GPP TS 36.300.

VoLTE UE: the VoLTE UE contains functionality to access the LTE radio access network (E-UTRAN) and the EPC to allow mobile broadband connectivity. An embedded IMS stack and VoLTE IMS application are required to access VoLTE services.

Radio Access Network: the Evolved Universal Terrestrial Radio Access Network (E-UTRAN).

Core Network: the Evolved Packet Core (EPC).

IMS Core Network: the IMS Core Network within the VoLTE architecture provides the service layer for providing Multimedia Telephony. This essential element shall be deployed over LTE network by telecom operators prior to delivering VoLTE services (Voice over IP over LTE). 3GPP IMS adopted IETF protocols such as Session Initiation Protocol (SIP) but many extensions have been made to the core SIP protocol for management, security and billing reasons (3GPP IMS are more complex in 3GPP system than they normally are in the Internet). Those extensions were specified by IETF working groups at the request of the 3GPP. Therefore, the SIP protocol used in 3GPP is upward compatible with the SIP protocol used on the Internet. It is to be noted that not all SIP implementations are fully interoperable with one another.

Telephony Application Server (TAS): an IMS/SIP Application Server supporting a minimum set of mandatory **MultiMedia Telephony (MMTel) services** as defined by 3GPP e.g. supplementary service functionality and profiled within GSMA PRD IR.92 (IMS specific services). The Application Server can be located and operated by a 3rd party (not necessarily the telecom operator itself).

3.1.1.4 Resource Management

The concept of QoS in LTE is based on bearers. An LTE bearer is a transmission path through the radio access network and the core network with a defined capacity, latency and packet loss. Based on the requirements, a proper bearer can be allocated either dynamically or statically. When a User Equipment (UE) attaches to the network, it always gets a subscription-based default bearer (called EPS default bearer). Additionally, dedicated bearers can also be set up based on the subscription or can be added later on when needed.

Voice is one of the LTE services that require a guaranteed bit rate (GBR) bearer, although it is a very low data rate compared to LTE peak rates. The GBR bearer for voice requests dedicated network resources related to the Guaranteed Bit Rate (GBR) for AMR codec values. The network resources associated with the EPS bearer supporting GBR must be permanently allocated by admission control function in the eNodeB at bearer establishment. Reports from UE, including buffer status and measurements of the UE's radio environment, must be required to enable the scheduling of the GBR. In uplink, it is the UE's responsibility to comply with GBR requirements .

Prioritization in scheduling and queuing of admitted flows uses QoS Class Identifiers (QCI) which can have values from 1 to 254. QCI values from 128 to 254 are operator-specific and their attributes must be provisioned into the network elements as there is no standard way of propagating such information with control signalling. VoLTE service uses QCI 5 for SIP signalling and QCI 1 for voice media.

Standardised QCI can be found in [3GPP TS 23 series] (Policy and charging control architecture).

3.1.1.5 VoLTE protocol stacks

The UE and network protocol stacks forming the scope of the IMS Profile for Voice and SMS are depicted in the figure below:

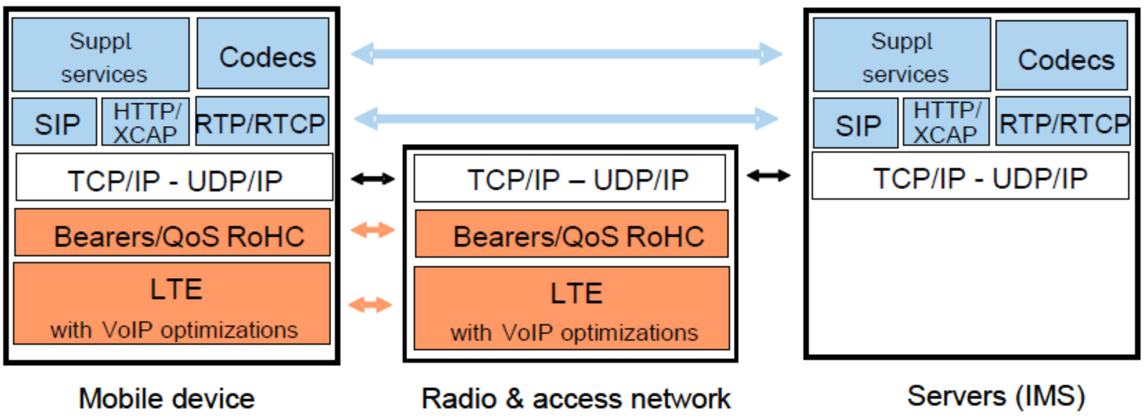

Figure 2. VoLTE protocol stacks (source: GSMA – PRD IR.92)

3.1.1.6 Interworking with 2/3G

VoLTE is designed to fully integrate with the existing user experience that is currently implemented with circuit switched voice User Equipment, and therefore whether the call is a CS call or a VoLTE call is **transparent to the end user** (including when moving in and out of LTE coverage) and is dependent only on which radio access technology the user is attached to.

VoLTE is designed to work over a Packet-Switched only network, namely LTE network (4G) firstly designed as a data-only path.

2G networks, the circuit-switched networks that are the baseline of GSM-R, are still used by telecom operators to provide voice communications for their customers, while LTE networks are mainly used for data communications providing a path to Internet and other data services.

Different mechanisms could be implemented by telecom operators based on their deployment strategy (LTE deployment and 2/3G deposit) to provide interworking between 2G, 3G and 4G networks.

3GPP addresses interworking of VoLTE services within the IMS domain and CS voice communications of a single telecom operator (including Supplementary Services) through Technical Specifications (refer to [3GPP TS 29.163]). For example, communications originating on VoLTE and breaking out to the CS network (2/3G) due to moving of UE losing the LTE/4G coverage (i.e. handover to 2/3G), are already addressed in the 3GPP system through a mechanism called Single Radio Voice Continuity Call

(SRVCC – refer to 3GPP TS 23.216). The same consideration happens in the 3GPP standard for communications originating on CS network (2/3G) and breaking into VoLTE. Supplementary Services are also considered in the 3GPP standard.

Another mechanism is the Circuit-Switched Fall-Back (CSFB), described in 3GPP TS 23.272, essential for telecom operators where IMS is not provided (which implies that VoLTE could not be delivered). When a User Equipment is attached to an LTE radio access network (E-UTRAN) and covered by both E-UTRAN and one another CS 2G/3G network of the same telecom operator (2G=GERAN or 3G=UTRAN), the UE automatically switch to the CS radio access network when provisioning voice communications. This is transparent to the UE. This mechanism is useful to telecom operators without any already-deployed IMS domain (not ready to deliver VoLTE to their customers) and should be implemented in a transition period before availability of fully compliant LTE/IMS/VoLTE network.

3.1.1.7 VoWi-Fi

VoWi-Fi is a complementary technology to VoLTE based on IMS technology to provide a packet voice service delivered over IP via a Wi-Fi network.

This feature is not further detailed in this report as not considered as a fundamental topic for this study, but VoWi-Fi is mentioned here just for the information.

3.1.2 Mission Critical Applications

Mission critical applications are generic communication applications with mission-critical characteristics, traditionally covering push-to-talk voice (MCPTT), real-time video (MCVideo) and real-time data (MCData). The acronym MCX is used instead of Mission critical applications, with X standing for PTT, Video or Data.

Mission critical applications can be defined as private and group communication services to exchange voice, real-time video or real-time data with strong performance (fast call setup times, low latency…), ability to handle large groups, strong security, priority and pre-emption handling on highly available, reliable and reachable transport networks (commercial and dedicated, not limited to LTE).

As only MCPTT are considered relevant for railway specific requirements, MCPTT is described later in this section as the architecture option to support voice over IP over LTE and supporting applications.

3.1.2.1 Description

Standardisation of Mission Critical Communications started with Mission Critical Push-To-Talk (MCPTT) within 3GPP, as such in accordance with 3GPP specifications (starting from Release 13). Prior to Release 13, 3GPP standardized functionality that was later to serve as an enabler or generic building blocks for Mission Critical Services such as:

- eMBMS (Evolved Multimedia Broadcast Multicast Services) and Group Communication System Enablers (GCSE) allowing public safety operators to implement LTE broadcast and multicast over E-UTRAN and the Core Network. The real need of Multicast for railways shall be studied based on traffic profile (maximum number of users per cell compared to spectrum availability => downlink bearers can be allocated as unicast i.e. multiple media paths with same content, or as multicast i.e. a single media path simultaneously to multiple users within a cell).
- D2D Proximity Based Services (ProSe) allowing public safety operators to determine whether critical communications occurs during on-network using the LTE network infrastructure, or off-network without the use of the LTE network infrastructure, or both.

MCPTT was the first major step of Mission Critical Communications, requested by the market. Mission Critical Push To Talk provides an arbitrated method to support voice communications between several users (group call), where each user has the ability to gain access to permission to talk. Mission Critical is referring to the ability to provide communication services with fast setup times, high availability, ability to handle large group of users, strong security, high reliability, priority handling and also specific features such as ambient listening and imminent peril call to enhance 3GPP service accessibility and quality.

As MCPTT reuses all of the LTE network elements (e.g. IMS/SIP core), developing MCPTT as an IMS application server allows telecom operators to leverage their investments in IMS made to support VoLTE, VoWi-Fi and future evolution of eCall (emergency call available for newly personal vehicles sold in Europe) in order to develop economies of scale.

A brief historical overview of standardisation of MCPTT within 3GPP is a specific point to keep in mind to understand the MCPTT services. The Push-To-Talk over cellular specified by OMA (called OMA PoC) was the foundation of MCPTT work. It is to be noted that a copyright agreement between OMA and 3GPP was made to allow the Open Mobile Alliance (OMA) Push-to-Communicate for Public Safety (PCPS) specifications - based on OMA Push-to-talk over Cellular (PoC) - to be used in 3GPP specifications as the foundation of mission-critical Push To Talk (MCPTT). First service requirements to develop MCPTT Technical Specifications were mainly elaborated by US and UK Public Safety community (e.g. FirstNet, USA Department of Commerce, UK Home Office, NPSTC, TCCA, APCO, OMA) to provide same features as already provided by legacy PMR systems such as P25 or TETRA.

Mission Critical Data (MCData) and Mission Critical Video (MCVideo) were added in Release 14.

Mission Critical Communications are further evolved in release 15 with the capability to interconnect 3GPP-based Mission Critical systems, interworking between 3GPP-based Mission Critical systems and legacy Private Mobile Radiocommunication (PMR) systems such as P.25 and TETRA for voice and short data service (e.g. SMS or SDS) and Mission Critical requirements for railways.

3GPP SA6 will have latest by May 2018 a work item ready that will study the impact of 5G. It is assumed that MCX-5G will be ready **3GPP Rel-16**.

Extract of WI FS_MCOver5G currently discussed at SA6 (16 to 20 April) to study MCX over 5G:

“3GPP has developed the 5G specifications, beginning in Release 15.

Based on input from 3GPP SA1, TSG SA#78 confirmed that the stage 1 Mission Critical specifications are applicable to LTE **and beyond, including 5G**.

Following up on the TSG SA#78 agreement the Mission Critical Services Architecture defined by SA6 needs to be reviewed to ensure that Mission Critical services are fully supported over 5G.”

3.1.2.2 Functions

The following functions are supported by a UE and a LTE network which are Release-13-Mission Critical compliant:

- User authentication and service authorization
- Configuration
- Affiliation and de-affiliation
- Group calls on-network and off-network (within one system or multiple systems, pre-arranged or chat model, late entry, broadcast group calls, emergency group calls, imminent peril group calls, emergency alerts)
- Private calls on-network and off-network (automatic or manual commencement modes, emergency private calls): full voice duplex call between two users without supplementary services’ capabilities

- MCPTT security: cryptographic protocols, authentication, access control, regulatory issues and storage control
- Encryption (media and control signalling)
- Simultaneous sessions for call
- Dynamic group management (group regrouping)
- Floor control in on-network (within one system or across systems) and in off-network: queue in priority order requests to speak, limit the time a user talk etc.
- Pre-established sessions
- Resource management (unicast, multicast, modification, shared priority)
- Multicast/Unicast bearer control, MBMS (Multimedia Broadcast/Multicast Service) bearers
- Location configuration, reporting and triggering including real time location information
- Use of UE-to-network relays

The following functions are supported by a UE and a LTE network which are Release-14-Mission Critical compliant:

- First-to-answer call setup (with and without floor control)
- Floor control for audio cut-in enabled group
- Updating the selected MC Service user profile for an MC Service
- Ambient listening call
- MCPTT private call-back request
- Remote change of selected group
- Plus, Release-13-MCPTT functions

The following functions are supported by a UE and a LTE network which are Release-15-Mission Critical compliant:

- Remotely initiated MCPTT call
- Enhanced handling of MCPTT Emergency Alerts
- Enhanced Broadcast group call
- Updating pre-selected MC Service user profile
- Temporary group call - user regroup
- Functional alias identity for user and equipment
- Multiple simultaneous users
- Plus, Release-13-and Release-14-MCPTT functions

3.1.2.3 Architecture

The MCPTT logical architecture is based on the 3GPP defined architecture and principles for MCPTT User Equipment (UE), radio access network (E-UTRAN), Evolved Packet Core network (EPC), and the IMS Core Network. MCPTT also leverages 3GPP enablers such as broadcast and multicast facilities (Group Communications System Enabler (GCSE) and enhanced Multimedia Broadcast Multicast Services (eMBMS)) and direct communications (Proximity Services (ProSe)). Those 3GPP enablers are considered to be the fundamental building blocks for supporting the group communications services in LTE (therefore being the fundamental building blocks of the MCPTT services).

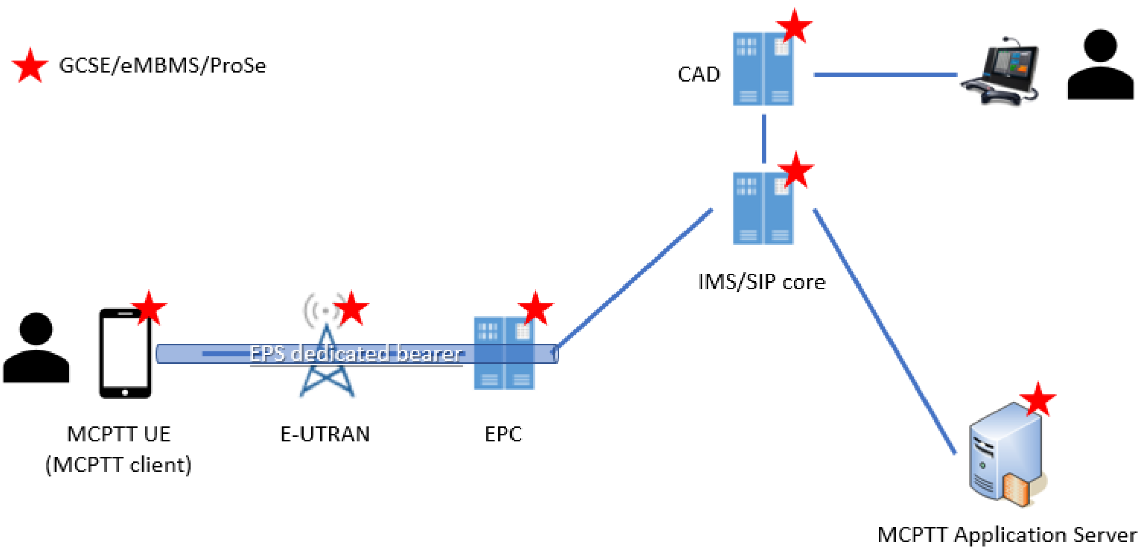

Figure 3. 3GPP/MCPTT block diagram

MCPTT UE: the MCPTT UE contains functionality to access the LTE radio access network (E-UTRAN), the EPC, the IMS/SIP core and the MCPTT application server to allow mission critical services. An embedded IMS stack and MCPTT IMS application (MCPTT client) are required to access MCPTT services. MCPTT client could be implemented as software application installed on 3rd party handsets. MCPTT client and MCPTT UE (hardware) could be fully decoupled to make it easy for end users to get access to the wide range of compliant Commercial-Off-The-Shelf (COTS) handhelds.

Radio Access Network: the Evolved Universal Terrestrial Radio Access Network (E-UTRAN).

Core Network: the Evolved Packet Core (EPC). The EPC provide both paths to unicast and multicast communications (unicast and multicast bearers).

IMS Core Network: the IMS Core Network within the VoLTE architecture provides the service layer for providing Multimedia Telephony. IMS uses IETF protocols such as Session Initiation Protocol (SIP).

MCPTT Application Server (MCPTT AS): an IMS/SIP Application Server providing support for a minimum set of mandatory Mission Critical Push-To-Talk services as defined by 3GPP (IMS specific services). The Application Server can be located and operated by a 3rd party (not necessarily the telecom operator itself).

3.1.2.4 Resource Management

The 3GPP admission control mechanism known as Allocation and Retention Priority (ARP) is valid for both non-GBR bearers and GBR bearers. Prioritization of GBR bearer for MCPTT service over regular VoLTE call could be supported. In that case, the dedicated GBR bearer for MCPTT call could have ARP priority higher than ARP priority of dedicated GBR bearer for VoLTE. If all GBR resources were consumed in a cell and pre-emption enabled, then a new MCPTT call could pre-empt an existing VoLTE call.

MCPTT is also one of the LTE services that require a guaranteed bit rate (GBR) bearer, as is the case for VoLTE. Every default and dedicated EPS bearer has a QoS class identifier (QCI) that defines its resource type (Guaranteed Bit Rate (GBR) or non-GBR), latency target, packet loss rate and priority level for scheduling. The original 3GPP Release 8 specified standard GBR QCIs from 1 to 4 and non-GBR QCIs from 5 to 9.

3GPP Releases 12 and 14 added additional QCIs for Mission Critical applications such as QCI 69 for delay critical MCPTT signalling and QCI 70 for mission critical data.

3.1.2.5 MCPTT protocol stacks

The UE and network protocol stacks forming the scope of the IMS/MCPTT are depicted in figure below:

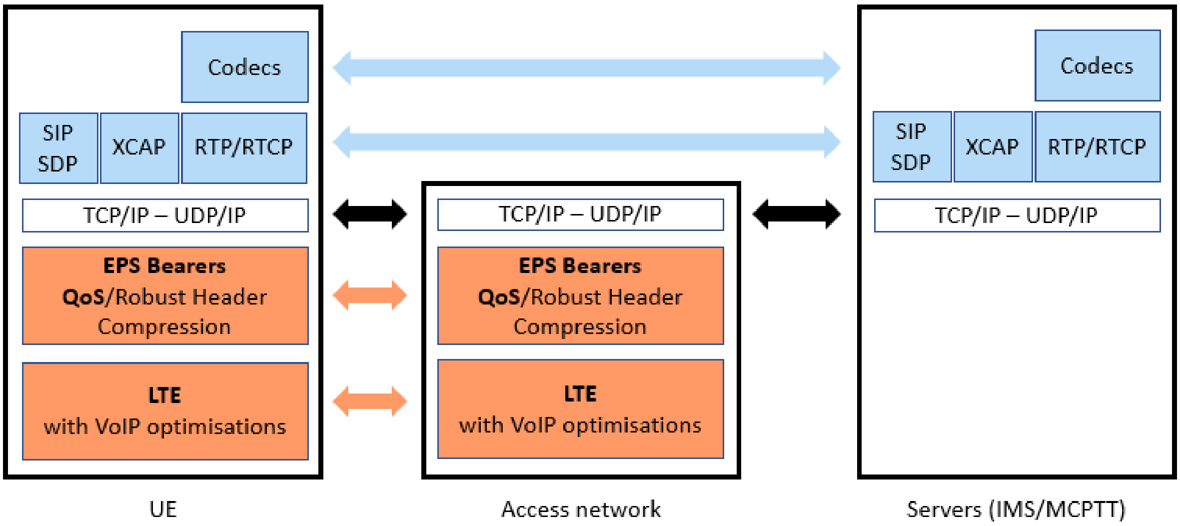

Figure 4. MCPTT protocol stacks

<u>Note:</u> Supplementary services are not (yet) standardised for Mission Critical Services (MCX) private (user-to-user) communications within 3GPP/IETF.

3.1.2.6 Interworking with 2G/3G

Public Safety is currently using Land Mobile Radio (LMR) systems which are not 3GPP-based networks such as TETRA/TETRAPOL in Europe or APCO P25 in the US. Therefore, they do not ask for interworking requirements between LTE network (all-IP network) and 2/3G networks (circuit-switched domain).

But they explicitly asked for the introduction of interworking facilities between LTE network (including MCPTT) and non-LTE systems such as TETRA and P25. This work item has been introduced by Public Safety to be standardised-ready from Release 15. The ongoing work will standardise interworking facilities for Push-To-Talk and short data messages to provide:

- Group calls over interworking groups (including group (de-)affiliation between groups defined in LMR and LTE/MCPTT systems)
- Private calls between users in LTE/MCPTT system and LMR systems
- Interworking for emergency related procedures
- Voice packet transcoding
- Interworking for one-to-one and group short data messages

Railways are asking for such 2G/3G interworking requirements (user-to-user and multi-user communications including GSM-R and FRMCS users), but these change requests have yet to be considered by 3GPP. In any case, 3GPP is already providing technical specifications to enable service continuity from Packet-Switched (PS) to PS networks and from PS to Circuit-Switched (CS) (and vice-versa[5]). Those mechanisms are already used by telecom operators to provide service continuity between VoLTE and legacy CS voice communications. As MCPTT and VoLTE are both based on IMS domain, they should probably be used as the foundation for interworking between Mission-Critical services and legacy CS voice communications, except if interworking requirements are requested between Advanced Speech Call Items (ASCI) calls and MCPTT calls. In that case, new mechanisms will need to be studied and then standardised by 3GPP members. But which companies within 3GPP would be interested in standardising such complex mechanism? What railway user would be ready to pay for such solutions for its migration phase? Other less complex solutions are likely to be considered by the Industry and by the Railway community.

3.1.3 Combined VoLTE and Mission Critical Applications (MCPTT)

3.1.3.1 Description

As presented in previous sections, VoLTE is the new de facto Telecom Operators' standard of delivering voice services over PS-only LTE networks. VoLTE includes similar voice services as the ones provided by legacy CS-networks such as one-to-one voice communications, supplementary services and interworking facilities to external networks.

For its part, MCPTT provides one-to-many voice communications (group communications) over PS-only LTE networks without supplementary services. The overall architecture looks quite similar as the VoLTE architecture but additional 3GPP features such as GCSE/eMBMS are considered essential features to make MCPTT works. It is important to note that MCPTT also provides private calls which are one-to-one voice communications such as VoLTE.

But would it be possible to combine VoLTE and MCPTT voice services to provide a full set of communication services for the Railways?

3.1.3.2 Architecture

Technically it is feasible to combine both VoLTE and MCPTT within a single network as depicted in figure below (this is one option supported by one IMS/SIP core and two application servers with one or two APN based on QoS requirements, one option amongst many) but restrictions occur in interworking of services. As Public Safety does not (yet) require interworking with VoLTE services (one-to-one calls are already supported by MCPTT), no specifications to date have supported communications between UEs involved in respectively VoLTE and MCPTT calls.

[5] Service continuity provides ability of the system to continue services such as ongoing voice call without interruption when users are moving from CS to PS e.g. moving from a 2G cell to a 4G cell.

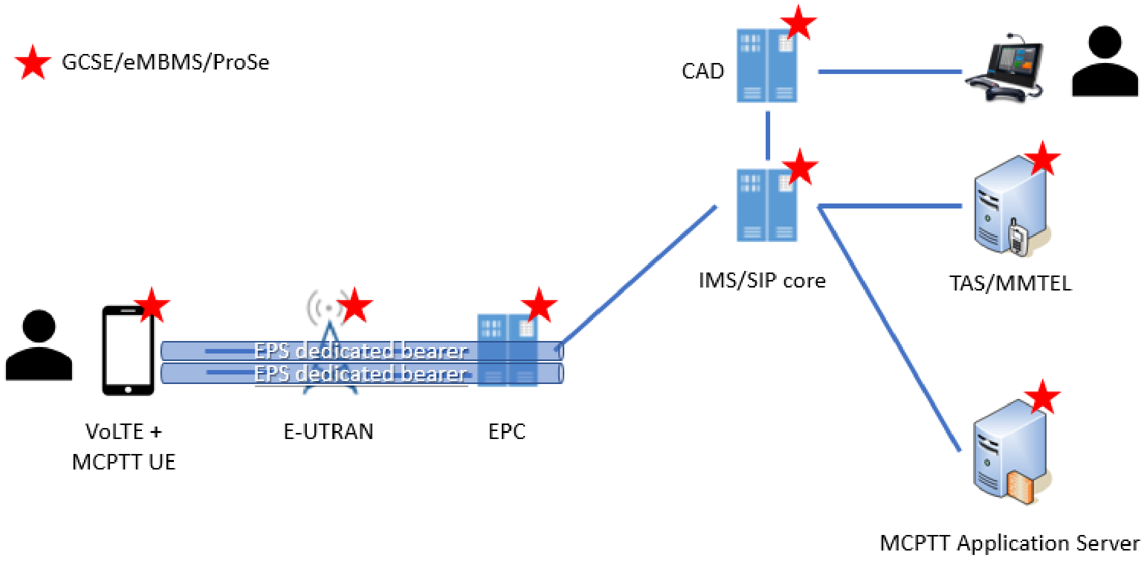

Figure 5. VoLTE + MCPTT block diagram

It is to be noted that some Public Safety organisations made the choice of MCPTT-only architecture where VoLTE could be separated and supported by telecom operators. UE that are both VoLTE- and MCPTT-capable can bring benefits of both voice services depending on location and network attachment (different end users with different needs).

3.2 Over-The-Top (OTT) IP-based Evolution

Every study that we are aware of[6] has seen merit in a non-3GPP fully over-the-top solution as a future solution to operational rail communication needs.

There are a number of advantages that might potentially flow from a full de-coupling of operational rail communications from specialised features of the mobile network:

- Ease of adding new applications to the operational rail communications environment.
- Ease of adding support for new transmission media, including networks that do not provide specialised support for operational rail communications.
  - Potential ability to use satellite communications, especially in remote areas (subject to suitable planning for delay characteristics, as noted in Section 3.2.3.3.4).
  - Potential ability to use Wi-Fi communications, especially in shunting areas and stations (again subject to suitable planning for delay characteristics, as noted in Section 3.2.3.3.3).
- Simplification of any future migration of the operational rail communications environment.
- Potentially greater vendor independence in procuring operational rail communications equipment and software.
  Note: 3GPP-based evolution should allow vendor independence (Telcos and MCX vendors) due to open interfaces.

[6] See Lovan Pushparatnam, Guillaume Gach, J. Scott Marcus, Catherine Maton (2017), "Study on Implications of the bearer independent communication concept"; J. Scott Marcus and Frédéric Pujol (2015), "Evolution of GSM-R"; and David Taylor, Nils Lofmark, Maria McKavanagh (2014), "Survey on operational communications (study for the evolution of the railway communications system)", all of which were conducted on behalf of ERA.

Despite these substantial advantages, the sector has apparently not been motivated to do concrete work to plan for a migration to this comprehensive form of bearer independence. In our literature search and in our interviews, we have identified a number of stakeholders who have considered the idea of OTT solutions, but we have not identified any serious work at all that seeks to standardise a version of FRMCS on a basis other than 3GPP standards and MCPTT.

The various VoLTE and MCPTT solutions seek to capitalise on economies of scale with 4G and 5G. The OTT solutions potentially benefit from synergies with internet transmission networks and services in general, and with OTT voice services in particular. OTT voice services have significant scale economies of their own, and they are growing – to the point where traditional network operators frequently complain about loss of market share. For international voice, a stronger area for OTT voice solutions than domestic, the traffic in billions of minutes per year for the Skype OTT voice service alone already exceeded that of all network operators worldwide put together in 2012, and it continues to grow.

Skype is a large OTT voice service provider, but there are more – some standards based, some proprietary. Bearing that in mind and considering the growth rate that is visible in, the aggregate OTT international voice traffic can be presumed to greatly exceed that of traditional telecommunications today in 2018. There are no current indications that OTT voice is going away any time soon.

Figure 6. Increase in international phone and Skype traffic.7

There are some experts who might argue that the voice services offered by network operators will eventually supplant OTT services once 5G is widely available; others might argue the reverse, that the days of non-OTT voice are numbered. Indeed, OTT messaging services such as WhatsApp have already decimated SMS services offered by the network operators. Nobody can predict this with certainty, but our belief is that MNO voice services and OTT voice services will co-exist in the market for some time to come, and that both will enjoy scale economies.

[7] Telegeography (2014), "Skype Traffic Continues to Thrive", 15 January 2014, viewed 26 December 2015, at https://www.telegeography.com/products/commsupdate/articles/2014/01/15/skype-traffic-continues-to-thrive/, as quoted in ITU Study Group 3 (2017), "Economic Impact of OTTs: Technical Report".

3.2.1 Description

We define the OTT solution as being any potential technical means of achieving the functional requirements of GSM-R, taking into account requirements identified by FRMCS, in a way that it is totally independent of the underlying network (other than its QoS capabilities such as availability, latency, and reliability).

As we explain in Section 3.2.3, since neither our interviews nor our desk research were able to identify serious sector efforts to define such a solution in detail, we are providing a candidate solution ourselves (a proof of concept) as a basis for discussion in this chapter. The high-level design appears in Section 3.2.3. The properties of an OTT approach are best understood in terms of that design, which serves as a basis for analysis and comparison throughout the balance of the report.

3.2.2 Functions

We assume in general that all current GSM-R requirements must be fulfilled by any OTT solution. We also assume that FRMCS requirements are relevant, except to the extent that they might be driven by the intended implementation rather than by rail functional needs.

This is the natural starting point for planning. In a number of instances, we have however identified GSM-R specific functionality that is currently slated for inclusion in FRMCS where some re-thinking might substantially simplify the FRMCS design, and might avoid needless standardisation and implementation cost. Candidates include:

- Stringent availability and latency in settings where they might not be strictly required to ensure safety (see Section 3.2.3.3.3).
- Simplification of requirements for Group Call and Rail Emergency Call (REC).
- Redesign and simplification (or possibly elimination) of features that are rarely if ever used.

In designing the OTT solution, we have found reasonably straightforward ways to implement Group Call and REC; however, the interworking with GSM-R (when for example some trains have only GSM R connectivity and others have no GSM-R connectivity) could potentially become exceedingly complex. We suspect that GSM-R to FRMCS interworking will likewise be complex. Furthermore, to the extent that both GSM-R and FRMCS solutions might co-exist at the same time as OTT solutions, design and implementation of the interworking solutions becomes truly daunting (see Section 3.2.3.4).

Anecdotally, we understand that the use of Group Call in practice differs from that anticipated by the standards. In practice, the average Group Call involves four participants, the maximum some twenty participants (i.e. not the 256 participants envisioned in the standards). In the case of Rail Emergency Call, the crucial communication is generally between the train driver who placed the call and the responsible controller, with other train drivers for the most part listening. We speculate that the push to talk function may be less critical than has generally been assumed in this scenario, and also in the scenarios where there are few participants to the Group Call.

We also understand anecdotally that some GSM-R features are used rarely if ever. For example, our understanding is that the Shunting Emergency Call is never used. This does not mean that the function is not needed; rather, it means that the need is being met in other ways, for example using Tetra (PPDR) technology.

These considerations strongly suggest that the sector could potentially profit from some re-thinking of requirements, rather than mechanically carrying over all of the requirements of the current GSM-R system.

This observation is in line with comments from several interviewees that requirements for FRMCS may be subject to "mission creep" that might not only endanger standardisation efforts, but might also lead to prohibitively high deployment costs.

In addition to current GSM-R functionality, we also recognise a long-standing strong interest on the part of the rail community in supporting additional communication media, notably satellite and Wi Fi, and place strong emphasis on both.[8] (The 3GPP solution has also established a satellite solution as a goal.) This is challenging no matter what solution is chosen because it is difficult for satellite or Wi-Fi to meet the availability and latency requirements of operational rail (see Section 3.2.3.3).

3.2.3 Architecture

Our Terms of Reference call on us to assess OTT solutions and to compare them with 3GPP solutions; however, neither our interviews nor our desk research have identified any serious work in the sector to create a design for an OTT solution (see Section 3.3). It is not possible to compare something (initial glimmerings of a 3GPP design) with a non-existent OTT design. In order to fulfil our Terms of Reference and to provide a meaningful assessment, and in light of the dearth of activity by the sector, we have felt ourselves obliged to provide our own informal, high level design as a proof of concept. This then affords a basis on which to consider what might be required in terms of (1) standards evolution and of (2) eventual product development.

The proof of concept seeks to fulfil the same basic requirements that were set forward in Section 2.2, with particular emphasis on those that ERA encourages us to emphasise. We have attempted to provide a high level conceptual sketch in order to demonstrate that the problem can be solved, but not to provide a detailed design for implementation.

We made a critical design choice to base the proof-of-concept design on the Session Initiation Protocol (SIP). For many reasons, this seems to be an obvious choice:

- SIP is a successful and widely implemented protocol – there is substantial experience with it, and the experience is generally good.
- There is a substantial base of existing software technology and tools, including a popular open source server implementation, Freeswitch.[9]
- SIP is the basis of the IMS, which is at the core of VoLTE, VoWi-Fi, MCPTT and future carrier services such as eCall. Much of the work already being done to design and implement FRMCS on a 3GPP basis can be re-purposed for an OTT solution on this basis.
- It might well be the case that some software developed to run in a 3GPP-based FRMCS can be converted at reasonable cost to run on a pure SIP basis. This might potentially offer the additional advantage that the graphically user interface to which rail staff have become accustomed is to some degree preserved.
- SIP also supports all kind of embedded information like sub-addressing or functional numbering as attached XML.
- Further conferencing, user mobility, ENUM, sequential calls to different functions within one physical address and parallel calls are possible with SIP.

This is not to say that a SIP-based solution is the only possible OTT solution. Many other approaches will have their advocates. For example, an approach could surely be worked up based on the basis of Web Real-Time Communication (WebRTC), a free, open source solution that offers simple Application Programming Interfaces. For our purposes, however, it is sufficient to put forward a

[8] This was already visible in J. Scott Marcus and Frédéric Pujol (2015), "Evolution of GSM-R".

[9] https://freeswitch.org/

single, workable proof of concept design as a basis for discussion and it would be a rational decision to use SIP.

3.2.3.1 High level architectural design

As already explained, we have made the strategic decision to base our proof of concept design on SIP.

Relative to the macro-architecture of VoLTE together with MCPTT that appeared in Figure 5 : VoLTE + MCPTT block diagram, this is in some sense not a large change. Instead of an IMS/SIP server inside the network, there is a now a stand-alone SIP server outside the network(s) (or more likely at least two so as to ensure redundancy).

This macro architecture is visible in Figure 7: Macro architecture of an OTT version of FRMCS. As in the VoLTE/MCPTT version, the UE (for instance a train driver) uses the UE to communicate over a wireless network, which in this case is not necessarily a 4G network. Data communications flow through a router and typically through an internal access network so as to reach proxy SIP servers, the called party (e.g. a controller) for a voice call, or an ETCS server for train control.

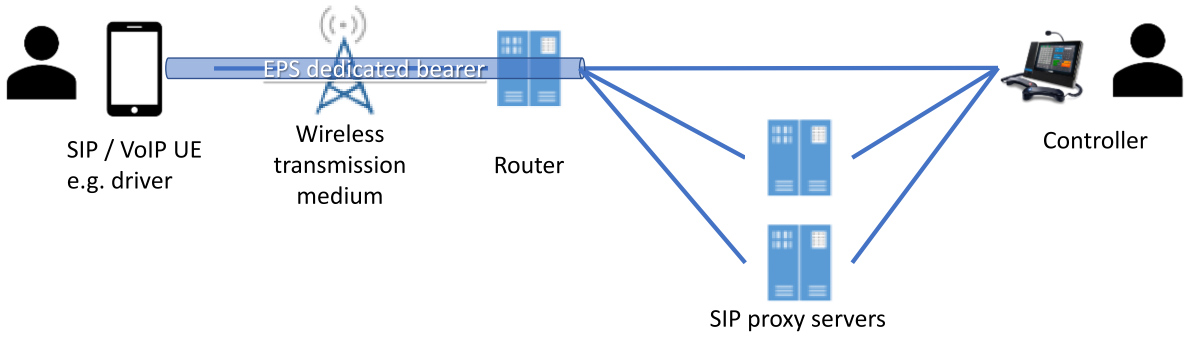

Figure 7. Macro architecture of an OTT version of FRMCS.

3.2.3.1.1 Implementing voice functionality

SIP provides the basic functions needed to enable the initiation of voice sessions, including functionality to initiate a session (e.g. make a call), to add users to a communication, to pre-empt, or to end a session.

As with IMS/SIP, once the session has been initiated, the voice communication RTP traffic does not flow through the server, but rather proceeds directly to the destination system. The protocol flow of the data is not very different from that previously depicted in Figure 3: 3GPP/MCPTT block diagram for MCPTT, as shown here in Figure 8: Protocol flows for voice services in the proof of concept OTT design.

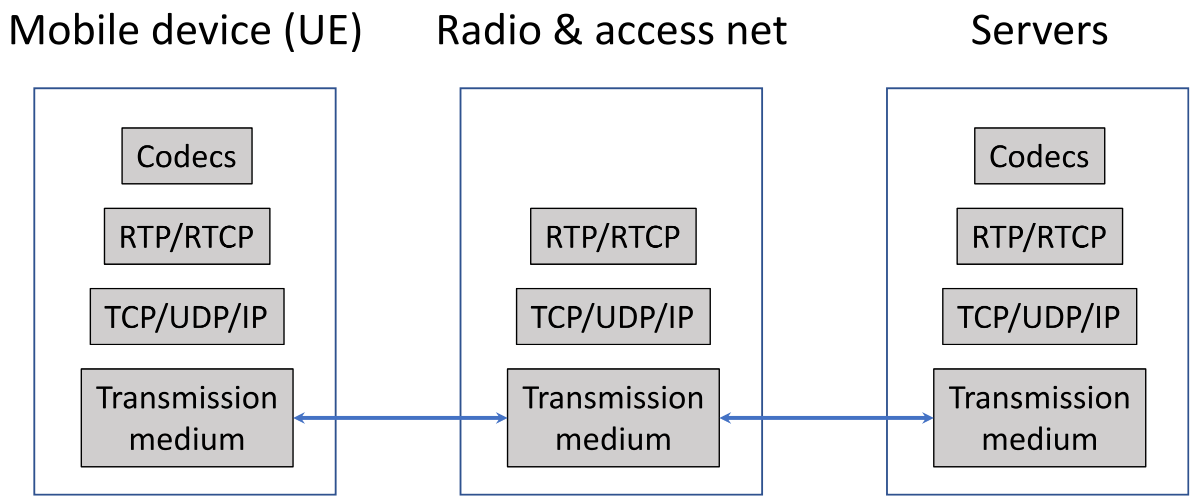

Figure 8. Protocol flows for voice services in the proof of concept OTT design.

3.2.3.1.2 Identifying the location of the train

We address the issue of train location here because (1) knowing the location of the train is essential to meet a number of critical operational rail functional requirements, (2) the most common solution used under GSM-R and presumably under the rail MCPTT solutions (which have not yet been specified) cannot work independent of a solution embedded in a mobile network, and (3) the sector does not appear to have considered the problem as yet.

We explain the determination and use of train location under GSM-R (Section 3.2.3.1.2.1) under the 3GPP solution as currently specified (Section 3.2.3.1.2.2), and under the proof of concept OTT design that we are providing for discussion (Section 3.2.3.1.2.3).

3.2.3.1.2.1 Determination and use of the train location under GSM-R

The train location is essential for two main reasons in GSM-R today:

- **Location Dependent Addressing (LDA)**: LDA is used for driver to controller communications. Communications originated by the train driver are automatically routed to the most appropriate controller, based on the controller's area of responsibility. Note that controller area boundaries can be changed dynamically (e.g. to allow for peak and off-peak periods). LDA is also used by ERTMS for automatic routing to most appropriate RBC based on the RBC's area of responsibility.
- **Railway Emergency Call (REC)**: REC initiates an urgent, pre-emptive call to the responsible controller and to potentially impacted trains. The location of the train placing the REC is needed when establishing communication is dependent on location such both to identify the responsible controller (as with LDA), and the location of all trains is needed in order to identify potentially impacted trains in a pre-defined area where the REC has been setup.

The implementation of REC under GSM-R uses LDA based on location of the train to route the high-priority group call to the most appropriate controller. In order to route the high-priority group call to potentially impacted trains, the group call is established from the serving cell (called n) of train that originates the REC to previous and next cells (called n-1 and n+1), and sometimes extended (n+2, n 2).

The location of the train placing the REC is clearly fundamental both for LDA and for REC. REC also depends on the location of other trains. How is the location obtained under GSM-R?

According to the EIRENE specifications, the current cell or base station serving the train's UE should be used at a minimum. Additional sources could be added to increase accuracy such as balises, GPS, an interlocking system, or ATC.

In practice, the cell ID serving the train's UE is used as common implementation to locate the train

3.2.3.1.2.2 Proposed determination and use of the train location under the 3GPP solution

The train location is just as important in the 3GPP rail MCPTT solution, based on the current requirements documents, and for the same reasons as under GSM-R. LDA and REC are required.

Under FRMCS requirements, the location is to be determined by using some combination of the track position (determined by an interlocking system, ATC, balises, RFID, GPS/Galileo, or from the FRMCS system (based for instance once again on the cell ID)) in conjunction with the direction of movement.

The direction of movement is intended to be used to limit the operational impact of an REC to only those trains likely to be impacted by the REC. For example, a nearby train might be moving in a different direction and outside the REC area, with no possibility of being impacted.

At the moment, there are requirements documents, but no reliable implementation documents.

3.2.3.1.2.3 Proposed determination and use of the train location under an OTT solution

Under GSM-R today, determination of the location of the train is based in practice on the cell ID, and is thus implicitly a function of the network to which a particular train currently has connectivity. Determination of potentially impacted trains for REC is based on adjacency of cells, and is thus likewise dependent on the network.

In a fully network-independent implementation, the cell ID information would not be reliably available, and might not be available at all for trains that are connected only via satellite or only via Wi-Fi. Consequently, a design is needed that does not depend on the cell ID, nor on the cell IDs of nearby trains (to determine potentially impacted trains for the REC function).

A shift away from primary reliance on the cell ID is arguably desirable for other reasons. There have been long-standing concerns that the cell ID does not represent a sufficiently granular indication of the train's location, especially when the train is close to the border of a controller zone of control.[10]

In the most obvious design, external servers keep track of the train's location, which can then be mapped against the location against the boundaries of the controllers. (This may seem radical, but our understanding is that it is already the case that some implementations of enhanced Location Dependent Addressing (eLDA) function partly outside of the network.) As we note shortly, there are many potential sources for the location of the train.

In the general case, once the train location is known, identification of the responsible controller for LDA purposes can be implemented by means of a simple point-in-polygon algorithm – the location of the train is the point, the controller's domain is the polygon. There are a potentially large number of controller responsibility polygons, and the software needs to allow for shifts over time (to allow for instance for a shift in controller responsibilities during off-peak hours), but this is easily within the capabilities of modern computer systems.

[10] The UIC's 2002 "Functional Requirements Specification for enhanced Location Dependent Addressing" already observed: "It is recognised that the accuracy of cell dependent addressing is not sufficient for all operational scenarios. … To provide a greater degree of accuracy, additional information from (external) location information sources is necessary."

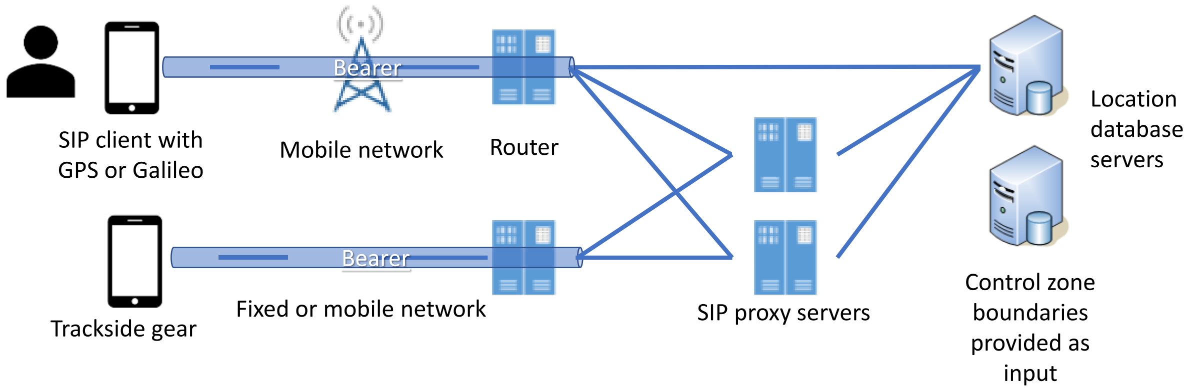

Figure 9. Maintaining location information as regards the train.

There are multiple possible ways to determine the location of the train. We suggest that more than one source report the location back to the servers (again more than one, again for reasons of redundancy). The information potentially available for determining the location of the train includes the supplementary information available contemplated under EIRENE (balises, GPS, an interlocking system, or ATC) plus some additional options identified under FRMCS (RFID, Galileo). Further elaborating or expanding on those options:

- Under ETCS2, the train should have a good sense of its location thanks to the Eurobalises and train odometers. Between two positioning beacons, the train determines its position via sensors (axle transducers, accelerometer and radar). This location is required for automated train control.
- On-board equipment might otherwise know the location by means of GPS or in the future by means of Galileo.
- Trackside equipment may be able to report the location of the train directly to the servers.
- The server itself could make a sanity check based on the last known position of the train and its known velocity and direction.

What should be done if the location reports do not match? There is an old Dutch proverb: “Never go to sea with two compasses. Take one or three.” The location server will need to have an algorithm that makes informed judgments in this case. If a report based on ETCS2 or later is available, it should probably always be assumed to be the best.

As the train moves, it will progress from one controller’s zone to another. The location server will presumably note this and can transmit the identity of the new controller to the onboard equipment for use in any subsequent attempts to call the controller. Providing this information in advance saves time and avoids certain risks of failure in case of an emergency.

If a call is in progress when the train crosses into another controller’s zone, it is not a concern. Standard practice today is that the call is maintained until one of the authorised users releases the call. No special handling appears to be required.

Late entry is also a railway feature to be considered in the design phase, allowing trains entering the REC area to be involved in the call. A continuous tracking of the location of all trains shall be considered in the design phase.

As non-train users such as maintenance workers could also be involved in a REC, identification and location of those users shall also be considered in the design phase.

3.2.3.1.2.4 Possible implications of the OTT design for the FRMCS 3GPP solution

As far as determination of the location of the train, the requirements for the 3GPP solution have been established, but the design has not. So far as we can see, there is no reason why a design along the lines of that which we have proposed for the OTT solution could not be considered for the 3GPP solution as well.

Whether location information is transmitted from trackside or onboard equipment, if it is transmitted by means of the IP protocol, it can just as easily be transmitted to secure external location servers as to servers inside the network.

The cell ID is known to the network, not in general to onboard or trackside equipment. There is no reason why the network could not send this information in an IP data stream to the same servers; however, since there are other and better sources of location information (see Section 3.3.3.1.2.3), the implementation of OTT train location in the 3GPP solution does not depend on the availability of cell ID information.

The most noteworthy challenge to taking this approach in a 3GPP solution world has to do with using the location information when placing calls. The location information that is outside the network must somehow steer point-to-point calls, Group Calls and REC that are typically implemented within the network.

There are multiple ways to solve this problem, some arguably more attractive than others. Among them, a few obvious alternative options are:

- The location server(s) could report the train's position back to the network. This seems unattractive to the extent that dependence on specialised network features is perpetuated.
- The location server(s) could report relevant dial codes to a device on the train (probably the cab radio) using OTT IP-based communications. For example, the dial code of the responsible controller would be provided to the train whenever the train passed from one zone of control to the next. A call to the responsible controller would then be routed directly to the correct primary controller. A similar approach could be used to identify potentially impacted trains for REC.
- The Group Call and REC functions could be implemented in a fully OTT manner, even if point-to-point remains within the network. This implies a blending of OTT and 3GPP approaches. In terms of possible future interworking between 3GPP and OTT solutions if that were ever to be needed (see Section 3.3.3.4), it greatly simplifies matters (since there would be no need to map 3GPP solution push to talk within the network to OTT push to talk outside of the network).

One could perhaps also consider retrofitting such a solution to GSM-R. Whether the complexity of software changes to deployed GSM-R systems is warranted is not something that we have analysed.

3.2.3.1.3 Identifying roles and responsibilities

When the user first brings up the equipment, he presumably also needs to identify his role (e.g. driver or controller). This is not significantly different than the MCPTT case, except in that once again servers external to the network will have to keep track of things.

3.2.3.2 Special voice features

Exchanges with very senior SIP experts[11] confirm that the SIP protocol already provides the essential building blocks for Group Call, Push to Talk,[12] and more. Special attention may be required, however,

[11] Henning Schulzrinne and Richard Shockey.

for the Supplementary Services (Call Hold, Call Forward, Call Completion on Busy Subscriber, and more …) that GSM-R inherited from GSM. This is a topic for further analysis.

They also claimed that there were no significant scalability problems. Existing SIP implementation can handle as many as 1,000 group call participants simultaneously, which is greatly in excess of known requirements for rail operations.

We have not yet identified a fully carrier-independent implementation of Push to Talk, but all indications (including the view of our expert interviewees) is that it would be straightforward to implement Push to Talk over SIP.

Direct Mode should also be straightforward. We assumed in Figure 7: Macro architecture of an OTT version of FRMCS. That most deployments would use a proxy server as a locus of control, and perhaps of admission control; however, the SIP protocol is inherently peer to peer. In other words, if the SIP INVITE message is sent directly to a UE device, a session can be established directly without intermediation. This presumes that the UE initiating the call already knows the identification (URI) of the target UE.

3.2.3.3 Quality of Service (QoS)

In the Rail sector, the discussion of OTT successors to GSM-R has largely been formulated in terms of Over-the-Top (OTT) services. This formulation is largely correct to the extent that the services would not depend on the network; however, in terms of QoS, it calls to mind services like Skype that have largely unpredictable performance.

This characterisation can be seriously misleading. Future operational rail communication systems are not going to run over an arbitrary mix of bearers, as Skype must. Future operational rail communication systems will necessarily run over a small number of bearers where the entity that provides the FRMCS environment (typically the IM, which we assume in the text that follows) has carefully considered the transmission characteristics so as to ensure that QoS requirements can consistently be met for the services required, whatever they are.

In the sub-sections that follow, we begin with a discussion of prioritisation, pre-emption, and admission control. We then consider mobile networks, Wi-Fi networks, and satellite networks in that order, in each case assuming that there is only a single hop. Finally, we discuss the multi-hop case (where there is more than one IP data transmission medium in the path).

3.2.3.3.1 Prioritisation, pre-emption, and admission control

QoS requirements were already discussed at length in Section 2.2. A few observations are worth re-emphasising at this point:

- Requirements for voice service are substantially different than those for data.
- Careful management and prioritisation is likely to be need for both in order to meet requirements of reliability and latency.
- Latency requirements for train operation using ETCS2 (and presumably successors) are quite stringent.

Implicit both in current TSI requirements and in FRMCS requirements is the need to manage capacity. The ETCS2 function for instance neither can be de-railed by normal operational rail traffic, nor

[12] See for instance IETF (2006), “A Session Initiation Protocol (SIP) Event Package and Data Format for Various Settings in Support for the Push-to-Talk over Cellular (PoC) Service”, RFC 4354.

certainly by unrelated traffic. When a Rail Emergency Call (REC) is initiated, it pre-empts other calls to the same users.

The main mechanisms that suggest themselves for traffic management are prioritisation, pre-emption, and admission control.

The Ipv4 protocol always contained a field for prioritisation (and this continues to be the case with the successor protocol Ipv6), but it was not consistently used in the past, and typically was not honoured by routers. As previously noted, the FRMCS will comprise a largely or fully special purpose IP-based network within which it should be quite workable to favour prioritised traffic over non-prioritised. This in and of itself could address many of the requirements, assuming that the underlying networks have sufficient overall capacity. It is to be noted that IP has been designed for Internet (fixed networks) and not for radio/cellular networks such as GSM-R. Industry should consolidate feasibility of such IP prioritisation for radio/cellular networks.

Pre-emption of non-REC voice calls is a function that could be implemented using standard capabilities of the Session Initiation Protocol (SIP). This is not implemented in all current SIP products, but we are not talking about standard SIP products since we have other needs such as Group Call and Push to Talk.

Finally, there is the possibility of using admission control to manage capacity at times of resource scarcity. If network capacity falls below a certain critical threshold, SIP would refuse to initiate more calls unless they were somehow defined as being of critical importance. In a more extreme case, calls that are already under way might be terminated if they were not deemed as being critical.

A challenge with admission control is that it would require a good practical definition of criticality. It is clear that a Rail Emergency Call pre-empts other traffic, but many other calls could potentially be prioritised. This is not a protocol or technical question, but rather a practical, operational resource management question. It is quite likely that MCPTT will have to address the same issues, in which case a subsequent OTT FRMCS might follow the same logic.

3.2.3.3.2 Mobile networks

Where the IM itself constructs or procures a mobile network, similar consideration applies to those which we experience today. The engineering of the network must provide sufficient coverage and capacity, as well as sufficient QoS in terms of Key Performance Indicators (KPIs) relevant to the services that the network must provide.

There has been growing interest in arranging for a commercial service provider to supply the FRMCS network instead (albeit not necessarily in all parts of the national territory).[13] If the services were provided using a 5G-capable network, that might well be done using network slicing technologies based on Software Defined Networks (SDN) and/or Network Function Virtualization (NFV).[14] If the services are provided by a mobile network that is not operated solely for operational rail

[13] See J. Scott Marcus and Frédéric Pujol (2015), "Evolution of GSM-R"; and Simon Forge, Robert Horvitz and Colin Blackman (2014), "Is Commercial Cellular Suitable for Mission Critical. Broadband?".

[14] SDN could in principle be applied to pre-5G networks, but we know of no initiatives to do so. By contrast, use of SDN is expected to be widespread for 5G. See for instance J. Scott Marcus and Gabor Molnar (2017), "Network Sharing and 5G in Europe: The Potential Benefits of Using SDN or NFV", and also Hakiri, A. and Berthou, P. (2015), "Leveraging SDN for The 5G Networks: Trends, Prospects, and Challenges", at https://arxiv.org/pdf/1506.02876.pdf, viewed 19 April 2018.

communications, the network operator will need to provide contractual QoS assurance through Service Level Agreements (SLAs). This further implies that the network operator will have to have technical means to ensure that the SLA QoS commitments are met, and to monitor whether they are being met.

Note, incidentally, that similar considerations apply if a network that is used solely for rail communications is shared between operational rail communications. It would be unacceptable for operational rail communications to be crowded out by for instance online video viewing on the part of passengers.

3.2.3.3.3 Wi-Fi

In previous studies, we found that the rail community is interested in using Wi-Fi primarily in stations and shunting yards, where the load can be high relative to available capacity. It is not suitable for long rural stretches.

The obvious challenge to be addressed is that, while Wi-Fi generally provides good throughput, its performance can never be guaranteed. This makes it challenging to ensure that quality and latency requirements are met.

As a first observation, we note that we are not talking about an ETCS2 system utilising the Wi-Fi system or, say, a Starbucks café in a station. All operational rail usage of Wi-Fi could be assumed to operate over infrastructure that the IM has somehow procured for the purpose. Even so, the risk of contention for access to spectrum in the band (especially in the 2400 MHz band today) could be a factor.

For shunting yards, this might not be much of an issue. Significant numbers of personnel that are not rail staff are not likely to be present in a shunting yard. Wi-Fi has a short propagation distance. Thus, Wi-Fi signals from sources other than rail are probably not great in most cases. Interference in a shunting yard could be measured, and periodically re-checked. For the voice communications that are typically used in a shunting yard, the level of interference might well be acceptable.

If we assume that we are talking about normal Wi-Fi equipment working in the normal bands, the same cannot be said of stations. There is a very real risk that large numbers of passengers, or even non-passenger shoppers, will be using Wi-Fi in a station at the same time. Moreover, there could be peaks, as for instance when people are watching a football championship game. Providing reliable QoS in stations could be extremely challenging.

We see two options that might be considered to mitigate these concerns, if not solve them:

- Today, we have a single latency requirement for ETCS2. The requirement is largely a reflection of the time it would take for a train travelling at high to brake or otherwise react. In shunting yards, and in stations (provided that the train will stop), trains will not be travelling at high speed. A more relaxed latency standard for ETCS2 might perhaps be considered for cases where it can be guaranteed that trains are moving slowly.
- Lack of predictable performance might be mitigated by operating using Wi-Fi-like services that enable priority management, such as 802.11e or one of the various prioritised LAN mechanisms that are now emerging for factory automation. This probably implies operating in a spectrum band other than the conventional Wi-Fi bands, since the installed base of consumer equipment cannot be expected to honour the prioritisation.

The notion of relaxing latency standards in cases where they are not required is entirely in line with what the Indra ALG (2017) proposes in regard to availability and latency standards in settings where satellite is the only means of communication. They go on to note that "similar situation have been considered in the aeronautical environment, where ATM (Air Traffic Management) applications requirements are classified according the airspace domain, such as the APT/TMA (Airport/Terminal Manoeuvring Area), ENR (En Route) and the ORP (Oceanic, Remote and Polar). For example, in the areas where SATCOM is the only mean of communications (i.e. ORP), QoS requirements (e.g. latency) are relaxed, and not only to make possible the use of SATCOM where no other terrestrial system is available, but also because the specific features of these domains (in terms of number of users, operations required, etc) make possible this relaxation keeping the safety case. For the contrary, in APT/TMA, it is mandatory the presence of, at least, two different links, i.e. multilink (LDACS/VDL2, AeroMACs)."[15]

3.2.3.3.4 Satellite

Satellites could be extremely attractive for the long rural stretches on which trains operate; unfortunately, there are practical problem. These are discussed at length in a recent study for ERA, which concluded that "there is not any SATCOM system fully compliant with current criteria identified."[16] The Indra and ALG (2017) study goes on to suggest, however, that the requirements themselves could be revisited to allow some relaxation in terms of "… (i.e. latency and availability) taking into account the safety cases for these scenarios where SATCOM could be working standalone (e.g. remote/rural areas)."[17]

The vast majority of communication satellites today are geosynchronous, which is to say that they appear to always be situated at the same point (directly above the equator) relative to the earth. In reality, they are not stationary; rather, their orbit around the earth takes one (sidereal) day.

Traffic to and from geosynchronous satellites is subject to substantial latency due to the altitude of the satellite. As a function of orbital mechanics, this is some 35,786 km. Even at the speed of light, this results in a round trip delay for signals of some 270 msec. For geosynchronous satellites, this is a hard limit that cannot be addressed by technological improvements.

For a latency-sensitive system like ETCS2, this is a serious limitation.

Satellites that operate closer to earth can however achieve much better latency. A new generation of Medium Earth Orbit (MEO) satellites is expected in the coming years, and one (O3b) is already deploying. These satellites could perhaps be quite interesting in the longer term for rail operations, especially in the remote countryside, if the economics are right. The Indra and ALG (2017) identified various problems with MEO solutions as well, however, and note in particular that C band MEO solutions remain quite speculative at present.[18]

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[15] Indra and ALG (2017), "Study on feasibility of SATCOM for railway communication: Final Report", Version 1/1, ERA 2016 01 SC, at http://www.era.europa.eu/Document-Register/Documents/SRAIL-FNR-010-IND%20-%20FinalReport_v1.1_20170216.pdf, viewed 19 April 2018 , page 32.

[16] Indra and ALG (2017), "Study on feasibility of SATCOM for railway communication: Final Report", Version 1/1, ERA 2016 01 SC, at http://www.era.europa.eu/Document-Register/Documents/SRAIL-FNR-010-IND%20-%20FinalReport_v1.1_20170216.pdf, viewed 19 April 2018 .

[17] Ibid., page 32.

[18] Ibid.

3.2.3.3.5 Combinations of networks (more than one hop)

In many practical applications, it will be convenient and cost-effective for the train to communicate using two or more "hops", potentially representing two or more technologies. The Wi-Fi network in the shunting yard might be connected to the controller over a fixed network, with routers forwarding the data.

In this case, the engineering design staff will need to consider performance over the entire path length for the data; however, this is not a fundamentally difficult problem. Designers of data networks have been doing this for decades, albeit mostly in less critical environments.[19]

As a general rule of thumb, and under suitable assumptions, the mean delay (wait time plus service time) for a network path comprised of multiple hops in series is the sum of the mean delays for each hop as given in equation (3.1)

$$E(X) = \bar{x} = \frac{1}{n}\sum_i^n x_i,\ \ i \in N \qquad (3.1)$$

with n = number of hops and x = the delay at hop i. The variance is given by the dispersion of values around a true value and is given with (3.2)

$$Var(X) = E[(X - E(X))^2] \qquad (3.2)$$

$$SD(X) = \sigma = +\sqrt{Var(X)} \qquad (3.3)$$

According to equation (3.3), the standard deviation is the square root of the variance, this tells us (1) that variability of delay in the network goes up as the number of hops increases, but (2) happily, the increase of the mean delay between two hops is considerably less than linear. The general problem is the number of hops. Between 5 hops and 10 hops the round trip time will increase 100% and additionally the more hops leads to an increased standard deviation. It is to be considered that the number of hops shall be limited for critical railway applications.

Taking all of this into account, the engineering design staff will need to ensure that end to end delay through all hops is well within the stringent limits imposed by ETCS2.

3.2.3.4 Interworking with GSM-R and 3GPP MCPTT solutions (2G/3G/4G/5G)

We are well along in examining interworking scenarios, but we consider it inappropriate to cover it in this report. It entails complicated problems.

A few tentative, preliminary findings are, however, worth reporting here:

- Different interworking solutions are needed for data versus voice.
- Data interworking for 2G/3G/4G/5G appears to be unproblematic.
- Basic voice interworking, for example for calls from train driver to controller or vice versa, appears to require work but is straightforward.
- Interworking of Group Calls and of REC between OTT and GSM-R is more complicated, and requires detailed mapping of protocol semantics between two distinct designs. This requires serious design work that we have not yet attempted (and we do not propose to do more than a high level review).

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[19] See for instance J Scott Marcus (1999), *Designing Wide Area Networks*, Addison Wesley. See also MIT Working Group (2006), "Inter-provider Quality of Service", at http://cfp.mit.edu/docs/interprovider-qos-nov2006.pdf.

- Interworking of Group Calls and of REC between OTT and the 3GPP MCPTT rail solution is likewise complicated, and would require detailed design work that cannot realistically be done until the basic implementation design for the 3GPP MCPTT rail solution is in place. This is impractical in the current study.

Noteworthy among the complexities identified, for instance for the case where some trains in an REC have only GSM-R connectivity and others have no GSM-R connectivity, include:

- Train location and its implication for how to reach the responsible controller and (in the event of an REC) potentially impacted nearby trains exists partly inside the network (GSM R) and partly outside (OTT).
- Call semantics must be mapped between GSM-R and OTT systems. This includes call pre-emption and push to talk capabilities. This can be done, and there are models of how to do it for PPDR and similar scenarios. If we consider however a three way mapping between GSM-R, FRMCS 3GPP solutions, and OTT solutions, the problem looks rather ugly (and this same argument would apply with even greater force to future evolution with even more solutions).

Some of the simplifications already suggested might reduce this complexity. If the location service were to move outside the network under the 3GPP solution, some interworking complexity and future migration complexity is avoided. If in addition Group Call and REC were implemented outside of the network, even while point-to-point calls and other functions continue to be tied to the network, interworking and future migration appear to be greatly simplified.

3.3 IP Addressing

In this report, we have not attempted a detailed assessment of the interaction of IP addressing with hand-overs from one network to another. The IP address is specific to the network topology, which means that a new IP address will be needed whenever the train roams to a new (national) FRMCS network. Unless special measures are taken, this switch will interrupt any TCP traffic, resulting for example in a break in a voice call.

We did not analyse the problem in depth because (1) this is already the case under GSM-R, and (2) the on board system is not managing the IP addressing. However the need for seamless user experience has been explicitly identified as a current requirement for FRMCS. The problem is well known in other contexts, and various mobile IP or tunneling solutions exist.

4. COMPLIANCE ANALYSIS OF ALTERNATIVE ARCHITECTURES: SNAPSHOT OF THE CURRENT SITUATION

This Section assesses the gaps of the different architecture approaches presented in Section 3 that remain to be addressed. The snapshot of the current situation was taken in April 2018 and consequently does not reflect the status of September 2018.

4.1 3GPP-Based Evolution

This chapter aims to describe the gap analysis status between the FRMCS UIC requirement and the 3GPP standardisation.

It is first essential to have a complete and clear view of the gap analysis process. The process may have its own weakness which may lead to increasing delays or technical difficulties, and at the end to a gap between the FRMCS requirement and the real product. The gap analysis process is also the occasion to summarise the applicable documents.

The gap analysis is currently ongoing and is led by the 3GPP. It is to be noted that UIC is full member of ETSI and full member of organizational partner of 3GPP. This chapter input comes from the technical report TR 22.889, which is currently under draft status, and its associated temporary working documents. These working documents also allow defining the prioritisation of wanted features/functions, the scope of 3GPP and the technical difficulties.

Note: due to lack of information, implementation/market interest is not detailed in this report.

4.1.1 Status of the Gap Analysis Process

Process is inspired from former GSM-R process: main stakeholders are UIC, ETSI and 3GPP.

UIC Organisation:

UIC has its own internal process for FRMCS:

FRMCS is a worldwide project, driven at UIC by a steering committee and includes 2 working groups:
- The Functional Working Group (FWG): identifies the railway needs and produces the User Requirement Specification (URS/FU-7100), and in a second more detailed step the Functional Use Cases (FU-7110). The FWG will be also in charge to produce a Functional Requirement Specification (FRS);
- The Architecture & Technology Working Group (ATWG): works on End-to-end architecture, on board architecture, writes the System Principles AT-2504 in addition to Functional Use Cases to be introduced in 3GPP specifications, and will be also in charge to produce a System Requirement Specification (SRS). The SRS will be mandatory for the interoperability.

On-board architecture is still in preliminary work: UNISIG and IEEE are currently missing as key stakeholders to complete this work.

FRMCS project is in relation to the UIC Group for Frequency Aspects (UGFA): this UIC group works on European problematics and cannot join FRMCS, as FRMCS is not only European.

UIC FRMCS Outputs:

The URS aims to capture the user requirements, real railway needs from communication perspective, understand why it is needed, categories applications (critical, performance and business), by writing user requirements from a user perspective on application level.

User Requirements are then translated into Use Cases (3GPP needs use cases to work on new requirements):
- Functional use cases (chaired by UIC FRMCS FWG)
- System Principles (chaired by UIC FRMCS ATWG)

When a set of Use Cases is complete, it is sent to ETSI TC RT for acceptance and approval.

ETSI as member of 3GPP send the ETSI TC-RT NG2R (RT) document to 3GPP through UIC member who translates it into 3GPP language, participates to prioritise the features and works with SA1 for gap analysis.

Most of UIC active members are European, for example, Asiatic stakeholders do not participate to the UIC FRMCS working groups. They address their use cases to the 3GPP SA1 for analysis through other 3GPP members. Consequence is that SA1 must summarize requirements from UIC European countries and Asiatic countries. This work analysis is not done by the UIC but by the 3GPP SA1, increasing use cases management delay.

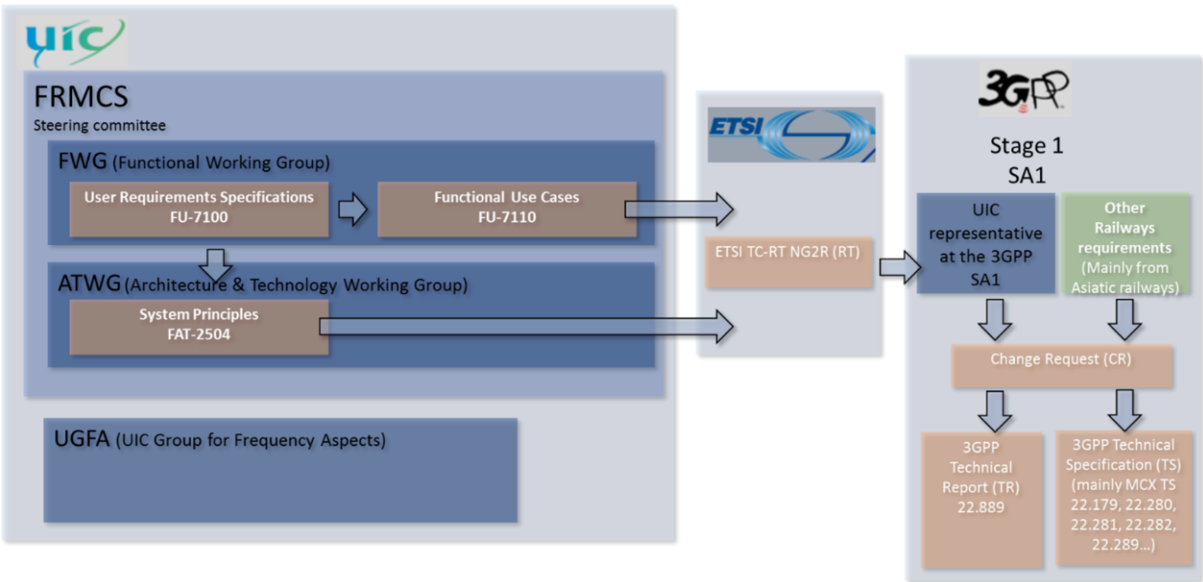

Figure 10. FRMCS organisation

3GPP FRMCS Organisation :

As described in chapter 6.3.1.4, FRMCS related stage 1, stage 2 and stage 3 are respectively managed by SA1, SA6 and CT.

Stage 1 documents references start with 22 numerations.

Stage 2 documents references start with 23 numerations.

Stage 3 documents references start with 24 numerations.

Figure 11. 3GPP Output

3GPP outputs

3GPP Technical Specification 22.179, 22.280, 22.281, 22.282, 23.280, 23.281, 23.282, 23.283, 23.379, 24.484 are about Mission Critical and do exist since Release 13. They must be updated for FRMCS.

TR 22.889 Study on Future Railway Mobile Communication System:

Use cases are translated into the Technical Report TR 22.889 in the context of a feasibility study for FRMCS. The goal is to produce a document for industrial companies. Industrial companies can then compare with their solution and propose a solution to fill the gaps.

UIC Use cases are introduced by Change Requests (CR) provided by industrial companies (and reviewed by TC RT) to 3GPP 22.889 Technical Report (TR), which is SA1 internal document (i.e. non-normative document). The FRMCS uses cases are translated in the TR 22.889 in a variable number of "Potential Requirements". After analysis during functional working groups meetings, when a gap is identified within 3GPP, the UIC or other industrial company can ask for a modification by writing a Change Request.

Some CRs (requirements not already covered by 3GPP stage 1) are already approved in working group (SA1) then approved at plenary (SA) to be included in a Technical Specification (TS).

Most of the identified requirement in TR 22.889 will be introduced to MCX specs of 3GPP (22.179, 22.280, 22.281, 22.282). Currently, many requirements are already covered within Mission Critical services specifications.

This Technical Report considers only railways requirements, but public safety, maritime, etc.… requirements do not appear within 22.889. Technical specifications as 22.179, 22.280, 22.281 and 22.282 are global and are the normative documents for MCX. for example, Automatic Train Operation (ATO) is a data point to point call but is not part of the Mission Critical: it is mentioned in the 22.889 but not in the 22.179/22.280.

TS 22.289 Mobile Communication System for railways:

A new document 22.289 is in preparation to include new functional requirements out of scope of MCX (mainly critical group communications). See Figure 12.

22.289 is in drafts status: with 80% completeness a TS will be put under change control. Currently TS 22.289 is used for very specific rail requirements. If FRMCS contributing 3GPP members may find another way to map the requirements to other applicable existing TS current requirements will be deleting from 22.289. The target is to have less as possible requirements in TS 22.289.

Currently, the requirements will not harm the principle 3GPP architecture as long as a bearer service with a certain bandwidth is required.

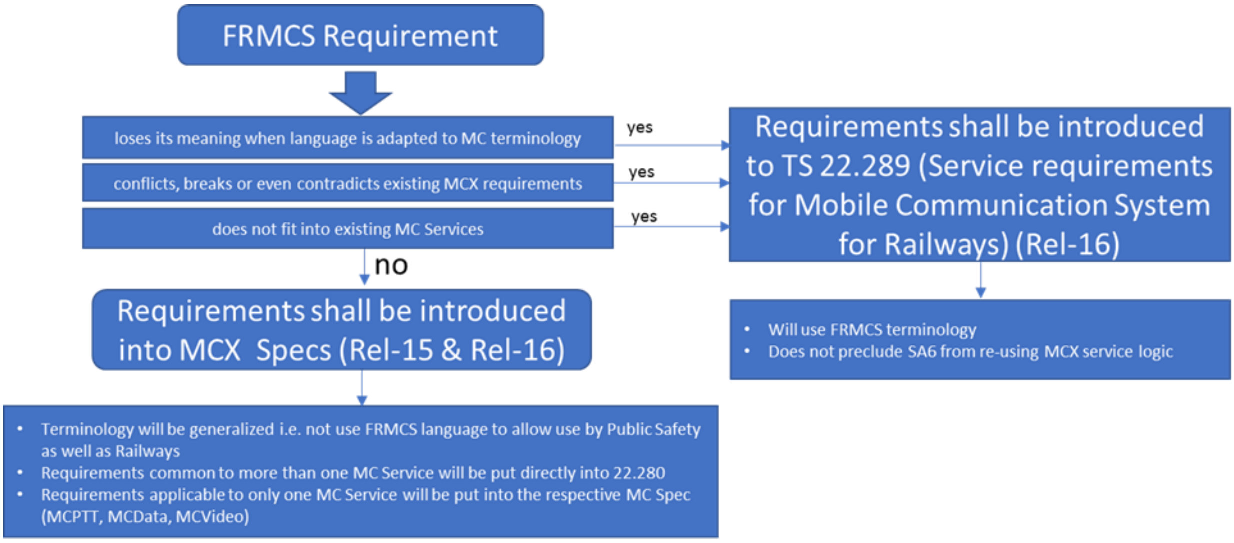

Figure 12. 22.289 Requirement Introduction Process

4.1.2 Prioritisation of Desired Features

For the introduction of specific (railway) features, the following scenarios are possible:

1. Develop in a first step, an FRMCS system with basic features such as point to point calls, group calls, and sometimes TCS..., and update it later with additional GSM-R features and new functionalities. This approach may be useful for railways stakeholders (mainly in Asia) which are still using an old analogue system and urgently need to modernise their network and are expecting a rapid standardisation. Such a system can also provide non standardised feature such as CBTC over LTE. The roadmap is to start laboratory tests and field tests around 2019 in release 15 including proprietary developments and perform later FRMCS software upgrades to fulfil UIC FRMCS requirements.
2. Develop in a first step an FRMCS system with the entire useful GSM-R feature and update it later for new functionalities (MCVideo …). This is the Public safety approach: Release 13 is a “TETRA-like” release, and Release 14 will add new 4G requirements, like MCVideo or MCData.
3. Develop all the features and deploy only the last release. This is the UIC approach for Europe. Most of European railways stakeholders have already deployed or are currently deploying GSM-R. FRMCS is not expected before 2027. Currently frequency spectrum is still in negotiation.

The 3rd approach is promoted by UIC and 3GPP. The target of UIC FRMCS project is to standardise all the FRMCS requirements (applications/use-cases) at latest in Release 16. Many requirements are flagged with a high priority and most of them cannot be integrated within release 15. Neither

Railway Emergency Calls (REC), nor train control for example will be incorporated in Release 15. Within the main features, only multi-user talker and most of functional alias requirements will be included in R15. The risk is that Release 15 could be useless: this is not a problem in Europe where there is no emergency, but some Asiatic countries may develop their own solution as they cannot wait until Release 16.

Given the situation above, some 3GPP members have indicated that it would be helpful when railways could indicate their priorities and could "filter" their requirements by removing the double/redundant use-cases.

Another issue is that there are too few railways contributors in SA6 to support the work and to push for progress. This may lead to the situation that several use cases, agreed by SA1 for release 16, may be postponed at stage 2 to a future Release 17, because of the lack of resources/support.

Europe has also some constraints that other countries do not have:

- Roaming and interoperability between networks is mandatory
- The frequency spectrum is not allocated. This is a problem as some possible features depend to the bandwidth. The wish is to get a bandwidth of, at least, 5MHz around 900MHz to reuse GSM-R sites. However, there is currently no attributed bandwidth. FM56 recommendations are expected. The frequency attribution in Europe is expected for Release 16 but not yet included in 3GPP specifications. Technically, the minimum LTE possible bandwidth is 1,4MHz: with such a bandwidth, only low rate data will be available, there will be few new features compared to GSM-R.

The figure below shows the current 3GPP roadmap for LTE releases 15 and 16:

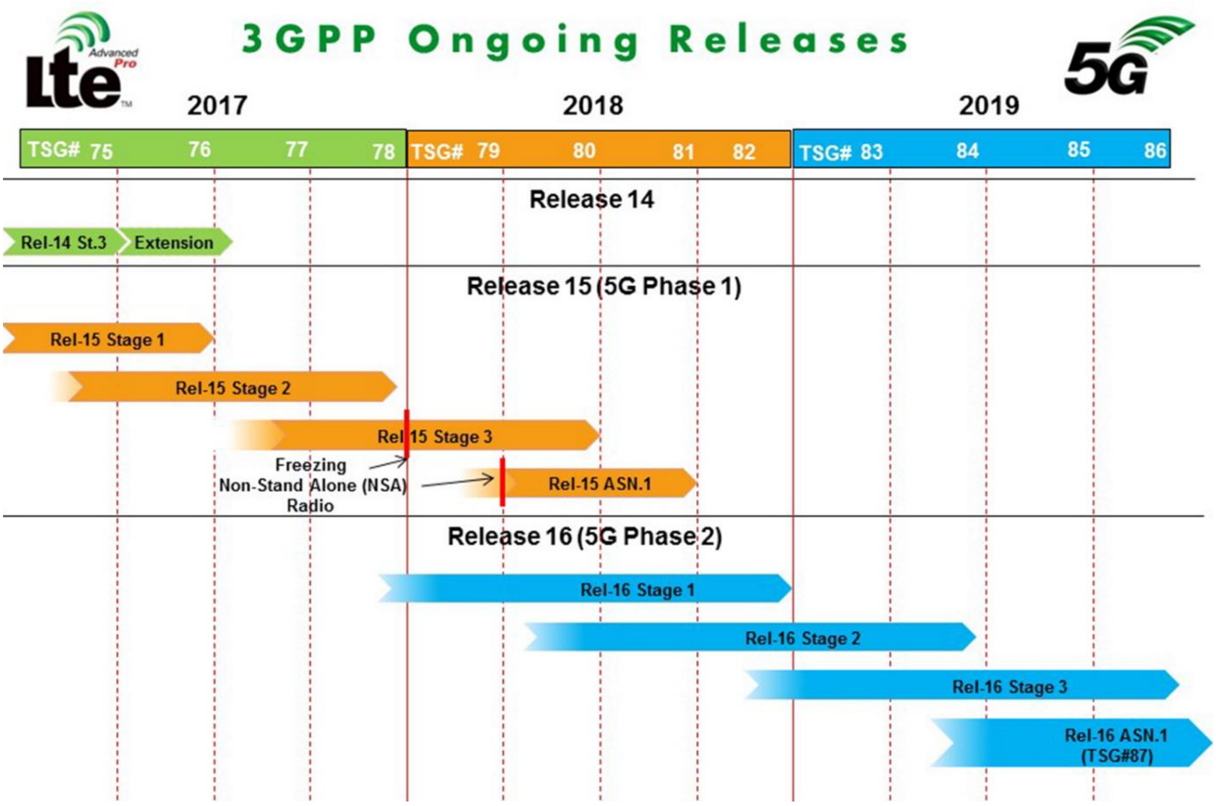

Figure 13. 3GPP Ongoing Releases

4.1.3 Scope of 3GPP-based architectural approaches

The SA1 is also in charge to identify to sort which requirement are in the 3GPP scope. Currently, in a first step, almost all the requirements have been accepted, at least for analysis.

The only requirement clearly identified as out of scope does concern the Assured Data Communication:

TR 22.889_CR_ Assured Data Communication.

3GPP delegates suggest that for data communication an OTT approach should be envisaged, because data is different to voice. Hence it is up to the data application to verify the availability of the entire protocol stack which is neither a matter of the 3GPP transport system nor the MCX Service system.

(W-AT 1303 V0.1.31 Tracking of applicable documents for TR 22.889 Sheet SA1#80 M4)

However, the analysis is still not complete. The ongoing work may lead to identify other out of scope requirements.

4.1.4 Technical Challenges

It is clear that user requirements such as these that are not yet covered with existing 3GPP Mission Critical communications specifications will lead to major technical complexity in the future system, potential feasibility constraints such as limitations in the number of simultaneous talkers due to spectrum availability, additional delay to standardise and develop such functionality, and at the end, who will be ready to pay for such a new application? No feasibility study has been conducted to identify which system could fulfil the railway needs, but the 3GPP system has been chosen. A gap analysis is ongoing to identify railway requirements that will be standardised within 3GPP and the ones to be standardised outside of the 3GPP system.

Several features are already identified as technically difficult to integrate. They are accepted in SA1 for functional aspect, but the complexity is estimated in SA6.

The following list provides a few examples of features technically difficult to integrate (this list is not exhaustive):

- Ultra-low latency (1ms): this requirement is reserved only for very short data (only a few bytes)
- Network slicing: the network slicing is useful in case of congestion within commercial LTE network using same QCI for different users but had no added value in a private (dedicated) network.
- Supplementary Services (Call Hold, Call Forward, Call Completion on Busy Subscriber, etc.): they exist in GSM-R because are exported from public GSM, they also exist in VoLTE but not within MCPTT. It is possible to develop an interworking between supplementary services and MCPTT, but the list of existing supplementary service is long: are they really all used and useful? Is it necessary to develop all the supplementary service in MCPTT? The ERA is currently working on a study in order to list which supplementary services are really needed.
- Multi user talker control related use cases:

  One significant new functionality is the multi-user talker control, which provides the ability for users involved in a group call to simultaneously talk (without the need for users to ask to talk as is the case in walkie-talkie communication). The multi-user talker control (section 8.2 of the URS – Critical support applications) is a kind of conference call without any limitation in the number of simultaneous talkers. The railway users accept the limitations of the GSM-R system today but want to get rid of such limitations when designing the new system. For example, they want to fully control who is allowed to talk in a more flexible way than in

GSM-R. This functionality is not specific to the shunting use case but could be employed for any voice communication.
Impact of developing such a system is very high in terms of implementation complexity, spectrum limitations, time to standardise, cost of such a new system with many options to implement… Multi user talker also requires a maximum of 256 talkers: this high number is very complex and may consume radio resources: is it really useful?

4.1.5 Implementation Status

4.1.5.1 Sources

This chapter presents the status as acted during the 3GPP Meeting SA1#81, held in Fukuoka (Japan) from the 05/02/2018 to the 09/02/2018 based on the following documents:

- Tracking of applicable documents for TR 22.989; Technical Specification Group Services and System Aspects; Study on Future Railway Mobile Communication System; Stage 1. Change Requests to TS 22.179 MCPTT; TS 22.280; TS 22.281; TS 22.282, FW-AT 1303 v.0.1.31 [20]
- TR 22.889; Technical Specification Group Services and System Aspects; Study on Future Railway Mobile Communication System; GAP Analysis and normative TS assignment, Tracking of normative work and GAP Analysis TR 22.889 v.0.0.10 [21]

4.1.5.2 Overview

This chapter gives an overview on 3GPP SA1 stage 1 gap analysis only, which is directly related to railway requirements. Details of stage 2 and 3 are depending of the contributing companies and are currently not fully tracked by the 3GPP.

For each Use Case, the TR 22.889 gives a variable number of “potential requirements” (term used in the Technical Report). For most of them, the target (R15 and R16) is estimated. The two next following tables give TR 22.889 potential requirements percentage of expectation in R15 and R16:

The figure 14 gives also User Requirements [4] and Functional Use Cases [5] chapter correspondences.

<u>Main Functional Uses case:</u>

Use Cases	FU-7100 Chapter	FU-7110 Chapter	22.889 Chapter	Total of potential requirements	Total of potential requirements in R15	% of potential requirements in R15	Total of potential requirements in R16	% of potential requirements in R16 (Cumulative)
On-train outgoing voice communication from the driver towards the controller(s) of the train	5.1	6	6.3	23	7	30%	16	100%
On-train incoming voice communication from the controller towards a driver*	5.2	7						
Multi-train voice communication for drivers including ground user(s)	5.3	8	6.2	22	0	0%	22	100%
Shunting voice communication**	5.6	11		28				
Automatic Train Control data communication	5.9	14	6.5	1	0	0%	1	100%
Automatic Train Operation data communication	5.10	15	6.12 9.13	4	1	25%	3	100%
Railway emergency communication	5.15	20	6.4	69	9	13%	60	100%
Assured voice communication	8.1	58	9.2	11	0	0%	11	100%
Multi user talker control	8.2	59	9.7	18	18	100%	0	100%
Role management	8.3	60	9.3	33	22	67%	11	100%
Location services	8.4	61	9.4	11	7	64%	4	100%
Authorisation of communication	8.5	62	9.8	3	0	0%	3	100%
Authorisation of application	8.7	63	9.9	9	0	0%	9	100%
QoS class negotiation***	8.8	64						
Inviting-a-user	8.11	67	9.5	9	3	33%	6	100%
Arbitration	8.12	68	9.16	2	2	100%	0	100%

Figure 14. Main functional use cases

* Will be updated with CR RT(17)065065 (available soon). Detail is not available yet, but the target is R16.

** Shunting voice communication related use cases are still not inserted in the 3GPP TR 22.889 current version. Following use case are extracted from the Change request CR 67006r5. Requirement will be added after 3GPP SA plenary approval. Detail is not available yet, but the target is R16.

*** See chapter 12.10 "QoS in a Railway Environment" in System Principles table. This use case will be updated with CR S1-173538. Detail is not available yet, but the target is R16.

Currently “Multi user talker control related use cases” feature is probably the only important feature to be fully ready for release 15, however, some requirements are also planned in Release 15, which may lead to partials releases.

<u>Main System Principles Use cases:</u>

Use Cases	FW-AT 2504 Chapter	TR 22.889 Chapter	Total of potential requirements	Total of potential requirements in R15	% of potential requirements in R15	Total of potential requirements in R16	% of potential requirements in R16 (Cumulative)
Interworking between GSM-R and FRMCS	5	12.8	3	0	0%	3	100%
Bearer Flexibility	3	12.9	9	0	0%	9	100%
QoS in a Railway Environment	4	12.10	21	15	71%	6	100%
FRMCS Positioning Accuracy	8	12.14	4	0	0%	4	100%
FRMCS System security framework	7	12.15	15	11	73%	4	100%
Interworking to External Networks	6	12.16	9	8	89%	1	100%
On-Off Net Communication	1	12.17	8	0	0%	8	100%
End-to-End Network Slicing for FRMCS	2	12.19	16	0	0%	16	100%

Figure 15. System principles use cases

Next System Principle version FW-AT 2504 will add the following items, once approved by 3GPP, they will appear in the TR 22.889:

- Satellite (with QoS requirements)
- Roaming
- Availability and maintainability
- Service awareness
- 3rd party info

However, a complete list of Functional Use Cases and System Principles Use cases - but less detailed - is also available in annex 9.4.

4.1.6 Findings

The findings can be categorized within the following items:

- Operational needs
- Standardisation process
- Operational constraints
- Technical constraints

4.1.6.1 Operational needs

Globally, many functionalities, existing in GSM and then in GSM-R, have probably never been used anywhere. It may be useful to identify these functionalities, in order to avoid useless development in FRMCS.

On-board architecture is still in preliminary work: UNISIG and IEEE are currently missing as key stakeholders to complete this work.

4.1.6.2 Standardisation process

3GPP SA1 must summarize requirements from UIC European countries and Asian countries. This work analysis is not done by the UIC but by the 3GPP SA1, increasing use cases management delay.

The risk is that Release 15 could be useless: this is not a problem in Europe where there is no urgency, but some manufacturers working in Asian countries may develop their own solution as they cannot wait until Release 16.

Some 3GPP members also alert that there are currently many use cases, and they are not always structured (some of them seem more or less redundant), without a real priority. There are too few railways contributors in SA6 and several use cases, agreed by SA1 for release 16, may be postponed at stage 2 to a future Release 17, because of the lack of resource.

4.1.6.3 Operational constraints

Europe has also some constraints that other countries do not have:

- Roaming and interoperability between networks is mandatory
- The frequency spectrum is not allocated (section 4.1.2 for more details).

4.1.6.4 Technical constraints

Several features are already identified as technically difficult to integrate, they are accepted in SA1 for functional aspect, but the complexity is estimated in SA6.

The risks are the followings:

- feature could to be postponed after Release 16, due to lack of resource in 3GPP SA6
- high cost for early implementers
- Insufficient bandwidth

4.2 Over-The-Top (OTT) IP-based Evolution

As noted in Section 3.2, we have not identified any specific standardisation activities or implementation efforts seeking to implement a FRMCS with zero dependency on the underlying mobile network.

It appears, however, that existing standards already address most of what is required,[20] or could easily be upgraded to address what is required.

There is also a substantial base of general SIP expertise in the developer community. Moreover, there is a popular open source server implementation that includes SIP, Freeswitch.

4.2.1 Status and Implications for the Relative Sequence of Development

As a practical matter, and in the absence of some large and unexpected change, there appears to be little question (based on the current path of the industry as determined in our interviews) that 3GPP based solutions based on MCPTT will emerge before OTT solutions. This is true even though there is a significant prospect of delay in the accommodation of UIC requests by 3GPP.

On one level, this might be viewed as unfortunate, inasmuch as an opportunity will not be seized as early as it might have been. On the other hand, the OTT solution might benefit greatly from work that will have already been done on MCPTT VoLTE solutions. The protocol flows to IMS SIP will in many cases be the same as those to an external SIP server. This could accelerate the standards development, and perhaps also the actual software development for OTT solutions.

With this in mind, we assume throughout this section that the likely evolution is that OTT solutions borrow from MCPTT work, and not the reverse. This should reduce the incremental cost of putting the OTT solution in place.

4.2.2 Prioritisation of Desired Features

The Proof of Concept design presented in Section 3.2 serves as the basis for discussion in this section (and also in Sections 4.2.3 and 4.2.4); however, a detailed assessment will not be possible until and unless the sector settles on a specific detailed design.

[20] This was the view of Henning Schulzrinne, a top SIP expert whom we interviewed.

4.2.3 Scope of OTT IP-based architectural approaches

For reasons already noted in Section 4.2.2, it is somewhat premature to speculate on what features would or would not be included in an OTT-based implementation. Other than the areas identified as technical challenges in Section 4.2.4, we have not identified any areas that are particularly difficult to implement in an OTT-based implementation.

4.2.4 Technical Challenges

We have identified two areas that appear to require particular attention in an OTT-based implementation:

- Quality of Service (QoS): How QoS is to be maintained when satellite and/or Wi-Fi are used as an underlying transmission needs to be addressed as part of the overall design process for an OTT-based solution. We believe that this is also the case for a 3GPP-based solution.
- Interworking: Interworking between an OTT-based solution and current GSM-R would clearly be required. We have some thoughts as to how this could be done. This interworking is not necessarily more difficult than interworking between GSM-R and a 3GPP-based solution, but one cannot be definitive until and unless an actual design has been developed. If it were to become necessary to maintain interworking not only between an OTT-based FRMCS and GSM-R, but also between a 3GPP-based FRMCS and an OTT-based FRMCS, that three-way interworking requirement might introduce significantly greater complexity.

4.2.5 Standards

The relationship between SIP and IMS is somewhat complex. IMS, which provides critical functionality for LTE networks, was based on SIP. The 3GPP standards group identified a number of IMS requirements which the IETF took up and implemented as IETF SIP standards (or formally Requests for Comments (RFCs), although it is important to bear in mind that not all RFCs are standards).

These de facto standards are in principle available for implementation in UE and servers that are not part of a mobile network; however, in many cases this has not been done due to lack of demand. Some of the standards that followed this path may contain dependencies on the presence of a mobile network that have not been identified.[21]

Other IMS SIP standards have been developed by 3GPP. It is even more so the case for these standards that their ability to function independent of a mobile network would need to be reviewed.

Much of the evolution of SIP in recent years has shifted from the internet community to the mobile operators. This has been accompanied by a growth in IMS SIP standards activity in 3GPP. This may again imply a need to review some standards to ensure that they can function in a different context than that for which they were designed.

We assume for now that large parts of the design of Group Call and of Push to Talk for an OTT solution can be based on the design work that will be needed for MCPTT for rail communications (not the current MCPTT work that has been done for PPDR). One might expect that the SIP protocol elements could in theory be the same.

Supplementary Services (Call Hold, Call Forward, Call Completion on Busy Subscriber, and more) is however an area that will require careful attention. They are available under GSM-R because GSM-R is based on GSM. They are also available under VoLTE. They are not, however, available in MCPTT

[21] RFC 4354 contains in fact a caution to this effect.

today (and thus not available in conjunction with, for instance, Group Call). For the many supplementary services, it is unclear whether the effort to implement each of them is warranted. The ERA is currently working on a study in order to identify the supplementary services that are really needed.

Our current expectation is that any necessary standards work for Supplementary Services for the OTT case could be done outside of 3GPP, but this needs further analysis.

An area that probably requires explicit development is the location service described in Section 3.2.3.1.2. The SIP event notification mechanism seems natural here. The location server would use the SIP subscribe function for providing information to the on-board and trackside equipment. The provided information contains relevant data for the addressed equipment as well as transmission goal for status updates. The on-board and trackside equipment would then from time to time be able to report on the status (location, and possibly speed and direction) of the trains by means of the SIP notify function.

Conversely, on-board equipment in the cab might subscribe to know the call attributes (i.e. the URI) of the responsible controller in case it is necessary to contact the controller. URIs for nearby trains might also be notified. In this way, the on-board equipment would know in advance how to initiate contact via SIP in order to implement the Rail Emergency Call function to the controller and to nearby trains should it be necessary, which would save time in an emergency.

There would likely also be a need for authentication, authorisation, and definition of roles (essentially a network logon feature) as described in Section 3.2.3.1.3. This would need to be integrated with security functions. We suggest once again that this be modelled on whatever is done in the MCPTT VoLTE solution.

Our SIP-knowledgeable interviewees felt that relatively little actual standards work would be needed to do what we have in mind, which accords with our judgment. A great many practical and management issues will need to be resolved, but the basic technical are for the most part in place.

We have not identified any functions that are impossible, impractical, or in conflict with other needs.

It is worth noting that there is considerable freedom as to which standards body should undertake any new standards that are likely to be needed, and for that matter any revisions to existing standards. Since these standards revisions by definition are independent of the underlying network, they need not be undertaken by 3GPP (a body over which ERA and Commission has little or no influence, and whose members may not have a commercial interest in a purely over-the-top solution). The forum in which revisions are undertaken must, however, have sufficient technical competence and should be open to the relevant stakeholders (mostly rail stakeholder and potential suppliers of hardware and software to the rail sector).

Consider for instance the location identification service as described in Section 3.2.3.1.2. The standard that is needed would describe an exchange of SIP protocol elements (e.g. subscribe, notify, and more) between location servers and equipment – either onboard equipment, or else trackside such as Eurobalises. This traffic could flow transparently over any TCP/IP network – no changes to the network are required.

Such a standard could be developed by the IETF, if it had an interest, or by the UIC, or could be developed by ERA itself (probably with help from competent experts). A particularly interesting option in our view is ETSI. Inasmuch as ETSI is one of the European Standards Organisation (ESOs), the Commission has legal authority to issue mandates for ETSI to take up work that is of interest.

4.2.6 Development

We assume once again that MCPTT solutions will deploy before OTT solutions.

In terms of development, a key open question is who will be doing it? The companies that provide GSM-R gear have an advantage in terms of experience with the subject matter; however, many of the over-the-top OTT applications could in principle be developed by any software developer with an understanding of SIP and the related protocols.

We assume that the existing suppliers are well positioned to deliver OTT solutions using the same software that they will have developed for the MCPTT VoLTE. An open question is whether the physical platforms for trackside and onboard equipment will be closed – a closed environment in the gear would make it difficult or impossible for third parties to develop software without explicit agreements with the platform providers. Conversely, if operational rail communications equipment were to be based on an open software platform such as Android or Linux, and with suitable open Application Program Interfaces (APIs), software from third parties might emerge. How realistic this hope might be in practice requires some reflection, given that these systems would still require rigorous certification.

4.2.7 Deployment

In previous work, we identified a strong preference for onboard equipment to be upgraded so as to support both GSM-R and a successor network before the networks are upgraded.

We are only beginning to think about migration scenarios for OTT bearer independent solutions, but it seems that the deployment timing should be largely independent of the timing for upgrade of the network. There is still a requirement that all parties to a call be upgraded to support the new standards (for instance, train drivers and controllers). Since an abrupt "flash cut" is unthinkable, this seems to still imply the need for a carefully orchestrated period of dual mode operation, with onboard and trackside equipment that supports both the old system and the new.

The need for interoperability and interworking is clear. It is fairly clear how some scenarios could be addressed; others, however, seem to involve tricky technical design. Notably, the case where a Group Call or REC must reach multiple trains, some of which use only GSM-R while others have no access to a GSM-R network, involves complicated information exchange of information between GSM-R and OTT solutions (see Section 3.2.3.4).

A detailed assessment of interworking between OTT solutions and 3GPP MCPTT rail solutions appears to be impractical in this study because the design work for the latter is not far enough along.

4.2.8 Findings

Over-the-top bearer independent solutions have been of interest to the rail community for many years. They potentially offer substantial advantages in comparison both to GSM-R, and to the MCPTT solutions that are widely viewed by the sector as GSM-R's natural successor. There has nonetheless been minimal concrete work by the rail community or their suppliers on specific standards or products. For that reason, this report provides a high-level proof of concept conceptual design.

We find that an over-the-top SIP-based solution is entirely feasible. It would not run over the public internet, but rather over some combination of QoS-assured public or private networks selected by the responsible entity (typically an IM).

In terms of standards, much of what would be needed for our proof of concept SIP-based design is already specified in IETF or 3GPP standards; some of these, however, would need to be carefully reviewed to ensure that standards designed to operate inside a single network would work just as well when the servers are outside the network. The implementation of Group Call and such could probably be carried over with little change from the standards work that 3GPP is now undertaking for the UIC. The Supplementary Services are however a tricky area that will require close attention.

A few new standards would likely be needed, notably for the location service. There is considerable flexibility as to where these standards should be developed, since by definition they do not change the underlying network. ETSI is a promising venue, not least because the Commission has the prerogative to mandate that ETSI undertake projects of interest.

As far as software development, we assume that MCPTT solutions for rail would emerge before fully OTT solutions. Given that VoLTE employs IMS SIP, we anticipate that much of the MCPTT VoLTE work could be re purposed for use by a pure SIP implementation. The implementation might also benefit from the existence of an open source SIP server product, Freeswitch.

Existing suppliers of operational rail communications equipment are well positioned to do the development work. Whether they would be motivated to do so is a question that would need to be explored. If the software development within operational rail equipment were open (e.g. an Android or Linux platform with published APIs), it is conceivable that third party software-only suppliers might enter the market. Again, this raises questions as to the commercial interests of the existing suppliers, which must be considered particularly carefully due to the limited size both of the market and of the supplier community.

As regards deployment and migration, we do not yet have a firm view. What is already clear is that the issues here are different than in our previous study of migration studies. There, we considered primarily the timing of network upgrades versus that of end user equipment. Here, the network upgrade timing is largely inconsequential (assuming that the network delivers suitable QoS), but the need to coordinate upgrade of onboard equipment such as cab radios with trackside gear such as that used by controllers to communicate still suggests the need for a carefully orchestrated period of parallel operation.

The need for interworking with GSM-R is clear. This is clearly feasible, but requires detailed analysis. Some scenarios seem straightforward, but others are technically quite involved (see section 3.2.3.4).

As an overall assessment, we would note that we developed the proof of concept OTT design with the FRMCS functional use cases and system principles in mind (as shown in Figure 14 and Figure 15, respectively). We believe that all requirements can be met.

4.3 Summary of Compliance

This chapter aims to answer the following question: which solution could be used for the FRMCS services defined in section 2? MCPTT? VoLTE? OTT? Or a hybrid solution?

MCPTT is since the release 13 the standard for Public Safety networks. This solution is the most appropriate for professional group communications, but as it is not used within public/commercial networks, many usual point-to-point or user-to-user functions, which further did exist in GSM-R, are no more available (for example the Supplementary Services).

On the contrary, VoLTE is perfectly adapted for point-to-point communications, as used in a public/commercial network, and supports all the usual Supplementary Services, interworking with 2G, 3G, PSTN, etc… But VoLTE is currently not adapted for professional group calls.

OTT solution is more flexible, but there is still no international standardised solution for professional networks. If an OTT solution shall be developed, it must be standardised first as an harmonised solution. Also, existing OTT applications have poor performances in terms of voice quality and latency, compared to VoLTE [22].

Co-existence between two of the three solutions, or even the three solutions will bring more problems than solution: very complex gateways between the systems shall be developed specifically for the railways, for example, how to merge two calls, one in VoLTE and one in MCPTT in one group call? Also, on board equipment shall be able to manage two or three solutions, which will certainly increase equipment's complexity, and then costs.

During the interviews, it appeared that almost all the stakeholders consider that the future will be based on an evolution of MCPTT; 3GPP has clearly started to work in this direction. However, final choice is not definitively acted.

For data services, for example ERTMS, OTT applications could be developed using the 3GPP LTE network.

5. ASSESSMENT OF POTENTIAL WAYS FORWARD AS REGARDS OVERALL ARCHITECTURAL APPROACHES

5.1 Findings for 3GPP-based Solutions

Based upon the interviews and our analysis, the main findings are:

5.1.1 Strategy

The strategy of 3GPP is obviously to include most of railway requirements in their Mission Critical Communication set of specifications ("MCX") to have as much as possible common MCX solution. This can be considered as a branch which is (partly) separated from the public/commercial branch. The MCX feature set will contain generic specifications, preventing the creation of elements which are relevant for a niche market, such as railways. This has advantages for users of professional voice communications, such as Public Safety, Railways, Maritimes, and Utilities, as MCX will provide similar or even improved voice communication features.

Note that new technical specification TS 22.289 is in preparation to include a minor set of new specific functional railway requirements out of scope of MCX (mainly critical group communications). It is advised to ensure that 3GPP is not developing a specific "R" solution, which may lead to a niche market.

5.1.2 Planning

Work on 3GPP Mission Critical Services standardisation for rail is ongoing, however, a few rail-specific features are standardised in Release 15. Some important features, including Rail Emergency Calls (REC) and train control, will not be available in Release 15. This would appear to imply that the European rail sector must wait for Release 16 (with protocols expected to be stable at the end of 2020), since Release 15 will lack essential operational rail functionality, due the difficulty for the 3GPP to identify the real priorities.

Some 3GPP members have expressed concerns that further delay is possible. They worry that the requirements that UIC is producing for 3GPP is producing too many use cases, that there is too much duplication among them, and that priorities are not clear. In this view, the railway sector is not sufficiently engaged and structured in the standards process, thus running the risk that European rail requirements are not met to a sufficient degree to enable real deployment until Release 17.

How this plays out in Asia and the Pacific will influence suppliers worldwide but is hard to predict. Some Asian countries may rush to deploy something other than a 3GPP-fully-compliant solution because they cannot wait for Release 16. That would seem to be unfortunate: the risk is that some vendors develop their own non 3GPP standardised solution, for some feature, with further potential interoperability issues.

5.1.3 Complexity

A number of features that have been requested by UIC have been identified by 3GPP as being technically complex to implement. Since different working groups in 3GPP analyse whether the feature is desirable versus what the implementation complexity might be, it is quite possible for a feature to be accepted in principle but then deemed to be too complex to implement. It is not yet clear whether these difficult features will be (1) delayed beyond Release 16, and/or (2) standardised, but at high cost for early implementers, and/or (3) problematic due to insufficient available bandwidth.

Among the difficult features, of particular interest are (1) interworking between GSM-R and FRMCS which is a challenge and will not be available at least before Release 16, (2) the Supplementary Services (Call Hold, Call Forward, Call Completion on Busy Subscriber, and many more). They are available under GSM-R because GSM-R is based on GSM, technology standard firstly implemented to provide voice services. They are also available under Voice over LTE (VoLTE). They are not, however, available under today's Mission-Critical Services (and thus not available in conjunction with, for instance, Group Calls). For the many supplementary services, it is unclear whether the effort to implement each of them is warranted.

So far, only one application (Assured Data Communication) has been judged to be out of scope by 3GPP. 3GPP recommends that an OTT approach be taken for this feature.

The spectrum that would be needed in some scenarios or for some features has not yet been allocated nor even standardised within 3GPP. The allocated bandwidth may be insufficient for some features. For example, the smallest allowed bandwidth in LTE is 1,4MHz, which may be not sufficient for MCVideo, Group calls with 256 simultaneous talkers, etc …

The next revision of System Principles document (FW-AT-2504) includes a number of requests for capabilities that could be potentially interesting, but that seem to us to be very problematic. For instance, there will be a request for support of satellites (with QoS requirements). We have our doubts as to whether 3GPP will take on a number of these requests, and we question whether suppliers would implement a number of these features even if they have been standardised.

5.2 Findings for Over-The Top (OTT) IP-based Solutions

This section presents our own assessments, since desk research and interviews turned up only limited and preliminary investigation of OTT solutions for operational rail communications.

5.2.1 Strategy

Over-the-top bearer independent solutions have been of interest to the rail community for many years. They potentially offer substantial advantages in comparison both to GSM-R, and to the MCX solutions that are widely viewed by the sector as GSM-R's natural successor. Advantages include:

- Enhanced flexibility to add applications to the operational rail communications environment.
- Enhanced flexibility to add support for new transmission media, including networks that do not provide specialised support for operational rail communications.
    - Potential ability to use satellite communications, especially in remote areas (subject to suitable planning for delay characteristics, as noted in Section 3.2.3.3.4).
      Note: the 5G system shall be able to provide services using satellite access as requested in service requirements for the 5G system (3GPP TS 22.261).
    - Potential ability to use Wi-Fi communications, especially in shunting areas and stations (again subject to suitable planning for delay characteristics, as noted in Section 3.2.3.3.3).
      Note: Wi-Fi integration could potentially benefits from 3GPP enhanced Wi-Fi integration capabilities, namely LWA (LTE-Wi-Fi Aggregation in Radio), or running LTE over unlicensed Wi-Fi band (LAA for Licensed Assisted Access). This benefit need to be consolidated by the industry.
- Simplification of any future migration of the operational rail communications environment.
- Potentially greater vendor independence in procuring operational rail communications equipment and software.

There has nonetheless been minimal concrete work by the rail community or their suppliers on specific standards or products. That is the reason why this report provides a high-level proof of concept conceptual design.

It is not altogether clear why the rail community has dropped consideration of fully bearer-independent designs. It is possible that none of the commercial suppliers of equipment had a business interest in exploring designs that might effectively make it easier for competitive suppliers to enter the market. It is possible that stakeholders did not believe that an OTT solution was technically feasible – a view that we do not share. Or it may simply be that stakeholders were not sufficiently familiar with the relevant technology to put forward a solution.

Our sense is that OTT solutions merit more consideration than they have received to date, at least as a long term consideration.

5.2.2 Planning

So far as we can determine, the sector has not undertaken serious planning for an OTT solution. This section reflects our own assessment.

In this report, we use the proof of concept SIP-based design that we developed ourselves as a basis for analysis. Other designs could however be considered, and might lead to somewhat different conclusions.

An over-the-top SIP-based solution appears to be entirely feasible. It would not be running over a random mix of public and private networks, but rather over some combination of QoS-assured public or private networks selected by the responsible entity (typically an IM).

In terms of underlying communication standards, everything (or nearly everything) that would be needed for our proof of concept SIP-based design is already specified in IETF or 3GPP standards; some of these, however, would need to be carefully reviewed to ensure that standards designed to operate inside a single network would work just as well when the servers are outside the network. We have not identified specific gaps in terms of underlying standards, but it is possible that a serious design effort might turn up gaps.

Standards for rail voice communications such as Group Call and REC could likely be carried over with little or no change from the work already under way for rail in 3GPP; Supplementary Services, however, may need special attention.

A few new standards would likely be needed, notably for the location service. There is considerable flexibility as to where these standards should be developed, since by definition they do not change the underlying network. [22]ETSI is a promising venue, not least because the Commission has the prerogative to mandate that ETSI undertake projects of interest.

As far as software development, we assume that MCPTT and/or VoLTE solutions would emerge before fully OTT solutions. Given that both employ IMS SIP for multimedia communications, we anticipate that some vendors might be able to re-purpose their MCPTT work for use by a pure SIP implementation. The implementation might also benefit from the existence of an open source SIP server product, Freeswitch.

Existing suppliers of operational rail communications equipment are well positioned to do the work. Whether they would be motivated to do so is a question that would need to be explored. If the software development within operational rail equipment were open (e.g. an Android or Linux platform with published APIs), it is conceivable that third party software-only suppliers might enter the market. Again, this raises questions as to the commercial interests of the existing suppliers, which must be considered particularly carefully due to the limited size both of the market and of the

[22] Bearer dependant sources are not considered as location sources anymore, such as Cell-ID.

supplier community. Synergies with the Public Safety sector should help to increase the size of the market.

As regards deployment and migration, we do not yet have a firm view. What is already clear is that the issues here are different than in our previous study of migration studies. There, we considered primarily the timing of network upgrades versus that of end user equipment. Here, the network upgrade timing is largely inconsequential (assuming that the network delivers suitable QoS), but the need to coordinate upgrade of onboard equipment such as cab radios with that of trackside gear such as that used by controllers to communicate still suggests the need for a carefully orchestrated period of parallel operation. This also implies a need for interworking between GSM-R and any OTT solution, and possibly for interworking between 3GPP solutions and interworking solutions.

5.2.3 Complexity

An OTT solution is not necessarily more complex overall than the 3GPP solution; however, it would require a somewhat different thought process than is common in the rail sector.

Train location services, for example, would require a new implementation; however, implementing as a normal software programme in an external server might be quicker and simpler than implementing inside the network. Moreover, testing and validation would tend to be easier.

Implementation of the key functions of operational rail networks (calls from train driver to controller and vice versa, Group Call, Rail Emergency Call, push to talk) does not appear to be particularly difficult with an OTT solution. Again, it may be simpler to implement them, and it is probable that it is easier to test and validate them, in an OTT setting than it would be working inside a network.

The greatest risk of complexity appears to arise in interworking scenarios. Two way interworking with GSM-R would take work. Three way interworking between OTT and both GSM-R and 3GPP solutions is not fundamentally hard, but it is quite complex. It is for that reason that we have suggested a number of possible simplifications that might conceivably simplify both migration and parallel operation of two or more rail operational solutions.

5.3 Longer Term Expectations

Our interviews have made clear that the sector is on a path where the MCX solutions will emerge first. It does not necessarily mean that the MCX solutions for railways will emerge quickly. As we saw in Section 5.1, MCX solutions will not be deployable in Europe until at least Release 16, and possibly not until Release 17. Some industry players are claiming that MCPTT solutions are already on the market but shall be limited to Release 12 compliancy.

The MCPTT-based solutions offer many advantages relative to GSM-R and address the fundamental need to migrate away from GSM-R before it becomes so out-dated as to be uneconomic to maintain. They capitalise, albeit to a limited degree, on the scale economies of the 4G LTE ecosystem. They are perceived, rightly or wrongly, as being relatively low risk. To the extent that they are similar to existing GSM-R, they are readily grasped by those who would need to develop them, and to those who would need to deploy them.

The deployment of network-dependent MCPTT solutions more or less guarantees, however, that a subsequent migration will be needed when 4G networks become uneconomic to maintain. They also are unlikely to support the satellite[23] and Wi-Fi capabilities that are desired by the sector (the use of

[23] UIC will be requesting that 3GPP incorporate support for satellite. Even if this were to make it into the standard, we are not convinced that it would be implemented.

which must be coupled with careful design in order to ensure QoS, as explained in Section 3.3.3.3). A direct or indirect migration to 5G should be considered as another path to tackle those challenges (as MCX, Wi-Fi integration and Satellite access should be supported by 5G).

A key question that will arise, possibly well before the 2030 date at which GSM-R is expected to no longer be maintainable and at which point LTE is likely to already be obsolescent itself, is whether and when the introduction of 5G and/or a migration to fully OTT bearer independence is warranted.

Interest in full bearer independence is unlikely to go away. As already noted in Section 3.3, a full de-coupling of operational rail communications from specialised features of the mobile network could offer many advantages beyond those of the MCPTT and/or VoLTE 3GPP solutions. However, an MCX or VoLTE based solution allows a certain level of bearer independence. Use of 3GPP-based commercial networks should be a viable option without loss of rail specific functionality. This is already a high step forward compared to GSM-R.

5.4 Risks And Threats

The following risks have been identified:

1. A key risk in all of these scenarios is that the players in the sector may not push ahead or may not push ahead quickly enough and in a structured way.
2. Given the large number of standards requirements that have been identified, and the lack of prioritisation among them, the risk on the standards side is significant. On this front, the risk is probably less with OTT solutions because there is little or no dependence on 3GPP.
3. Meanwhile, it is already clear that the 3GPP standards process will address basic underlying needs, but will not deal with rail-specific standardisation out of scope of MCX. This process must then be driven within the rail community, starting with Functional and System requirements.
4. On the development side, there is the risk that the standards bodies produce standards that are too complex and/or too expensive for the firms to develop. This risk is compounded by the small number of firms that actually make hardware and software for the railway market, and is considerable. The incentives of the supplier community need to be carefully explored and considered.
5. On the deployment side, it is likely that early implementers will implement under 4G, and later implementers under 5G (assuming that the MCX solutions function well under 5G, as is hoped and intended). The impact on interoperability of this 2G->4G->5G scenario has to be identified.

Note that in section 7.9 of this report, the impact of the 3GPP/OTT options on the on-board architecture itself will be analysed.

6. CURRENT SITUATION AS REGARDS ON-BOARD OPERATIONAL RAIL SYSTEMS

This chapter describes the current situation as regards to the on-board rail environment based upon interviews[24]. In doing so, it seeks to bring out the lessons learned from experience to date, including experience with migration, in order to explore opportunities to benefit from those lessons in developing and deploying the FRMCS.

The chapter is comprised of six sections:
- Hardware and Software architecture
- Installation and upgrade mechanisms
- Maintainability
- EC Certification
- Migration
- Limitations and opportunities for improvement

6.1 Hardware and software architecture

In light of the large number of national and proprietary interfaces, it is impractical to describe exhaustively all of the existing architectures for on-board systems and equipment. This chapter aims instead to briefly describe a generic interoperable hardware architecture for CabRadio and EDOR, with the corresponding standardised interfaces and protocols, and to provide global system security principles.

6.1.1 GSM-R CabRadio

Generic HW architecture:

The CabRadio comprises one product (rack) including one 8W MRM dedicated for voice, one dedicated antenna, and one or two DMI's. Redundancy is not mandatory; train operator may temporarily replace it by the use of GSM-R handset and/or apply specific operational rules.

[24] Interviewees do not represent in a complete way the different opinions and knowledge of the railway community, and that input provided by them has been taken into account but cannot be used as a reference.

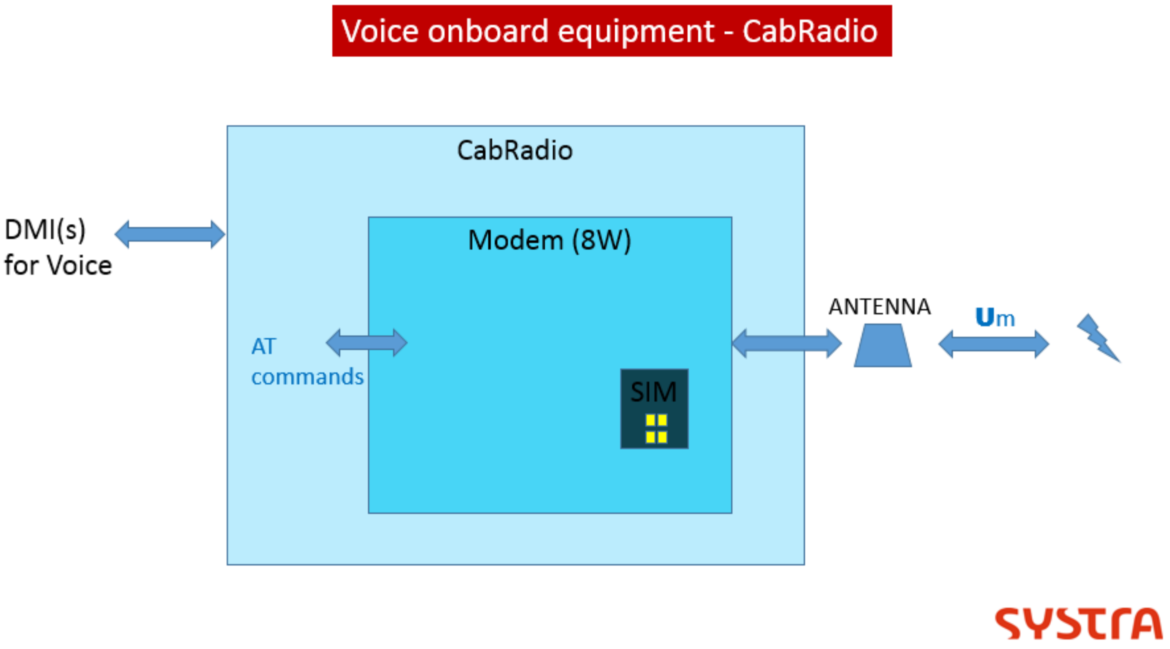

Figure 16. CabRadio – Internal HW architecture

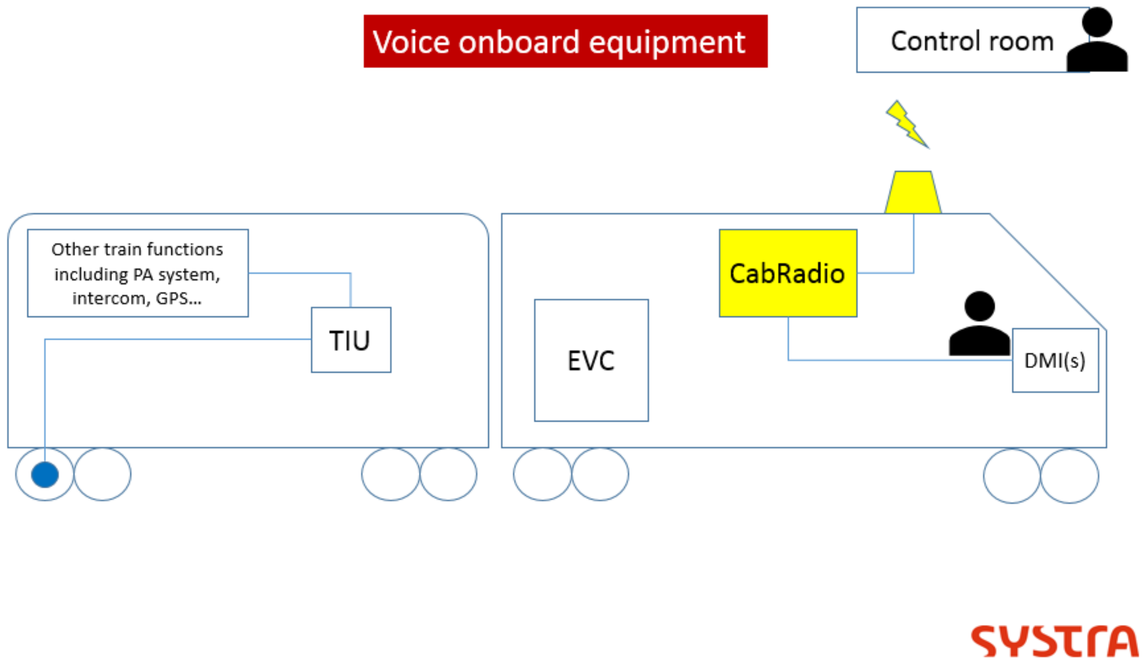

Figure 17. CabRadio – On-board architecture

<u>Interfaces & Protocols:</u>

The radio system can be linked to many proprietary interfaces to train systems with different life cycles such as:

- Other signalling systems than ETCS
- Driver Safety Device
- Juridical recording unit
- Public Addressing system

- Intercom system
- GPS (used for eLDA GPS)
- ETCS onboard/ EVC (for exchange of train number) …

Security:

Security mechanisms (Authentication, encryption…) in GSM-R are described within ETSI specifications (documents [7] and [8] – see page 21):
- Authentication is based on SIM card and authentication algorithm implemented in the cab radio terminal and in the network
- User and control planes privacy: based on A5 algorithm for GSM-R and GEA algorithms for GPRS. Encryption is only from on-board to the base station, no end-to-end encryption. Some types of communication (group calls) do not make use of these algorithms.

Security issues with GSM-R:
- Authentication and privacy algorithms are old can be broken in a few minutes. A5/3 and A5/4 (preferred option) are recommended by GSMA for MNO
- Some protocols weaknesses such as Man in the Middle attacks using SDR, as explained by the ETSI TC CYBER Chairman, Mr Charles Brookson, during the 3rd Telecom conference organised by UIC in May 2017[25].

The security protocols of the transport domain are used to secure voice communication. This choice has been made by the Railway community to learn from a well-established standard. But this implies to update security patches periodically to fill the security gaps.

6.1.2 GSM-R EDOR

HW architecture:

The EDOR (ETCS Data Only Radio) comprises a GSM-R radio module with a modem and it is connected to an antenna. It is managed by the ETCS On-Board Unit (OBU, also called “European Vital Computer” EVC). At least two 8W modems and 2 dedicated antennas are installed; the usual configuration is having two per cabin.

[25] Session 7.1 of the 3rd UIC Telecom conference: paper from Charles Brokson « Railway: security aspects ».

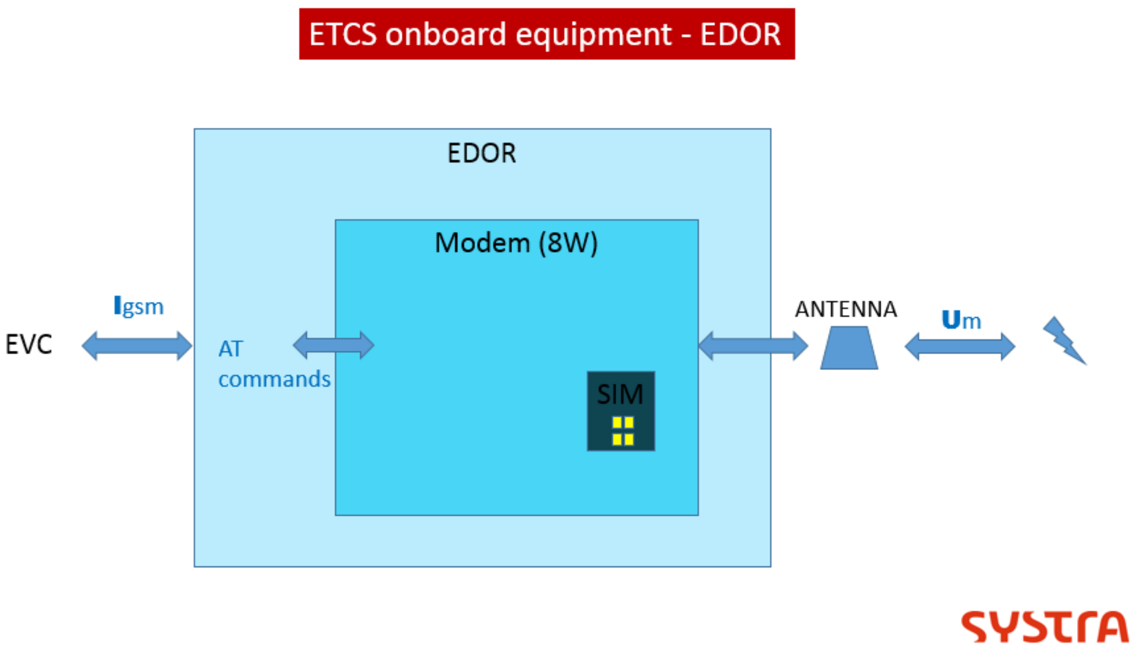

Figure 18. EDOR – Internal HW architecture

The train has to allow the establishment of two simultaneous communication sessions with the ETCS trackside equipment.

For normal operation of ETCS on Circuit Switch (CS) (mainly for inter RBC Hand-Over and for network border crossing), two EDORs are necessary: call clearing and re-establishment is longer than the time considered to be safe by the ETCS application to continue running without having contact with the Radio Block Center (RBC) (timer TNV_CONTACT), therefore the train will initiate the programmed reaction (such as applying the service brake or the emergency break) until the communication is re-established with the RBC. That is why a second EDOR is necessary to establish a new call to the RBC that will be controlling the movement of the train before the end of the call with the RBC that has been controlling the train movement until that moment.

Most of the time, one or two EDORs with shared antenna are installed for redundancy reasons. Additional modems are an operator's choice to fulfil reliability requirements.

Multiplication of the antennas is not always possible; two parameters must be considered:

- Space on the rooftop's train
- Spacing between the antennas to avoid interferences in case of simultaneous usage

For example, on French TGV, only 3 GSM-R antennas are allowed on each locomotive: one for voice calls, two for EDORs, even if 3 EDORs are actually present (they share the use of one of the antenna).

In some configurations, the antenna may be considered as a Single Point Of Failure (risk of broken antenna). In that case, only one modem can operate ETCS and inter RBC Hand-Over in Circuit Switch mode works under degraded conditions, which lead to the application of the programmed reaction, as previously explained, resulting in an operational impact.

In ETCS on GPRS/EGPRS with usage of packet switch (PS), inter RBC Hand-Over management can be handled with one EDOR only for normal operations.

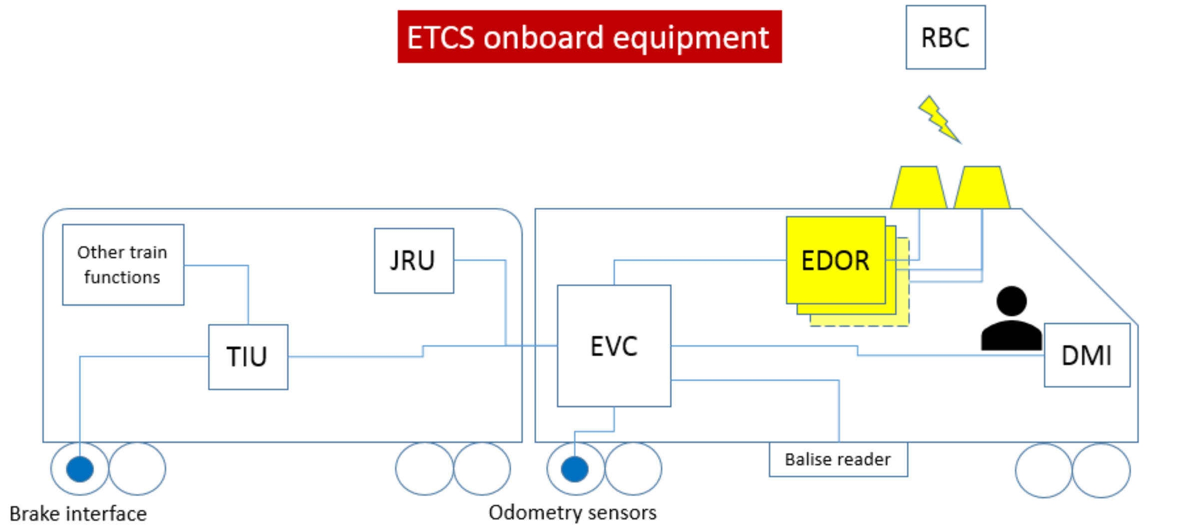

Figure 19. EDOR – On-board architecture

Interfaces & Protocols:

Depending on specific national needs, other signalling systems than ETCS (with proprietary interfaces) are added to the train systems described above.

The interface of the EDOR with the ETCS OBU (EVC) is called IGSM: it is standardised and referenced in document [9] (see page 21) based on AT commands over serial line. This interface supports both Circuit-Switched (CS) and Packet-Switched (PS) transmission modes.

Electrical properties of IGSM shall conform to ITU-T Recommendations V.28 (also known as RS232) or V.11 (also known as RS422 and RS485).

Mechanical properties shall conform to ITU-T Recommendations V.24 using a DB25 connector.

Euroradio protocol description

Euroradio is part of ETCS On Board Unit using HDLC as data link control protocol used by the ETCS application to increase the reliability of the transmission.

For CS, where the transparent transmission bearer service is used, HDLC parameters are determined to control matters such as the number of retransmissions to consider the connection is dropped.

For PS, GPRS and MAC/LLC data link control protocols are used at the transport layer.

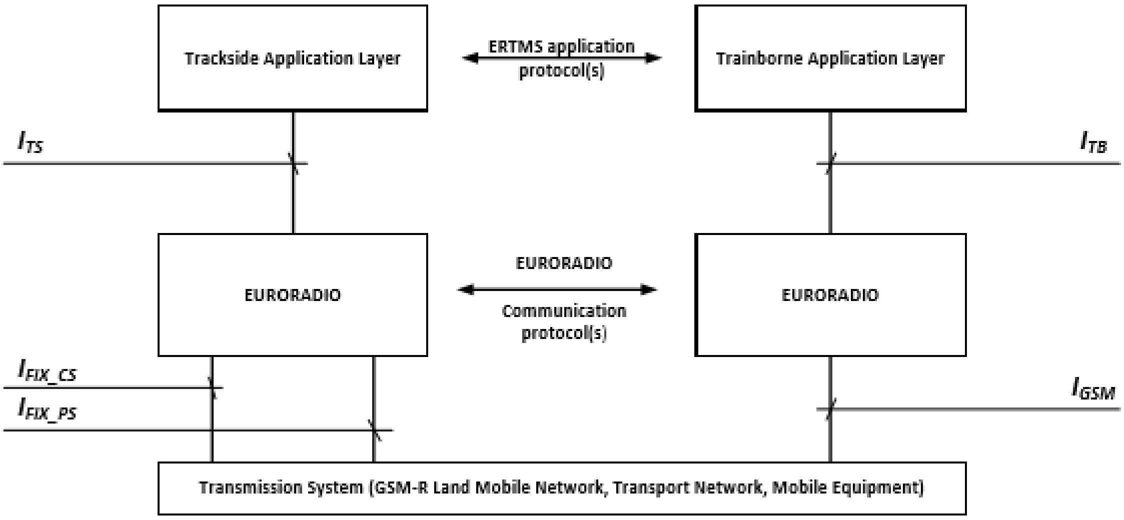

Figure 20. Extract from "Radio Transmission FFFIS for Euroradio" (A11T6001 v13.0.0)

Security

To secure ERTMS data communication, the security protocols are implemented in the application domain.

ERTMS applications use GSM-R and fixed transmission networks to transfer messages between ETCS OBU and ETCS trackside equipment. GSM-R and fixed transmission networks are considered as open transmission systems (also known as non-trusted transmission media).

As ERTMS messages such as Movement Authority are considered critical for train operations, it is important to secure the integrity and authentication of messages sent over GSM-R and fixed transmission networks.

ERTMS security mechanisms (principles, functions and messages) are described together with the keys/algorithms used for encryption and the Key Management System (ERTMS KMS) in UNISIG documents.

A new on-board entity has been described, the Key Message Authentication Code (KMAC) on-board entity part of the ETCS OBU, where ERTMS keys are installed.

Each RU who want to operate trains on railway lines operated with ETCS Level 2 or 3 has to request the corresponding ERTMS keys from the Home Key Management Center (KMC) of each vehicle. The ERTMS keys are generated by the KMC in charge of doing so for the geographical area intended to be visited. A single key may be valid to be used with one or many ETCS entities and for a limited duration, depending on the security policy agreed between the parties.

6.2 Installation and upgrade mechanisms

The following chapter provides installation and upgrade mechanisms for CabRadios and EDORs followed by some of the interviewees (RU) for international trains . Note that this is not a generic installation and upgrade mechanism in Europe.

But it provides lessons learned on the whole process, constraints and limitations that RU faces every day to provide interoperable on-board subsystem. Opportunities for improvement are then highlighted based on lessons learned.

6.2.1 Software

Installation and upgrade mechanisms of software cover system software as well as configuration of software parameters.

Process & tools, specific to Railway users:

The same process as previously detailed for hardware applies except the SW update process in depot by maintenance team: the product supplier provides an update tool (e.g. Windows application to be executed on a laptop using Ethernet/RJ45, serial or USB interface) used by the maintenance team for the SW upgrade. A wired or low-range radio link is needed between the maintenance laptop and the EDOR or CabRadio.

It is to be noted that an OTA SW upgrade could not be started on running trains for critical functions as the maintenance team has to enter routine test and complete testing of critical applications (relevant to EDOR and CabRadio).

Note also that some suppliers propose OTA upgrade possibilities via GSM-R: the main difficulty is that operation success cannot be systematically checked if used on running trains. The functionality is mainly used for non-critical functionality.

6.2.2 Hardware

Process & tools, specific to Railway users:

- Requirements are first coming from RU activities or obsolescence of a component or bug fixing. Compliancy to a new TSI is mandatory only for new equipment installed (or for new trains)
- Telecom/GSM-R program manager is collecting all requirements to prepare a requirement specification together with a vehicles roll-out planning
- On-board equipment supplier (or consortium) reply with an offer
- On-board supplier enters the design & build phase
- On-board supplier delivers the product
- RU enters lab testing phase (including regression testing phase)
- RU enters vehicle testing phase of all interfaces (not available on the lab)
- RU enters pilot service on a couple of vehicles -> lessons learned to fix bugs
- RU starts the installation of the product in the vehicles: internal safety commission to ensure that critical applications are running without any regression (impact assessment etc.)
- RU starts in parallel the certification and authorisation process in the Member State with the National Safety Authority (based on the assessment provided by the Notified Body for the interoperability requirements and the Designated Body for the national requirement). Then RU can start the deployment phase: maintenance teams receive modification order to update the product in depots
- Maintenance team in depots replace the complete on-board product with the new one
- Maintenance team in depots run routine tests
- Maintenance team in depots complete testing in-situ for critical applications only including regression test on other applications (interfaces)

This process takes around 2 to 3 years to be completed (from collection of requirements to deployment) and could be extended **from 6 months to 5 years** (and even more are reported) due to the NSA authorisation process in each Member State to assure that the vehicle is compliant to interoperability **AND** national requirements.

The introduction of a new or upgraded non-critical functionality or train borne equipment leads to a long and systematic process.

6.2.3 Software upgrades for commercial smartphones

This section has not direct relevance for the current on-board system but is added here for comparison.

The process that is typically used to update consumer smartphones and tablets could be considered for on-board equipment in the future, and would seem to be promising; however, the need to ensure reliability, and the verification that the update does not negatively impact critical functionality (presumably through a certification process) would need to be addressed. We are describing this process as part of the current situation, even though it is not currently used for operational rail communications (to the best of our knowledge), in order to provide context for the discussion of software upgrade processes.

Typically, the user of an iPhone, iPad, or Android smartphone or tablet is notified that an operating system update is available. The device loads the update and installs it either (1) when the user wishes, or (2) automatically when conditions are suitable – power and Wi-Fi are available, for instance, and the user has configured the device to update automatically.

Apple is a vertically integrated supplier of both hardware and software, which gives it considerable control over the operating system update process. Android, by contrast, is distributed by many smartphone and tablet makers (referred to as *OEMs*) such as Samsung, Nokia, and Sony. The distribution of updated versions of the Android operating system takes place through these OEMs, (which can introduce delay) [26].

Updates to the Android operating system may require the user to intervene, perhaps multiple times .

Android apps can be set up for automatic update. Alternatively, the user can configure automatic update of Android apps by invoking the Google Play Store app, selecting the app of interest, and choosing the option to *Enable auto update*. As another alternative, the user can manually, individually initiate updates to Android apps by invoking the Google Play Store app, selecting the app of interest, and choosing to *Update* or to *Update all*.

Similar considerations apply to the Apple iPhone. Manual updates to iPhone apps can be initiated by opening the iTunes App Store on the device, and choosing the *Updates* icon that appears on the screen.

6.3 Maintainability

Telecom system and train subsystems such as PA or intercom systems have different life cycles. Managing obsolescence of those systems shall be considered independently by separating applications and transport (radio) in different products with separate life cycles.

Due to maintainability reasons and for consideration, a suggestion may be to separate the hardware for critical and non-critical equipment to allow independent updates. This solution would have the advantage to decrease the amount of non-regression test, but would also have an impact on the architecture, with addition of hardware components. The use of standardised interfaces between hardware components is an essential condition for success to improve maintainability.

[26] See https://twitter.com/secx13 viewed 17 August 2018.

6.4 Certification of Software and Hardware

6.4.1 Initial Certification

Interoperability Directive

Directive 2017/797, which replaces Directive 2008/57/EC, establishes the conditions of the defined parts of the rail system to be met in order to achieve interoperability in Europe, regarding the design, construction, placing in service, upgrading (improving the overall performance of the subsystem), renewal (no impact on the overall performance of the subsystem), operation & maintenance (O&M) of these parts. Conditions are known as essential requirements in the Interoperability Directive.

Subsystem

Each part of the system is called subsystem, and it is covered by one Technical Specification for Interoperability – TSI. The Control-Command and Signaling (CCS) is the subsystem of the rail system in the scope of this study.

TSI CCS is the relevant TSI for this study ; CCS subsystems shall comply with the TSI in force at the time of their placing in service, upgrading or renewal. The TSI shall not apply to existing subsystems of the rail system already placed in service at the date of entering into force.

The latest of the TSIs relating to the CCS subsystems of the rail system in the European Union and its revisions are listed below:

- Commission Decision 2012/88/EU
- Commission Decision 2012/696/EU
- Commission Decision 2015/14/EU
- Commission Regulation 2016/919/EU

The TSI shall apply to all new, upgraded and renewed trackside and onboard CCS subsystems.

The following CCS Subsystems of the rail system in Europe are identified in the TSI CCS:

- Onboard CCS subsystem consisting of three parts (train protection, voice radio communication and data radio communication) characterized by basic parameters (functions, interfaces and performance critical to interoperability) to be compliant with mandatory specifications and standards
- Trackside CCS subsystem

The mandatory set of specifications defined in last TSI CCS are listed below:

- Set of specifications #1: ETCS Baseline 2 and GSM-R Baseline 1
- Set of specifications #2: ETCS Baseline 3 Maintenance Release 1 and GSM-R Baseline 1
- Set of specifications #3: ETCS Baseline 3 Release 2 and GSM-R Baseline 1

A subsystem shall comply to one of the 3 sets of specifications listed in the CCS TSI to meet its requirements. The radio technology (GSM-R) is referenced in the TSI and mandatory as the communication technology for the voice communication with the traffic controller and for the transmission link of ETCS on-board to ground via radio (Levels 2 and 3). The TSI shall be updated in the future to include new communication technology (FRMCS) or to be technology agnostic by specifying interfaces, functions, performance and availability requirements to the communication subsystem (and by removing all notion of telecom – and may be security – in the ETCS subsystem) as defined in the bearer independent concept.

Current CCS On-board Subsystems are limited to train protection (ETCS) and radio communications (GSM-R) for voice and ETCS data. Strategic direction of the rail system in the development of CCS TSI will potentially extend the scope of CCS TSI with Automatic Train Operation (ATO) including additional critical communication needs (such as critical real-time video between ATO On-board and trackside). A new interface between ETCS and ATO systems or a direct interface from ATO on-board and ETCS TS (Telecom subsystem) might be defined.

Interoperability Constituents

Interoperability Constituents (IC) part of the Onboard CCS subsystem (of interest for our study) can be considered as components of on-board equipment and are listed below:

- ETCS part:
  - ETCS On-board (ETCS OBU) including GSM-R - EDOR interfaces
- GSM-R (radio) part:
  - GSM-R ETCS Data Only Radio (EDOR)
  - GSM-R voice cab radio (CabRadio)
  - GSM-R SIM Cards (although they are considered as part of the CCS Trackside Subsystem, they are installed on-board)

On-board radio equipment is duplicated, having at least two EDOR and one CabRadio for voice per train or per cabin as detailed in section 6.1.2[27]. Some RU are considering redundancy, where more than two GSM-R on-board equipment for ETCS are installed (and as many SIM cards as GSM-R on-board equipment).

Each of the Interoperability Constituents of the onboard CCS subsystem can be certified independently.

Focusing on the GSM-R part, it is to be noted that some HW components are not listed as IC even if they can be considered as critical for interoperability, such as external filters and antennas, with direct impact on the performance of ETCS and GSM-R: these are assessed at the Subsystem level.

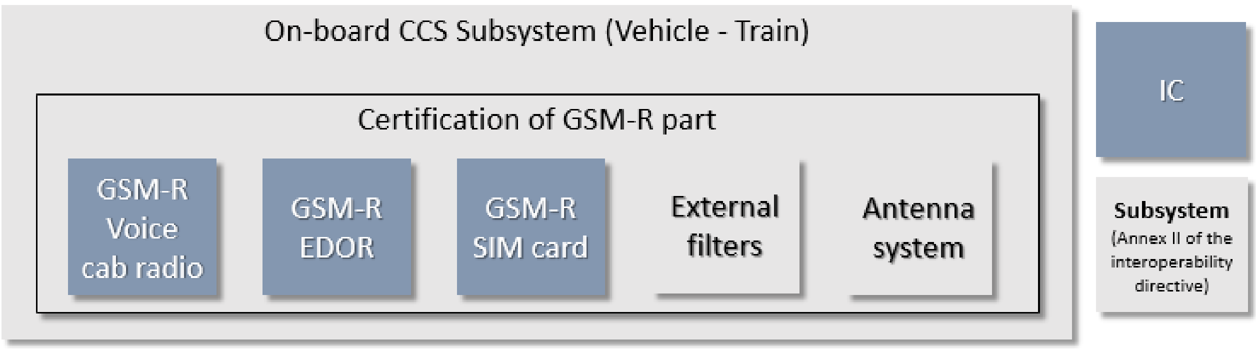

Figure 21. On-board CCS subsystem –> GSM-R part –> Interoperability Constituents

Before placing on the market an interoperability constituent, the manufacturer shall draw up an EC declaration of conformity for the ICs and an EC declaration of verification for the Subsystem.

[27] For GSM-R Baseline 0 (CS only), modems which are part of EDOR and CabRadio are similar equipment.

For GSM-R Baseline 1 (introducing PS), modems could be different as PS is mandatory for EDOR and CS is optional for CabRadio.

EC certification for subsystems and IC

The mission of Notified Bodies is described in Commission Decision 2010/713/EU (relevant for all subsystems, not only CCS). Their activity is based on the assessment of conformity to the requirements using procedures or modules relevant for subsystems and ICs.

Notified Body (NoBo) are accredited in Europe by the competent authority in each Member State and are responsible of matters relating to the application of:

- the relevant TSIs
- the procedures for assessing EC conformity of interoperability constituents (compliance with relevant basic parameters of the TSI CCS and other directives such as 2014/30/EU on Electromagnetic compatibility, 2014/53/EU on Radio equipment and 2011/65/EU on RoHS) using different modules. EC declarations of conformity of IC are issued by Manufacturers including among others the assessment by NoBos.

  Note: EC suitability for the use is not required for CCS IC.

- the procedures for the EC verification of subsystems. EC declarations of verification of subsystem are issued by Manufacturers including among others the verification by NoBos.

The Interoperability Directive allows Member States to mandate essential requirements (called national technical rules) to a subsystem that are not included in the relevant TSI when found to be needed to ensure the safe operation in their railway system. This may include specific interfaces, functions or performance to the on-board CCS subsystem for trains willing to run in the lines of the Member State, which may have a huge impact on on-board architecture. These national rules are being analysed in order to reduce the number of them, since this diversity is clearly against the objectives of the interoperability directive to provide a single EC certification for subsystem crossing the European borders.

Designated Body (DeBo), designated by each Member State for the verification of the rules laid at national level, are responsible of matters relating to the application of these national technical rules (NTR) (similar role to NoBo but for the national requirements).

Commission Decision 2010/713/EU provides ability for NoBos and Manufacturers to choose between different processes (called modules) for EC certification of subsystems and IC. The list of applicable modules for the assessment of the requirements in a specific TSI is included in the TSI itself.

The choice for a specific module shall be made prior to the beginning of the certification process. Some modules are testing-oriented, others are quality-oriented. Examples of commonly agreed modules for IC verification between NoBo and IC Manufacturers:

- Module CB (NoBo is in charge): type-examination. Testing activity on one piece of equipment (EIRENE MI requirements as a minimum), review of documentation. Conducted in a lab. Coupled with module CD.
- Module CD (NoBo is in charge): quality approval of Management system (production sites). Audit of production sites and documentation. Coupled with module CB.
- Module CH1 (NoBo is in charge): standalone module on quality approval, less testing activity.
- Module CA (NoBo not required): manufacturer internal specification, specific to SIM Card.

Examples of commonly agreed modules for subsystem verification between NoBo and IC Manufacturers:

- Module SH1
- Module SB
- ....

Differences between EC certification of subsystem and IC

- IC certification is the assessment of a product or set of products as “interoperable equipment” (interchangeable between different manufacturers) assessed by NoBo in a laboratory environment. No verification of End-to-End (E2E) functional requirements are made, no verification of external equipment (such as external filters or antenna system), no verification of installation on-board.
- Subsystem certification is the assessment of the complete (sub)system. No verification of E2E functional requirements is included since the TSI clearly separate the trackside and the onboard requirements.
- The assessment of E2E requirements is out of the scope of the NoBo (since there is a clear separation in the TSI between Onboard and Trackside requirements). Measurements such as the end to end quality of service for ETCS Level 2 or 3, as presented in the subset-093 and document O-2475, have to be done for each combination of vehicle and trackside due to the fact that the KPIs expressed are not split between onboard and trackside.

6.4.2 Certification after upgrades

Evolution of a subsystem (already authorized by NSA and operating)

NSA determines if a re-certification is needed. If not, there is no need to re-certify.

Evolution of an IC (already operating)

Many versions/releases have to be managed by RU. It is possible a new SW version is requested to address the following:

- Bug fixing, part of maintenance procedures
- Introduction of a new feature

The management of updates or evolutions in the certification process could be described as followed:

- The manufacturer (or RU) shall notify the NoBo about changes.
- The NoBo asks for description of changes.
- The manufacturer (or RU) shall provide an impact assessment (impact on interfaces, functions and performance). Based on impact assessment conclusion, a common decision is taken by NoBo and Manufacturer (or RU) with two options:
  - A new certification from NoBo is needed
  - Update the technical files to provide an updated declaration of conformity from Manufacturer
- If a new certificate is requested, the NoBo provides a restricted assessment activity (compared to the initial certificate) mainly based on documentation review, and sometimes with additional testing activity.
- No general process but always adapted with the applicant (Manufacturer or RU) depending on needs for such certification. The process shall be clarified prior to the certification request.

Note that if the maintenance procedures (that have been assessed by the NoBo as part of the IC certification) contemplate the activity of updates due to maintenance, these updates do not trigger the process above.

6.4.3 Lessons learnt

Interviewees considered that the following lessons were learnt:

From Notified Bodies (NoBo)

- Test specifications: test specifications to assess GSM-R MI requirements have been listed recently in the CCS TSI Application Guide (cf. document O-3001). Before this, test specifications had to be agreed with the applicant (manufacturer or RU/IM). It is not considered as an issue by NoBo for onboard certification as complete testing activity to certify CabRadio is no more than one full week in a lab.
- Verification of Quality of Service requirements: subset-093 [3] is not mandatory in CCS TSI but often mandatory in tender requirements. Subset-093 defines QoS KPI of the GSM-R system as E2E KPI. Some NoBo recommend splitting QoS requirements per subsystem (onboard and trackside) independently. ERA has been requesting to have this split done for the last years; currently undertaking review of the KPIs and methodology for testing them in order to include PS. After including PS, the splitting of onboard and trackside is expected.

From Railway Undertakings (RU) and Infrastructure Manager (IM) representing the Railway sector

- EC certification is a long and costly process. A stable release of CCS TSI valid for a long period of time is requested by the Railway sector.
- As long as NSA and IM are requesting national requirements (National Technical Rules – NTR) to be implemented by RU as mandatory requirements, this will add complexity to the on-board equipment and the related certification.
- A long list of on-board requirements (interoperability related and national) lead to a complex HW and SW on-board architecture, hard to maintain for industry and for RU. Most requirements are mandatory for on-board and optional for infrastructure. On-board subsystem is the weak part of the whole system, as a complex subsystem and shall be simplified by adding some kind of modularity.

From the European Economic Interest Grouping ERTMS Users Group (EEIG EUG)

- On-board subsystem – functions: decoupling ETCS and Telecom as fully independent parts. The Euroradio and the security protocols shall be (re)designed and transferred to the Telecom part. This is for further consideration as security protocols are not of the same level considering multiple radio technologies based upon the Bearer Independent Communication concept (e.g. Wi-Fi and 3GPP 4G have not been designed on the same security requirements).
- On-board subsystem – interface: IP based interface between Critical equipment (such as ETCS OBU and ATO OBU) and Telecom shall be considered
- On-board subsystem – IC: a shared Communication gateway to be considered as a single (radio) IC to avoid multiple certificate for IC as it is managed today in silos (EDOR and CabRadio).

6.5 Experience Based on Previous Examples of Migration

6.5.1 Analogue > GSM-R

GSM-R is an interoperable system: trains moving abroad no longer have to be equipped with the national analogue systems used in each visited country, when GSM-R is used, it replaces all of them.

However, during the migration phase - which takes several years for large countries - while GSM-R is being deployed, all trains, both national and international trains must install on board either multi-mode radio equipment or install separate receivers for the analogue and GSM-R systems.

In some countries, it was considered as absolutely necessary to equip all trains before GSM-R exploitation could start: to equip all trains is a long-term process which takes several years and was started before GSM-R deployment.

Interconnection between both systems (e.g. REC on border between GSM-R and analogue domain) is usually managed by the Infrastructure Manager.

6.5.2 ETCS GSM-R > GPRS

Document [9] (see page 21) allows the reuse of the serial link for the IGSM interface: this interface supports then both Circuit-Switched (CS) and Packet-Switched (PS) transmission modes. Modems compliant to GPRS (3GPP specification) have been also available for quite a long time.

It is then possible to upgrade EDORs from Circuit Switch to Packet Switch without any hardware upgrade on the radio side, to prepare the evolution to PS.

However, the ETCS OBU has to be upgraded in order to be able to use PS to communicate with the RBC (note that existing RBCs also have to be upgraded in order to handle communication sessions both in CS and PS). Only the new ETCS Baseline (Baseline 3 release 2) includes this functionality: on-board and trackside ETCS equipment that follow previous versions of the specifications do not support the use of PS. Only newly installed EDOR include an Ethernet interface, currently not used, and reserved for a future usage (e.g. supporting the IGSM interface instead of serial link). Some of the existing EVC and EDOR equipment do not include ethernet interface (not a mandatory requirement). It should be considered as a normal evolution of telecom interfaces to an all-IP world.

It is to be noted that there is very little interest in GPRS (except DK and UK) and very little experience in migration from CS to PS, despite the fact that PS is mandatory for EDOR (from GSM-R Baseline 1).

6.6 Limitations and Opportunities for Improvement

This section only lists findings with direct relevance for on-board architecture:

- Monolithic and silo architectural approach (ETCS, GSM-R voice) with dedicated modems for critical applications
- Security protocols are implemented in the application domain for ETCS traffic (i.e. included in the ETCS OBU) and in the transport domain for voice communication (i.e. included in the Modem of the CabRadio).
- Security protocols are not periodically updated with security patches (to fix known security breaches)
- Space limitation for roof-top antennas. In some configuration, the antenna may be considered as a Single Point Of Failure

- Many proprietary interfaces to external on-board systems
- The introduction of a new or upgraded non-critical functionality or train borne equipment leads to a long and systematic assessment process
- Hardware upgrade is a long-term process which may take several years
- National Technical Rules and optional features complicate the onboard equipment. The fact that the on-board hardware and software are not very modular is complicating the upgradability.

7. FUTURE DEVELOPMENTS AND ONGOING INITIATIVES AS REGARDS ON-BOARD OPERATIONAL RAIL SYSTEMS

This chapter presents an overview of the future trends of railway radio communications and how they may or may not have an impact on on-board architecture. By analysing the current work in areas such as standardisation it is possible to form an opinion on the likely evolutions to come as well as to highlight the advantages and disadvantages which may help to inform the various ongoing debates.

Each of the following areas will be addressed:

- Functionality
- Technology
- Spectrum
- Migration
- Hardware limitations
- Software-Defined Radio (SDR)
- Future research projects
- Security
- Architecture concepts

It is clear that each of these areas may have impact on the on-board architecture and equipment. This impact is summarised in a table at the end of this chapter.

7.1 Functionality

7.1.1 UIC User Requirements Specification (URS) versus TSI CCS

The UIC URS contains descriptions of many critical and performance applications, in particular in comparison to EIRENE and to applications referenced in TSI CCS. In fact, ETCS and driver-signaller and Railway emergency voice communications are the only mandatory applications to be supported by the on-board CCS subsystem today. It is not expected that a lot of URS applications will become Mandatory in future CCS TSI's.

However, in order to allow the installation of more and more applications on on-board (or handheld) devices, a flexible approach and architecture is required. The General Principles given in the URS, as well as the app base approach which is likely to appear in the Functional Requirement Specification (FRS, in an early drafting phase) may lead to an onboard architecture based upon a (redundant) shared communication gateway for all critical applications to optimise sharing of resources, and to decouple applications and transport.

The FRMCS functionality developments have been described in section 2.

7.1.2 Location services for ETCS and voice communications

A key challenge going forward will be to provide location information from or to the train under FRMCS, to be used by several applications and functions. It is assumed that, using information about the serving radio cell (the one used by the on-board radio) cannot always be used as a suitable indicator, as is also the case in the GSM-R (that's why eLDA has been specified). Notably, FRMCS is intended to support transmission not only by means of a mobile network, but also by means of satellite and Wi-Fi services using an integrated service. For satellite and for Wi-Fi, and perhaps in other cases, the serving mobile network cell identifier is no longer relevant. For cellular networks, the serving mobile network cell identifier should not be considered as accurate enough to meet railway requirements.

This shift poses challenges for operational voice services, but not for ETCS, because ETCS does not depend on the cell identifier. For ETCS, the Eurobalise functions as a location reference, providing accurate location information directly to the train.[28] Eurobalises are generally deployed in pairs, such that the sequence in which they are crossed also indicates the direction of travel to the train.

The exact position of the train at every single moment is calculated taking into account the reference provided by the Eurobalises and the distance run by the train after having read the Eurobalise group. The distance run is obtained via an odometry system (counting the number of wheel turns, or rail beams passed …), which has to be very accurate. The challenge lies in obtaining the absolute position of the train with high accuracy based on the combination of the reference point provided by a Eurobalise group and the odometry system used. The shift to FRMCS, irrespective of the technology used, does not need to modify these principles for ETCS.

Work is ongoing to include other reference systems (i.e. virtual balises using satellite positioning systems).

The future inability to rely on the mobile network cell identifier poses challenges, however, for operational rail voice communication functions. Location services are essential for certain voice functions. Consider, for instance, Railway Emergency Call (REC). The REC is a pre-emptive call placed from the train driver to the responsible controller and to train drivers in the area. Location information is needed to determine to whom the call is placed.

In section 3.2.3.1.2, we suggested possible use of an external location server, which could be contacted using SIP/IMS in the case of an FRMCS 3GPP deployment or using open SIP protocols to an external SIP server in the case of our proof-of-concept OTT FRMCS deployment. For either deployment, it is difficult to see how to handle location information without some kind of server-based solution. The on-board equipment could provide the location server with whatever location information it has, based on Eurobalise information, GPS or Galileo, or any of a number of other means as described in section 3.2.3.1.2.

Some re-design of software for operational rail voice communications would be required to implement such a system, since the location would need to be obtained from the location server (instead of relying solely on the cell identifier). At the same time, voice services might benefit from such a design to the extent that they could use more accurate location information (derived from Eurobalises, from satellite positioning systems, or from other sources), which is not the case today.

7.2 Radio technology

7.2.1 4G and/or 5G

A decision has yet to be made on the choice of technology, 4G and/or 5G, by the railway community (UIC asks for 4G <u>and</u> 5G to be supported in the bearer flexibility UC).

A number of the UIC FRMCS System Principles Use Cases are already solution-dependent focusing specifically on 5G technology (e.g. network slicing). Based on this, it seems clear that the target is to deploy a 5G network in the long term.

[28] Work is ongoing to support additional reference systems, such as satellite positioning systems.

Some industry players are pushing for 4G because of Railway/Urban Rail customers outside Europe, whilst European Railways push for 5G looking for the future. Additionally, some Railways expressed their fears while going to MCX which is voice-group oriented as the future of communication should be data-driven, even for railways with future autonomous trains (referring to what is currently happening in the automotive industry).

On the other hand, the fact that the latest EC Decision on spectrum for Short Range Devices reserves 1,6 MHz (including a 0,2 MHz guard band) for railway use, will prevent the Railways from an initial implementation of 5G in this band, since the minimum bandwidth expected for 5G is 5 MHz, unless the GSM-R band can shared by 5G using a specific technology (see Section 7.3).

Depending of the roadmap products, migration strategy and upgrade capacity, the question is more to know if 4G will be an intermediate step, or if the future will be a direct upgrade from 2G to 5G.

Based upon interviews and desktop research, the following advantages and disadvantages have been identified for each of the generations.

4G system (LTE)

Advantages:

- Mature communications technology
- 3GPP MCX specifications are included in 4G requirements since Release 12.

Disadvantages:

- Likely not able to meet very tight latency and reliability requirements of use cases described in Section 2, due to limitations in user plane and in particular control plane latency.
- Fixed and limited set of numerologies and “hard-coded” design of control signals, reference signals etc. may require rail-specific amendment of standard, for instance for rail operation in the anticipated bands
- Inefficient support of use cases with very diverse requirements, as no in-bearer QoS differentiation possible.
- Lack of support of dynamic time division duplex (TDD) may be problematic w.r.t. the burstiness of traffic and temporary uplink/downlink imbalance.
- Possibly limited technology support over time (at the time that FRMCS is fully rolled out, LTE will already be a 15-25-year-old communication technology).
- The 4G system does not support services using satellite access.

5G system

Advantages:

- Future-proof communications technology with a high level of configurability, allowing tailoring of, e.g., numerology (i.e., system bandwidth, symbol length, FFT size, used sub-carriers, etc.), control and reference signals (e.g., the signals used to estimate radio channels, which could be adapted to train speed) to rail-specific needs at limited effort.
- Novel QoS architecture allowing for a differentiated handling of packets (e.g., in terms of latency and reliability requirements) related to different use cases.
- Native network slicing support, enabling the definition and operation of virtually separated E2E networks, which is especially relevant if critical rail operations may have to share the same spectrum and/or communications infrastructure with non-critical services.

- Native support of (massive) multi-antenna (MiMO) or coordinated multi-point (CoMP) transmission and reception with highly configurable reference signals and channel feedback schemes. This would for instance allow MIMO operation that is highly optimized for rail scenarios, with no or limited need for standardization, allowing to meet also increased rail requirements with a lesser degree of deployment densification and hence reduced cost.
- Native support of efficient device-to-device (D2D) communication (for instance with more efficient sidelink estimation than in 4G), for instance for train-to-train communication in virtual coupling scenarios.
- Native support of a variety of function splits, allowing for instance the deployment of inexpensive remote radio heads at the trackside with reduced requirements on the transport network infrastructure.
- Service based architecture in the core network and generally better virtualization support, for more flexible, inexpensive and future-proof network implementation.
- Possibility to still influence the "basic" releases of NR technology (e.g., 3GPP Release 16, 17). A new WI at SA6 is to study impact of MCX on 5G.
- 5G core can support both 4G and 5G access networks (the opposite is not supported).
- The 5G system shall be able to provide services using satellite access.

Disadvantages:

- 3GPP MCX are not supported in 5G Release 15 but foreseen from Release 16. The conclusions of the 3GPP gap analysis, which is expected in the second half of 2018, should clearly state in favor of 4G and/or 5G as the appropriate technology.

7.2.2 Satellite communication

As already studied by the ERA (Study on feasibility of satcom for railway applications, performed by INDRA/ALG on behalf of the Agency), satellite communication is not suited for ETCS Level 2/3 use unless the application is configured to allow a higher latency (depending on the safety case, for lines with lower density of traffic) .

The ESA (European Space Agency) is currently working in the scope of the IRIS project, on railway applications.

Note also that Satellite communication is not included in 4G as it is a non 3GPP bearer but will be included in 5G [10].

7.2.3 Wi-Fi

Contrary to Satcom, Wi-fi is already included in 4G as 3GPP bearer [10]. Wi-Fi is also considered as support for the future Train Communication Network.

7.2.4 Multiple bearers

The trend to have multiple radio bearer modules combined with a shared communication gateway fully decoupled from applications (conditions: no telecom and security protocols in the application anymore) clearly minimises the impact of lifecycles management . But the layer between application and transport such as security protocols shall be designed

7.3 Spectrum

Radio spectrum allocation is a main challenge for the future Railway Communication System. The CEPT/ECC FM56 working group is considering spectrum identification of railway needs (Report A) and the potential frequency bands (Report B). The last available draft CEPT/ECC Report A could be downloaded from the CEPT/ECC portal:

https://cept.org/ecc/groups/ecc/wg-fm/fm-56/client/introduction/

The European Commission is drafting a mandate to CEPT/ECC on spectrum for the FRMCS (DG CONNECT/B4/RSCOM18-05rev3 Final – July 12th 2018) to provide deliverables according to the following schedule:

- The final CEPT/ECC Report A to the European Commission in July 2020
- The final CEPT/ECC Report B to the European Commission in November 2020

In 4G, LTE technology requires only some possible bandwidths: 1,4MHz; 3MHz; 5MHz; 10MHz; 20 MHz and beyond using Carrier Aggregation feature. For example, if a 4MHz bandwidth is allocated, only 3 MHz can be used, the remaining 1 MHz band is “lost”.

5G allows more flexibility (as an example a 5.4 MHz bandwidth is supported) but a minimum of 5 MHz bandwidth is supported in the 3GPP standard. Looking for less than 5 MHz bandwidth shall be addressed at the standardisation level with the consequence of potential niche market providing non-competitive and scalable conditions.

7.3.1 Spectrum options

ETSI study [11] (see page 21) has been conducted to find out the minimum necessary bandwidth in LTE to get a service equivalent to the current GSM-R for voice calls functions and ETCS: the study concludes that a 1,4MHz bandwidth is enough.

A possible scenario is to open a LTE service in the ER-GSM band, adjacent to the existing 4 MHz existing GSM-R band. A 1,4MHz LTE band, plus a 200kHz guard band would be added for railways usages to the GSM-R band (refer to the EC Decision on SRDs voted in July 2018), for a total of 5,6 MHz. During migration phase, both technologies will coexist, until GSM-R end. After decommissioning of GSM-R, a 5MHz bandwidth could be available, offering new data services capacities and possibly 5G compliancy for main lines only (as addressed in document FM56(18)047).

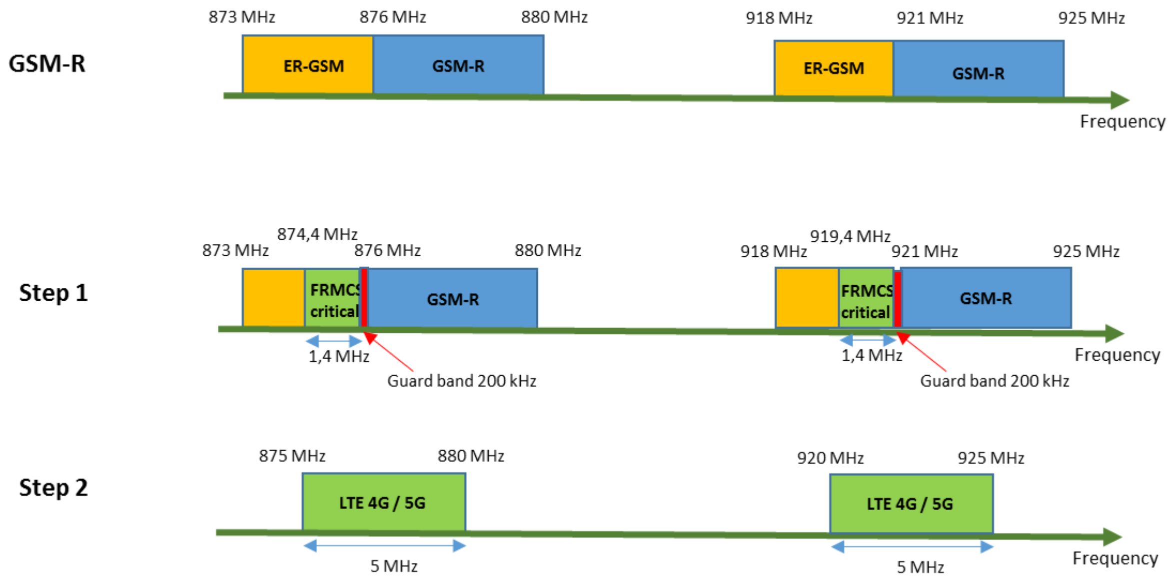

Figure 22. Example of spectrum migration scenario in 900 MHz band

Other spectrum options in Europe are considered such as the 1900 MHz and 2300 MHz frequency bands (refer to FM56(18)041, FM56(18)042 and FM56(18)043) .

For interoperability reasons, European trains could then have to support at least 3 different frequency bands only for FRMCS dedicated networks.

In case of non-attribution of a dedicated frequency band, or when as an additional option, the usage of the public networks can be considered, this may require additional frequency bands to be supported by on-board equipment.

UIC has recently released a position paper[29] on spectrum options for the European Commission and for all European spectrum working groups. This position paper is clearly challenging on-going findings on spectrum options, requesting more flexibility in terms of spectrum options, recommending new thoughts and inputs to evaluate the railway needs, proposed frequencies arrangements and the impacts caused by protection and limitation rules.

One of the items railways are struggling with is the difficulty to predict future applications and the generated traffic. One of the ideas for the traffic model is to distinguish between a “conservative” model containing traffic that can be seen as continuation of GSM-R, and a “progressive” model, containing the potential effects of digitalisation of railways, including critical real time video, for example to support ATO GoA4. Both models may lead to different spectrum requirements, which has impact on requirements for onboard equipment, in terms of the amount of frequency bands to be supported by one or more radio modules (and as a consequence impact on antennas).

7.3.2 Restriction on modem emission power

In addition to the spectrum allocation, FRMCS power transmission may also have a significative impact: today, 8W modems are allowed specifically for GSM-R. In FRMCS, we do not know the future bandwidth nor the future allowed UE output power. On public 4G networks, UE output power is limited to 23 dBm (200 mW). To get an equivalent range in FRMCS and GSM-R, UEs transmitting at least 30/31 dBm (1.25 W) are necessary. The same limitation applies for some EU Public Safety UEs compliant to 4G and 5G standards, where the overlay network (sharing of public/private commercial/dedicated networks) is designed in a way that all UEs (COTS and dedicated) are able to attach to the network irrespective of their output power.

Reducing the mobile power transmission may impose to reduce eNodeB distance – in comparison to GSM-R BTS – and to create new sites, which could create severe economic impact.

3GPP has defined power class 1 UE called High Power UE (HPUE) transmitting +31 dBm for US Public Safety band 14 (700 MHz)[30]. But requesting new normative standard to extend UE output power to at least 30/31 dBm to FRMCS Spectrum band(s) will likely emphasise a niche market as in GSM-R with specific UEs for Railways providing non-competitive and scalable conditions. Recommendation is to reduce the impact on on-board equipment and carrying restriction on modem emission power to the network design to avoid a niche market and paving the way for ensuring greatest economies of scale for on-board equipment.

[29] ERIG E-3936 version 2.0 “FRMCS Frequencies Position Paper” – Jean-Michel Evanghelou – June 27th 2018)

[30] 3GPP TR 36.837.

7.4 Migration scenarios

7.4.1 Purpose

Using the outcome of CEPT/ECC FM56 Report A and Report B, railways may need to define their strategy for the short term (introduction of FRMCS) and for the longer term evolution (objective for e.g. 2030) in terms of spectrum and technology. Although Report A and B are not available yet and any decision on 4G or 5G is still pending, an overview of possible scenarios could help.

The following section describes some scenarios and steps to be taken, and is addressing a couple of questions.

7.4.2 Overview of spectrum and radio technologies

The figure below illustrates the relationship between the current spectrum bands under discussion and the different current and candidate radio technologies, as far as relevant for dedicated networks. The involved bands are in 900 MHz (2x4 MHz, 2x1.6 MHz, 2x5 MHz) as well as 1900 or 2300 MHz (1x10MHz)[31]. Radio technology options are 4G LTE and 5G[32]. The 900 MHz are FDD, the 1900/2300 are TDD.

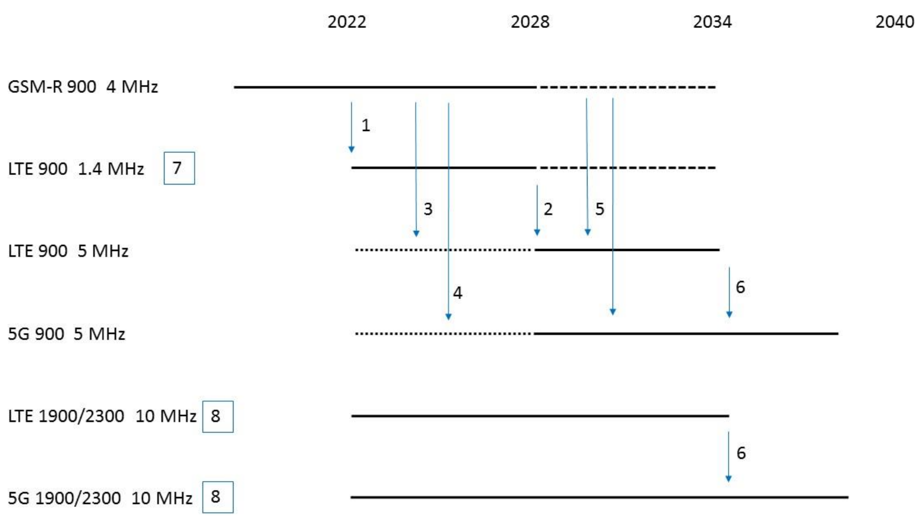

Figure 23. Spectrum and technology options

Note that the numbers in this picture refers to questions in section 7.4.4, not to scenarios. The timescales are just indicative.

[31] Both 1900 and 2300 are under investigation by CEPT/ECC FM56.

[32] LTE supports 1.4, 3 and 5 MHz (and beyond), 5G supports 5 MHz (and beyond, including 5.4 MHz)

7.4.3 Potential Scenarios

Using the figure above, a set of potential scenarios can be derived. Note that some of these scenarios maybe just theoretical, but they are included for completeness.

A. Keep **GSM-R** as long as possible (no migration plan; the supply industry has indicated that GSM-R support would be possible until at least 2034[33]). When needed, PS (GPRS) can be introduced for ETCS, to increase capacity. A next migration step to be planned around 2030.

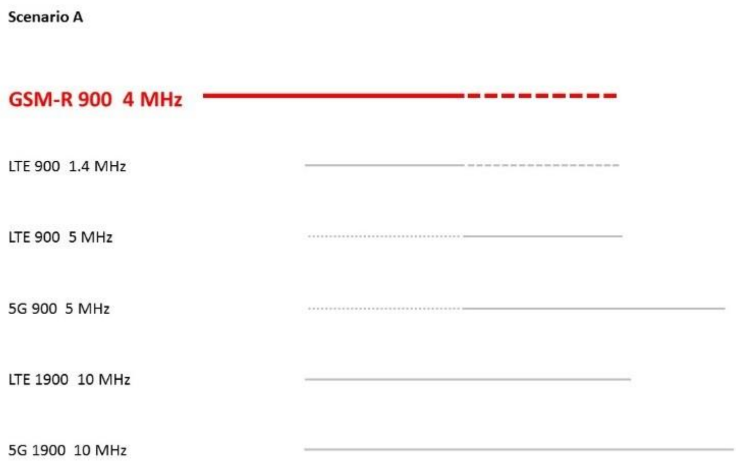

Figure 24. Migration scenario A: keeping 4 MHz GSM-R in 900 band

B. Keep GSM-R as long as needed, introduce in parallel a **1.4 LTE** system[34] in the in the [874.4-876 / 919.4-921] MHz band. After decommissioning GSM-R, the 1.4 MHz LTE system can be extended to a **5 MHz LTE or 5 (or even 5.4) MHz 5G** system. Related questions: 1, 2, 4, 7.

Figure 25. Migration scenario B: keeping GSM-R while introducing 1.4 MHz LTE in 900 band

[33] As contracted in Poland

[34] Introducing a 1.4 MHz LTE carrier requires 1.6 MHz of available spectrum to include guard band

C. Keep GSM-R as long as needed, introduce in parallel a **5 MHz LTE** system in the [875-880 / 920-925] MHz band in the case that a technical solution is available to allow co-existence of GSM-R and 5 MHz LTE [35]. Decommissioning of GSM-R has no adverse impact on LTE. Depending of the lifetime of LTE technology, a decision on a next migration could be needed around 2030. Related questions: 3, 6.

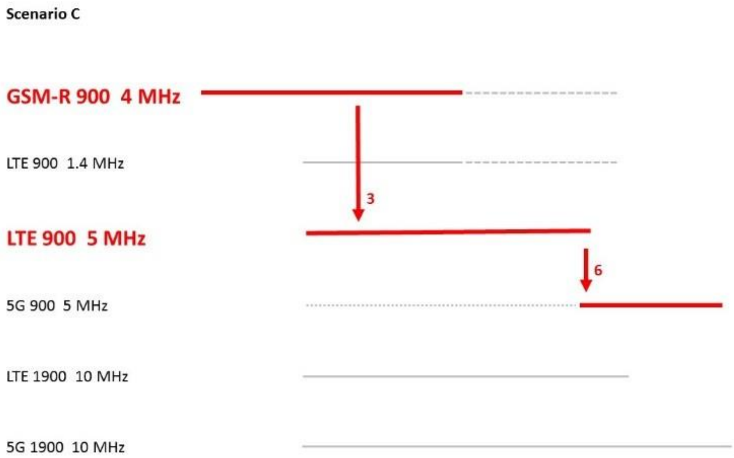

Figure 26. Migration scenario C: keeping GSM-R while introducing 5 MHz LTE in 900 band

D. Keep GSM-R as long as needed, introduce in parallel a **5 (or even 5.4) MHz 5G** system in the [875-880 / 920-925] MHz band in the case that a technical solution is available to allow co-existence of GSM-R and 5 (or even 5.4) MHz 5G. Decommissioning of GSM-R has no adverse impact on 5G. This scenario could be interesting in the case that the lifetime of 5G ends later than LTE. Related question: 4.

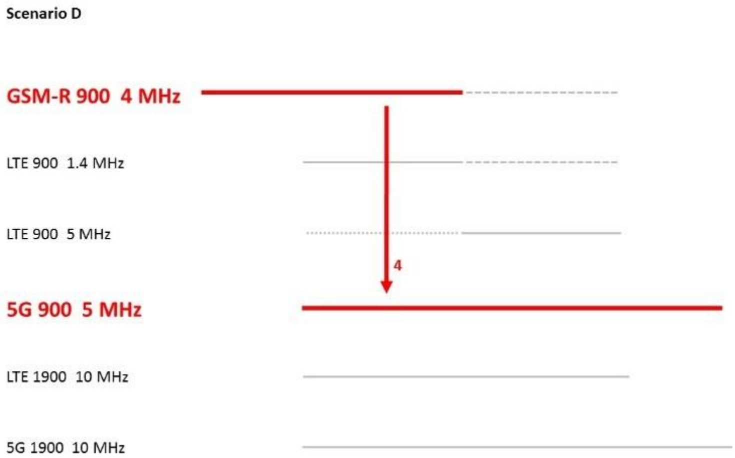

Figure 27. Migration scenario D: keeping GSM-R then introducing 5 MHz 5G in 900 band

[35] Concept being discussed by Industry to avoid spectrum juxtaposition by superimposing a 5MHz wideband system (875-880/920-925 MHz) over the existing GSM-R band (876-880/921-925 MHz)

E. Keep GSM-R as long as needed, introduce via an overnight switch a **5 MHz LTE** system[36] in the in the [874.4-880 / 919.4-925] MHz band. Depending of the lifetime of LTE, a next migration step to be planned around 2030. It is worth considering introducing a 5MHz 5G system instead of LTE. Related question: 5.

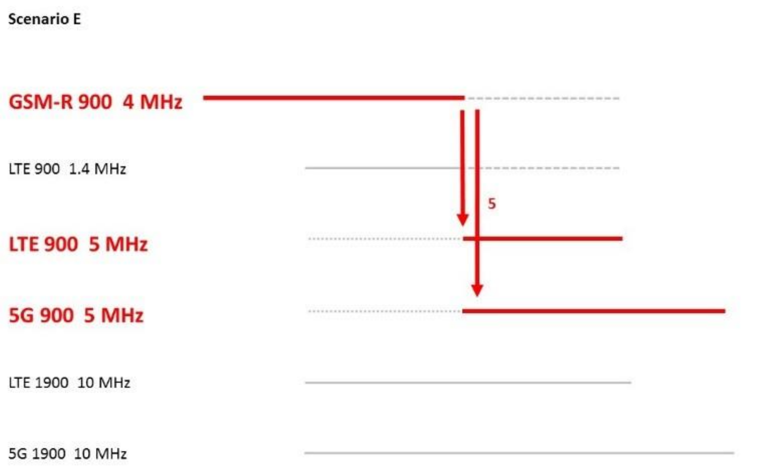

Figure 28. Migration scenario E: keeping GSM-R then introducing 5 MHz LTE or 5G in 900 band

F. Keep GSM-R as long as needed, introduce in parallel a **10 MHz LTE** system in the 1900/2300 MHz band[37]. Decommissioning of GSM-R has no adverse impact on LTE. Depending of the lifetime of LTE technology, a decision on a next migration could be needed around 2030. Note that introducing this LTE system on hotspots only to increase the capacity, does not provide a solution after decommissioning of GSM-R (unless a densification of sites is performed). Related questions: 6, 8.

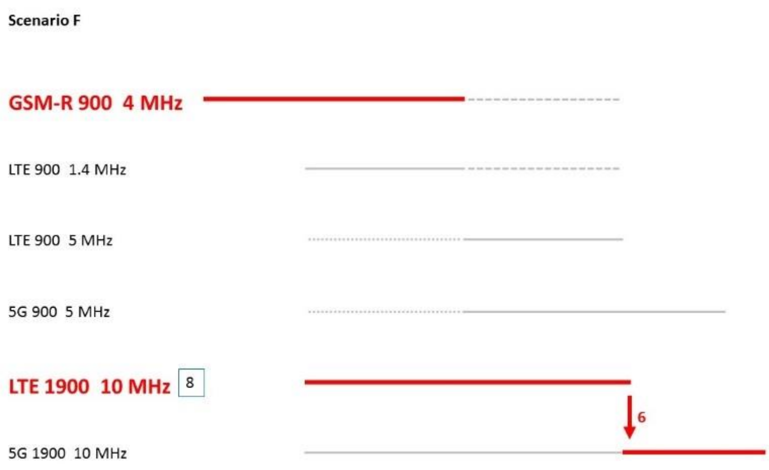

Figure 29. Migration scenario F: keeping GSM-R while introducing 10 MHz LTE in 1900 band

[36] Introducing a 1.4 MHz LTE carrier requires 1.6 MHz of available spectrum to include guard band

[37] Most probably [1900-1910] MHz band, depending on coexistence studies performed in CEPT/ECC FM56.

G. Keep GSM-R as long as needed, introduce in parallel a **10 MHz 5G** system using the 1900/2300 MHz band. Decommissioning of GSM-R has no adverse impact on 5G. This scenario could be interesting in the case that the lifetime of 5G ends later than LTE. Note that introducing this 5G system on hotspots only to increase the capacity, does not provide a solution after decommissioning of GSM-R (unless a densification of sites is performed). Related question: 8.

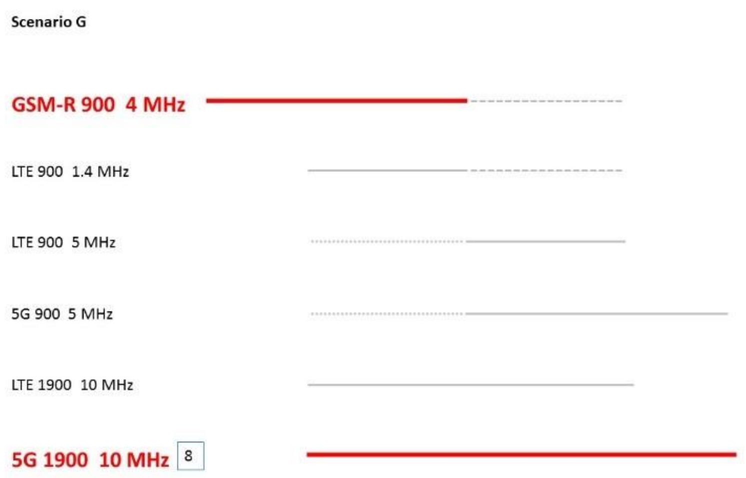

Figure 30. Migration scenario G: keeping GSM-R while introducing 10 MHz 5G in 1900 band

Note that also a combination of scenarios may be possible, e.g. migration scenario D (5 MHz 5G in 900 band, using white space) for the whole network and in addition on hot spots migration scenario G (10 MHz 5G in 1900 band).

7.4.4 Questions to be answered

In order to make a selection of feasible scenarios, the following technical questions have to be answered (referring to the figures in the previous section), related to technical and operational aspects (mainly radio engineering aspects, operational impact). Some information is already available and is added below.

1. Conditions for co-existence between GSM-R and LTE 1.4 MHz

   The technical conditions for co-existence between GSM-R and LTE 1.4 MHz have been addressed in FM56, resulting in 100kHz edge to edge guard band (so driving the 1.6MHz). No further study on this is needed. [38]

2. Conditions and impact of switching from LTE 1.4 MHz to LTE 5 MHz

   To be investigated

3. Feasibility of “White Space” for 5 MHz LTE system in the 1.4 plus 4 MHz band

[38] FM56 will investigate if 1.4 MHz is sufficient to carry the applications and traffic as required by the rail sector.

The whitespace solution needs some 5G capabilities; current 4G is not enough. It remains to be seen if it might become possible in a 4.x G version, but that is at this moment unknown, and probably depends on activities from the vendors. Further investigation needed.

4. Feasibility of “White Space” for 5 (or even 5.4) MHz 5G system in the 1.4 plus 4 MHz band

   It is not clear yet is whitespace solution is fully covered by 5G. Further investigation needed.

5. Conditions and impact of overnight switch from GSM-R to LTE or 5G

   In FM56 there have been quite some discussions on the feasibility of an overnight switch-over from GSM-R to FRMCS. Conclusion: not feasible.

6. Conditions and impact of switching from LTE 5MHz to 5G 5 MHz

   It is expected that radio technology will mainly be based on software (SDR). This should allow a SW based migration from 4.x G to 5G, which may not be not a big issue. The real limitation is in the frequency bands that need to be supported, as that is more dependent upon more hardware related aspects such as the filtering in both Rx and Tx paths.

In addition, economic aspects have to be investigated (mainly additional costs related to additional assets)

7. Impact of power limitation of LTE 1.4 MHz (mainly additional trackside costs related to additional assets). This may also influence the remaining capacity of a 1.4 LTE system, leading to non-compliancy to capacity requirements during the migration phase.
8. Impact of higher frequency bands, for hotspots or for full network (mainly additional trackside costs related to additional assets)
9. Impact of performing one or more migration steps (also depending of the lifetime of LTE and 5G technologies) for both trackside and on-board

There are also other, less technical questions to be answered, such as:

10. it is assumed that functionality and (quality of) services are not influenced by the variants of spectrum and radio access technology as described in the scenarios above. Confirmation of this assumption is necessary.
11. Are the options, as described above, sufficient to carry the traffic which could be expected in the coming decades, in particular when real-time video (e.g. for ATO GoA4) and further digitalisation of railways (e.g. massive IoT)

Once the picture is completed and the preferred spectrum and technology options are defined, the final impact on on-board equipment, in terms of amount and type of radio modules, antenna configuration, and so on can be analysed.

7.5 Impact on the antennas

The impact of the spectrum and the radio technology on the antenna system are huge, basically three options are possible:

- Mono-band antenna
- Wideband antenna
- Multiband antenna

Mono-band antenna

In case 3 different bandwidths are used in Europe, its means at least 3 antennas shall be installed on-board, plus the GSM-R existing antennas, mandatory during migration phase. The following gives a non-exhaustive list of services which may require an antenna:

- FRMCS bandwidth #1
- FRMCS bandwidth #2
- FRMCS bandwidth #3
- MNO bandwidths
- GSM-R Voice service
- GSM-R EDOR
- Wi-Fi Access
- Satellite Access
- …

In addition, it may be recommended to double some antenna for following purposes:

- redundancy,
- MiMO,
- Diversity (against fading effect)

It seems obvious that most of the trains are not able to carry so many antennas. That's the reason why this option is considered as a non-viable option.

Wideband antenna

Usage of wideband antenna allows an important reduction of the number of antennas, except Satellite, for which, a specific antenna is recommended, one antenna - plus an additional for redundancy – could be enough to cover the used frequency bands.

The disadvantage of such an antenna are:

- its performances are not equal on the totality of the bandwidth and may be degraded for some frequencies. Received signal strength will be then reduced. The following diagram gives an example of VSWR of a wideband antenna, depending of the frequency:

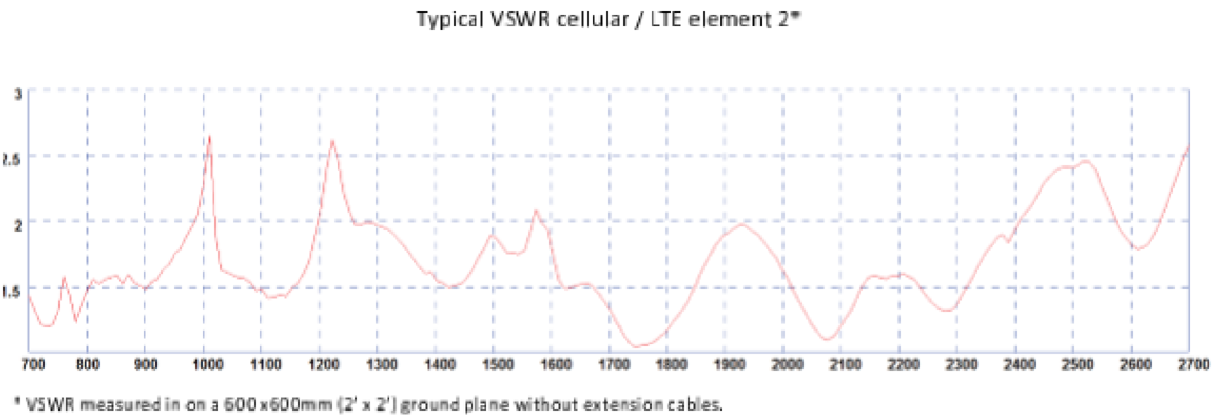

Figure 31. Example of vswr for a wideband antenna

- In case of one antenna shared with several modems, received signal strength is divided by the number of receivers using the same antenna.

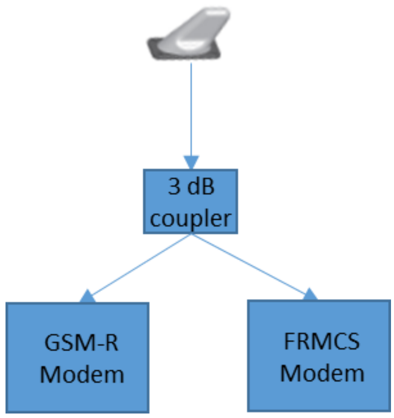

Figure 32. Coupling situation with one shared antenna

Consequence of signal strength reduction may have a big impact on the radio infrastructure, if it becomes necessary to increase the radio coverage level.

Difference between a Wideband or Multiband antenna

It is possible to consider the possibility of having an antenna covering several bands in two ways:

- Wideband antenna: the antenna has one connector, and therefore, there is a need to add a multiplexer to separate the bands to feed systems of each band. This device is likely to add 0.5 dB to 1 dB extra losses.
- Multiband antenna: the antenna actually is hosting several antennas in the same enclosure, and therefore there are several connectors, one for each band. The benefit is that the antenna is optimized for each band. The disadvantages are that the size of the antenna may be increased, and adding a new band – for example, in case of a roaming agreement with a MNO - means to change the antenna.

7.6 Hardware limitations

The following section covers hardware limitations in supporting power requirements and rail-specific frequency bands.

The proliferation of multiple railway-specific frequency bands, together with operational-rail specific transmit power requirements, might have important economic implications. The European railway market is very limited in size. It may prove challenging to induce vendors to produce multi-band chipsets solely for the European railway market.

We assume that the chipsets will need to explicitly support the FRMCS bands. If it were to prove feasible to implement functions such as modulation/demodulation entirely in software or firmware (or via programmable gate arrays or whatever), these concerns might be ameliorated (see Section 7.7).

This situation could lead to a niche market with few suppliers or perhaps with only one supplier, creating dependencies and high prices.

7.7 Software-Defined Radio (SDR)

There could be substantial merit in employing *Software-Defined Radio* (*SDR*). With SDR, components that have been traditionally implemented in hardware are instead implemented by means of configurable software, ideally with the ability to update the software over the air. *This implies that the hardware has been designed to support any necessary capabilities.*[39] See the discussion of software update procedures used for smartphones and tablets in Section 6.2 the discussion of chipset dependencies in Section 7.5, and the discussion of future research directions in Section 7.8.

So far as we can determine, neither the railway community nor the railway equipment vendor industry has seriously considered the use of SDR for operational rail communications to date.

SDR could potentially offer configuration flexibility in comparison with current GSM-R systems. This flexibility could facilitate future migrations. SDR might also contribute to solving the frequency band issues described in Section 7.3, provided that the hardware (e.g. chipsets and antennae) affords the necessary flexibility.

For on-board equipment that implements only non-critical functions, over-the-air software updates would seem to be especially desirable.

For mission critical functionality, it would be necessary to consider safety and security aspects, and whether it would be needed to re-certify. As we have seen in Section 6.4.1, certification processes may be longer than desired. Distinct procedures may be in order for operating system updates, app updates, and configurable parameter updates, bearing in mind that implications for certification may differ.

As noted in Section 6.2.1, for the RUs that we interviewed, the software upgrade process is not very different from hardware upgrade process today. For analogous reasons, we do not expect that the any shift from hardware to software would have much impact on the upgrade process; however, it can be expected that the certification process would need to be carefully reviewed and adapted to accommodate any shift to SDR.

Software updates of on-board systems, especially if implemented over the air, would need to be done with care; however, many of the issues that would need to be addressed are already visible with current software updates. It would for instance be necessary to ensure that updates are virus-free, and that they do not impact the functionality already available. To the extent that the update process entails multiple responses, staff responsible for the on-board equipment would need to be carefully instructed as to how to respond.

A shift from hardware to software might make it necessary to install software updates more often than is the case today (especially in the case of security patches).

7.8 Future research projects

Closed, ongoing and potential future research projects in the railway domain should be considered by the rail industry to partially or totally answer some of the issues highlighted in this study. A non-exhaustive list of some of the research projects to be considered are the following:

- Smart radio (or Software-Defined Radio – SDR) already pushed in the ERA Bearer Independent Concept study [12].
    - Single modem: it is clear that a single modem should support multiple radio access technologies based on software.
    - Multiple modems: Integral project with 3 modems on multiple technologies with an abstraction layer above to select the right modem based on criteria such as cost…

[39] In this section, we assume that the chipset will need to provide support for a given frequency band. It is not inconceivable, however, that this support might be entirely implemented in software or firmware.

- Antennas: academics are working on small antennas (approximatively the size of a 8W GSM-R modem) using metamaterials (such as antenna in your commercial smartphones) to increase performance of miniaturised antenna systems, working on spectrum bands from 400 MHz to 6 GHz including (massive) MiMO.

Any Recommendation?

7.9 Security

The security model for FRMCS seems to be at a very early design stage.

Our sense is that FRMCS security, whether implemented using 3GPP 4G/5G protocols[40] or fully OTT, would most appropriately be done on an *end-to-end* basis (i.e. between the on-board equipment and the servers with which the equipment communicates) rather than a *point-to-point* basis (i.e. between routers that are logically adjacent to one another in the FRMCS network).[41] In other words, FRMCS security will need to be closely linked to the operational rail *application*, rather than being embedded in the underlying *network*.

This follows from the same logic as for location services – if both voice and ETCS data services are IP-based and need to be supported not only over conventional networks but also over satellite and Wi-Fi, then point-to-point link security would imply the need for every conceivable link to support the FRMCS security architecture, which seems unlikely (and perhaps also expensive). End-to-end security would avoid this requirement, and would also make the use of multiple hops in different technologies possible (subject to QoS constraints). This is possibly a good idea both for OTT versions and for 3GPP versions.

It might make sense to have an adaptation layer between the communications substrate and the various services. Call it a Presentation Layer. It could deal both with authentication and encryption (privacy and integrity as referred to in cybersecurity). This Presentation Layer security service could be common to both ETCS and the voice services. In the case of ETCS, the security adaptation layer would need to maintain a stringent level of security consistent with SIL-4 requirements, which is to say that the rate of dangerous failures (i.e. the Tolerable Hazard Rate) must be no greater than 10^{-8}. The security mechanisms employed for ETCS today[42] were already designed to meet these standards, and therefore represent a natural starting point for the FRMCS security model.

If there were indeed a decision to implement FRMCS security in a bearer-independent way, this would have wide-ranging implications for development and for standardisation. NIST publication 800-187[43] (Guide to LTE security) recommends using an OTT solution to provide strong

[40] LTE security does not provide similar security functions to meet ETCS requirements. For instance, although the LTE standards require integrity protection for critical signalling traffic, integrity protection for user traffic is explicitly prohibited, as stated in section 3.4 on the NIST SP 800-187 publication.

[41] For an explanation of the difference between point to point versus end to end implementation, see J.H. Saltzer, D.P. Reed and D.D. Clark (1981), "End-to-End Arguments in System Design", at http://web.mit.edu/Saltzer/www/publications/endtoend/endtoend.pdf

[42] These mechanisms include the time-stamping, numbering, and acknowledgment of ETCS messages, together with protection of the ETCS message stream by appending to each message a hashed CRC based on a session key computed using public-private keys and triple DES encryption.

[43] NIST SP 800-187 is available free of charge from https://doi.org/10.6028/NIST.SP.800-187

authentication, integrity and confidentiality protection for user data over LTE, considered as a data pipe. Additionally, OTT solution can act as a defense in depth measure, enabling railways to choose between both public and/or private networks. OTT solution addresses mitigations to the following threats:

- Downgrade attacks,
- Air interface eavesdropping,
- Attacks via compressed femtocell,
- Backhaul and core eavesdropping,
- Attacks against cryptographic keys.

Certification processes will need careful consideration if specific security requirements are mandated in the legal framework.

Security measures are evolving rapidly. Product life cycles might be seriously impacted if the rail community were to move to IP with strong security supervision. It is important for software suppliers to be able to deploy security patches quickly in order to avoid security breaches in their products, but impact on other applications might imply delay. Separation of critical from non-critical functions might help to mitigate this problem.

7.10 Architecture concepts

7.10.1 MCX, VoLTE and OTT impact on the architecture

Using VoLTE and MCX services in parallel to make use of the advantages of both and eliminate the disadvantages: this solution was discarded by the fact that the interworking between IMS and an MCX server application needs to be improved (cf. IR#1). The dedicated GSM-R P2P call could be realised via VoLTE in FRMCS, this ensures the compatibility with the GSM supplementary services (like Call Forwarding which are used by the railways) and which are not defined for the equivalent MCX private calls. But some MCX advantages will not work with VoLTE, e.g. extending a private call to a group call dynamically or the support of call priorities in the requested granularity (call arbitration handling between both systems).

The encountered limitations and restrictions are more related to the infrastructure and trackside systems. The impact for the on-board is compared to that much smaller. The on-board equipment shall be able to support an MCX or VoLTE solution already (but not both in parallel due to functional restrictions as stated in the first intermediate report). The implementation of OTT/SIP could also be possible.

Despite the fact that MCX is considered essential to fulfil major railway requirements (group communications, and so on), the choice of MCX has already an economic impact: chipsets able to manage MCX (e.g. integrating building blocks to enable eMBMS) are not used by consumer products. As Critical Communication (CC) is a small market, only a limited number of vendors propose a MCX-capable modem, which leads to higher prices for radio modules and supplier's dependency. On the other hand, the CC market is bigger than just GSM-R or TETRA, so there will be some improvements regarding economies of scale.

7.10.2 Under investigation from different bodies (rail sector and others)

<u>UIC FRMCS ATwG on-board architecture options:</u>

- On-board is clearly not in a final stage
- MCX-only based

- Shared gateway for critical and non-critical applications (refer to SP UC on FRMCS equipment shared with multiple FRMCS users)

ETSI TC RT FRMCS reference architecture model (draft Technical Report 103 459):

- On-board is clearly not in a final stage
- FRMCS on-board requirements limited to UIC URS
- Both 4G and 5G are addressed
- MCX-only based
- Shared gateway for critical and non-critical applications (FRMCS gateway or Gateway UE as defined by 3GPP)
- On-board communication network based on TCN (IEC 61375 series)

SBB Smartrail 4.0 – Functional requirements for FRMCS on-board system:

- Scalable and open architecture
- Decoupling applications and transport
- Cloud-based railways
- Service-based Quality of Service
- Shared gateway for critical and non-critical applications (gateway UE)
- Supporting PLMN and multiple MNOs
- Supporting direct mode capabilities (called off-network communication or proximity services as described in 3GPP)
- Neither 4G or 5G are addressed but requirements could not be met by 4G

This document should be considered as an input to UIC FRMCS ATwG on-going work on the on-board architecture. More railways should collect requirements for FRMCS on-board system, to be merged in a UIC document as input to UIC FRMCS ATwG.

S2R on-board architecture options:

- On-board is clearly not in a final stage
- TCN architecture (IEC 61375 series) is studied in working group

A new on-board architectural approach is considered by the railway community based on open source “containers” (from Docker Inc.) to isolate mission and non-mission critical applications (different level of criticality) and to minimise the mutual impact of modifications/updates.

EEIG ERTMS Users Group

- New ETCS communication philosophy
- New ETCS OBU – EDOR interface

No initiative yet taken by EEIG EUG, only high-level principles have been presented (*Ideas for a new ETCS radio communication concept/ Pr180618 ETCS comms*).

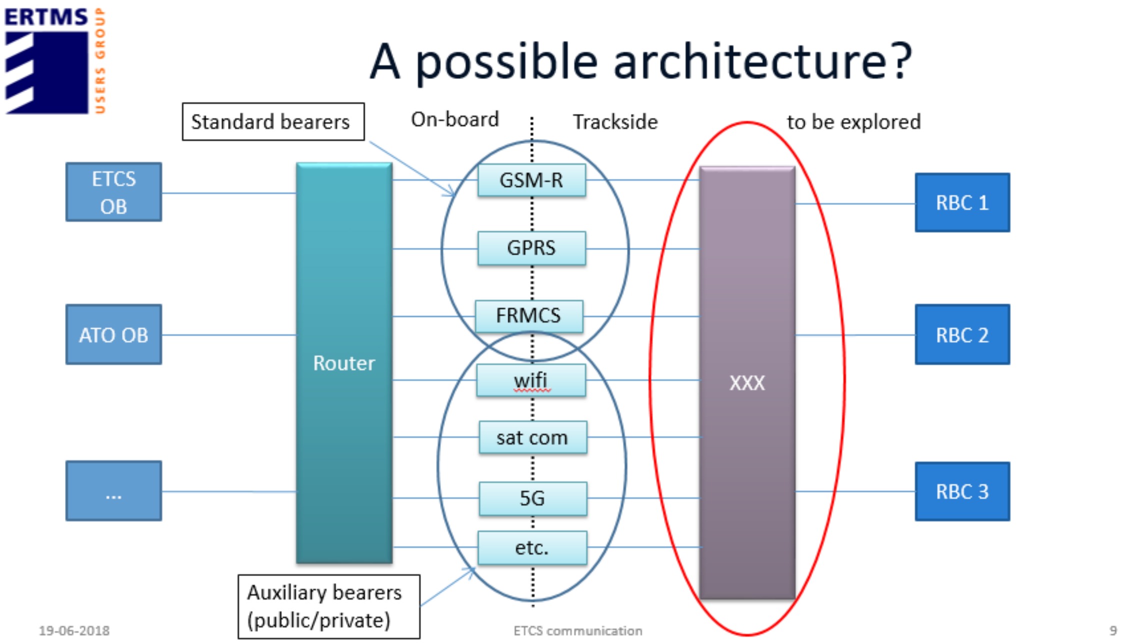

Figure 33. Ideas for a new ETCS radio communication concept (source: EEIG EUG)

Some highlights with a potential impact on the on-board architecture can be extracted from EUG presentation:

“Keep the ETCS on-board (SIL4 system) as small and simple as possible: no telecom related functions in ETCS-OBU”

This principle has a very important impact: in GSM-R (in CS mode and PS mode), communications between ETCS Onboard and RBC are managed by the Euroradio protocol, which is part of On Board Unit (see chapter 6.1.2).

It means, In FRMCS, the ETCS communication shall be managed by the communication system.

Two other principles are extracted from the EUG presentation:

- Bearer independence
- Allow multi-path communication (i.e. multi-link)

The “new EDOR”/communication system will then have at least to:

- Select communication parameters depending on the request received by the application;
- Choose continuously the most appropriate bearer, this involves that the device shall be able to estimate each bearer performances, and to find a bearer offering a good enough QoS; alternatively, multiple links could be established in parallel time over different bearers, and at the receiving side, the first received information packet could be transmitted to the application;
- Manage safety functions (authentication and encryption)

But the main challenge will be for On Board architecture to manage simultaneously 2G-EDOR, piloted with AT commands by the ETCS OBU, and the “FRMCS-EDOR” carrying its own communication protocol during the migration phase.

Note: the concept of mobility across multiple radio does already exist; for example, Cisco proposes the Mobile Access Router:

https://www.cisco.com/c/en/us/td/docs/solutions/Enterprise/Mobility/Mobile_Access_Router_DG.html

IEC 61375 [13]

Train communication network (TCN) provides ability for on-board and trackside components to communicate to each other using a gateway on-board with multiple bearers, including Wi-Fi. There is a clear separation of functionality between critical and non-critical functionality in the TCN. But the gateway is not ready for critical communication as this was not part of the requirements (so not studied by IEC TC9 WG 43 members). There is no redundancy provided by the gateway.

A European project called CONNECTA is addressing the need for a wireless TCMS for safety on-board to ground communications. Physical separation of modem between critical and non-critical applications is foreseen but coupling with the same roof-top antenna to avoid space limitation. A liaise with such project could be considered by the UIC FRMCS project to share experience and knowledge.

Cybersecurity is not provided nor even foreseen yet in the TCN.

7.10.3 Findings

- UIC FRMCS System Principles Use Cases are already solution-dependent focusing specifically on 5G technology (e.g. network slicing); however, 5G requires a minimum of 5 MHz bandwidth, which is potentially conflicting with the scenario that in a first stage of migration 5MHz will not be available.
- Industry players push for 4G because of Railway/Urban Rail customers outside Europe while European Railways push for 5G looking for the future.
- Depending of the roadmap products and upgrade strategy, the question is more to know if 4G will be an intermediate step, or if the future will be a direct upgrade from 2G to 5G.
- Frequency bands allocation is a main challenge for FRMCS: European countries may have different spectrum, or no spectrum at all.
- A long-term migration (evolution) strategy for spectrum and radio technologies is not available yet.
- Supporting all European frequency bands eligible for critical applications shall be mandatory for the on-board equipment. Trains are not able to carry an antenna per bearer/bandwidth.
- On public 4G networks, UE output power is limited to 23 dBm (200 mW). To get an equivalent range in FRMCS and in GSM-R, at least 30/31 dBm are necessary. Two potential translations of the impact for the on-board equipment: one way is to change the standard for UEs with a potential development of a niche market for UE specific to Railways. One other path is to avoid impact on on-board equipment and carrying restriction on modem emission power to the network design to avoid a niche market and paving the way for ensuring greatest economies of scale for on-board equipment.
- Security: no shared views on security requirements. Few experts are attending and being active in the international railway groups and few detailed studies are available.
- MCX or VoLTE or OTT: impact is economic and longer term support: only a limited number of vendors propose MCX-capable modems, which leads to higher prices for radio modules and supplier’s dependency, in particular on the longer term.
- TCN is not ready for critical communication and was not part of the requirements (so not studied by IEC TC9 WG 43 members). There is no redundancy nor cybersecurity provided by the gateway.

7.11 Overview of impact on on-board equipment

The following table summarises the potential impacts on on-board architecture of the future developments:

IMPACTS on on-board system/architecture
Functionality
UIC User Requirements Specification (URS) versus TSI CCS
Three different architecture approaches have been described in section 3 to cover the Railway functionality, focusing on voice services and more precisely on Voice over IP: VoLTE, MCX and OTT. The growth in the list of functional requirements carries risks that the on-board equipment shall support all of the critical applications to achieve interoperability, bringing complexity and cost to the on-board architecture. Impact on on-board equipment are detailed in section 7.10 related to the different architecture approaches.
Location services for ETCS and voice communications
If the option of using an external location server is confirmed, some re-design of software for operational rail voice communications would be required, since the location would need to be obtained from the location server (instead of relying solely on the cell identifier). In any case, decoupling on-board communication services from location services should be considered based on an open and harmonised interface (such an API). The location services should be able to provide the most accurate location information available from different sources (e.g. GPS, Galileo, odometry…).
Technology
4G and/or 5G
Based on migration strategy, adding an intermediate step to 4G will add additional complexity to the on-board architecture with an additional radio module and associated antenna system. Decoupling of application and transport layers as soon as possible (at least for this intermediate step) will make the migration of on-board equipment for 4G to 5G easier. Impact on on-board equipment are detailed in section 7.2.1.
SatCom
Supporting SatCom will have direct impact on the on-board architecture such as: • An additional modem dedicated to SatCom, which is not supported by current 3GPP-compliant chipset (commercial smartphone).

• An additional antenna system specific to SatCom frequency bands, required coverage and depending on satellite orbits (requiring potentially complex on-board antenna tracking) to be supported. The size of the roof-top antenna shall be considered as a major criteria to define conditions for success of supporting SatCom for the on-board equipment. Impact on on-board equipment are detailed in section 7.2.2.
Wi-Fi
Supporting Wi-Fi on on-board equipment will not bring major impact on the on-board equipment from a hardware perspective. The on-board equipment shall support a Wi-Fi modem with associated antenna system (in addition to the 3GPP and SatCom modems and antenna systems, and likely to include a Bluetooth module compliant to Bluetooth Special Interest Group in a combined module). The type of 801.11 WLAN to be supported shall be considered (802.11a/b/g/n/ac and beyond). Impact on on-board equipment are detailed in section 7.2.3.
Multiple bearers
The impact on on-board equipment is a combination of impacts previously described in section 7.2.4.
Spectrum
Supporting all frequency bands that may be eligible for critical applications shall be mandatory for on-board equipment. Spectrum options combined with the usage of public networks, either temporary (e.g. to bridge a gap in any migration step), or structurally (e.g. for capacity of fallback purposes) shall be considered also. This has direct impact on the frequency bands to be supported by the on-board equipment. When investigating spectrum options for on-board equipment, the antenna system shall be included, e.g. the impact on the number of roof-top antennas and the application of MiMO shall be considered carefully as the free space on top of the trains is very limited. The coupling device between the new equipment and GSM-R UE need to be considered also. Impact on on-board equipment are detailed in section 7.3.
Migration scenarios
In principle it will required that the next generation on-board equipment is capable (by default or by upgrading) to support all scenarios which are selected and may be applied in the different Member States. However, it has to be taken into account that each of the scenarios could be combined with the usage of public networks, either temporary (e.g. to bridge a gap in any migration step), or structurally (e.g. for capacity of fallback purposes), when this option is selected in a Member State. This has direct impact on the overall set of frequency bands and technologies to be

supported by on-board equipment. Reducing the “catalogue”, in terms of spectrum (dedicated and public) and radio technology options and combinations, may lead to cost reduction of on-board equipment installation or upgrades. Impact on on-board equipment are detailed in section 7.4.
Hardware limitations in supporting power requirements and rail-specific frequency bands
This situation could lead to a niche market with few suppliers or perhaps with only one supplier, creating dependencies and high prices for the on-board equipment. Recommendation is to reduce the impact on on-board equipment and carrying restriction on modem emission power to the network design to avoid a niche market and paving the way for ensuring greatest economies of scale for on-board equipment. Impact on on-board equipment are detailed in section 7.6.
Shift from Hardware to Software
The hardware shall support any necessary capabilities to implement Software-Defined Radio. SDR could potentially offer configuration flexibility in comparison with current GSM-R systems. This flexibility could facilitate future migrations. SDR might also contribute to solving the frequency band issues. A shift from hardware to software might make it necessary to install software updates more often than is the case today (especially in the case of security patches). Impact on on-board equipment are detailed in section 7.7.
Future research projects
A liaison with future research projects in the railway domain (such as smart radios, antennas using meta materials) should mitigate the impact on on-board system. Impact on on-board equipment are detailed in section 7.8.
Security
FRMCS Security is foreseen to have major impact on the on-board architecture. Our sense is that FRMCS security, whether implemented using 3GPP or fully OTT, would most appropriately be done on an end-to-end basis (i.e. between the on-board equipment and the servers with which the equipment communicates). A fully OTT solution should be investigated as a potential solution to mitigate LTE security breaches and provide a bearer independent solution. The ERTMS Users Group is also expecting that the new EDOR shall manage safety functions (authentication and encryption) instead of legacy Euroradio protocols.

Impact on on-board equipment are detailed in section 7.9.
Architecture concepts
Impact on on-board architecture are detailed in sections 7.10.3 and **Error! Reference source not found.**.

8. FINDINGS AND RECOMMENDATIONS

We distinguish among findings relevant to the current state of affairs, versus those relevant to migration to FRMCS (in Sections 8.1 and 8.2, respectively).

We also distinguish among recommendations that are generally relevant, those that are specifically relevant to a migration to FRMCS based on 3GPP MCX solutions, and those relevant to migration to FRMCS based on pure OTT solutions (in Sections 8.3, 8.4, and 8.5, respectively).

In Section 8.6, we identify a number of activities that could commence (or in some cases *should* commence) prior to finalisation of FRMCS standards.

Lists of all Findings and all Recommendations, together with the page numbers on which they appear, are provided following the table of contents at the beginning of this report.

8.1 Findings as regards the current state of affairs

The findings as regards the current state of affairs can be categorised as relating to (1) fragmentation, complexity and rigidity of the on-board development ecosystem, (2) challenges in terms of security, (3) challenges in the time and complexity of upgrading systems while ensuring safety and reliability, and (4) other considerations.

8.1.1 Fragmentation, complexity and rigidity

Finding 1. The evolution of voice and (ETCS) data in separate silos, both in terms of architecture and implementation, results in needless cost for on-board equipment.

In terms of both architecture and implementation, ETCS and GSM-R voice are largely maintained in distinct monolithic silos with less than ideal integration. This results for instance in separate but identical dedicated on-board modems for these critical applications (which may however be advantageous when recertification is required after a change). Scale economies, such as they might be, are also lost.

Finding 2. Proprietary interfaces increase the complexity of on-board systems, and contribute to vendor lock-in.

There are many proprietary interfaces to external on-board systems. This tends to increase complexity, and effectively reduces flexibility when new on-board equipment is procured (i.e. it creates a vendor lock-in problem). Consider for example the proprietary interfaces to intercom or to public address (PA) systems (i.e. serial data links using protocol stacks such as Profibus).

Finding 3. Lack of harmonisation in country-specific *de facto* requirements imposes additional costs on suppliers of on-board equipment and on Railway Undertakings (Rus). There is a need to conform to multiple requirements, since the train must be able to roam from one country to another.

Lack of harmonisation in country-specific *de facto* requirements imposes additional costs on suppliers of on-board equipment and on RUs in order to enable the train to roam from one country to another. Many requirements are mandatory for on-board, but optional for infrastructure. This can lead to complex hardware and software, both in terms of architecture and of implementation, which leads in turn to increased cost and complexity both for equipment providers and for RUs.

Finding 4. The on-board antenna system poses special challenges. Space on the roof of the train is limited, making it challenging to simultaneously satisfy all requirements (including redundancy).

The on-board antenna system poses special challenges. Space on the roof of the train is limited, making it challenging to simultaneously satisfy all requirements (including redundancy). If one antenna serves multiple modems, the signal must be split among the modems. GSM-R voice uses a separate modem from ETCS (which uses an EDOR), and at least two EDORs are needed to enable hand-over. Often, one or two additional modems are provided for reasons of redundancy. All of this is problematic because there are space limitations on the roof of the train (in France, only three antennae are permitted on the roof of a TGV locomotive). In some configurations, moreover, the antenna may constitute a Single Point of Failure (SPoF).

8.1.2 Security

Finding 5. Specificities of the transmission system and the ERTMS security system are managed as part of ETCS. This fragmentation of the architecture contributes to complexity and thus to cost of on-board systems.

Specificities of the transmission system and the ERTMS security system are managed as part of ETCS. This might be a problem to the extent that it contributes to the silo effects, and thus contributes indirectly to greater complexity for suppliers of on-board equipment and consequently to greater cost for the RUs that deploy that equipment.

Finding 6. There is a need to modernise the security architecture.

The security architecture needs to address the threats that are relevant today, both for on-board and for trackside systems. Aging GSM-R security protocols represent a risk. Experts say that they can easily be broken in a few minutes.

8.1.3 Challenges of upgrading systems while ensuring safety and reliability

Finding 7. The duration and complexity of recertification and readmission of trains and on-board equipment can be substantial.

The duration and complexity of recertification and readmission of trains and on-board equipment can be substantial. It is clear that safety standards must be maintained. Nonetheless, migration to FRMCS in whatever form can be expected to put additional strains on the recertification and readmission system.

Finding 8. Even for non-critical on-board functionality, the duration for readmission can be substantial.

In order to avoid needless delay of the migration process to FRMCS, the means of identifying and accommodating the less stringent safety requirements of non-critical on-board functions may need special attention.

8.1.4 Other considerations

Finding 9. The specification of transmission parameters is insufficiently tight, meaning that full interoperability cannot be guaranteed for trains that roam from one country to another.

There are no specified values for the parameters related to data transmission, only ranges. means that full interoperability cannot be guaranteed.

8.2 Findings as regards FRMCS migration

In this section, we cover FRMCS migration, whether (initially) implemented using 3GPP-based MCX / MCPTT solutions or fully OTT solutions.

8.2.1 General considerations

Finding 10. The relative sequencing of migration to 4G and/or 5G is not altogether clear. This has implications for migration of on-board equipment to FRMCS, and even more so for on-board equipment than for trackside due to the likely sequencing of the migration.

A key open question is whether 4G will be deployed as an interim solution FRMCS solution in Europe. Some supply industry players are pushing to deploy under 4G because of railway / urban rail customers with near term needs outside of Europe. MCPTT for public safety and urban transport has been defined since 3GPP Release 13. If this MCPTT were somehow adapted to meet operational rail communication needs, it might be possible to take advantage of it with 4G networks and equipment.

The European rail community is for the most part pushing for 5G with an eye to future deployments. UIC FRMCS System Principles Use Cases depend on 5G technology (e.g. network slicing). MCX solutions are unlikely to be deployable in Europe until at least 3GPP Release 16 (i.e. 5G), and possibly not until Release 17. This would imply a direct upgrade from 2G to 5G in Europe.

This lack of clarity as to the migration path has implications both for trackside on for on-board, but the on-board implications are more challenging and more immediate for two reasons. First, the certification process can be more complex and expensive than for trackside because equipment has be upgraded and tested one by one. Second, the migration of on-board equipment can be expected to take place before trackside equipment is switched over. There is also a risk of multiple migration steps which may require multiple onboard upgrades.

Finding 11. Despite strong interest over the years in fully OTT solutions, the sector is on a trajectory where MCX-based solutions are likely to appear before fully OTT solutions (if fully OTT solutions emerge at all).

Despite strong interest over the years in fully OTT solutions, the sector is on a trajectory where MCX-based solutions are likely to appear before fully OTT solutions (if fully OTT solutions emerge at all). The MCPTT-based solutions offer many advantages relative to GSM-R and address the fundamental need to migrate away from GSM-R before it becomes so out-dated as to be uneconomic to maintain. They capitalise, albeit to a limited degree, on the scale economies of the 4G LTE ecosystem and on the expected scale economies. They are perceived, rightly or wrongly, as being relatively low risk. To the extent that they are similar to existing GSM-R, they are readily grasped by those who would need to develop them, and to those who would need to deploy them.

Based on our analysis, together with the proof-of-concept design provided in this report, our sense is that an OTT migration path is not prohibitively difficult or expensive.

Train location services, for example, would require a new implementation; however, implementing as a normal software programme in an external server might be quicker and simpler than implementing inside the network. Moreover, testing and validation would tend to be easier.

Implementation of the key functions of operational rail networks (calls from train driver to controller and vice versa, Group Call, Rail Emergency Call, push to talk) does not appear to be particularly difficult with an OTT solution. Again, it may be simpler to implement them, and it is probable that it is easier to test and validate them, in an OTT setting than it would be working inside a network.

The greatest risk of complexity appears to arise in interworking scenarios. Two-way interworking with GSM-R would take work. Three way interworking between OTT and both GSM-R and 3GPP MCX solutions is not fundamentally hard, but it is quite complex.

Finding 12. The limited number of vendors who are prepared to create MCX-capable modems implies a risk of vendor lock-in.

The limited number of vendors who are prepared to create chipsets suitable for operational rail communications implies a risk of vendor lock-in. Rail specificities are possible for instance as regards (1) the frequency bands supported, (2) the transmit power, where the levels required for operational rail are expected to exceed those permitted in general for 4G, and (3) the broadcast feature (requiring an eMBMS enabled modem), which is not specific to rail but is limited to the mission critical ecosystem. The limited number of vendors is likely to lead to supplier dependency and higher prices for radio modules. This is an issue both for on-board and for trackside systems.

8.2.2 Standards

Finding 13. The current approach of the European rail sector is embodied in having UIC specify requirements to the 3GPP standards development process.

The current strategy of European rail sector 3GPP is to include most operational rail communication requirements in their Mission Critical Communication set of specifications ("MCX"), a branch of the standards that will be somewhat distinct from the public/commercial branch. MCX will provide enhanced voice communication capabilities that GSM-R, Tetra and DMR applications can capitalise on; however, the MCX specifications themselves will be generic, without sector-specific elements.

Technical specification 22.289 is in preparation in order to provide standards support for the operational rail sector-specific capabilities that are out of scope of MCX (mainly critical group communications).

Finding 14. There is significant risk of delay in the 3GPP standards process, largely due to the perceived complexity of the functionality that has been requested in conjunction with limited resources to work on the standards.

Work on 3GPP Mission Critical Services standardisation for rail is ongoing; however, only a few rail-specific features are standardised in Release 15. Some important features, including Rail Emergency Calls (REC) and train control, will not be available in Release 15. This would appear to imply that the European rail sector must wait for Release 16 (with protocols expected to be stable at the end of

2020), since Release 15 will lack essential operational rail functionality due the difficulty for the 3GPP to identify the real priorities.

A number of features that have been requested by UIC have been identified by 3GPP as being technically complex to implement. Since different working groups in 3GPP analyse whether the feature is desirable versus what the implementation complexity might be, it is quite possible for a feature to be accepted in principle but then deemed to be too complex to implement. It is not yet clear whether these difficult features will be (1) delayed beyond Release 16, and/or (2) standardised, but at high cost for early implementers, and/or (3) problematic due to insufficient available bandwidth.

Among the difficult features, of particular interest are (1) interworking between GSM-R and FRMCS, which is a challenge and will not be available at least before Release 16, (2) the Supplementary Services (Call Hold, Call Forward, Call Completion on Busy Subscriber, and many more). They are available under GSM-R because GSM-R is based on GSM, technology standard firstly implemented to provide voice services. They are also available under Voice over LTE (VoLTE). They are not, however, available under today's Mission-Critical Services (and thus not available in conjunction with, for instance, Group Calls). For the many supplementary services, it is unclear whether the effort to implement each of them is warranted.

So far, only one application (Assured Data Communication) has been judged to be out of scope by 3GPP. 3GPP recommends that an OTT approach be taken for this feature.

Some 3GPP members have expressed concerns that further delay is possible. They worry that the requirements that UIC are producing for 3GPP contain too many use cases, that there is too much duplication among them, and that priorities are not clear. In this view, the railway sector is not sufficiently engaged and structured in the standards process, thus running the risk that European rail requirements are not met to a sufficient degree to enable real deployment until Release 17.

The next revision of System Principles document (FW-AT-2504) includes requests for various capabilities, some of which could be potentially interesting but seem to us to be very problematic. We question whether suppliers would implement all of these features, even if 3GPP agrees to standardise them.

As previously noted, how this plays out in Asia and the Pacific will influence suppliers worldwide and may lead to interoperability challenges, but is hard to predict.

8.2.3 Frequency bands and power

These issues are applicable both the trackside and to on-board equipment.

Finding 15. Allocation of frequency bands in support of eventual FRMCS migration needs careful study and planning.

Allocation of frequency bands in support of eventual FRMCS migration needs careful study and planning. A European decision based upon conclusions from the CEPT/ECC FM56 drawn from SE7 and PT1 coexistence studies is expected in November 2020[44]. For 5G, a minimum of 5 MHz bandwidth is

[44] RSCOM18-05rev3 Final – Draft Mandate to CEPT on spectrum for the FRMCS, released by the European Commission – DG CONNECT/B4, July, 12th 2018

necessary. Frequency band allocation can be expected to pose a major challenge for FRMCS, since it is unlikely that a single harmonised band in a desirable frequency range can be found and agreed on across all European countries. All desirable bands have incumbents and/or parties who desire the spectrum, and these will vary from country to country.

Finding 16. Antenna system design is a significant risk area that requires attention, especially during the migration period.

Antenna design is a significant risk area that requires attention, especially during the migration period. It will presumably be necessary for on-board equipment to support multiple European FRMCS frequency bands (plus the GSM-R band during an extended migration period) in order to enable roaming. This has implications for antenna design if the supported bands are widely separated from one another. The number of antennae that can be carried on the roof of a train is quite limited.

Finding 17. Power requirements for GSM-R are greater than those typical for 4G LTE today. If this were to be the case for FRMCS, concerns over health effects might possibly arise. Careful study and planning of these aspects is called for.

Power requirements for GSM-R are greater than those permitted for 4G LTE today. For future FRMCS systems, aside from the possible concerns about rail specificities in chipsets that were previously discussed, these transmit power requirements might conceivably raise concerns over health effects. On public 4G networks, UE output power is limited to 23 dBm (200 mW). To get an equivalent range in FRMCS and GSM-R, at least 30/31 dBm are necessary. Given that power of 8W (39 dBm) was permitted under 2G, this is not necessarily a concern, but careful study and planning of these aspects is called for.

8.2.4 Security

Finding 18. There appears to be insufficient number of rail experts engaged in the normative work.

There appears to be insufficient number of rail experts engaged in the normative work.. Few rail communication experts are visible in the international standards groups,. For example, this raises the risk that FRMCS security is considered only belatedly, as was largely the case with GSM-R, rather than being integral to the design of FRMCS. "Grafted on" security is likely to be less effective or more costly than it needs to be. This is a concern both for trackside and for on-board equipment.

Finding 19. Cybersecurity aspects of the Train Communication Network (TCN) have received little attention to date.

Cybersecurity aspects of the on-board Train Communication Network (TCN) do not appear to have been studied to date (e.g. by IEC TC9 WG 43 members). The gateway provides neither redundancy nor cybersecurity. To the extent that the TCN does not carry mission critical traffic, this is possibly not a concern, but should be assessed.

8.3 Overall recommendations related to onboard architecture

8.3.1 General considerations

Recommendation 1. ERA should explore and carefully consider the incentives of the supplier community.

There is the risk that the standards bodies produce standards that are too complex and/or too expensive for the vendors to develop. This risk is compounded by the limited size of the market and the small number of vendors that actually make hardware and software for the railway market, and is considerable. There is another risk that the standards are too heavily slanted to the vendors, rather than the railway users. There is also the risk that too few suppliers of chipsets will emerge, potentially leading to higher prices or vendor lock in problems.

Recommendation 2. Standardised interfaces should be used wherever possible.

Standardised interfaces should be employed wherever feasible with external on-board systems (e.g. SIP/RTP for on-board voice such as PA and intercom systems). Liaise with ITxPT initiative in urban rail would be appropriate in order to standardise the interface between non-critical modules so as to facilitate interchangeability of components within a competitive industrial ecosystem.

Recommendation 3. Single points of failure (SPoFs) should be avoided.

Single Point of Failure (SPoFs) for critical applications (e.g. modems, antennas) should be avoided if at all possible. TCN be viewed as a SPOF, but it is not used for critical applications. There are in principle three ways to reduce SPoF risks: (1) increase the reliability and security of individual components, (2) increase redundancy among components, or (3) avoid using systems that are less than optimally robust for critical applications.

Recommendation 4. Software should be designed to be configurable / parameterisable where feasible, with due concern for reliability and safety.

As much as possible, software should be configurable based on specified parameters. Some thought will be required as to which parameters can be changed without triggering a requirement for partial of full recertification of the train or its equipment.

Recommendation 5. The use of over-the-air update should be considered where feasible, with due concern for reliability and safety.

For on-board equipment that implements only non-critical functions, over-the-air software updates would seem to be particularly desirable. The use of eSIM (where instead of a replaceable SIM card, a non-replaceable embedded chip is used) should be considered by the railway sector. eSIM is coming into use for the critical function “eCall” in the road transport sector, and is beginning to come in to use in commercial smartphones. Again, this may simplify maintainability of on-board equipment without requiring full recertification.

Recommendation 6. ERA and the sector should keep an eye on research trends that may provide solutions that can profitably be applied to operational rail communications.

Ongoing and future academic and industry research projects about smart radio (including Software-Defined Radio (SDR) and Cognitive Radio (CR)), about network "slicing" (including Software Defined Networks (SDN) and Network Functional Virtualisation (NFV)), and about the use of metamaterials to increase the performance of miniaturised antenna systems) may hold promise for the future evolution of operational rail communications.

8.3.2 Migration

Recommendation 7. Fallback to GSM-R must be maintained.

Fallback to GSM-R is likely to be needed for an extended period of time. On-board solutions must in one way or another fully support both GSM-R and FRMCS during the possibly lengthy migration phase.

Recommendation 8. In terms of the frequency bands and technologies to be used, careful migration planning at national level will need to be complemented by coordination at European level.

When they are available, CEPT/ECC FM56 Report A and Report B can be expected to play a key role in defining operational rail communications strategy for the short term (introduction of FRMCS) and for the longer term evolution (objective for e.g. 2030) in terms of both spectrum and technology. Report A and B are not yet available, and any decision on 4G or 5G is still pending; nonetheless, enough is known about the available options to enable preliminary planning. This report includes a summary of possible migration scenarios in light of the current state of play.

It is conceivable that a single preferred solution for all of Europe will emerge, but it is more likely that a list of preferred scenarios will emerge. The resulting set of preferred frequency bands and technologies will serve as input for the a future CCS TSI, taking into account the interoperability requirements for mandatory functions. Each Member State would select one or more scenarios for national use, together with an associated implementation timeline, for its National Implementation Plan. ERA would use the CCS TSI and other mechanisms to ensure continued interoperability (especially when roaming from one country to another) during the transition to FRMCS.

8.3.3 Security

Recommendation 9. ERA and the rail community should consider as part of the FRMCS migration the adoption of a modernised and integrated security architecture that addresses both voice and data / ETCS services in an integrated way.

Migration to a comprehensive, integrated security architecture that covers both voice and data should be considered as part of the evolution to FRMCS. In the case of ETCS, the security adaptation layer would need to maintain a stringent level of security consistent with SIL-4 requirements, which is to say that the rate of dangerous failures (i.e. the Tolerable Hazard Rate) for ETCS must be no greater than 10^{-8}. Some thought would be needed as to where responsibility for maintenance and evolution of the security should lie, since it would no longer purely be an ETCS function.

The security architecture needs attention in any event – it is outmoded, and provides only limited security again today's threats.

A coherent, integrated approach is likely to reduce costs for equipment suppliers, and to simplify future evolution of operational rail communication systems.

8.3.4 Updates and certification

Recommendation 10. ERA should seek to revise the CCS TSI and other standards that are relevant to recertification as infrequently as practical.

EC certification is a long and costly process. The CCS TSI and any other relevant standards should be revised only infrequently, in order to avoid needless cost and delay for the RU.

Recommendation 11. In terms both of standardisation and of implementation, strong separation of critical versus non-critical applications should be practised. Recertification of non-critical functions should be as lightweight as possible, consistent with reliability and safety requirements.

Critical applications should be strongly separated from non-critical applications. The use of for instance separate modems for each should be considered. Even though this implies some loss of integration, it potentially simplifies recertification and admission when changes are made.

8.3.5 Interoperability

Recommendation 12. Greater harmonisation of national requirements is called for.

In order (1) to ensure full interoperability (such that international trains with compliant FRMCS voice/ETCS on-board equipment can cross borders without loss of operational rail communications functionality), (2) to avoid a needlessly long recertification process for trains and on-board equipment, and (3) to reduce costs for on-board equipment suppliers and for the RU, it would be highly desirable to keep unique national requirements to a bare minimum. How best to achieve this while still addressing legitimate country-specific needs would require some study, since it seems unlikely that all needs can be anticipated and accommodated in advance.

Recommendation 13. An overall re-thinking of the approach to QoS is called for.

A more holistic solution is needed. The current CCS TSI does not specify KPIs for transmission QoS. QoS will become much more complicated if Wi-Fi or satellite is to be used, or in case of considering the telecommunication provided as a service by a third party. It is possible that not all trains in all locations require the same QoS. The Indra ALG (2017) study made similar observations in the case of satellites that provide the only means of contact to trains in remote, rural areas.

8.4 Recommendations as regards FRMCS migration using 3GPP-based solutions

Recommendation 14 . ERA should monitor the progress of UIC and 3GPP on FRMCS standards.

The target of 2022 for completion of FRMCS standards and their incorporation into a new CCS TSI, so as to enable first deployments in 2023, seems achievable but ambitious. There are several time dependencies that are tight – in the expected case, the dates should be achieved, but there is little slack in the schedule.

- The decision between 4G and 5G is still open.
- The full required operational rail communications capability is expected to be specified in 3GPP Release 17, which can be presumed to be available late in 2020. Assuming a typical

time to market of two years, products will first appear in 2022, just in time for deployments in 2023.
- For operational rail applications, work has not yet begun on the Functional Requirements Specification (FRS) or the Software Requirements Specification (SRS).

This concern is especially relevant for on-board equipment. Our previous studies strongly imply that upgrade of on-board equipment to accommodate both GSM-R and FRMCS (i.e. dual-mode) should take place before trackside gear is switched over.

Based on our interviews, progress is being made, but risks to further progress should not be underestimated or ignored. ERA should pay attention to any gaps identified in the course of the standards development process. If functions that are truly needed are not on track to be standardised and implemented, ERA may need to discuss further steps with the sector.

Recommendation 15 . ERA should continue to monitor the standards dialogue between UIC and 3GPP.

The growth in the list of requests carries risks that standardisation either might be substantially delayed, or that the resultant standards might become unwieldy and therefore expensive to implement. ERA would be well advised to stay on top of this.

Interviews suggest that FRMCS requirements may be subject to “mission creep”. This could contribute to risks either that some truly needed features are not standardised, or that features are standardised that are prohibitively expensive to implement. A realistic and long term view on operational needs is essential in order to reduce the risk for a small niche market like operational rail.

Recommendation 16. In the interest of avoiding needless complexity and associated cost for the rail community, consideration should be given to not carrying GSM-R capabilities that are not used or very rarely used over without change into 3GPP FRMCS standards. Detailed analysis of real needs from an operational perspective is required.

It is our understanding that some GSM-R features (notably Group Call and REC) are not used as envisioned in the standards, while others (notably Shunting Emergency Call) are not used at all.

FRMCS must serve as a successor to GSM-R, but this does not necessarily mean that every function should be carried over without a critical assessment. Some functions could perhaps be re-thought in ways that reduce implementation complexity, or that simplify future interworking requirements. Others that are barely used, or not used at all, should either be re-conceptualised so as to truly meet operational rail needs, or else should be considered for deletion.

Failure to do so would both increase risks to standardisation and implementation of 3GPP-based FRMCS, and might needlessly complicate interworking both with GSM-R and with future solutions.

Recommendation 17. In designing train location capabilities for FRMCS, consideration should be given to possible implementation of these capabilities on a purely OTT basis, which is to say entirely outside of the network. This potentially simplifies interworking with GSM-R, and also simplifies any future migration.

The location of the train plays a crucial role in a number of critical functions, including ETCS, Group Call and REC. For voice calls, this has routinely been based on the cell ID. Under FRMCS, a better solution is needed. The cell ID is only one location identifier out of many possible identifiers, it is not very accurate, and it will not always be available (e.g. using Wi-Fi or satellite transmission).

Taking this critical function out of the network (which is to some extent already done in enhanced ELDA solutions) potentially simplifies the interworking problem, and facilitates future ease of migration of operational rail solutions.

This report provides preliminary design concepts, but further study is needed.

8.5 Recommendations as regards FRMCS migration using over-the-top (OTT) solutions

Recommendation 18. ERA should use this report as an opportunity to explore the openness of the sector to OTT solutions, together with the feasibility and practicality of OTT solutions.

Despite strong interest over the years in a fully bearer independent approach for future operational rail communications, very little concrete requirements or design work has been undertaken by the sector. This possibly reflects the lack of any single champion whose commercial interests would be furthered by an OTT solution, together with a lack of familiarity with the technology on the part of the rail sector.

This study has produced a fairly fully elaborated proof of concept design that, while surely not the only possible design, can serve as a meaningful starting point for discussions.

Care should be taken in doing so, so as not to disrupt ongoing 3GPP work.

Our sense is that OTT solutions merit more consideration from the sector than they have received to date, at least as a long-term consideration. This report could serve as a catalyst for that discussion.

Recommendation 19. If there were a decision to commence work in earnest on the standardisation of OTT solutions, it would likely be necessary to identify and engage with a suitable standards body. We consider it unlikely that 3GPP would be willing to undertake standardisation of a fully OTT solution, and they are possibly not the most appropriate standards body in any case.

The 3GPP standards body has done a great deal of good work for the rail community, but their membership largely reflects network operators and the vendors who sell equipment to them. For a purely network-independent OTT solution, it is not clear that 3GPP would be the best body to engage the full range of relevant stakeholders.

3GPP has already signalled (presumably for other reasons) that rail sector-specific facilities are not appropriate for 3GPP, only the underlying capabilities needed to support them. Again, this suggests that a different (or additional) standards body is likely to be needed.

If revisions to the SIP protocol were needed, they could be undertaken either by 3GPP or by the IETF; however, our belief is that no revisions to the SIP protocol itself are required.

This means that the choice of standards body is open.

ETSI is not the only option, but it is an interesting option. First, the material is consistent with their remit. Second, the European Commission has the authority to issue mandates to ETSI to request that they address topics of interest.

8.6 Identification of recommendations that are candidates for implementation in the nearer term

Many of the recommendations made in Sections 8.3, 8.4, and 8.5 reflect medium to long term considerations. A number of the recommendations made correspond however to measures that are somewhat independent of architecture decisions, and that are independent in particular of final decisions on functionality and spectrum. Some of these measures could be (or *should* be) initiated in the nearer term, prior to finalisation of the architecture. The Finding and Recommendation numbers in the following paragraphs correspond to those used in the previous sections of this chapter. Lists of all Findings and all Recommendations, together with the page numbers on which they appear, are provided following the table of contents and the lists of tables and figures at the beginning of this report.

- **Decision to implement with 4G, 5G, or both (Recommendation 8):** This decision is more fundamental than the overall set of technologies and frequency bands to be used. Achieving early clarity on this might simplify many other discussions.
- **Understanding incentives of the suppliers (Recommendation 1):** These are somewhat visible through the interviews in our study, but only to a limited extent. Understanding the relationship between supplier industry incentives and the standards development process may prove to be important in ensuring that the standards that emerge strike a suitable balance. The risk that necessary chipsets either do not become available, or that there is not sufficient diversity of supply of chipsets (see Finding 12), needs to be better understood as an input to the standardisation process.
- **Launch a discussion of situation-specific ETCS latency requirements (Recommendation 13):** In line with the interest in accommodating the use of satellite transmission in remote rural areas, and of Wi-Fi in stations and shunting yards, discussion is warranted as to whether latency requirements must necessarily be set to a single value for all situations.[45] This is logically an input to the standards process, not necessarily an output from it.
- **Modernisation and integration of the security architecture (Recommendation 9):** That little work has been done to on the security architecture of FRMCS might prove to be advantageous. The current security architecture is weak by modern standards, and also suffers from fragmentation between voice and ETCS data security (see also Finding 18 and Finding 19).[46]
- **Identification of non-critical applications (Recommendation 12):** A more lightweight approach to certification of non-critical applications would appear to be in order (see Finding 8). This is often the case in practice, but is not approached in a consistent way from country to country. Identifying the applications that could benefit from such a lightweight standard is a process that serves mainly as an input to the standards development process, but is not dependent on the results of the standards process.
- **Challenges regarding antennas (Recommendation 6):** Possible proliferation of the number of frequency bands be supported may compound the problems already experienced in provided a sufficient number of antennas in light of limited space on the top of the train (see Finding 4). ERA and the sector should track ongoing research that might possibly provide solutions, but there is no assurance at present that new technology will solve this problem in the near to medium term.
- **Location service (Recommendation 17):** The rail community is generally on a track to implement location services as an OTT service. In the interest of simplifying future migration, some steering of the process may be needed to ensure full bearer independence of the location service. The interfaces by means of which location data is provided to the location server, and by means of which on-board equipment learns the best estimate of its location

[45] The Indra/ALG (2017) study for ERA made similar observations. See Indra and ALG (2017), "Study on feasibility of SATCOM for railway communication: Final Report", Version 1/1, ERA 2016 01 SC, at http://www.era.europa.eu/Document-Register/Documents/SRAIL-FNR-010-IND%20-%20FinalReport_v1.1_20170216.pdf, viewed 19 April 2018.

[46] Bearing in mind, however, the ETCS security requirements are more stringent than those for operational rail voice communications.

and the means of contacting the relevant controller and nearby trains, could be specified now. These interfaces are largely independent of other standards. Specification of interfaces would enable vendors to begin work on prototype implementations.

- **ERA should initiate a discussion with the sector on when and how migration to full bearer independence should ultimately be achieved (Recommendation 18):** Despite strong interest from the sector over the years in a fully bearer independent approach for future operational rail communications, very little concrete requirements or design work has been undertaken by the sector as part of the FRMCS process. We believe that this report demonstrates that full bearer independence is technically feasible. Lack of full bearer independence will be an issue for any future migration of operational rail communications. In terms both of short term and of long term planning, a clear vision is needed as to when and how fully bearer independent solutions are to work their way into the operational rail communications environment, and we believe that this report could be used as a catalyst to launch that discussion.

9. ANNEX A: OVERALL ARCHITECTURAL APPROACHES

9.1 Matrix

In order to create the matrix, an initial list of references has been established as key documents and inputs to the study. Most of them are working documents and new versions have been released during the first stage of the study. The list has been updated accordingly.

A short explanation of some of the owners of the documents is provided in the context of this study:

- UIC can be considered as the organisation which drafts railway requirements and specifications at the application level
- 3GPP, OMA, IEEE, IETF are drafting technical specifications
- ETSI is drafting European standards for telecommunication systems

It is to be noted that the manufacturing industry is involved in those organisations except in UIC.

Some of the relevant interworking processes between these organisations are described in annex 9.3.2.

Reference	Title	Version	Owner	Date	Ref#
E-FRS	EIRENE Functional Requirements Specification	8.0.0	UIC	21/12/2015	[1]
E-SRS	EIRENE System Requirements Specification	16.0.0	UIC	21/12/2015	[2]
Subset-093	GSM-R bearer service requirements	3.0.25	UNISIG		[3]
FU-7100	Future Railway Mobile Communication System - User Requirements Specification	3.0.0	UIC	24/01/2018	[4]
FU-7110	Future Railway Mobile Communication System – Functional use cases	0.2.7	UIC	22/11/2017	[5]
FW-AT 2504	Future Railway Mobile Communication System Architecture and Technology - System Principle Use Cases	0.0.3	UIC	20/12/2017	[6]
TS 22.280 TS 122.280	Technical Specification - MCS Common Requirements	R.14 R.15	3GPP ETSI		[7]
TS 22.179 TS 122.179	Technical Specification - MCPTT over LTE requirements	R.14 R.15	3GPP ETSI		[8]

Reference	Title	Version	Owner	Date	Ref#
TS 22.281 TS 122.281	Technical Specification - MCVideo over LTE requirements	R.14 R.15	3GPP ETSI		[9]
TS 22.282 TS 122.282	Technical Specification - MCData over LTE requirements	R.14 R.15	3GPP ETSI		[10]
TS 22.289	Technical Specification - Mobile Communication Systems for Railways		3GPP		[11]
TR 22.889	Technical Report - Study on Future Railway Mobile Communication System (FRMCS)		3GPP		[12]
PRD IR.92	IMS profile for voice and SMS	9.0	GSMA	08/04/2015	[13]
OMA-TS-PoC	OMA Push to talk over Cellular (PoC) System Description	2.1	OMA	02/08/2011	[14]
OMA-AD_PCPS	OMA Push-to-Communicate for Public Safety (PCPS) Architecture	1.0	OMA	24/01/2017	[15]
RFC3261	SIP: Session Initiation Protocol		IETF (J. Rosenberg et al)	2002	[16]
RFC3550	RTP: A Transport Protocol for Real-Time Applications		IETF (H. Schulzrinne)	2003	[17]
RFC3966	The tel URI for Telephone Numbers		IETF (H. Schulzrinne)	2004	[18]
RFC4412	Communications Resource Priority for the Session Initiation Protocol (SIP)		IETF (H. Schulzrinne, J. Polk)	2006	[19]
FW-AT 1303	Tracking of applicable documents for TR 22.989; Technical Specification Group Services and System Aspects; Study on Future Railway Mobile Communication System; Stage 1. Change Requests to TS 22.179 MCPTT; TS 22.280; TS 22.281; TS 22.282	0.1.31	UIC	09/02/2018	[20]
	Technical Specification Group Services and System Aspects; Study on Future Railway Mobile Communication System; GAP Analysis and normative TS	0.0.10	3GPP	09/03/2018	[21]

Reference	Title	Version	Owner	Date	Ref#
	assignment, Tracking of normative work and GAP Analysis TR 22.889				
	VoLTE and OTT Voice Quality Report		Huawei		[22]

Annex_Gap_analysis_Matrix_v0.5.xlsx

9.2 Questionnaire

Internet research is not the most valuable source of information because most outputs and deliverables of above projects are of restricted access. It was agreed with the Agency that a detailed questionnaire would be developed to provide a picture of the current situation of 3GPP and OTT gap analysis.

The questionnaire was sent by e-mail with an introductory letter from ERA to the contact list identified in section 9.3.3.

The questionnaire was prepared mainly focusing on 3GPP gap analysis to provide status and background of the overall process to feed user requirement specifications (UIC FRMCS URS) into 3GPP specifications.

The questionnaire also addresses ongoing OTT initiatives in the railway and the mission critical communications domains together with the market status (maturity of product development and planned roadmaps).

The full questionnaire and list of questions can be found in the annex 9.2.2.

9.2.1 Introduction letter

EUROPEAN UNION AGENCY FOR RAILWAYS

Making the railway system work better for society.

To the attention of:
The interested organisations
(sent by email)

ERA/ERTMS/CS/PG/D1370

Valenciennes, 15th December 2017

Subject: **Study on the architecture of on-board radio communication equipment**
Ref: *ERA 2017 31 OP*

Dear Madam, Dear Sir,

The European Union Agency for Railways (ERA) is leading the EVORA Program dealing with the evolution of the radio communication system for railways. This Program includes a comprehensive set of studies investigating different topics, such as aspects of migration, feasibility of satellite communication, the bearer independency concept and others. You or your company may have already contributed to these studies.

In the next step of this Program, ERA aims at collecting and analysing the options for the architecture of on-board radio communication equipment, and has contracted Systra to perform a study on this. Systra is requested to provide two reports: a first report on the options for the overall architecture of the radio ecosystem and the anticipated compliance to the requirements, and a second report focusing on the subsequent options for the on-board equipment. The reports are expected to be available respectively in April 2018 and October 2018.

In order to collect relevant information and data from different sources, a number of interviews will be conducted by Systra in the coming months. The Agency would highly appreciate your support in this study. The team of Mr. Lovan Pushparatnam from Systra will be in charge of this task. The information provided will be used in the study and will be framed in the reports. Any information that would need to be handled with confidentiality should give rise to particular arrangements.

We thank you in advance for your cooperation in this important stage of our Program. The Reports of the study will be kindly sent to you.

If you do not consider yourself to be the right addressee to deal with this request, please notify this and, if possible, indicate to us the correct addressee in your organisation.

For any further information regarding this study, please contact Mr. Chiel Spaans (chiel.spaans@era.europa.eu).

Yours sincerely,

Pio GUIDO
Head of ERTMS Unit

120 Rue Marc Lefrancq | BP 20392 | FR-59307 Valenciennes Cedex
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9.2.2 List of Questions

In order to collect information on 3GPP gap analysis, a main questionnaire was prepared with 18 questions regarding the 3GPP gap analysis status and some known OTT initiatives in the railway and the mission critical communications domains. The purpose was to check if different stakeholders share views and objectives of on-going process to feed URS into 3GPP specifications (target release is Rel-16) and to have a clear picture of what is missing in the 3GPP specifications and shall be included at application level.

#	Items	#	Sub-items/Details
1	***First name***		
2	***Name***		
3	***Organisation***		*Including bodies, consortium or associations related to FRMCS activities*
4	***Address***		
5	***Contact Email***		
6	***Contact Phone Number***		
7	***Position***		*Your position in the organisation and bodies, consortium or associations related to FRMCS activities*
8	***3GPP involvement***		*Your involvement in 3GPP working groups*
9	***Recording (y/n)***		*Do you agree if this interview is recorded (not applicable for questionnaire only)*
10	***Interview purpose***		*FRMCS status within the 3GPP (refer to ERA introduction letter): our study aims to report on the level of compliancy of 3GPP based solutions and to identify what has to be solved at application level. We would like to understand the 3GPP methodology to conduct the 3GPP gap analysis of the Railway requirements, the status and roadmap of the analysis, and understand why some of the "basic" telephony services are considered not covered in the gap analysis.*
11	***FRMCS UIC/ETSI/3GPP organisation***		*Short description of the relationship between these organisations and your position in this context*
12	***22.889 Study of FRMCS V16.0.0 (2017-09)***	1	*Who are the stakeholders involved in the gap analysis?*
		2	*Can you provide the 22.889 roadmap (inputs, analysis and TR releases)?*
		3	*Are all FRMCS FU 7110 v2.7 uses cases considered in the 22.889 document? See column I in table2 in questionnaire, e.g. use cases section 7*
		4	*How are the UIC use cases translated into the "Requirement text" column?*
		5	*How is the "SA1 spec covering" column filled? (details on methodology)* *Is there a detailed and available analysis? (access to deliverable?)*
		6	*"Not covered" items : Planned to be covered in a further release (Y/N)?* *If yes, in which release?* *If no, what is the plan to fill this gap?*
		7	*What are the blocking technical points? (see table 2, example for uses cases 6.2 to 6.4 and Systra question on column I)*
		8	*"Partly covered": please precise what is not covered? See table2 in questionnaire*

		9	*"[Needs analysis]" When will it be analysed? (roadmap)* *Who is in charge of the analysis?*
		10	*CR_TR22_889v0_4_0_new_use_cases_shunting is not included within 22.889 Study of FRMCS V16.0.0 (2017-09). Is it definitive?*
		11	*If yes, how are Shunting requirements reported in the 22.889 document?*
13	***Questionnaire Table 1***		*Cf. Annex, Table1: this table gives a selection of the UIC FU7110 use cases and the corresponding 3GPP requirements in the 22.889. In some cases, there is no obvious correspondence. See questions in column H.*
14	***Questionnaire Table 2***		*Cf. Annex, Table2: this table details the UIC FU7110 use cases and the corresponding 3GPP requirements in the 22.889. Many requirement are "Not covered", "partly covered" or "Need analysis":* *-Not covered : Are they covered in a further release (Y/N)? see column J* *-Partly covered : Please precise what is not covered? see column K* *-Need analysis : Could we have some roadmap details? see column L* *Very often, it is not obvious to understand why some requirements are not covered (see examples of questions, in column I for chapter 6): Could you give some explanation about what is not covered exactly?* *- See also in column I : in some cases, we have not found the corresponding requirement*
15	***Over The Top initiatives***	*1* *2* *3*	*Are you aware of any Railway activity or initiatives (bodies, association, industry, academics, R&D…) related to future communications architecture specification and/or standardisation based on OTT?* *If yes, could you provide some information (name of the projects, description, geographic scope, stakeholders, functional scope, roadmap, maturity)?* *Could you provide link or access to the project(s)?*
		4 *5* *6*	*Are you aware of any Critical Communications activity or initiatives (bodies, association, industry, academics, R&D…) related to future communications architecture specification and/or standardisation based on OTT?* *If yes, could you provide some information (name of the projects, description, geographic scope, stakeholders, functional scope, roadmap, maturity)?* *Could you provide link or access to the project(s)?*

16	***Market Status***		*indicate maturity of product development (3GPP Mission Critical/FRMCS and OTT portfolios) and planned roadmap (COTS and bespoke products)*
17	***API (Application Programming Interface)***	*1*	*Is there any study and/or specification of API within 3GPP scope*
		2	*If the answer is yes, is it relevant for the UE (e.g. harmonised access to the device – SIM, eMBMS, APN, OTA…)?*
		3	*Are you aware of any Mission Critical initiative(s) to specify API for UE?*
18	***Additional Comments***		*If something is considered missing in this questionnaire regarding known project(s) on Future Railway Communication System standardisation / Specification, feel free to add any additional elements*

Table 1. List of questions

Categories of Railway Applications	Use Cases	FU-7110	22.889	SYSTRA question	Answer
Critical communication applications	On-train outgoing voice communication from the driver towards the controller(s) of the train	6	6.3		
Critical communication applications	On-train incoming voice communication from the controller towards a driver related use cases	7	?	No corresponding chapter in 22.889.	
Critical communication applications	Multi-train voice communication for drivers including ground user(s) related use cases	8	6.2	8.3 and 8.4 : no corresponding requirement in 22.889	
Critical communication applications	Shunting voice communication related use cases	11	6.X	No specific chapter for shunting in 22.889 > Will CR_TR22_889v0.4.0 be integrated in the 22.889 ? If not, why? And can the information in the CR be used for FRMCS study?	
Critical communication applications	Automatic Train Control data communication related use cases	14	6.5	Only one requirement about QoS (R-6.5-001)	
Critical communication applications	Automatic Train Operation data communication related use cases	15	6.12		
Critical communication applications	Railway emergency communication related use cases	20	6.4		
Critical support applications	Assured voice communication related use cases	58	9.2		
Critical support applications	Multi user talker control related use cases	59	9.7		
Critical support applications	Role management related use cases	60	9.3		
Critical support applications	Location services related use cases	61	9.4		

Critical support applications	Authorisation of communication related use cases	62	9.8		
Critical support applications	Authorisation of application related use cases	63	9.9		
Critical support applications	QoS class negotiation related use cases	64	?	No corresponding chapter in 22.889.	
Critical support applications	Inviting-a-user related use cases	67	9.5		
Critical support applications	Arbitration related use cases	68	9.16		

Table 2. Questionnaire Table 1

Categories of Railway Applications	Use Cases	Sub-use ucases	FU-7110	Service flows	22.889	3GPP					
						Status	SYSTRA question	Covered in a further release (Y/N)?	Precision about partly covered functions	Roadmap details	Answer
Critical communication applications	On-train outgoing voice communication from the driver towards the controller(s) of the train	Initiation of driver to controller(s) voice communication	6.2	Driver to responsible controller(s)	R-6.3.2-001	Not covered	Basic call. What is not covered ? Priorisation? Responsible controller?		NA	NA	
					R-6.3.2-002	Not covered	What is not covered ?Location information depending controller ? Functional identity?		NA	NA	
					R-6.3.2-003	Not covered	What is not covered ? Add or remove FRMCS users?		NA	NA	
					R-6.3.2-00	Not covered	What is not covered ? Normal setup time ?		NA	NA	
					R-6.3.2-005	Partly covered in 22.179	What is not covered ? Identities but not "functional" identities?	NA		NA	
					R-6.3.2-006	Not covered	What is not covered ?Location of the driver?		NA	NA	
					R-6.3.2-007	Not covered	What is not covered ?Location of the driver?		NA	NA	
					R-6.3.2-007b	Not covered	What is not covered ? Group call to ptp ?		NA	NA	
					R-6.3.2-008	Not covered	What is not covered ? Multi user talker control? (See chapter 9.7)		NA	NA	
					R-6.3.2-009	Not covered	What is not covered ? Prioritisation?		NA	NA	
					R-6.3.2-010	Not covered	What is not covered ? Recording?		NA	NA	
				Driver to another controller(s)	R-6.3.2-011	Not covered	What is not covered ? Priorisation & Responsible controller?		NA	NA	
					R-6.3.2-012	Not covered	What is not covered ? Location services, functional Id, Responsible controller ...?		NA	NA	
		Termination of driver to controller(s) voice	6.3	Driver termination	R-6.3.3-001	Partly covered in 22.179	What is not covered ? What is not covered ? Only for ptp calls?	NA		NA	
				Controller on hold	R-6.3.3-003	Not covered	What is not covered ? CH?		NA	NA	
					R-6.3.3-004	Not covered	What is not covered ? CH?		NA	NA	

		communication		Controller leaving	R-6.3.3-002	Not covered	What is not covered ? Is the driver able to leave?		NA	NA	
					R-6.3.3-005	Not covered	What is not covered ? Is the controller able to leave?		NA	NA	
				Controller termination	R-6.3.3-006	Not covered	What is not covered ? Termination conditions?		NA	NA	
		Service interworking and service continuation with GSM-R	6.4	Driver attached to GSM-R	R-6.3.4-001	Not covered	Basic call between GSM-R user and FRMCS user. What is blocking?		NA	NA	
				Driver attached to GSM-R	R-6.3.4-002	Not covered	Does basic ptp call from FRMCS to GSM-R user works? Are blocking points only for MCPTT (group call) when some drivers are in FRMCS and some in GSM-R ?		NA	NA	
				Driver attached to FRMCS	R-6.3.4-001	Not covered	Basic call between GSM-R user and FRMCS user. What is blocking?		NA	NA	
				Driver attached to FRMCS	R-6.3.4-002	Not covered	Does basic ptp call from FRMCS to GSM-R user works? Are blocking points only for MCPTT (group call) when some drivers are in FRMCS and some in GSM-R ?		NA	NA	
				Driver moving from GSM-R to FRMCS	R-6.3.4-003	Not covered	An interruption of voice communication is acceptable. What is blocking?		NA	NA	
				Driver moving from FRMCS to GSM-R	R-6.3.4-004	Not covered	An interruption of voice communication is acceptable. What is blocking?		NA	NA	
Critical communication applications	On-train incoming voice communication from the controller towards a driver related use cases	Initiation of controller to driver voice communication	7.2	Driver logged-in into only one user equipment			No corresponding requirement?	NA		NA	
				Driver logged-in into multiple user equipments			No corresponding requirement?	NA		NA	
		Termination of	7.3	Driver on			No corresponding requirement?	NA		NA	

		controller to driver voice communication		hold							
				Driver termination			No corresponding requirement?	NA		NA	
				Controller on hold			No corresponding requirement?	NA		NA	
				Controller termination			No corresponding requirement?	NA		NA	
		Service interworking and service continuation with GSM-R	7.4	Driver attached to GSM-R			No corresponding requirement?	NA		NA	
				Driver attached to FRMCS			No corresponding requirement?	NA		NA	
				Driver moving from GSM-R to FRMCS			No corresponding requirement?	NA		NA	
				Driver moving from FRMCS to GSM-R			No corresponding requirement?	NA		NA	
Critical communication applications	Multi-train voice communication for drivers including ground user(s) related use cases	Initiation of Multi-train voice communication for drivers including ground user(s) communication	8.2	the FRMCS Users shall be able to initiate the voice communication to FRMCS Users in trains or on ground.	R-6.2.2-001	Partly covered in 22.179		NA		NA	
				the application layer priority of the communication shall be managed by the prioritisation application	R-6.2.2-002	Not covered			NA	NA	

				the FRMCS System shall be able to determine the FRMCS User(s) to be included in the voice communication, based, amongst others, on the following criteria: location information, speed and direction of travel provided by the locations services application, and/or functional identity provided by the Role management and presence application. System configuration on which Controller is responsible for which part of the track/station /etc.	R-6.2.2-003	Not covered			NA	NA	

				the FRMCS System shall be able to add or remove FRMCS User from the communication once criteria are met or no more met, e.g. by a FRMCS User entering or leaving an area	R-6.2.2-004	Not covered			NA	NA	
				the FRMCS System shall establish the communication within a setup time specified as NORMAL (see 12.12).	R-6.2.2-005	Not covered			NA	NA	
				The FRMCS System shall be able to mutually present the identities of all communication partners	R-6.2.2-006	Partly covered in 22.179		NA		NA	
				The FRMCS System shall be able to present the location of the Driver(s) to the	R-6.2.2-007	Not covered			NA	NA	

				Ground FRMCS Users							
				The FRMCS System shall be able to update the presentation of the location of the Drivers as they move.	R-6.2.2-008	Not covered			NA	NA	
				always includes more than two participants. If only two participants remain, the communication shall be treated as a user-to-user communication.	R-6.2.2-009	Not covered			NA	NA	
				multi user talker control shall be used (See "9.7 Multi user talker control related use cases").	R-6.2.2-010	Not covered			NA	NA	
				on the application layer the precedence of the incoming voice	R-6.2.2-011	Not covered			NA	NA	

				communication at the Driver and the Ground FRMCS User shall be managed by the prioritisation application.							
				The FRMCS System shall be able to make available the speech and communication related data of a Multi-train voice communication for Drivers including Ground FRMCS User(s) for recording	R-6.2.2-012	Not covered			NA	NA	
		Join an on-going Multi-train voice communication for drivers including ground user(s) communication	8.3				No corresponding requirement ?	NA		NA	
		Receive an option of remain connected in the Multi-train	8.4				No corresponding requirement ?	NA		NA	

		voice communication for drivers including ground user(s) communication									
		Terminate a Multi-train voice communication for drivers including ground user(s) communication	8.5	Driver on hold	R-6.2.3-001	Partly covered in 22.179		NA		NA	
				Driver leaving	R-6.2.3-002	Partly covered in 22.179		NA		NA	
					R-6.2.3-003	Not covered			NA	NA	
					R-6.2.3-005	Not covered			NA	NA	
				Ground user on hold	R-6.2.3-001	Partly covered in 22.179		NA		NA	
					R-6.2.3-006	Partly covered in 22.179		NA		NA	
					R-6.2.3-007	Not covered			NA	NA	
		Service interworking and service continuation with GSM-R	8.6	Driver attached to GSM-R	R-6.2.4-001	Not covered			NA	NA	
					R-6.2.4-002	Not covered			NA	NA	
				Driver attached to FRMCS	R-6.2.4-001	Not covered			NA	NA	
					R-6.2.4-002	Not covered			NA	NA	
				Driver moving from GSM-R to FRMCS	R-6.2.4-003	Not covered			NA	NA	
				Driver moving from FRMCS to GSM-R	R-6.2.4-004	Not covered			NA	NA	
Critical communication applications	Shunting voice communication related use cases	Initiation of a shunting voice communication	11.2	Shunting team communication	R-6.x.2-001	Not covered			NA	NA	
					R-6.x.2-002	Not covered			NA	NA	
					R-6.x.2-003	Not covered			NA	NA	
					R-6.x.2-004	Not covered			NA	NA	
					R-6.x.2-005	Not covered			NA	NA	
					R-6.x.2-006	Not covered			NA	NA	
					R-6.x.2-005	Not covered			NA	NA	

				Shunting team member to driver	R-6.x.2-006	Not covered			NA	NA	
					R-6.x.2-007	Not covered			NA	NA	
					R-6.x.2-008	Not covered			NA	NA	
					R-6.x.2-009	Not covered			NA	NA	
					R-6.x.2-010	Not covered			NA	NA	
					R-6.x.2-011	Not covered			NA	NA	
		Invoke / stop supervision of the voice communication	11.3		No 3GPP relevant potential requirements identified.			NA		NA	
		Inviting-a-user to a shunting voice communication	11.4		No 3GPP relevant potential requirements identified.			NA		NA	
		Join a shunting voice communication	11.5		R-6.x.5-001	Not covered			NA	NA	
					R-6.x.5-002	Not covered			NA	NA	
					R-6.x.5-003	Not covered			NA	NA	
					R-6.x.5-004	Not covered			NA	NA	
					R-6.x.5-005	Not covered			NA	NA	
					R-6.x.5-006	Not covered			NA	NA	
		Leave a shunting voice communication	11.6		R-6.x.6-001	Not covered			NA	NA	
					R-6.x.6-002	Not covered			NA	NA	
					R-6.x.6-003	Not covered			NA	NA	
		Service interworking and service continuation with GSM-R	11.7	Driver attached to GSM-R	R-6.x.7-001	Not covered			NA	NA	
					R-6.x.7-002	Not covered			NA	NA	

Critical communication applications	Automatic Train Control data communication related use cases	Initiation of an Automatic Train Control data communication	14.3				Chapter 6.5 only about QoS R-6.5-001	NA		NA	
		Termination of an Automatic Train Control data communication	14.4					NA		NA	
		Service interworking and service continuation with GSM-R	14.5	Initiating ATC application attached to GSM-R	?		No corresponding requirement?	NA		NA	
				Initiating ATC application attached to FRMCS	?		No corresponding requirement?	NA		NA	
				ATC application moving from GSM-R to FRMCS	?		No corresponding requirement?	NA		NA	
				ATC application moving from FRMCS to GSM-R	?		No corresponding requirement?	NA		NA	
Critical communication applications	Automatic Train Operation data communication related use cases	Initiation of an Automatic Train Operation data communication	15.3		R-6.12.3-001	[Needs analysis]		NA			
		Termination of an Automatic Train Operation data communication	15.4		R-6.12.3-001	[Needs analysis]		NA			
		Service interworking and service continuation	15.5	Initiating ATO application attached to	?		No corresponding requirement?	NA		NA	

		with GSM-R		GSM-R							
				Initiating ATO application attached to FRMCS	?		No corresponding requirement?	NA		NA	
				ATO application moving from GSM-R to FRMCS	?		No corresponding requirement?	NA		NA	
				ATO application moving from FRMCS to GSM-R	?		No corresponding requirement?	NA		NA	
Critical communication applications	Railway emergency communication related use cases	Initiation of the Railway emergency alert	20.3	Controller initiated	R-6.4.3-001	Not covered			NA	NA	
					R-6.4.3-002	Not covered			NA	NA	
					R-6.4.3-003	Not covered			NA	NA	
					R-6.4.3-004	Not covered			NA	NA	
					R-6.4.3-012	Not covered			NA	NA	
					R-6.4.3-005	Not covered			NA	NA	
					R-6.4.3-006	Not covered			NA	NA	
					R-6.4.3-007	Not covered			NA	NA	
					R-6.4.3-008	Not covered			NA	NA	
					R-6.4.3-009	Not covered			NA	NA	
					R-6.4.3-010	Not covered			NA	NA	
					R-6.4.3-011	Not covered			NA	NA	
					R-6.4.3-012	Not covered			NA	NA	
				External system initiated	R-6.4.3-001	Not covered			NA	NA	
					R-6.4.3-002	Not covered			NA	NA	
					R-6.4.3-003	Not covered			NA	NA	
					R-6.4.3-004	Not covered			NA	NA	
					R-6.4.3-012	Not covered			NA	NA	
					R-6.4.3-005	Not covered			NA	NA	

					R-6.4.3-006	Not covered			NA	NA	
					R-6.4.3-007	Not covered			NA	NA	
					R-6.4.3-008	Not covered			NA	NA	
					R-6.4.3-009	Not covered			NA	NA	
					R-6.4.3-010	Not covered			NA	NA	
					R-6.4.3-011	Not covered			NA	NA	
					R-6.4.3-012	Not covered			NA	NA	
				Mobile user initiated	R-6.4.3-001	Not covered			NA	NA	
					R-6.4.3-003	Not covered			NA	NA	
					R-6.4.3-012	Not covered			NA	NA	
					R-6.4.3-005	Not covered			NA	NA	
					R-6.4.3-006	Not covered			NA	NA	
					R-6.4.3-007	Not covered			NA	NA	
					R-6.4.3-008	Not covered			NA	NA	
					R-6.4.3-009	Not covered			NA	NA	
					R-6.4.3-010	Not covered			NA	NA	
					R-6.4.3-011	Not covered			NA	NA	
					R-6.4.3-012	Not covered			NA	NA	
		New entry to the Railway emergency alert	20.4		R-6.4.4-001	Not covered			NA	NA	
					R-6.4.4-002	Not covered			NA	NA	
					R-6.4.4-003	Not covered			NA	NA	
					R-6.4.4-004	Not covered			NA	NA	
					R-6.4.4-005	Not covered			NA	NA	
					R-6.4.4-006	Not covered			NA	NA	
					R-6.4.4-007	Not covered			NA	NA	
					R-6.4.4-008	Not covered			NA	NA	
					R-6.4.4-009	Not covered			NA	NA	
		Changing of the Railway emergency alert	20.5		R-6.4.5-001	Not covered			NA	NA	
					R-6.4.5-002	Not covered			NA	NA	
					R-6.4.5-003	Not covered			NA	NA	
					R-6.4.5-004	Not covered			NA	NA	

					R-6.4.5-005	Not covered			NA	NA	
					R-6.4.4-006	Not covered			NA	NA	
					R-6.4.5-007	Not covered			NA	NA	
					R-6.4.5-008	Not covered			NA	NA	
					R-6.4.5-009	Not covered			NA	NA	
		Leaving of the Railway emergency alert	20.6	Mobile user	R-6.4.6-001	Not covered			NA	NA	
				Controller	R-6.4.6-001	Not covered			NA	NA	
					R-6.4.6-002	Not covered			NA	NA	
					R-6.4.6-003	Not covered			NA	NA	
		Termination of the Railway emergency alert	20.7		R-6.4.7-001	Not covered			NA	NA	
					R-6.4.7-002	Not covered			NA	NA	
		Initiation of railway emergency voice communication	20.8	Automatic initiation of Emergency Voice Communication	R-6.4.8-001	Not covered			NA	NA	
					R-6.4.8-002	Not covered			NA	NA	
					R-6.4.8-005	Not covered			NA	NA	
					R-6.4.8-006	Not covered			NA	NA	
					R-6.4.8-007	Not covered			NA	NA	
					R-6.4.8-008	Not covered			NA	NA	
					R-6.4.8-009	Not covered			NA	NA	
					R-6.4.8-011	Not covered			NA	NA	
				Manual initiation of Emergency Voice Communication	R-6.4.8-002	Not covered			NA	NA	
					R-6.4.8-003	Not covered			NA	NA	
					R-6.4.8-005	Not covered			NA	NA	
					R-6.4.8-006	Not covered			NA	NA	
					R-6.4.8-007	Not covered			NA	NA	
					R-6.4.8-008	Not covered			NA	NA	
					R-6.4.8-009	Not covered			NA	NA	
					R-6.4.8-011	Not covered			NA	NA	
		Termination of railway emergency	20.9	Controller on hold	R-6.4.9-002	Not covered			NA	NA	
				Controller	R-6.4.9-003	Not covered			NA	NA	

		voice communication		leaving							
				Controller termination	R-6.4.9-004	Not covered			NA	NA	
		Initiation of Data communication during Railway Emergency Alert	20.10		R-6.4.10-001	Not covered			NA	NA	
					R-6.4.10-002	Not covered			NA	NA	
					R-6.4.10-003	Not covered			NA	NA	
					R-6.4.10-004	Not covered			NA	NA	
					R-6.4.10-005	Not covered			NA	NA	
		Service interworking and service continuation with GSM-R	20.11	Mobile user attached to GSM-R	R-6.4.11-001	Not covered			NA	NA	
					R-6.4.11-002	Not covered			NA	NA	
					R-6.4.11-003	Not covered			NA	NA	
					R-6.4.11-004	Not covered			NA	NA	
					R-6.4.11-005	Not covered			NA	NA	
					R-6.4.11-006	Not covered			NA	NA	
					R-6.4.11-007	Not covered			NA	NA	
					R-6.4.11-008	Not covered			NA	NA	
					R-6.4.11-009	Not covered			NA	NA	
					R-6.4.11-010	Not covered			NA	NA	
				Mobile user attached to FRMCS	R-6.4.11-001	Not covered			NA	NA	
					R-6.4.11-002	Not covered			NA	NA	
					R-6.4.11-003	Not covered			NA	NA	
					R-6.4.11-004	Not covered			NA	NA	
					R-6.4.11-005	Not covered			NA	NA	
					R-6.4.11-006	Not covered			NA	NA	
					R-6.4.11-007	Not covered			NA	NA	
					R-6.4.11-008	Not covered			NA	NA	
					R-6.4.11-009	Not covered			NA	NA	
					R-6.4.11-010	Not covered			NA	NA	
				Mobile user moving from GSM-R to FRMCS	R-6.4.11-011	Not covered			NA	NA	

				Mobile user moving from FRMCS to GSM-R	R-6.4.11-012	Not covered			NA	NA	
Critical support applications	Assured voice communication related use cases	Invocation of Assured Voice Communication	58.2	Automatic Activation	R-9.2.2-001	Not covered			NA	NA	
				Manual Activation	R-9.2.2-002	Not covered			NA	NA	
		Stopping Assured Voice Communication	58.3	Automatic Activation	R-9.2.3-001	Not covered			NA	NA	
				Manual Activation	R-9.2.3-002	Not covered			NA	NA	
		Degradation of a communication link	58.4	Positive Notification	R-9.2.4-001	Not covered Not covered Not covered		NA		NA	
					R-9.2.4-003	Not covered			NA	NA	
					R-9.2.4-004	Not covered			NA	NA	
				Negative Notification	R-9.2.4-001	Not covered			NA	NA	
					R-9.2.4-002	Not covered			NA	NA	
					R-9.2.4-003	Not covered			NA	NA	
					R-9.2.4-005	Not covered			NA	NA	
					R-9.2.4-006	Not covered			NA	NA	
		Joining an Assured Voice Communication	58.5		R-9.2.5-001	Not covered			NA	NA	
		Service interworking and service continuation with GSM-R	58.6				No corresponding requirement?	NA		NA	
Critical support applications	Multi user talker control related use cases	Set the number of simultaneous talkers	59.3		R-9.7.2-001	Not covered			NA	NA	
					R-9.7.2-002	Not covered			NA	NA	
		Set initial talker permissions and priorities	59.4		R-9.7.3-001	Not covered			NA	NA	
					R-9.7.3-002	Not covered			NA	NA	
					R-9.7.3-003	Not covered			NA	NA	

					R-9.7.3-004	Not covered			NA	NA	
					R-9.7.3-005	Not covered			NA	NA	
		Request permission to talk	59.5		R-9.7.4-001	Not covered			NA	NA	
					R-9.7.4-002	Not covered			NA	NA	
		Grant permission to talk	59.6	Automatic management of requests	R-9.7.5-001	Not covered			NA	NA	
					R-9.7.5-002	Not covered			NA	NA	
					R-9.7.5-003	Not covered			NA	NA	
					R-9.7.5-004	Not covered			NA	NA	
					R-9.7.5-005	Not covered			NA	NA	
				Management of requests by an entitled user	R-9.7.5-006	Not covered			NA	NA	
		Revoke permission to talk	59.7		R-9.7.6-001	Not covered			NA	NA	
					R-9.7.6-002	Not covered			NA	NA	
Critical support applications	Role management related use cases	Registration to a functional identity	60.3	Requested functional identity not in use	R-9.3.3-001	[Needs analysis]		NA			
					R-9.3.3-002	[Needs analysis]		NA			
					R-9.3.3-003	[Needs analysis]		NA			
					R-9.3.3-006	[Needs analysis]		NA			
				Requested functional identity is in use	R-9.3.3-004	[Needs analysis]		NA			
				Registration by the system	R-9.3.3-005	[Needs analysis]		NA			
		Deregistration of a functional identity	60.4	Deregistration functional identity by the user	R-9.3.4-001	[Needs analysis]		NA			
					R-9.3.4-002	[Needs analysis]		NA			
					R-9.3.4-003	[Needs analysis]		NA			

					R-9.3.4-004	[Needs analysis]		NA			
				Deregistration by the system	R-9.3.4-005	[Needs analysis]		NA			
		Change of a functional identity	60.5		?		No corresponding requirement?	NA		NA	
		User login to the system	60.6	Successful identification	R-9.3.5-001	[Needs analysis]		NA			
					R-9.3.5-002	[Needs analysis]		NA			
				Unsuccessful identification	?		No corresponding requirement?	NA		NA	
		User logout from the system	60.7	Succesfull logout	R-9.3.6-001	[Needs analysis]		NA			
					R-9.3.6-002	[Needs analysis]		NA			
					R-9.3.6-003	[Needs analysis]		NA			
					R-9.3.6-004	[Needs analysis]		NA			
				Unsuccesfull logout	?		No corresponding requirement?	NA		NA	
		Presentation of identities	60.8	Prior to communication initiation	?		No corresponding requirement?	NA		NA	
				During communication initiation	R-9.3.7-001	22.280*		NA		NA	
					R-9.3.7-003	[Needs analysis]		NA			
					R-9.3.7-004	[Needs analysis]		NA			
					R-9.3.7-005	[Needs analysis]		NA			
				During a communication	R-9.3.7-002 R-9.3.7-003 R-9.3.7-004 R-9.3.7-005	22.280*		NA		NA	
					R-9.3.7-003	[Needs analysis]		NA			

					R-9.3.7-004	[Needs analysis]		NA			
					R-9.3.7-005	[Needs analysis]		NA			
		Interrogation of identities within a certain context	60.9	Interrogation of a functional identity	R-9.3.8-001	Not covered			NA	NA	
					R-9.3.8-002	Not covered			NA	NA	
				Interrogation of a user identity	R-9.3.8-003	Not covered			NA	NA	
					R-9.3.8-004	Not covered			NA	NA	
				Interrogation of a subscriber identity	R-9.3.8-005	Not covered			NA	NA	
				Interrogation of indentity(ies) in a certain context	?		No corresponding requirement?	NA		NA	
		Service interworking and service continuation with GSM-R	60.10	Mobile user attached to GSM-R	?		No corresponding requirement?	NA		NA	
				Mobile user attached to FRMCS	?		No corresponding requirement?	NA		NA	
				Mobile user moving from GSM-R to FRMCS	?		No corresponding requirement?	NA		NA	
				Mobile user moving from FRMCS to GSM-R	?		No corresponding requirement?	NA		NA	
				Numbering plan support	?		No corresponding requirement?	NA		NA	
Critical support applications	Location services related use cases	Provide location information	61.2		R-9.4.2-001	22.280**		NA		NA	
					R-9.4.2-002	22.280**		NA		NA	
					R-9.4.2-003	22.280**		NA		NA	
					R-9.4.2-004	22.280**		NA		NA	

					R-9.4.2-005	Not covered			NA	NA	
		Request for location information	61.3	Positive outcome	R-9.4.3-001	22.280***		NA		NA	
					R-9.4.3-002	22.280***		NA		NA	
					R-9.4.3-003	22.280***		NA		NA	
				Negative outcome	?		No corresponding requirement?	NA		NA	
		Request for identities based on area	61.4	Positive outcome	R-9.4.4-001	22.280***		NA		NA	
					R-9.4.4-002	22.280***		NA		NA	
		Request for identities based on area			R-9.4.4-003	22.280***		NA		NA	
				Negative outcome	?		No corresponding requirement?	NA		NA	
Critical support applications	Authorisation of communication related use cases	Permit/Deny communication	62.2		R-9.8.2-001	Not covered			NA	NA	
					R-9.8.2-002	Not covered			NA	NA	
					R-9.8.2-003	Not covered			NA	NA	
Critical support applications	Authorisation of application related use cases	Enabling/Disabling applications	63.2	Power-on	R-9.9.2-001	Not covered			NA	NA	
					R-9.9.2-002	Not covered			NA	NA	
					R-9.9.2-003	Not covered			NA	NA	
					R-9.9.2-005	Not covered			NA	NA	
					R-9.9.2-006	Not covered			NA	NA	
					R-9.9.2-009	Not covered			NA	NA	
				Change of registration status	R-9.9.2-004	Not covered			NA	NA	
				Change of location	R-9.9.2-007	Not covered			NA	NA	
					R-9.9.2-008	Not covered			NA	NA	
Critical support applications	QoS class negotiation related use cases	Requesting/(re) negotiating QoS profile classes (including latency and reliability)	64.2	Grant the requested QoS class	?		No corresponding requirement?	NA		NA	
				Downgrade the QoS classes of ongoing communicati	?		No corresponding requirement?	NA		NA	

				ons with lower priority							
				Release ongoing communications with lower priority	?		No corresponding requirement?	NA		NA	
				Offer a lower class or reject the request	?		No corresponding requirement?	NA		NA	
		Service interworking and service continuation with GSM-R	64.3	For user-to-user/Multi-user communication in the direction from GSM-R to FRMCS	?		No corresponding requirement?	NA		NA	
				For user-to-user/Multi-user communication in the direction from FRMCS to GSM-R	?		No corresponding requirement?	NA		NA	
Critical support applications	Inviting-a-user related use cases	Invite-a-user to a voice communication	67.2	Inviting user	R-9.5.2-001	22.280		NA		NA	
					R-9.5.2-002	Not covered			NA	NA	
					R-9.5.2-003	b		NA		NA	
		Receiving an invitation to a voice communication	67.3		R-9.5.3-001	Not covered			NA	NA	
		Accepting an invitation to a voice communication	67.4	Invited user not involved in a voice communication	R-9.5.4-001	Not covered			NA	NA	
				Invited user	R-9.5.4-001	Not covered			NA	NA	

				is involved in a voice communication:							
				a) Leave	R-9.5.4-002	Not covered			NA	NA	
				b) Terminate	R-9.5.4-002	Not covered			NA	NA	
				c) Merge	R-9.5.4-002	Not covered			NA	NA	
		Rejecting an invitation to a voice communication	67.5		R-9.5.5-001	Partly covered 22.179		NA		NA	
					R-9.5.5-002	Partly covered 22.179		NA		NA	
		Ignore an invitation to a voice communication	67.6		R-9.5.6-002	Not covered			NA	NA	
		Service interworking and service continuation with GSM-R	67.7	Group call in GSM-R and controller in FRMCS	?		No corresponding requirement?	NA		NA	
				Group call in FRMCS and controller in GSM-R	?		No corresponding requirement?	NA		NA	
Critical support applications	Arbitration related use cases	Arbitration	68.2	Incoming communication	R-9.16.2-002	[Needs analysis]		NA			
				Outgoing communication	R-9.16.2-001	[Needs analysis]		NA			
		Service interworking and service continuation with GSM-R	68.3	For user-to-user/Multi-user communication in the direction from GSM-R to FRMCS	?		No corresponding requirement?	NA		NA	

				For user-to-user/Multi-user communication in the direction from FRMCS to GSM-R	?		No corresponding requirement?	NA		NA	

Table 3. Questionnaire Table 2

9.3 Interviews

9.3.1 Purpose of the interviews

The purpose of the interviews is to fill the missing information to get a clear picture of where we are in the 3GPP gap analysis:

- which functional needs and system principles are covered or partially covered within 3GPP technical specifications,
- what is currently not but should be included within 3GPP technical specifications,
- what is currently not but should be added at the application level (railway domain).

The purpose is also to provide a high-level feasibility study of the purely OTT based approach with senior advisors or the OTT ecosystem (mainly SIP/RTP specialists), independent from the Rail industry.

9.3.2 Overview/explanation of related organisations

Standards are critical to the interoperability of ICTs and whether we exchange voice, video or data messages, standards enable global communications by ensuring that countries' ICT networks and devices are speaking the same language.

This section provides to the reader an overview and explanations of key organisations in charge of specifications and standardisations of both 3GPP-based and Over-The-Top (OTT) communications technologies as candidate options for the communication architecture of the evolution of European railway radio.

Each organisation is briefly described, including their working groups and publications relevant to the study, summarized in a factsheet available in the Appendix 6.3:

- International Telecommunication Union – ITU: ITU is the United Nations specialized agency for information and communication technologies – ICTs. ITU allocates global radio spectrum and satellite orbits, develops international technical standards that ensure networks and technologies seamlessly interconnect, and strives to improve access to ICTs to underserved communities worldwide. Two ITU sectors are of particular interest for this study:
    - ITU-R (ITU Radiocommunication sector)
    - ITU-T (ITU Telecommunication Standardization sector)
- 3rd Generation Partnership Project – 3GPP: The 3GPP unites Organizational Partners and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies (3GPP mobile systems such as GSM/GPRS and EDGE, UMTS, LTE, LTE-Advanced, LTE-Advanced Pro, 5G NR). The project covers cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities - including work on codecs, security, quality of service - and thus provides complete system specifications. The specifications also provide hooks for non-radio access to the core network, and for interworking with Wi-Fi networks.
- European Telecommunications Standards Institute – ETSI: ETSI is an independent, non-profit organisation, recognized as a regional standards

body – European Standards Organization (ESO) – dealing with telecommunications, broadcasting and other electronic communications networks and services. ETSI was set up in 1988 by the European Conference of Postal and Telecommunications Administrations (CEPT) in response to proposals from the European Commission. ETSI is supporting European regulations and legislation through the creation of Harmonised European Standards. Only standards developed by the three ESOs (CEN, CENELEC and ETSI) are recognized as European Standards (ENs). As a partner in the international Third Generation Partnership Project (3GPP), ETSI is helping to develop 4G and 5G mobile communications.

- GSM Association – GSMA: GSMA represents the interests of mobile operators worldwide.
- Open Mobile Alliance – OMA: OMA is a non-profit organization (forum for industry) that delivers open specifications for creating interoperable services (applicative protocols only) for the Mobile phone industry that work across all geographical boundaries, on any bearer network. OMA's specifications support the billions of new and existing terminals across a variety of wireless networks, including traditional cellular operator networks and emerging networks supporting machine-to-machine device communications for the Internet of Things (IoT).
- Internet Engineering Task Force – IETF: The IETF is a large open international community concerned to make the Internet work better by producing high quality, relevant technical documents that influence the way people design, use, and manage the Internet.
- Session Initiation Protocol Forum – SIP Forum: The SIP Forum is a non-profit organization devoted to advancing the adoption of the Session Initiation Protocol (SIP), a signalling protocol for use in initiating, modifying, and terminating an interactive session among two or more users that involves multimedia elements such as voice, video, instant messaging, online games, and virtual reality.
- World Wide Web Consortium – W3C: The World Wide Web Consortium (W3C) is an international community where Member organizations, a full-time staff, and the public work together to develop Web standards. The W3C mission is to lead the World Wide Web to its full potential by developing protocols and guidelines that ensure the long-term growth of the Web.

9.3.2.1 ITU

Name:	**International Telecommunication Union**
Acronym:	ITU
Sphere of activity:	ICT / Worldwide
Approach to standard development:	Consensus-based, Contribution-driven
Publications:	ITU-T Recommendations (standards defining how telecommunication networks operate and interwork)

Description:	ITU is the United Nations specialized agency for information and communication technologies – ICTs. ITU allocates global radio spectrum and satellite orbits, develops **international technical standards** that ensure networks and technologies seamlessly interconnect, and strives to improve access to ICTs to underserved communities worldwide.
Members:	ITU currently has a membership of 193 countries and almost 800 private-sector entities and academic institutions. ITU membership represents a cross-section of the global ICT sector, from the world's largest manufacturers and telecoms carriers to small, innovative players working with new and emerging technologies, along with leading R&D institutions and academia.
Technical areas and study groups:	▪ SG2 - Operational aspects ▪ SG3 - Economic and policy issues ▪ SG5 - Environment and circular economy ▪ SG9 - Broadband cable and TV ▪ SG11 - Protocols and test specifications ▪ SG12 - Performance, QoS and QoE ▪ SG13 - Future networks (& cloud) ▪ SG15 - Transport, Access and Home ▪ SG16 - Multimedia ▪ SG17 - Security ▪ SG20 - IoT, smart cities & communities
Relevance to our study (Critical Communications, Railways, OTT)	▪ Multimedia (VoIP) ▪ QoS (quality of voice conversation) ▪ Economic (adaptation to the growth of IP and OTT services)
More information:	https://www.itu.int/en/about/Pages/default.aspx

9.3.2.2 ITU-R

Name:	**International Telecommunication Union**
Acronym:	ITU-R (ITU Radiocommunication sector)
Sphere of activity:	ICT / Worldwide
Approach to standard development:	Consensus-based, Contribution-driven
Publications:	▪ ITU-R Recommendations (Satellite, fixed and mobile services, spectrum management) ▪ Radio Regulations (RR) revised during World Radiocommunication Conferences (WRC) every 3-4 years ▪ Master International Frequency Register (MIFR)
Description:	ITU is the United Nations specialized agency for information and communication technologies – ICTs. ITU allocates **global radio spectrum and satellite orbits**, develops international technical standards that ensure networks and technologies seamlessly interconnect, and strives to improve access to ICTs to underserved communities worldwide.
Members:	ITU currently has a membership of 193 countries and almost 800 private-sector entities and academic institutions. ITU membership represents a cross-section of the global ICT sector, from the world's largest manufacturers and telecoms carriers to small, innovative players working with new and emerging technologies, along with leading R&D institutions and academia.
Technical areas and study groups:	▪ SG1 - Spectrum management ▪ SG3 - Radiowave propagation ▪ SG4 - Satellite services ▪ SG5 - Terrestrial services ▪ SG6 - Broadcasting service ▪ SG7 - Science services
Relevance to our study (Critical Communications, Railways, OTT)	▪ Spectrum (managing interferences) ▪ Terrestrial (mobile and wireless broadband communications such as IMT systems 3G, 4G and 5G; Public Protection and Disaster Relief; Intelligent Transport Systems)
More information:	https://www.itu.int/en/ITU-R/information/Pages/default.aspx

9.3.2.3 ITU-T

Name:	**International Telecommunication Union**
Acronym:	ITU-T (ITU Telecommunication Standardization sector)
Sphere of activity:	ICT / Worldwide
Approach to standard development:	Consensus-based, Contribution-driven
Publications:	ITU Recommendations (standards defining how telecommunication networks operate and interwork)
Description:	ITU is the United Nations specialized agency for information and communication technologies – ICTs. ITU allocates global radio spectrum and satellite orbits, develops **international technical standards** that ensure networks and technologies seamlessly interconnect, and strives to improve access to ICTs to underserved communities worldwide.
Members:	ITU currently has a membership of 193 countries and almost 800 private-sector entities and academic institutions. ITU membership represents a cross-section of the global ICT sector, from the world's largest manufacturers and telecoms carriers to small, innovative players working with new and emerging technologies, along with leading R&D institutions and academia.
Technical areas and study groups:	▪ SG2 - Operational aspects ▪ SG3 - Economic and policy issues ▪ SG5 - Environment and circular economy ▪ SG9 - Broadband cable and TV ▪ SG11 - Protocols and test specifications ▪ SG12 - Performance, QoS and QoE ▪ SG13 - Future networks (& cloud) ▪ SG15 - Transport, Access and Home ▪ SG16 - Multimedia ▪ SG17 - Security ▪ SG20 - IoT, smart cities & communities
Relevance to our study (Critical Communications, Railways, OTT)	▪ Multimedia (VoIP) ▪ QoS (quality of voice conversation) ▪ Economic (adaptation to the growth of IP and OTT services) ▪ ITU-T E.164: "The international public telecommunication numbering plan", ITU-T Recommendation E.164.
More information:	https://www.itu.int/en/about/Pages/default.aspx

9.3.2.4 3GPP

Name:	**3rd Generation Partnership Project**
Acronym:	3GPP
Sphere of activity:	Telecommunication / Worldwide
Approach to standard development:	Consensus-based, Contribution-driven
Publications:	▪ Technical Specifications (TS) and reports (TR). Updates are based on Releases to allow manufacturers and operators to choose which release to build their systems). Specifications are categorized through a three-stage methodology: stage 1 for service description, stage 2 defines an architecture to support service requirements, and stage 3 for implementation of the functionality and protocols Studies
Description:	The 3GPP unites Organizational Partners and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies (3GPP mobile systems such as GSM/GPRS and EDGE, UMTS, LTE, LTE-Advanced, LTE-Advanced Pro, 5G NR). The project covers cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities - including work on codecs, security, quality of service - and thus provides complete system specifications. The specifications also provide hooks for non-radio access to the core network, and for interworking with Wi-Fi networks.
Members:	Members of telecommunications standard development organizations (ARIB, ATIS, CCSA, **ETSI**, TSDSI, TTA, TTC), known as Organizational Partners.
Technical areas and study groups:	▪ Services & Systems Aspects (SA) ▪ Radio Access Networks (RAN) ▪ Core Network & Terminals (CT)

Relevance to our study (Critical Communications, Railways, OTT)	▪ SA WG1 – Services (including VGCS, VBS, GCSE, ProSe, MBMS, IMS, MCPTT, MCData, MCVideo and FRMCS):
	    ○ TR 22.889 - Study on Future Railway Mobile Communication System (FRMCS)
	▪ SA WG6 – Mission critical applications (including MBMS, MBMS API for UE, MCPTT, MCData, MCVideo, migration, interconnection, interworking, and FRMCS):
	    ○ TR 23.790 - Study on application architecture for the Future Railway Mobile Communication System (FRMCS); Stage 2

More information:	http://www.3gpp.org/ftp/Information/presentations/3gpp_brochure_04/index.html#p=11

9.3.2.5 ETSI

Name:	**European Telecommunications Standards Institute**
Acronym:	ETSI
Sphere of activity:	Telecommunication / Europe
Approach to standard development:	Consensus-based, Contribution-driven (from members), openness (publicly available, free of charge)
Publications:	▪ European Standard (EN), produced in response to an EC mandate ▪ ETSI Standard (ES) ▪ ETSI Guide (EG) ▪ ETSI Technical Specification (TS) ▪ ETSI Technical Report (TR) ▪ ETSI Special Report (SR) ▪ ETSI Group Report (GR) ETSI Group Specification (GS)
Description:	ETSI is an independent, non-profit organisation, recognized as a regional standards body – European Standards Organization (ESO) – dealing with telecommunications, broadcasting and other electronic communications networks and services. ETSI was set up in 1988 by the European Conference of Postal and Telecommunications Administrations (CEPT) in response to proposals from the European Commission. ETSI is supporting European regulations and legislation through the creation of Harmonised European Standards. Only standards developed by the three ESOs (CEN, CENELEC and ETSI) are recognized as European Standards (ENs). As a partner in the international Third Generation Partnership Project (3GPP), ETSI is helping to develop 4G and 5G mobile communications.
Members:	800 members from 66 countries across five continents, representing a cross-section of our industry: manufacturers, network operators, service and content providers, national administrations, universities and research bodies, user organizations and consultancy companies and partnerships.
Technical areas and study groups:	▪ TC RRS - Reconfigurable Radio Systems Technical Committee ▪ TC BRAN - Broadband Radio Access Networks committee ▪ TC SES - Satellite Earth Stations and Systems committee ▪ TC MSG - Mobile Standards Group ▪ TC CYBER - Cyber Security committee ▪ TC SCP - Smart Card Platform committee ▪ TC STQ - Speech and Multimedia Transmission Quality committee ▪ TC ITS - Intelligent Transport Systems committee ▪ TC ERM - Electromagnetic Compatibility and Radio Spectrum Matters committee ▪ TC RT - Rail Telecommunications committee ▪ TC NTECH - Network Technologies committee ▪ TC INT - Core Network and Interoperability Testing committee ▪ TC TCCE - TETRA and Critical Communications Evolution committee ▪ TC Smart M2M - Smart Machine-to- Machine Communications committee
Relevance to our study (Critical Communications,	▪ TC RT - Rail Telecommunications committee ▪ TC TCCE - TETRA and Critical Communications Evolution committee

Railways, OTT)	
More information:	http://www.etsi.org/about/what-we-are

9.3.2.6 GSMA

Name:	**GSM Association**
Acronym:	GSMA
Sphere of activity:	Telecommunication / Worldwide
Approach to standard development:	Consensus-based, Contribution-driven
Publications:	▪ Guidelines ▪ Recommendations to support efficient roaming, interconnection and interworking (IMS, VoLTE, RCS, Wi-Fi roaming…) Processes
Description:	GSMA represents the interests of mobile operators worldwide
Members:	800 operators with more than 300 companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies, as well as organisations in adjacent industry sectors.
Technical areas and study groups:	▪ Fraud and Security Group ▪ Interoperability Data specifications and Settlement Group (including billing) ▪ Networks Group ▪ SIM Working Group (including embedded SIM) ▪ Terminal Steering Group ▪ Internet Group ▪ Wholesale Agreements and Solutions Group
Relevance to our study (Critical Communications, Railways, OTT)	▪ Networks Group: ○ **IR.92** - IMS Profile for Voice and SMS, defining a voice over IMS profile by listing number of Evolved Universal Terrestrial Radio Access Network (E-UTRAN), evolved packet core (EPC), IMS core, and UE features which are considered essential to launch interoperable IMS based voice services. To be considered as a Technical requirement for Voice over LTE (**VoLTE**). ○ **IR.94** - IMS Profile for Conversational Video Service, defining an IMS profile by listing a number of E-UTRAN), EPC, IMS core, and UE features which are considered essential to launch interoperable IMS based conversational video services. To be considered as a Technical requirement for Voice over LTE (**ViLTE**). ○ **IR.51** – IMS over Wi-Fi, defining a minimum mandatory set of features which are defined in 3GPP specifications that a UE and network are required to implement in order to guarantee interoperable, high quality IMS-based telephony and conversational video services over Wi-Fi access networks ○ **IR.34** - Guidelines for IPX (IP eXchange) Provider networks, defining the requirement for IP interworking and IPX. It covers the background to the forerunner of the IPX, the GRX. ▪ NG.102 - IMS Profile for Converged IP Communications, defining a profile that identifies a minimum mandatory set of common IMS functionalities that are defined in 3GPP specifications and other GSMA documents that a UE and network are required to support in order to guarantee interoperable, high quality IMS-based and Mobile Operator provided Converged IP Communications Services.

More information:	https://www.gsma.com/aboutus/

9.3.2.7 OMA

Name:	**Open Mobile Alliance**
Acronym:	OMA
Sphere of activity:	Telecommunication / Worldwide
Approach to standard development:	Unknown
Publications:	▪ Specifications
Description:	OMA is a non-profit organization (forum for industry) that delivers open specifications for creating **interoperable** services (applicative protocols only) for the Mobile phone industry that work across all geographical boundaries, on any bearer network. OMA's specifications support the billions of new and existing terminals across a variety of wireless networks, including traditional cellular operator networks and emerging networks supporting machine-to-machine device communications for the Internet of Things (IoT). The principles of the Open Mobile Alliance are: ▪ Products and services are based on open, global standards, protocols and interfaces and are not locked to proprietary technologies ▪ The applications layer is **bearer agnostic** (GSM, GPRS, EDGE, CDMA, UMTS…) ▪ The architecture framework and service enablers are independent of Operating Systems (OS) ▪ Applications and platforms are interoperable, providing seamless geographic and inter-generational roaming
Members:	OMA member companies fall into 4 categories that define the various parts of the end-to-end value chain, including Wireless Vendors, Information Technology Companies, Mobile Operators and Application & Content Providers. Both the U.S. First Responder Network Authority (FirstNet) and U.K. Home Office, which are pushing nationwide public-safety LTE initiatives in their respective countries, are members of OMA as governmental agencies.
Technical areas and study groups:	▪ OMA LOC WG – Location Working Group ▪ OMA API WG ▪ OMA ARC WG – Architecture Working Group ▪ OMA COM WG – Communications Working Group, responsible for service layer standardization of communications related technologies, allowing companies to build communications solutions on top of OMA Service Enablers ▪ OMA CD WG - Content Delivery Working Group ▪ OMA DM WG - Device Management Working Group ▪ OMA IOP WG – Interoperability Working Group
Relevance to our study (Critical Communications, Railways, OTT)	▪ OMA COM WG: specifications include areas such as Messaging, Push-to-talk over Cellular (**OMA PoC**) and Push-to-Communicate for Public Safety (**OMA PCPS**), Presence, Contact Information and Address Book, Media and Data Management, Enhanced Visual Voice Mail and Spam Reporting. With a focus on interoperability among a wide variety of legacy systems and the convergence of those systems with new IP based services and technologies, the primary goal of OMA COM is to enhance the user experience and the operator's ability to build comprehensive messaging and communications systems.

More information:	http://openmobilealliance.org/about-oma

Note on OMA license granted to 3GPP: a copyright agreement has been signed on March 30, 2015 to allow the Open Mobile Alliance (OMA) Push-to-Communicate for Public Safety (PCPS) specifications - based on OMA Push-to-talk over Cellular (PoC) - to be used in 3GPP specifications for mission-critical Push To Talk (MCPTT). OMA PCPS was part of the basis to define 3GPP MCPTT Release 13 together with 3GPP enablers such as GCSE http://www.3gpp.org/news-events/partners-news/1676-oma_poc

9.3.2.8 IETF

Name:	**Internet Engineering Task Force**
Acronym:	IETF
Sphere of activity:	ICT / Worldwide
Approach to standard development:	Due process, consensus, transparency, balance and openness https://open-stand.org/about-us/principles/
Publications:	▪ Internet Standards - Requests for comment (RFCs): RFCs cover many aspects of computer networking, including protocols, procedures, programs, and concepts, as well as meeting notes, opinions, and sometimes humour (https://www.ietf.org/download/rfc-index.txt)
Description:	The IETF is a large open international community concerned to make the Internet work better by producing high quality, relevant technical documents that influence the way people design, use, and manage the Internet.
Members:	The Internet Engineering Task Force (IETF) is a large open international community of network designers, operators, vendors, and researchers.
Technical areas and study groups:	There are typically over 100 active Working Groups at any particular time, and each is part of an Area that is most relevant to its work (https://datatracker.ietf.org/wg/): ▪ Applications and Real-Time Area (art) including the *SIPCore WG* ▪ General Area (gen) ▪ Internet Area (int) ▪ Operations and Management Area (ops) ▪ Routing Area (rtg) ▪ Security Area (sec) ▪ Transport Area (tsv) including *Multipath TCP WG*
Relevance to our study (Critical Communications, Railways, OTT and all VoIP solutions)	▪ IETF RFC 3261: "SIP: Session Initiation Protocol" ▪ IETF RFC 3312: “Integration of resources management and SIP” (QoS management of underlying bearers from SIP) ▪ IETF RFC 3550: "RTP: A Transport Protocol for Real-Time Applications", ▪ IETF RFC 3966: "The tel URI for Telephone Numbers", ▪ IETF RFC 3996: "Uniform Resource Identifiers (URI): Generic Syntax", ▪ IETF RFC 4083: “Input 3GPP Release 5 requirements on the SIP” (IMS/SIP for operation in a cellular network) ▪ IETF RFC 4412: "Communications Resource Priority for the Session Initiation Protocol (SIP)" ▪ IETF RFC 4566: “SDP: Session Description Protocol” (Description of media such as audio or video, associated with SIP) ▪ IETF RFC 7826: "Real Time Streaming Protocol (RTSP) ▪ IETF RFC 7840: “HELD: HTTP-enabled Location Delivery protocol” (SIP/OTT VoIP emergency caller location) ▪ https://tools.ietf.org/rfc/index
More information:	https://www.ietf.org/about/

Note: IETF has developed many protocols based on open standards to implement **Voice-over-IP (VoIP)** protocol suite such as Session Initiation Protocol (SIP), Real-Time Transport Protocol (RTP), Real-Time Transport Control Protocol (RTCP) including Quality of Service (QoS) and Quality of Experience (QoE) protocols for VoIP calls. 3GPP asked IETF for introduction of IMS/SIP for operation in a cellular network.

9.3.2.9 SIP Forum

Name:	**Session Initiation Protocol Forum**	
Acronym:	SIP Forum	
Sphere of activity:	ICT / Worldwide	
Approach to standard development:	The SIP Forum is not a standards-setting body	
Publications:	▪ Technical documents (https://www.sipforum.org/documents/)	
Description:	The SIP Forum is a non-profit organization devoted to advancing the adoption of the Session Initiation Protocol (SIP), a signalling protocol for use in initiating, modifying, and terminating an interactive session among two or more users that involves multimedia elements such as voice, video, instant messaging, online games, and virtual reality. The SIP Forum is explicitly not a standards-setting body, the Internet Engineering Task Force (IETF) defines the core SIP protocol. Work on SIP is accomplished primarily in the IETF SIP working group. The primary goals of the SIP Forum are to foster interoperability and adherence to standardization efforts and provide educational resources and a platform for productive communication among industry participants.	
Members:	The SIP Forum was formed in 1999 by 7 founding Full Member companies. Todays, 15 full members from IT companies (such as Microsoft) to MNOs (e.g. Deutsche Telekom).	
Technical areas and study groups:	Technical activities: while the IETF is the body that establishes the core SIP protocol definitions in Internet standard documents (RFCs), the SIP Forum performs ancillary technical activities: Develops industry-wide technical recommendations and best-practice implementation guides. The SIP Forum Technical Working Group (techwg) was established in 2004. The principal goal of the Technical Working Group (TWG) is to produce technical documents, software, training and not-for-profit services for and using SIP-based technology for a variety of applications and services. Active working groups: ▪ ATIS/SIP Forum NNI Task Force ▪ SIPconnect 2.0 Task Group ▪ SIPconnect Interoperability Certification [SC-IT] Task Group ▪ SIP Over IPv6 [IPv6] Task Group ▪ Fax-over-IP [FoIP] Task Group ▪ Video Relay Services [VRS] Task Group ▪ WebRTC Task Group	
Relevance to our study (Critical Communications, Railways, OTT)	▪ SIP Expertise	

More information:	https://www.sipforum.org/about/mission-scope-and-structure/

9.3.2.10 W3C

Name:	**World Wide Web Consortium**	
Acronym:	W3C	
Sphere of activity:	IT / Worldwide	
Approach to standard development:	Due process, consensus, transparency, balance and openness https://open-stand.org/about-us/principles/	
Publications:	▪ Technical specifications ▪ Guidelines ▪ APIs	
Description:	The World Wide Web Consortium (W3C) is an international community where Member organizations, a full-time staff, and the public work together to develop Web standards. The W3C mission is to lead the World Wide Web to its full potential by developing protocols and guidelines that ensure the long-term growth of the Web.	
Members:	ICT companies, academics. http://www.w3.org/Consortium/Member/List	
Technical areas and study groups:	▪ Web Design and Applications involve the standards for building and Rendering Web pages, including HTML, CSS, SVG, device APIs, and other technologies for Web Applications (“WebApps”) ▪ Web of Devices to enable Web access anywhere, anytime, using any device ▪ Web Architecture focuses on the foundation technologies and principles which sustain the Web, including URIs and HTTP. ▪ Semantic Web enable people to create data stores on the Web, build vocabularies, and write rules for handling data ▪ XML Technologies including XML, XML Namespaces, XML Schema, XSLT, Efficient XML Interchange (EXI), and other related standards ▪ Web of Services refers to message-based design frequently found on the Web and in enterprise software. ▪ Browsers and Authoring Tools	
Relevance to our study (Critical Communications, Railways, OTT)	▪ W3C Mobile Web Initiative including **Web Real-Time Communications** (WebRTC), **geolocation API** for locating the device, independently of the underlying technology, **geofencing API** made it possible to wake up a Web app when a device enters a specified geographical area http://www.w3.org/Mobile/	
More information:	http://www.w3.org/	

9.3.3 Contact list

Organisations	Surname Name	Roles within company and FRMCS/Mission critical communications	Dates of interview
French Home Office TCCA/CCBG	Emmanuelle VILLEBRUN	Technical architect of the “Réseau Radio du Futur” (Next generation radio network) Mission Critical Communications	09/02/2018
Cabinet Roland Berger	Matthieu ROCHE TOUSSAINT	Solution architect Mission Critical Communications	09/02/2018
SBB UIC	Ingo WENDLER	UIC representative within 3GPP working groups (mainly SA1 WG) to introduce railway requirements	16/02/2018 12/03/2018
Softil	Amir ANGEL	VP Sales EMEA & APAC Mission Critical Communications	22/02/2018
Frequentis AG	Markus MYSLIVEC	Solution designer	23/02/2018
KCC	Michael MIKULANDRA	Standardization and regulatory topics Architecture and product development for network and on-board equipment	27/02/2018
Nokia	Juergen MERKEL	3GPP Technical rapporteur of the Technical Report TR 22.889 (3GPP gap analysis of railway requirements) within SA1 WG	28/02/2018
Funkwerk	Jens KOECHER	Single point of contact for any issues related to FRMCS, member of FM56 and UIC UGFA	01/03/2018
Harris corporation	Ashwin DINKAR	Mission Critical Communications	No answer

Organisations	Surname Name	Roles within company and FRMCS/Mission critical communications	Dates of interview
Columbia University	Henning SCHULZRINNE	(was a) Chief architect of IETF SIP protocols (served as) Chief Technologist for the US FCC	05/03/2018
KCC	Christophe GRUET	Solution Architect for Rail	13/03/2018
KCC	Olivier EUDES	Standardisation Manager for Rail	13/03/2018
Nokia	Michael KLOECKER	Head of E2E Solution Management for Railway	15/03/2018
ProRail UIC	Erik VANBOMMEL	Product Manager Group leader of Functional WG (UIC FRMCS project)	16/03/2018
Huawei	Joerg HUTH	Product & standardisation Manager of the Transportation Solution Unit (TSU)	19/03/2018
Huawei	Felix ALONSO	Solution Architect of the Transportation Solution Unit (TSU)	19/03/2018
SNCF R UIC	Fred COURSANT	Group leader of Architecture & Technology WG (UIC FRMCS project)	20/03/2018
Research Institutes of Sweden	Eilert JOHANSSON	Senior project manager	28/03/2018
SIP Forum Washington University	Richard SHOCKEY	Chairman of the board of Directors SIP Forum	31/03/2018

9.4 Features overview: priorities and targets

The following table is extracted from the document [21]:

Section	Basic Title	Priority	Target
5	Basic functionality use cases	Medium	Rel. 16
5,2	Device power on and shut-down related use cases	Medium	Rel. 16
5,3	Use case: Power on the UE	Medium	Rel. 16
5,4	Use case: Access to the FRMCS System to activate the FRMCS Equipment	Medium	Rel. 16
5,5	Use case: Controlled power down of UE	Medium	Rel. 16
5,6	Use case: Uncontrolled power down UE	Medium	Rel. 16
6,2	Multi-train voice communication for Drivers including Ground FRMCS User(s)	High	Rel. 16
6,3	On-train outgoing voice communication from the Driver towards the Controller(s) of the train	High	Rel. 16
6,4	Railway emergency communication	High	Rel. 16
6,5	Use case: Automatic Train Control (ATC) support by the FRMCS System	High	Rel. 16
6,6	Trackside Maintenance Warning System communication related use cases	High	Rel. 16
6,7	Pushed Real Time Video streaming	High	Rel. 16
6,8	Public emergency call related use cases	Medium	Rel. 16
6,9	Data communication for possession management related use cases	High	Rel. 16
6,10	Recording of communication	High	Rel. 16
6,11	Remote control of engines communication related use cases	High	Rel. 16
6,12	Automatic Train Operation data communication	High	Rel. 16
6,13	Monitoring and control of critical infrastructure related use cases	High	Rel. 16
6,16	data communication for Train Operation System Communication	High	Rel. 16
7,1	Use cases related to transmission of real time video	Medium	Rel. 16
7,2	Transfer of CCTV archives related use cases	Low	Rel. 16
7,3	Use Case: Massive Inter-carriage data transfer	Low	Rel. 16
7,4	Use case: Data transmission in real time	Low	Rel. 16
8,2	Use Case: Live streaming of multimedia	Low	Rel. 16
8,3	Use Case: Bulk transfer of multimedia from ground to train	Low	Rel. 16
9,2	Assured voice communication (AVC)	Medium	Rel. 16
9,3	Functional identities and role management	High	Rel. 16
9,4	Location services related use cases	High	Rel. 16
9,5	FRMCS-user communication handling related use cases	High	Rel. 16
9,7	Multi user talker control related use cases	High	Rel. 15
9,8	Authorisation of communication	High	Rel. 16
9,9	Authorisation of application	High	Rel. 16
9,10	Sharing FRMCS Equipment by FRMCS Users	Medium	Rel. 16
9,11	FRMCS naming authority	High	Rel. 16
9,12	Wayside-Centric Automatic Train Control	Medium	Rel. 16
9,13	Autonomous Train Control and Operation	Medium	Rel. 16
9,14	Virtual Coupling	Medium	Rel. 16
9,15	Composite-based train operation	Medium	Rel. 16
9,16	Arbitration related use cases	Medium	Rel. 16
12,2	Area Broadcast Group Communication interworking between GSM-R and FRMCS Users	Medium	Rel. 16
12,3	Location Service interworking between GSM-R and FRMCS Users	Medium	Rel. 16
12,4	Presence interworking between GSM-R and FRMCS Users	Medium	Rel. 16
12,5	Point to Point communication between GSM-R and FRMCS Users	Medium	Rel. 16
12,6	Use case: Interworking with legacy systems including (GSM-R) LMR and TRS	Medium	Rel. 16
12,7	Use case: Builds stable positioning framework for FRMCS services and devices including trainborne and	Medium	Rel. 16
12,8	Interconnection between GSM-R and FRMCS	Medium	Rel. 16
12,9	Use case: Bearer flexibility	High	Rel. 16
12,10	Use case: Quality of Service and railway environment	High	Rel. 16
12,11	Use case: Provide broadband and mission critical services with seamless connectivity	High	Rel. 16
12,12	Use case: Offer railway services high-quality control functions with real-time train status monitoring	Medium	Rel. 16
12,13	Use case: Provide call priority during interworking with LMR	Medium	Rel. 16
12,14	Use Case: FRMCS Positioning Accuracy	High	Rel. 16
12,15	Use Case: FRMCS System security framework	High	Rel. 16
12,16	Interworking between GSM-R and FRMCS	Medium	Rel. 16
12,17	On-network/Off-network communication	Medium	Rel. 16
12,19	Allocation and Management of Communication Resources	Medium	Rel. 16

10. ANNEX B: ON-BOARD SYSTEM

10.1 Questionnaire

Internet research is not the most valuable source of information because most outputs and deliverables of above projects are of restricted access. It was agreed with the Agency that a detailed questionnaire would be developed to provide a picture of the current situation of 3GPP and OTT gap analysis.

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(1) Current situation with GSM-R
  a. Description of on-board radio communication architecture for both ETCS (EDOR) and voice radio (CabRadio): components, CPU/UC, RTOS, interfaces…
  b. Description of vehicles/trains composition (multiple radio units, shared components such as antennas, RF cabling…)
  c. Manufacturers product portfolio and roadmap
  d. Processes highlighting economic and operational impact of O&M due to existing architecture
    i. Certification/Authorisation for placing in service (Interoperability directive and TSI CCS, CE marking), interaction GSM-R/ETCS (in-dependent projects, in-dependent time-line)
    ii. Installation (initial process): description of the process (areas, tools, time to update…)
    iii. Evolutions/Upgrades (use cases: patches, improved receivers and new GSM-R baseline…): description of the process (planned or unplanned programs, areas or remote, tools, time to update…)
      1. HW
      2. SW & FW
      3. Phone books and other configuration files
      4. SIM Cards
    iv. Cost ratio: product design VS EU/TSI CCS certification vs installation
  e. Major challenges encountered, constraints and limitations (including both migrations from analog to CS GSM-R and from CS GSM-R to PS GSM-R)
    i. Economic
    ii. Legal
    iii. Standards and specifications (e.g. test specifications for ICs)
    iv. Procurement (e.g. Subset-093, RAM requirements)
    v. Technology
    vi. Others

(2) Future situation with FRMCS and other alternatives (all-IP based communication flows)
  a. FRMCS Requirements

i. Supporting new (mission and non-mission critical) applications with communication needs (e.g. ATO, TCN introducing TCMS and OTMS…)
ii. Supporting new bearers
iii. Supporting new frequency bands
iv. Supporting new interfaces (e.g. APIs), protocols and standards

b. Opportunities with
i. other sectors/markets (e.g. urban rail, PPDR)
ii. commercial smartphone ecosystem (chipsets, form factors, Android)
iii. "Softwarisation" (shift from HW to SW e.g. Software-Defined Radios or Reconfigurable Radio Systems)
iv. open source and open stack (e.g. openRBC)

c. Impact of new EU directives (e.g. RED)
d. Criteria to define the future architecture to minimise economic and operational impact of O&M (such as enabling flexible evolutions when new application must be supported, new RAT, new band…)
e. Architecture concept (functional, HW & SW): ongoing initiatives inside and outside Europe
f. Major challenges ahead (e.g. Migration, spectrum, IP addressing) and first proposals
g. Manufacturers product portfolio and roadmap (mono mode & dual mode & multi modes including shared components for migration or other communication needs, form factors, CPU, OS, interfaces, positioning, SDR, MTBF, scalability, HW and SW upgradeability, accessibility, DMI…)

(3) AOB/expectations regarding the study

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The questionnaire was sent by e-mail with an introductory letter from ERA to the contact list identified in section 10.2.

10.2 Contact list

Organisations	Surname Name	Roles within company and FRMCS/Mission critical communications	Dates of interview
KCC	Michael MIKULANDRA	Standardization and regulatory topics Architecture and product development for network and on-board equipment	08/06/2018
S2R	Ulrich GEIER	Project leader for Work Package 3: new Adaptable	25/06/2018

Organisations	Surname Name	Roles within company and FRMCS/Mission critical communications	Dates of interview
		Communication System (ACS)	
ALSTOM	Pierre COTELLE	Networks & Telecom Solution Director Alstom representative at ROC Industry Group, S2R (IP2 TD2.1) and ETSI TC RT JTFIR	11/06/2018
HFWK	Gottfried WINTER	Sales director Representative at ROC IG	20/06/2018
HFWK	Alexander ENDE	Product manager & standardisation expert of FRMCS Representative at ETSI TC RT Representative at ROC IG	20/06/2018
ALSTOM	Pierre LAMBERT	Representative at UNISIG	25/06/2018
SNCF	Franck MATHEAU	Direction Interoperability & standards	27/06/2018
SNCF	Laurent LLERENA	TCN	27/06/2018
SNCF	Nordine NAAMOUNE	Référent radio GSM et GSM-R à la Direction du Matériel roulant (Centre d'Ingénierie Matériel - CIM)	27/06/2018
SNCF	Pierre JUVENTY	Rolling stock department	27/06/2018
EEIG EUG	Rob DIJKMAN	Technical director in EUG	21/06/2018
DB Netz AG	Jochen WALZ	Responsible of the "yellow fleet"	28/06/2018
SIEMENS	Ciro DECOL	Head of Sales	25/06/2018
RINA	Federica FORNARI	RINA Services S.p.A	13/06/2018
RINA	Daniele ANGIATI	RINA Services S.p.A	13/06/2018
RINA	Fabrizio CRISMER	RINA Services S.p.A	13/06/2018

10.3 Example of FRMCS On-board architecture

The following figure shows an example of possible architecture, with following options:

- Ethernet interfaces, except for already existing legacy systems;
- Usage of a redundant Shared Communication Gateway, with separation between critical and non-critical applications;
- “Telecom box” for ETCS managed by the communication gateway in FRMCS;
- Usage of 2 wideband antennas;

Usage of TCN, but this entity is not ready for critical communication (no redundancy, no cybersecurity …).

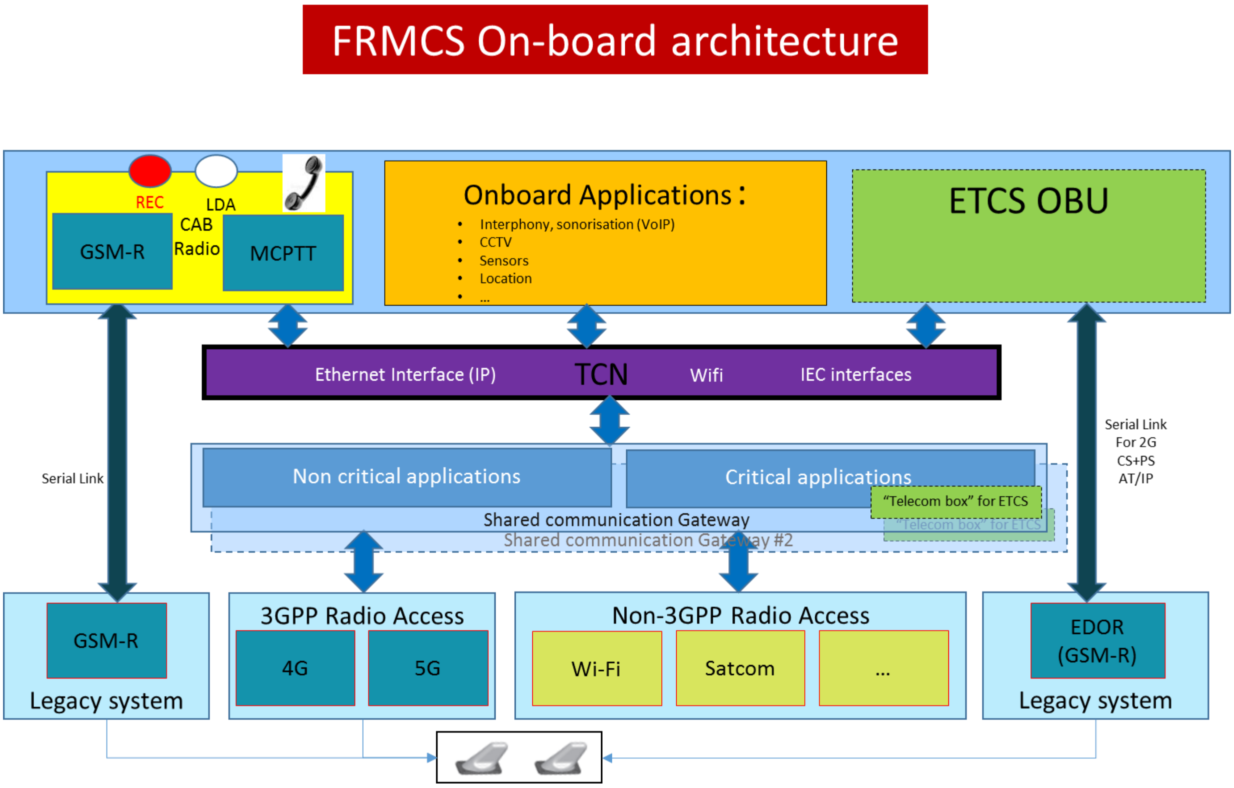

Figure 34. Example of FRMCS on-board architecture