Deliverable D1.4

Test report conclusion from real-world environment

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5GRAIL

5G for future RAILway mobile communication system

D1.4 Test report conclusion from real-world environment

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Executive Summary

Test report conclusion from real-world environment (D1.4) is the last deliverable of Work Package 1 (WP1) within 5GRAIL Project. This document is the complementary one of D1.2 Test report conclusion from lab environment. Where D1.2 was focused on the conclusions, observations and outcomes of lab environments, D1.4 comments the outcome of a subset of tests, the most representative ones, that have been repeated in real railway environment, in the field testbeds, in the framework of WP5, in Germany led by DB Netz AG and/or in France led by SNCF Reseau.

As often repeated in our deliverables, one of the main achievements of 5GRAIL was the development of the first FRMCS prototypes: On-board FRMCS (Telecom On-Board Architecture, TOBA box)**,** Trackside FRMCS Gateway and Railway Applications, all tested in a 5G SA environment, supporting MC layer features to validate the FRMCS V1 specifications.

These devices were not available before this project, neither the OBapp compatible versions of the applications.

With the build and integration of this ecosystem, and testing it in lab first, we were able to further on test them in two real railways line – field tests – lines that were very different, which allowed us for better experience and lessons learnt.

We were able to test all the applications and scenario we have envisaged for field tests. Most of them were successful and offered us a first view on behaviour and performance. We also had few tests that were unsuccessful. Which occurs on this prototyping level, this however offered us very valuable lessons learnt.

Abbreviations and Acronyms

Abbreviation	Description
3GPP	3rd Generation Partnership Project
5GC	5G Core
5G NSA	5G Non-Stand Alone
5G SA	5G StandAlone
aka	Also Known As
AMF	Access and Mobility Management Function
API	Application Programmable Interface
APN	Access Point Name
ATO	Automatic Train Operation
ATSSS	Access Traffic Steering, Switching & Splitting
BX	Border-Cross
CCTV	Closed Circuit TeleVision
COTS	Commercial Off The Shelf
CP	Control Plane
CSCF	Call/Session Control Functions
CU	Centralized Unit
DMI	Driver Machine Interface
DN	Domain Name
DSCP	Differentiated Services Code Point
DU	Distributed Unit
ES3	Engineering Sample 3 (reference to the Thales n39 band chipset)
ETCS	European Train Control System
EU	European Union
FDD	Frequency Division Duplexing
FFIS	Form Fit Functional Interface Specification
FIS	Functional Interface Specification

fps	frames per second
FRMCS	Future Railway Mobile Communication System
FRS	Functional Requirements Specification
GA	Grant Agreement
GBR	Garanteed Bit Rate
GoA	Grade of Automation
GRE	Generic Routing Encapsulation (RFC8086) -> Tunnel GRE
GTW or GW	GaTeWay or GateWay
H2020	Horizon 2020 framework program
HD	High Definition
HMI	Human Machine Interface
HSS	Home Subscriber System
IMS	IP Multimedia Subsystem
IMPI	IP Multimedia Private Identity
IMPU	IP Multimedia Public Identity
IP	Internet Protocol
IWF	Inter Working Function
JSON	JavaScript Object Notation
KPI	Key Performance Indicators
MCX	Mission Critical, with X=PTT (Push-To-Talk forVoice) or X=Video or X=Data
N3IWF	Non-3GPP Inter Working Function
NR	New Radio
OB	On Board
OB_GTW	On-Board Gateway
OBA	On-Board Application (e.g. ETCS on-board, ATO on-board)
OBU	On-Board Unit
O&M	Operation & Maintenance
OTA	Over The Air

OTT	Over The Top
PCC	Policy and Charging Control
PCRF	Policy and Charging Rules Function
P-CSCF	Proxy - Call Session Control Function
PPDR	Public Protection and Disaster Relief
PER	Packet Error Rate
PIS	Passenger Information System
PKI	Public Key Infrastructure
QCI	QoS Class Identifier
5QI	5G QoS Identifier
QoS	Quality Of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RBC	Remote Block Centre
REC	Railway Emergency Communication
RF	Radio Frequency
RTP	Real Time Transport Protocol
RTCP	Real-Time Transport Control Protocol
RSRP	Reference Signal Received Power
S-CSCF	Servicing-Call Session Control Function (Correspondence IMPU - @ IP)
SDP	Session Description Protocol
SINR	Signal to Interference and Noise Ratio)
SIP	Session Initiation Protocol
SMF	Session Management Function
SSH	Secure Shell
SRS	System Requirements Specification
SVGA	Super Video Graphics Array
TDD	Time Division Duplex

TE	Test Environment
TFT	Traffic Flow Template
TLS	Transport Layer Security
TC	Test case
TCMS	Train Control Management System
TCP	Transmission Control Protocol
TOBA	Telecom On-Board Architecture
TS	Track Side
TS_GTW	TrackSide Gateway
TSE	Track Side Entity (e.g. RBC, KMC, ATO trackside)
TSI	Technical Specification for Interoperability
UE	User Equipment
UIC	Union Internationale des Chemins de fer
UP	User Plane
URS	User Requirements Specification
VGA	Video Graphics Array
VMS	Video Management System
VoNR	Voice over New Radio
VoLTE	Voice over LTE
VPN	Virtual Private Network
WP	Work Package (e.g. WP1, WP2, WP3, WP4, WP5)

Definitions

Term	Definition
Application	Provides a solution for a specific communication need that is necessary for railway operations. In the context of this document, an application is interfacing with the FRMCS on-board system, through the OB_{APP} reference point, to receive and transmit information to ground systems, (for example, ETCS, DSD, CCTV, passenger announcements, etc.).
Application Coupled mode	It defines if an application is aware of the services used in the FRMCS service layer.
Application Service	Application part responsible of the UP management
Communication Services	Services enabling the exchange of information between two or more applications
Communication service availability	Percentage value of the amount of time the end-to-end communication service is delivered according to an agreed QoS, divided by the amount of time the system is expected to deliver the end-to-end service according to the specification in a specific area.
Communication service reliability	Ability of the communication service to perform as required for a given time interval, under given conditions.
Control Plane	The control plane carries signalling traffic between the network entities.
Data communication	Exchange of information in the form of data, including video (excluding voice communication).
End-to-End	Including all FRMCS ecosystem elements
End-to-end latency	The time that takes to transfer a given piece of information unidirectional from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination.
"Flat-IP" Coupling Mode	This is a sub-mode of Loose-coupling type with static configuration of the requested session. Hence, flat-IP applications can only use the static session configured in FRMCS OB_GTW and TS_GTW.
GoA2	**Grade of Automation 2**: Starting and stopping are automated, but a driver operates the doors, drives the train if needed and handles emergencies.
Interworking	Interworking is the function that enables two different networks to communicate with each other, enabling services to be delivered across them
iPerf	Open source tool used to evaluate network performances in a client-server architecture, available in different operating systems.

NG interface	The NG interface is a logical interface between an NG-RAN and 5GC. There are two interfaces under NG interface: NG-C for control plane and NG-U for user plane.
Priority service	A service that requires priority treatment based on operator policies.
PIS controller	She/he is the individual responsible for managing passenger information.
QCI (or 5QI)	A scalar that is used as a reference to a specific packet forwarding behaviour (e.g. packet loss rate, packet delay budget) to be provided to a SDF. This may be implemented in the access network by the QCI referencing node specific parameters that control packet forwarding treatment (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.), that have been pre-configured by the operator at a specific node(s) (e.g. eNodeB)
Reliability	In the context of network layer packet transmissions, percentage value of the amount of sent network layer packets successfully delivered to a given system entity within the time constraint required by the targeted service, divided by the total number of sent network layer packets.
Service continuity	The uninterrupted user experience of a service that is using an active communication when a UE undergoes an access change without, as far as possible, the user noticing the change.
Super-loose mode	As considered by the application, can be characterized as a “flat IP”. An ‘agent’ is located between the application and the On-board Gateway, to make this mode OBapp compatible.
Transport Domain	A Transport Domain is the administrative realm of the Transport Stratum. The Transport Stratum comprises one or more access technologies controlled by a core network. A Transport Domain is uniquely identified by the PLMN-ID.
User Equipment	An equipment that allows a user access to network services via 3GPP and/or non-3GPP accesses.
User plane	The user plane (sometimes called data plane or bearer plane), carries the user/application traffic.
Voice Communication	Exchange of information in the form of voice requiring corresponding QoS treatment, regardless of the transmission method.

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1 INTRODUCTION

5GRAIL, as part of the FRMCS readiness activities is focused on:

- the development of the Telecom On-board Prototype (TOBA box),
- validate the first set of specifications
- test the FRMCS On-Board and application prototypes, in lab and **field** environments, and
- providing feedback and lessons-learnt to standardization organizations for consideration in updates of the specifications.

The content of D1.4 is mainly the analysis of results and observations of both **field** testbeds in Germany and France, which is an important step for reaching the main objectives of this project. These observations validate the behaviour of prototypes in real environment and assess the performance measurements methodology, as derived from lab testing and described in D1.3 deliverable.

It is important to note that the UIC FRMCS v1 specifications, currently part of the European CCS TSI 2023 (Control Command System Technical Specifications for Interoperability) and compatible with 3GPP R18 and early R19 specifications amendments, were developed in parallel with this project, so the complete consolidation of them by lab and field verifications was important for the railway community.

To understand the orchestration position of WP1, as interacting with all the other 5GRAIL work packages, the following figure depicts how the inputs of the other work packages are processed by WP1 to create the D1.4 and where the outcome of D1.4 is used to:

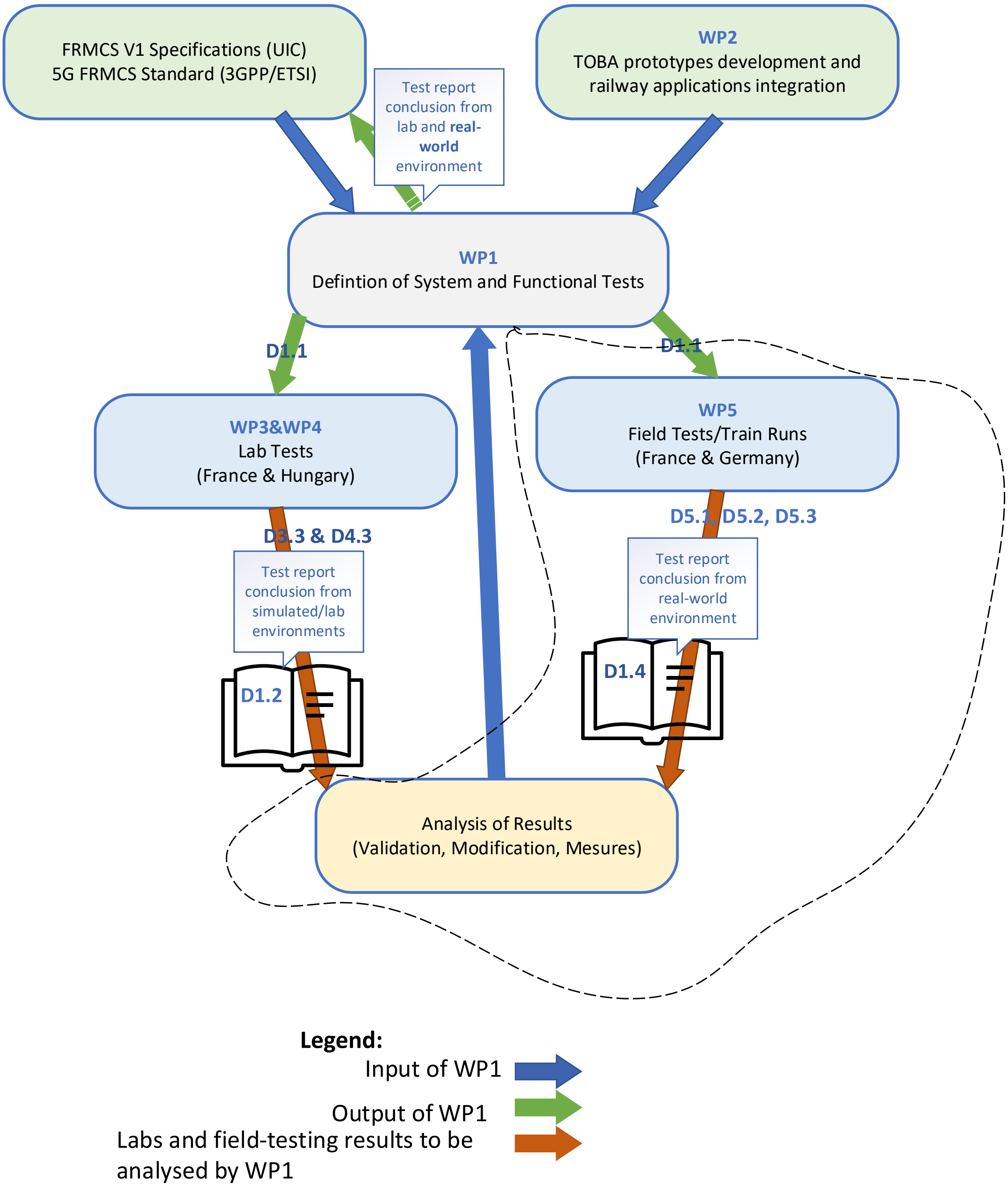


Figure 1: WP5 outcome in German and French testbed defines the content of D1.4 (loop-back to the FRMCS specifications)

Part of information can also be found in D5.1 and D5.3, however it is also repeated in this deliverable, in some cases, to provide a full context.

2 Two complementary field testbeds

The following figure summarizes the location, the 5G bands used and the applications that were tested respectively in each testbed. The tests in German testbed were focused on voice applications with some data applications testing. The tests in French testbed were only focused on data applications. In both testbeds combined scenarios were performed with two applications in parallel which is one important difference with the current GSM-R set-up where the On-board FRMCS device supports all on-board applications.

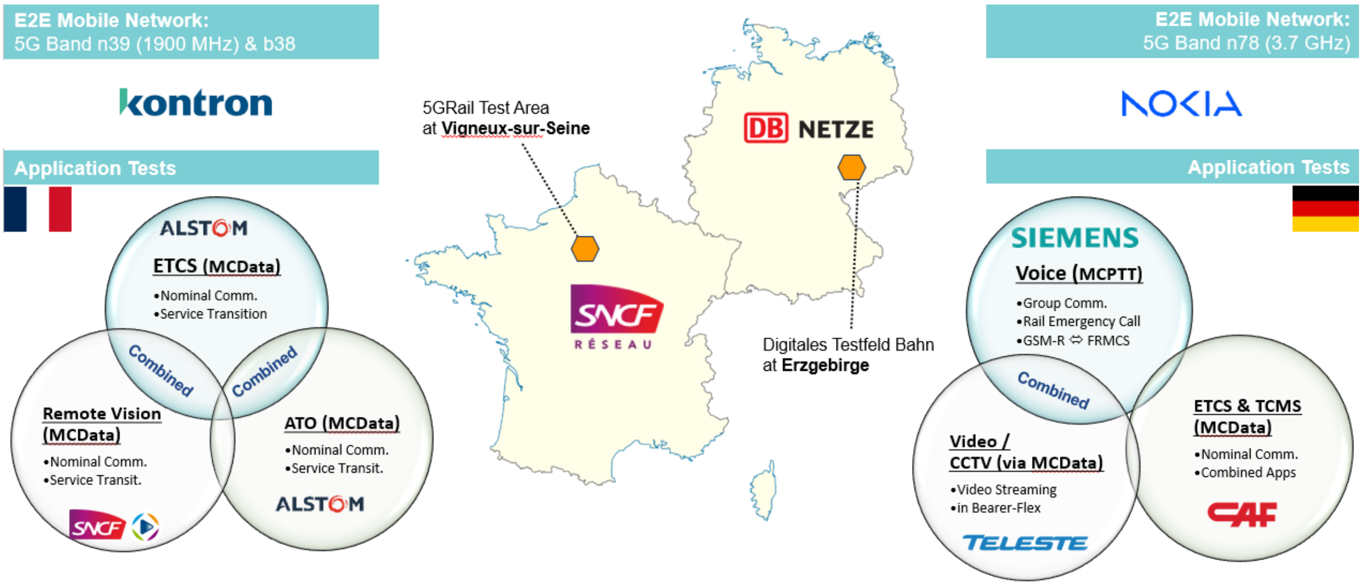


Figure 2: 5GRAIL field testbeds in a nutshell (Ref. D5.1)

2.1 Overview of German testbed (DB Netz AG)

DB Netz, the infrastructure manager of DB, used a test track in the Erzgebirge region, Germany, which is known as *Digital Rail Testbed / Digitales Testfeld Bahn* and which is located between the towns of Schwarzenberg and Annaberg-Buchholz in a rural and moderately hilly area. The testbed includes a 10 km segment of railway tracks equipped with the necessary infrastructure to operate a mobile test network, e.g., antenna masts, fiber-optical connectivity and a central facility with server rooms at the station of the village Scheibenberg. The radio site of the central location uses a 15 m high antenna mast while remote radio sites use antenna masts of 10 m height. 7 radio sites have been realized with 14 cell sectors within the 10 km segment (see Figure 3 below). The track is intended for experimental trials with a train speed of 50-80 km/h. The 5G radio access network in the German testbed was running at 3.7 GHz (band n78).

Figure 3:Test site in Germany in the scope of WP5 (Ref. D5.1&D1.1)

Below figure is an overview of the German field set-up. It is worth mentioning the presence of the leased line that connects the onboard devices through N2 and N3 interface of the Radio sites in WP5 field trial with the Core and trackside equipment in Budapest. The connectivity is secured by firewalls maintained by Deutsche Bahn and Nokia.

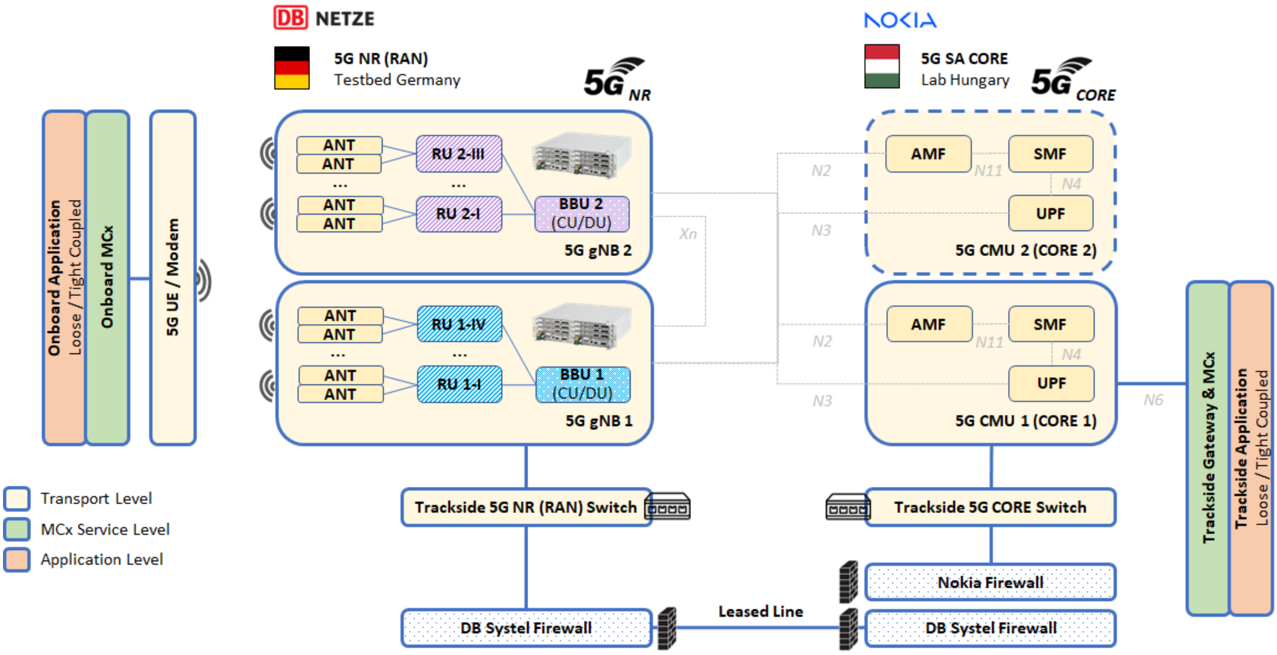


Figure 4:End-to-end architecture of the German testbed (Ref. D5.1)

2.1.1 Reminder of the supported use cases in field in Germany.

The supported use cases in German testbed are listed below, as per D1.1 test plan definition:

- MCPTT / Voice communication
  - 5G/FRMCS point-to-point voice call
  - 5G/FRMCS group voice call
  - 5G/FRMCS rail emergency call
  - 5G/FRMCS to 2G/GSM-R interworking via lab
- MCData
  - Automatic Train Protection communication (ETCS simulation)
  - TCMS telemetry
  - Non-critical video
  - Transfer of CCTV archives

Cross-border and bearer-flex simulation test cases in the German field:

- Cross-border test with voice application, considering a network transition GSM-R-FRMCS with REC test case, also using interworking function (IWF)

- Transfer of CCTV archives in a bearer-flex scenario, realized as transition from one 5G/FRMCS bearer to a second 5G/FRMCS bearer (2 subbands of n78) using the same 5G (Core) network.

2.2 Overview of French testbed (SNCF Reseau)

In France, the SNCF Test Site is a portion of a busy commercial line in the suburb of Paris southeast as depicted in Figure 5. 5G RAN is to be deployed in 3 sites with possible reuse of existing GSM-R/GPRS installation. The train speed is up to 70 km/h. The RU, CU/DU equipment of 5G RAN, 4G BBU and RRHs as well as 5GCore and 4GCore, all supplied by Kontron, are installed on SNCF's sites (antenna masts). The Central site ("Command Centre"), encompassing 5G CU/DU, 5GC and 4GBBU, EPC was connected to WP4 lab at Kontron premises in Montigny, located in the western part of Île-de-France, where also some Trackside equipment is installed, as presented in Figure 6.

The antenna and masts were provided by SNCF. The frequencies used was n39, where n101 (TDD) is a sub band, based on a temporary test license from the ARCEP. Second frequency band to be used was 4G b38 (2600 MHz)

It is to be mentioned that this line was a difficult line from train traffic point of view, with minimum speed of 30km/h, and also from radio point of view, being installed in a dense urban area, neighbour with Paris Orly airport, and crossing the river Seine.

The following figure is presenting the French testbed at Vigneux-sur-Seine with the 3 radio sites to be used for the field activities:

Figure 5:Test site in France in the scope of WP5 (Ref. D5.1)

The following figure is presenting the set-up of the field testbed and the interconnection with WP4 lab:

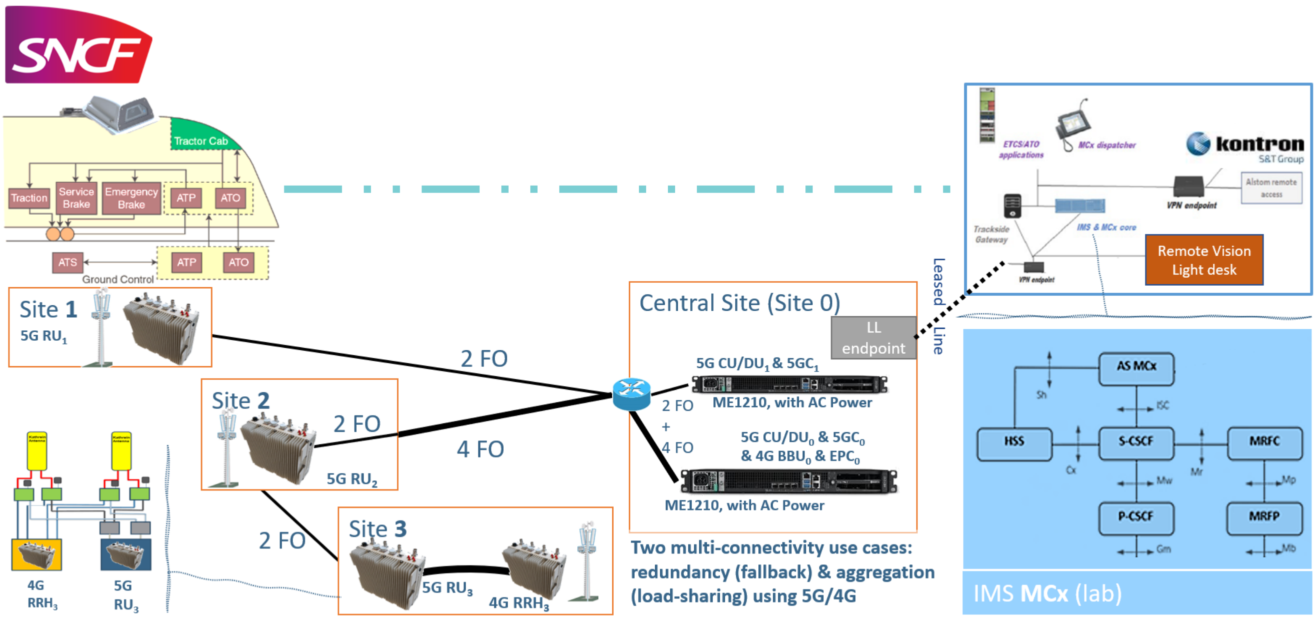


Figure 6: End-to-end architecture of French testbed (Ref. D5.1)

2.2.1 Reminder of the supported use case in field France.

The supported use cases in French field are as follows.

- ETCS in static and dynamic (moving) conditions including mobility (intra/inter – gNodeB HO).
- ATO in static and dynamic (moving) conditions including mobility (intra/inter – gNodeB HO).
- Train front camera real-time video (Remote Vision, subsystem of remote driving operations) in static and dynamic (moving) conditions (intra/inter – gNodeB HO).
- Combined scenarios with ETCS and ATO in dynamic (moving) conditions (intra/inter – gNodeB HO).

The bearer flexibility use cases with ETCS/ATO applications in link redundancy (5G/4G) or link aggregation conditions (5G and 4G) and the cross-border ones with ETCS application, also based in the multi-connectivity principle as described in D1.1 Test plan, were not finally conclusive due to field set-up constraints however they were offered valuable lessons learnt, as extensively described in many deliverables, e.g., D5.2 chapter §5.2 Retrospective on BX Test Experience and Conclusion, D1.3 chapter §3.5 Handling MNO interference in n39 RMR band, D2.4 chapter §4 Learnings.

3 Radio 5G observations in field testbeds

3.1 Radio conditions in testbed in Germany

In the scope of D1.3 FRMCS Performance Measurements methodology §9[41] chapter §3.6, some 5G radio KPIs have been proposed to be further investigated in future projects to determine the KPI values to be chosen for FRMCS.

During the field tests campaign in Germany, some KPIs have been measured in the air interface for the control plane. These are:

- RSRP (Reference Signal Received Power)
- SINR (Signal to Interference and Noise Ratio)

However, the measurements and the analysis provided in D5.1 §9 [43] are only indicative of the radio environment in the testbed in Germany, to explain some applications behaviour. They can be used as only as indicative feedback to FRMCS, since they are performed in n78 TDD band (3.7 GHz), although the RMR TDD band is n101 (1.9GHz).

The figure below shows an example of a drive test along the railway track between site (A) in *Markersbach* and site (G) in *Scheibenberg.* It can be noticed that some areas with low coverage existed, i.e., in the order of -110 dBm or below, which were often related to (intra- or inter-gNB) handover zones.

In most of the cases when performance measurements for the applications occurred in low coverage areas, the 5G n78 modem of the TOBA gateway was able to automatically re-connect to the cell, only in few cases manual procedure of attachment/detachment of the modem had to be performed. More though RSRP and SINR analysis have been provided in D5.2.

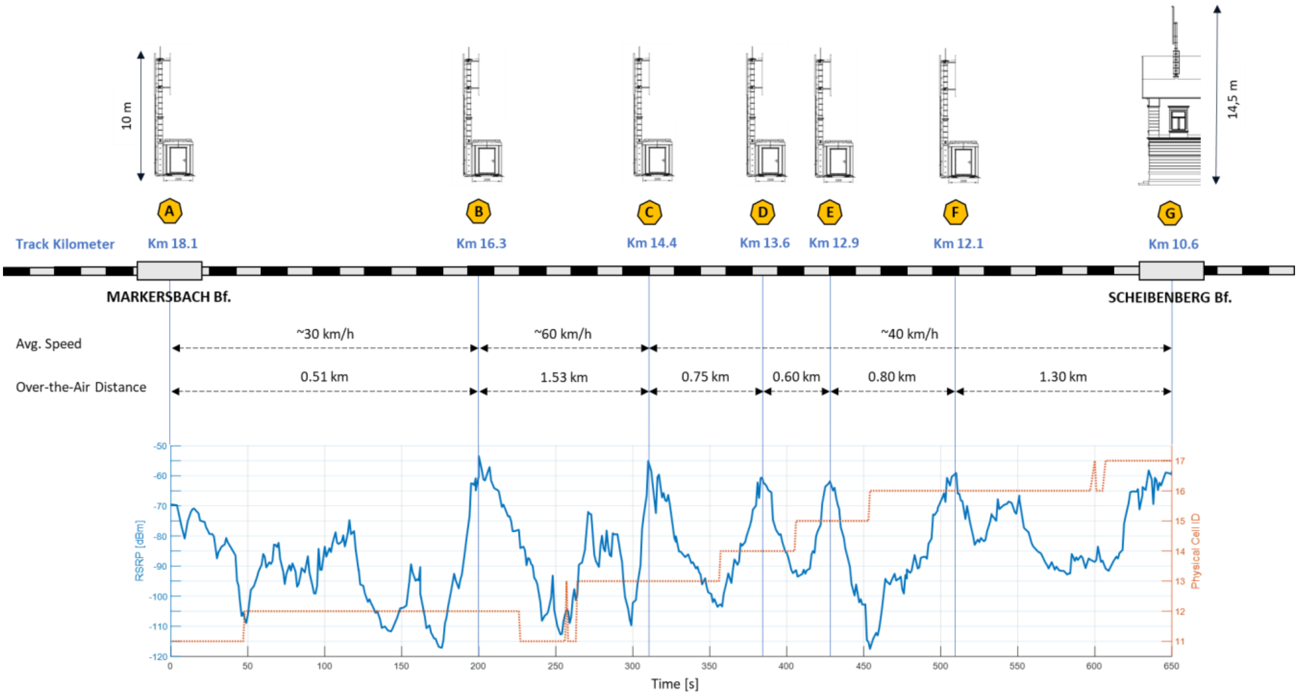


Figure 7: Observed RSRP evolution depending on Cell IDs during a drive test (Testbed Germany)

3.2 Radio conditions in testbed in France

The following figure is summarizing the predictions performed by RF planning tool for the three sites ("Rives", "Marin", "Bourbonnais") in the testbed in France. At the installation of gNodeBs in the testbed in France, radio measurements have been performed with ES3 modem in n39 TDD band that have confirmed the predicted path losses. This was an important step to consider in future projects preparations of field testing.

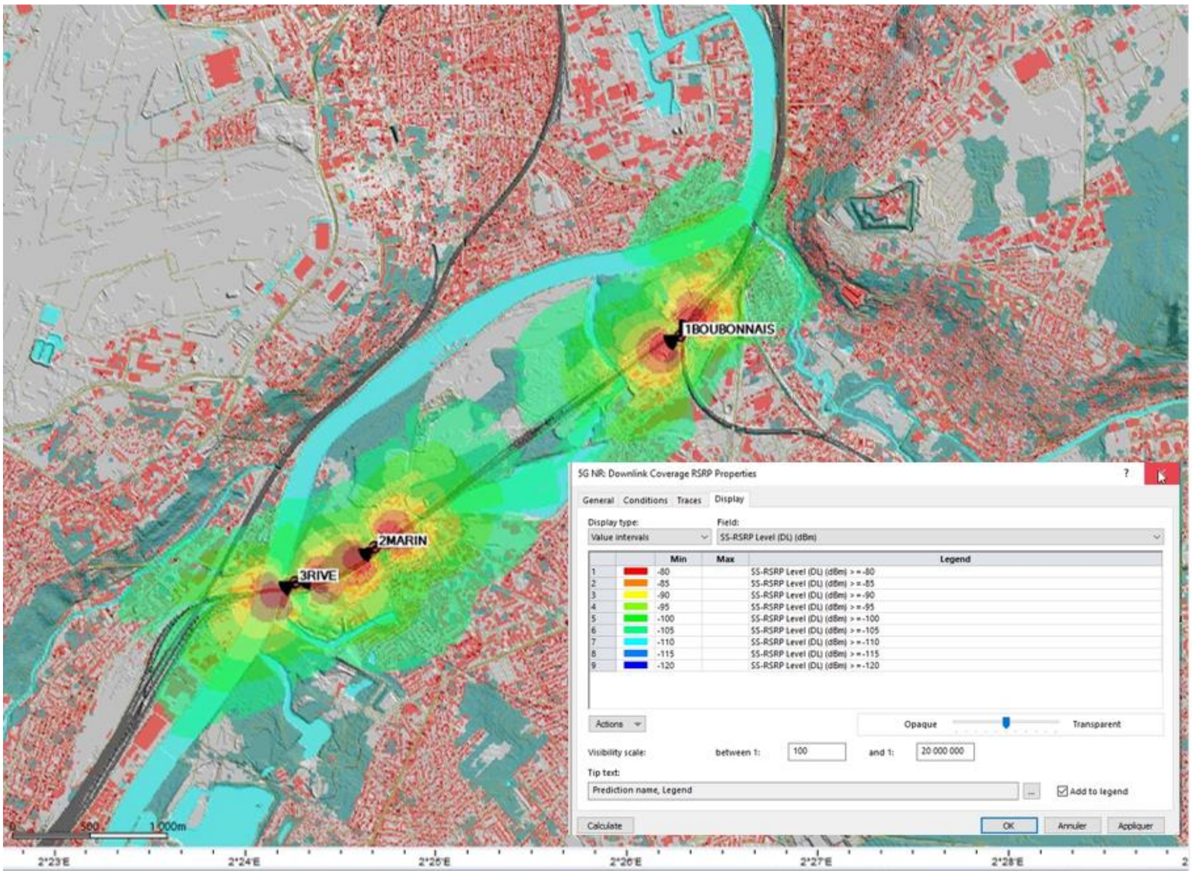


Figure 8: RF conditions analysis of testbed area in France (Ref. D4.3)

The conclusion was that expected path loss between TOBA and gNodeB should be around 70dB-80dB in areas with good radio propagation and around 100dB at cell edge. These observations were very useful because later in WP4, using attenuators, the same conditions were created to prepare a realistic lab testing with about 100dB attenuation for handover related tests and around 70dB for all other tests, meaning better prepare field testing.

Another issue faced in the testbed in France was the short coverage region, mainly when using equipment in protype status. French testbed was using a commercial dense train line, with important mobile public operators' activity in the surroundings and close to an airport area with important radio activity, as well. The following figure summarizes the final coverage at SNCF's testbed, for 5GRAIL testing:

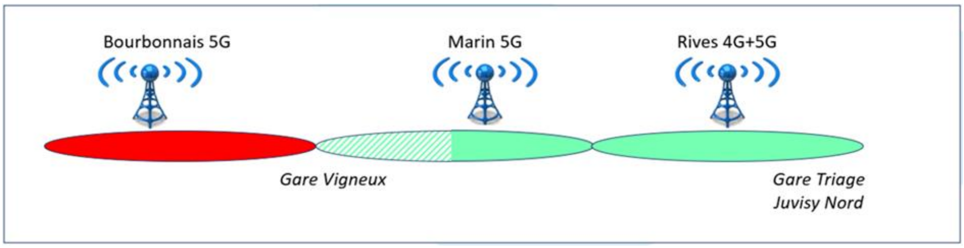


Figure 9: Network coverage in WP5's testbed in France (Ref. D5.2)

The effect of these rough radio conditions was that the effective coverage area was far less than what was expected, as Bourbonnais RU was turned off and half of Marin's network coverage was also inoperable. This set-up was obtained via a workaround to be able to still perform field tests, since the available RU was supporting the whole n39 (1880 – 1920 MHz) band, instead of being strictly limited to the 10 MHz (1900 – 1910 MHz) of n101 band, which is the official RMR band. Consequently, the RU was suffering from a strong interference coming from public operators, which were in very close vicinity.

Since the coverage area was shorten, the ES3 modem, being a prototype, used took longer time to attach to the network and sometimes manual commands were needed to accelerate the attachment to the network. This was corroborated with a minimum speed of the train in the area (30 km/h). Consequently, some procedures went out of time.

However, the situation faced in the French testbed was a good lesson learnt for the deployment using the 1900 MHz TDD band of FRMCS which will be a pre-requisite for some countries mainly during the migration period. In this case, FRMCS band will be adjacent to Mobile/Fixed Communication Network (MFCN) which operates in 1920-1980 MHz / 2110-2170 MHz. This may result in interference between MFCN Base Station (BS) and nearby FRMCS BS.

4 Remote connexion in field testbeds

The impact of the remote connexion due to the leased line characteristics must be considered in field testbeds, where part of the end-to-end architecture is in field and other in lab. This was the case in both field testbeds.

5G RAN, located in the Testbed in Germany, was connected to the 5G CORE, located in Nokia's lab premises in Budapest/Hungary, corresponding to a distance of approx. 570 km over-the-air. The leased line has been ordered with 20 Mbps bandwidth which was considered sufficient for the planned tests but impact has been observed with the uplink video streaming application in the order of Mbps.

The following figure reminds the set-up of testbed in Germany where same devices and trackside infrastructure as in WP3 lab were used and where a dedicated leased line between field network radio sites and Budapest laboratory was integrated.

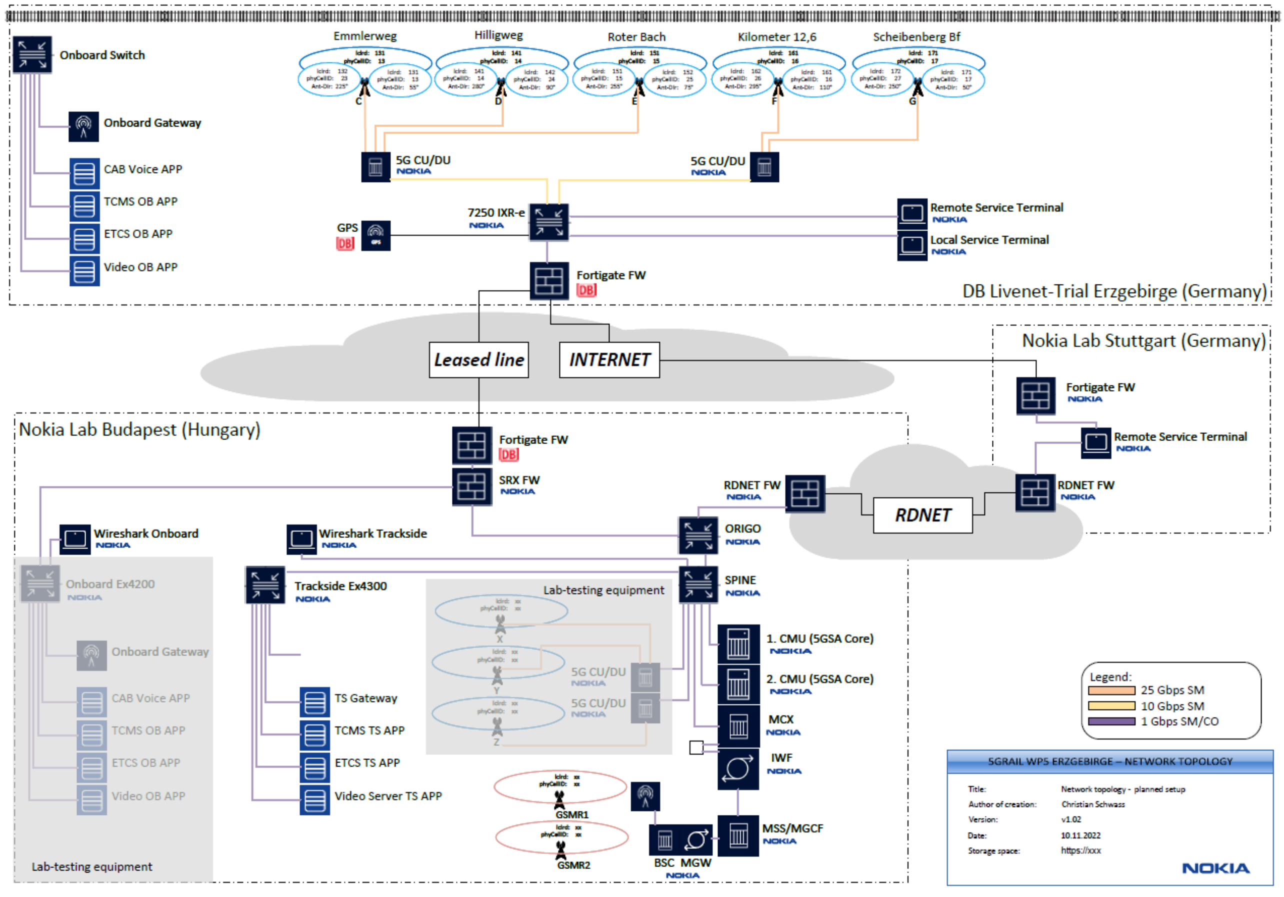


Figure 10: WP3-WP5 field test configuration (Ref. D3.3v2)

This leased line connects the On-board devices through N2 and N3 interface of the Radio sites in WP5 field trial with the Core and trackside equipment in Budapest. The connectivity is secured by firewalls maintained by Deutsche Bahn and Nokia.

There were three mirroring points integrated to monitor all interfaces: on the onboard switch, on the Radio switch and on the trackside switch. To ensure best combining and analysis of end-to-end data flow, all mirroring devices were connected to same NTP-Server (Nokia 7250 IXR in Erzgebirge). For the evaluation of log files additional measures to synchronize the Wireshark systems on field and lab using a NTP server were deployed in Budapest lab.

The round-trip time of the leased line was evaluated as 19 ms (or 9.5 ms one-way latency) and needs to be considered in the end-to-end user plane and application latencies of the FRMCS tests, as presented in the following figure:

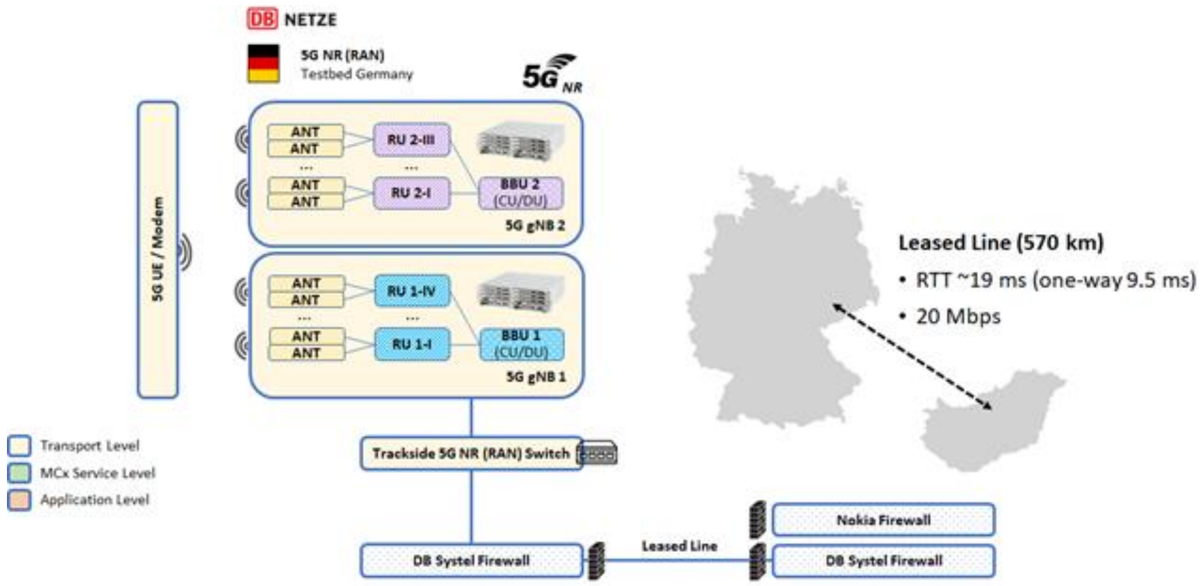


Figure 11:Leased line characteristics between testbed in Germany and WP3 lab in Hungary (Ref. D5.1)

- Leased Line Impact on Video Quality (Throughput)

The configuration of the leased line needs to be seriously considered, for instance a "managed leased line" is probably recommended in identical situations for future projects with remote connexion between field testbed and lab premises because some QoS degradations were observed in the HD video transmission with the current "unmanaged leased line" configuration at one end of the line. The impact of the leased line for different resolutions can be visualised in the following figure:

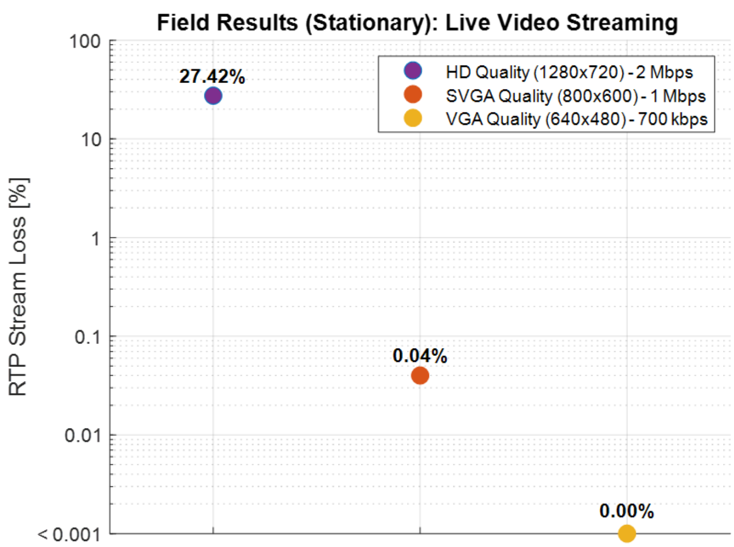


Figure 12: Comparison of different resolutions in Video Streaming Stationary Test (Testbed Germany)

- Video Latency observations

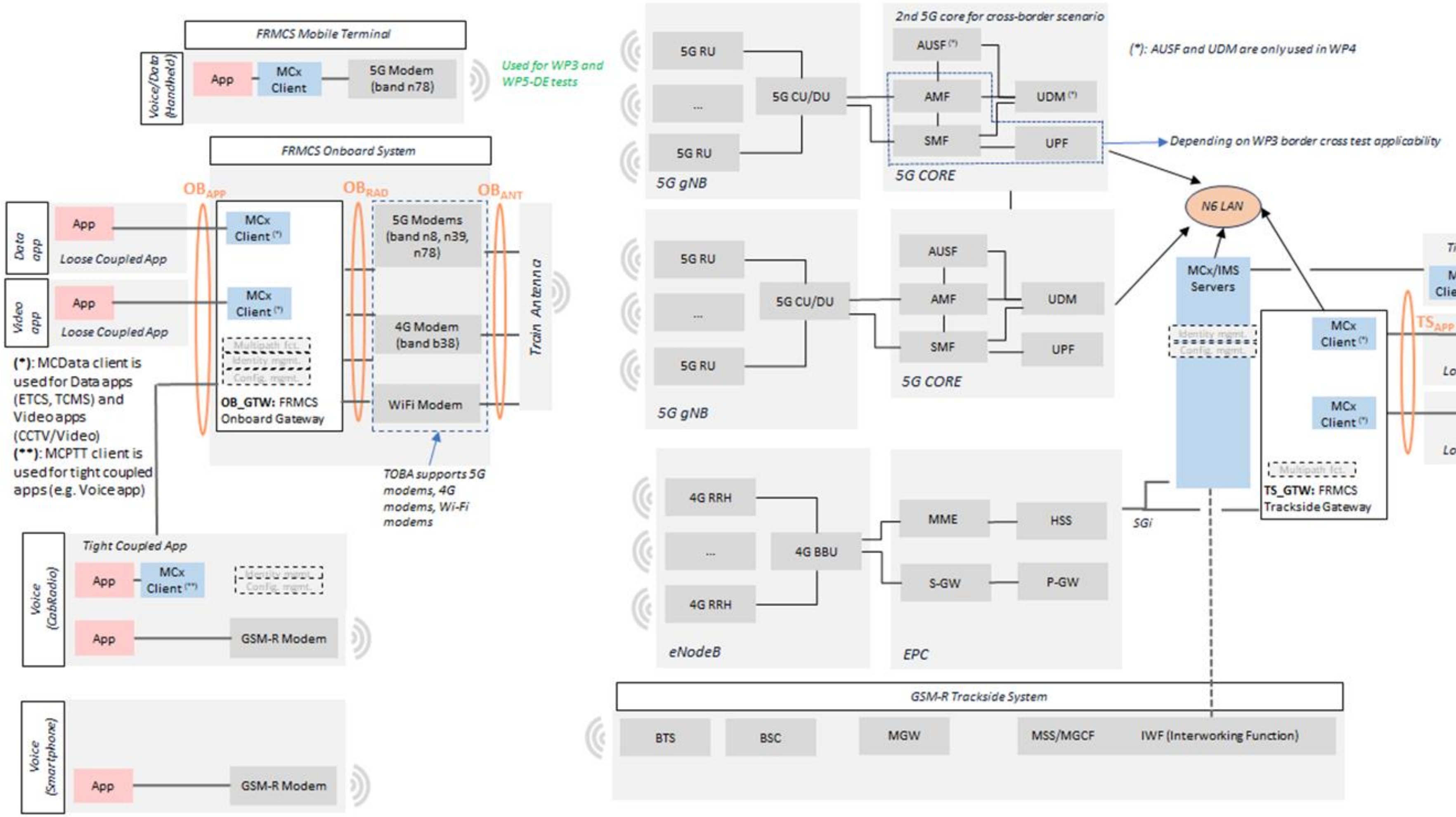
Camera, Train computer and Trackside VMS computer were NTP synchronized with two different NTP used, one in the trackside and one in the onboard. The time synchronization was checked with 1 second precision and the conclusion can be only indicative in such case. The video latency was considered real-time as both the application seen on onboard computer and trackside VMS computer had the same time stamp on second level, i.e., the delay was smaller than 1 second. With the current setup it was not possible to evaluate lower latency differences.

5 Reminder of the global end-to-end architecture

The figure below reminds the end-to-end architecture of 5GRAIL project, which is considering the main constituents of the FRMCS ecosystem (also including the elements of the GSM-R system). In field, as for lab case, subparts of this architecture will be involved to every test performed.

The mission-critical service and application strata are shown with blue and red colours, respectively. The On-Board FRMCS gateway, also known as TOBA (Telecom On-board Architecture) is connected to the applications through OBapp interface and on the other side to the 5G Radio Access Network, through a set of 5G modems. The Trackside FRMCS gateway is connected to the applications through TSapp interface and on the other side to the 5G Core Network. The usage of these standardized interfaces allows any newly and compatible created application to be easily connected to the FRMCS system.

In case of voice applications, the mission-critical application (MCx) client is the MCPTT service client realized in the cab radio device or in the handhelds and, hence, tight coupled. For data/video applications the MCx client is the MCData service client being implemented in the TOBA GW and, hence loose-coupled.



5GRail Generic e2e Test Architecture

6 In field observations per application and future perspectives

A subset of lab tests, the most representative ones and for which the field configuration was suitable have been repeated in field either in Germany or France. ETCS application was tested in both field testbeds, since there are two ETCS applications providers, CAF in Germany and Alstom in France. The other applications tested in the field tests are Voice (including REC), TCMS, CCTV/Video in Germany and ATO, Remote Vision in France.

In this chapter, the specificities and performances of the field implementation, the validation of FRMCS and MCX features will be commented per application, to provide some ideas of improvement in the FRMCS V2 specifications but also highlight test scenarios that must be repeated or added in future projects like MORANE2.

6.1 Voice/REC (using MCPTT) – Testbed in Germany

For the Voice application testing, DB Netz AG has provided the track and rolling stock infrastructure and coordinated the tests progress. Nokia has provided the 5G SA trackside network and Voice dispatcher and Kontron has provided the MCX system as well as the On-board connectivity using TOBA Gateway and 5G modem.

The voice test cases repeated in field, as per §9[30] D1.1 Test plan, have been listed in the following, per category. The **FRMCS Principle/MCX feature** column highlights the FRMCS principle or MCX building block that has been validated by each test case:

- **General functionalities**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
Voice_006	Arbitration	- Arbitration - Application plane of MCPTT service - Floor Override

- **Point-to-Point voice calls**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
Voice_008	Initiation of a voice communication from a train driver (CabRadio) towards a train controller (Dispatcher) responsible for the train movement area	- Functional alias - Private call

		- MCPTT private call request (MCPTT client to MCPTT server) - MCPTT private call response
Voice_009	Initiation of a voice communication from a train controller (Dispatcher) towards a train driver (CabRadio)	- Functional alias - Private call - MCPTT private call request (MCPTT client to MCPTT server) - MCPTT private call response
Voice_019	MCPTT private point-to-point voice call (driver to controller) with HO (inter or intra) gNodeB	- Functional alias - Private call - MCPTT private call request (MCPTT client to MCPTT server) - MCPTT private call response - Intra or Inter gNodeB Xn-HO

- **Group voice calls**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
Voice_005	Multi-user talker control	- Multi-user talker control - Media distribution function - Media mixer - Multi-talker floor release - Multi-talker floor taken.
Voice_010	Initiation of a multi-train voice communication from a train driver (CabRadio) towards train drivers and ground users (FRMCS only)	- Group call ID - Information flows for group call in on-network.

Voice_021	Initiation of a multi-train voice communication from a train driver (CabRadio) towards train drivers and ground users (FRMCS and GSM-R)	- Reference point IWF-1 (between the MCPTT server and the interworking function to legacy systems) - Reference point IWF-1 (between the IWF and the MCPTT server - Reference point IWF-3 (between the IWF and the group management server)

- **REC – Railway emergency calls**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
Voice_011	Railway Emergency Call initiated by a train controller (Dispatcher) without interworking (FRMCS only)	- Location management (on-network) - Location reporting configuration - Location information report And all other MCX features of REC, as per Voice_22
Voice_022	Railway Emergency Call initiated by a train driver (CabRadio) without interworking (FRMCS only)	- Information flows for group call in on-network. - MCPTT emergency group call request - MCPTT emergency group call response and Termination - Client determination can use internal server rules which triggers the notification Subsequent trigger the client-based affiliation. - Pre-arranged group call
Voice_012	Railway Emergency Call initiated by a train driver (CabRadio) including interworking (FRMCS and GSM-R)	REC MCX and IWF features

- **Combined Voice Calls (using MCPTT) and Video Uplink (using MCDATA)**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
Voice_017	Combined MCPTT private point-to-point voice call in parallel with MCData application	- Same features as for Voice_019 and MCData IPConn features - QoS handling

6.1.1 Arbitration (Voice_006)

The purpose of the FRMCS arbitration functionality is to avoid disturbing the human user's attention from critical railway operations by defining the behaviour of the end user device in case of multiple competing communications.

Due to the lack of FRMCS arbitration standards, the 5GRAIL project applied the GSM-R EIRENE arbitration tables.

Additionally, there is no specification defining how the functional identities of all other participants in a group call, such as the REC call, should be displayed on each participant's terminal. Moreover, there are doubts about the necessity to present the identities of all other participants on each participant's terminal. Probably only the controller involved in the REC, needs to know the identities of all other participants.

Another topic to be clarified in the arbitration scope, also mentioned during the lab testing, is what happens after the high priority call is released- if back switching to the lower priority call is possible. This is under investigation by the specifications WGs, trying to implement the 'queuing' of at least a second communication at the application level. In that case, an 'inactivity' indication is needed, currently not available in 3GPP, to be provided to the 'queued' call participants, for instance, for the duration a user is engaged in the REC.

The main improvement of arbitration handling in FRMCS will be the introduction of 'application category' considering not only the call type importance (e.g. REC, group call, private call) but also the functional role (through functional alias) of the human user.

6.1.2 Point-to-point voice calls (Voice_008, Voice_009, Voice_019)

The purpose of these tests was to demonstrate that point-to-point communication between a train driver and a train controller, responsible for the train movement area, can be established in both directions and will be maintained without drops and with good quality, even in mobility conditions, i.e., with inter- and intra-gNodeB handover situations.

The following figure presents the entities in green involved in these test cases, considering voice application as a tight coupled one, where MCPTT client is embedded in the application:

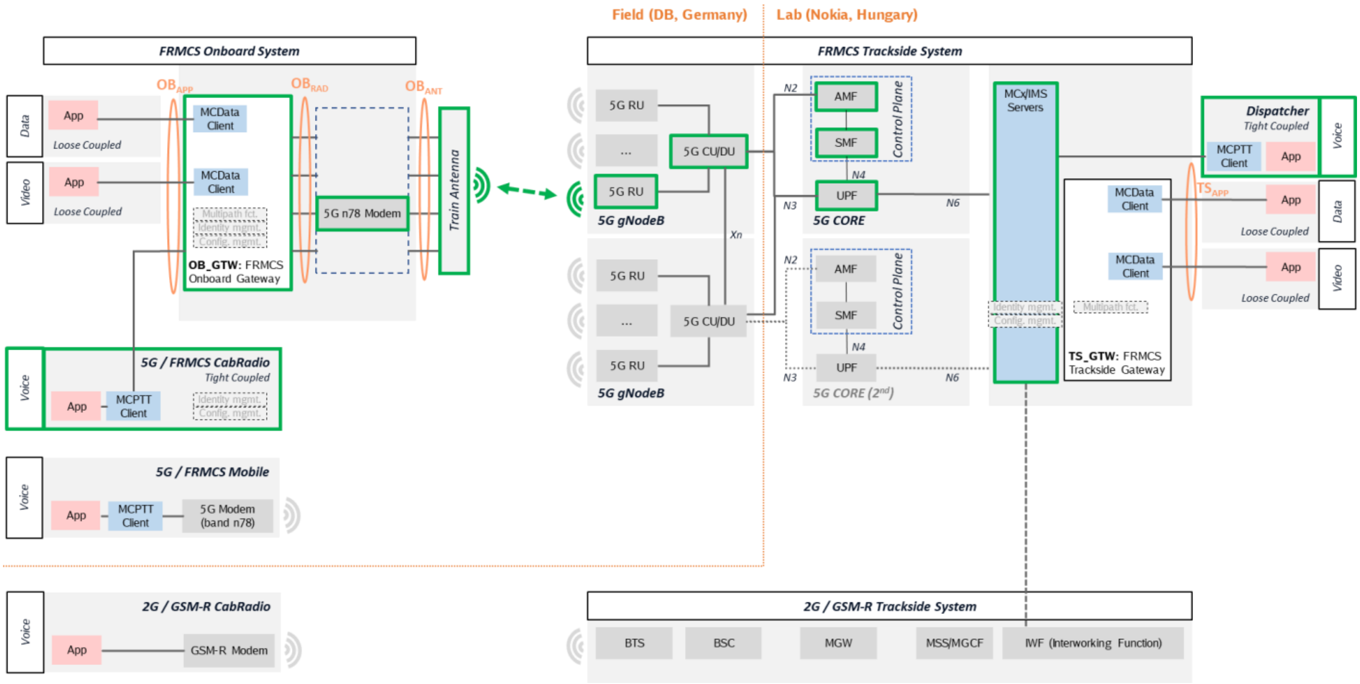


Figure 13: Set-up for test cases Voice_008 and Voice_009 (Testbed Germany) (Ref. 5.1)

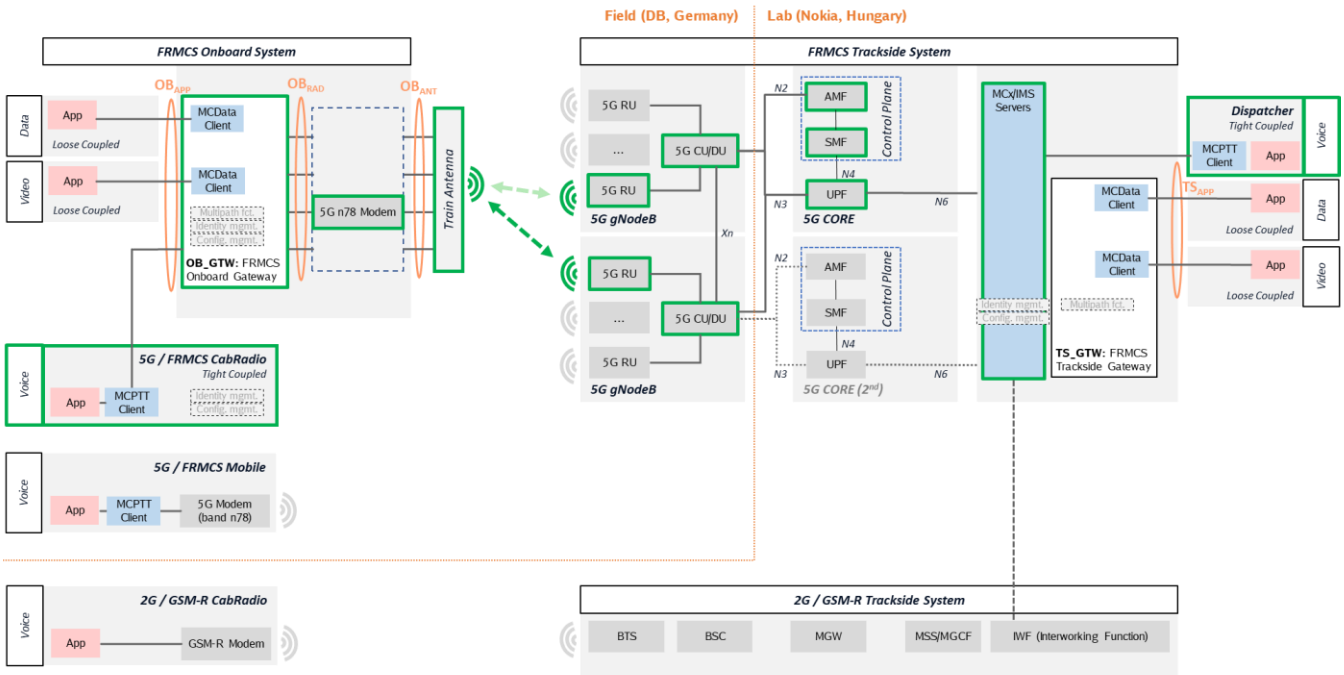


Figure 14: Set-up for test cases Voice_019 with intra and inter-gNodeB handover (Testbed Germany) (Ref. 5.1)

6.1.2.1 Observations/comments on Point-to-point calls

Some limitations were observed in field as in lab testing due to the dispatcher terminal, which was not being able to register to a functional alias, instead the MCID of the controller is displayed. In addition to that, the functional alias of the cab radio could not be displayed on the controller's terminal.

Another limitation of the controller's terminal was the incapacity to initiate a call with a manual answer option; consequently, the call was automatically accepted by the cab radio.

The configuration of lab and field was with only one dispatcher, so the location dependency was not tested for this scenario. This is an open point to address in the scope of MORANE's project.

6.1.2.2 Performance measurements on Point-to-point calls

The MCPTT KPI1, as defined in D1.3 FRMCS Performance measurement methodology, chapter §4.1, §9[41]was used for field performance evaluation where all captured PTT requests for Voice_008 and Voice_019 were below 300ms (which requires 95% of all requests below the limit). The mean value of KP1 being 86ms, with few requests showing higher access times.

Higher access times occur likely due to an inter-gNB handover situation or a short coverage gap which leads to increased re-transmission attempts, reminding that the coverage was well designed for prototyping testing but not for performance testing, which must be considered in a future field-testing project as MORANE2. Detailed results of field testing can be retrieved in §9[43]. D5.1 Test results on FRMCS Functions and Performance chapter §6.4.4 Results and Observations

6.1.3 Group voice calls (Voice_005, Voice_010, Voice_021)

The purpose of these tests was to demonstrate that multi-user voice communication between train drivers and a train controller, responsible for the train movement area, can be established where all participants are subscribed to the same valid MCPTT Group ID. The communications were maintained without drops and with good quality, even in mobility conditions, i.e., with inter- and intra- gNodeB handover situations.

Through these tests two other important features were validated in field as well, multi-user talker control (Voice_005) and interworking function (Voice_021), where the participants of the group calls are mixed FRMCS and GSM-R users.

The following figure is presenting the entities in green involved in the voice group call tests:

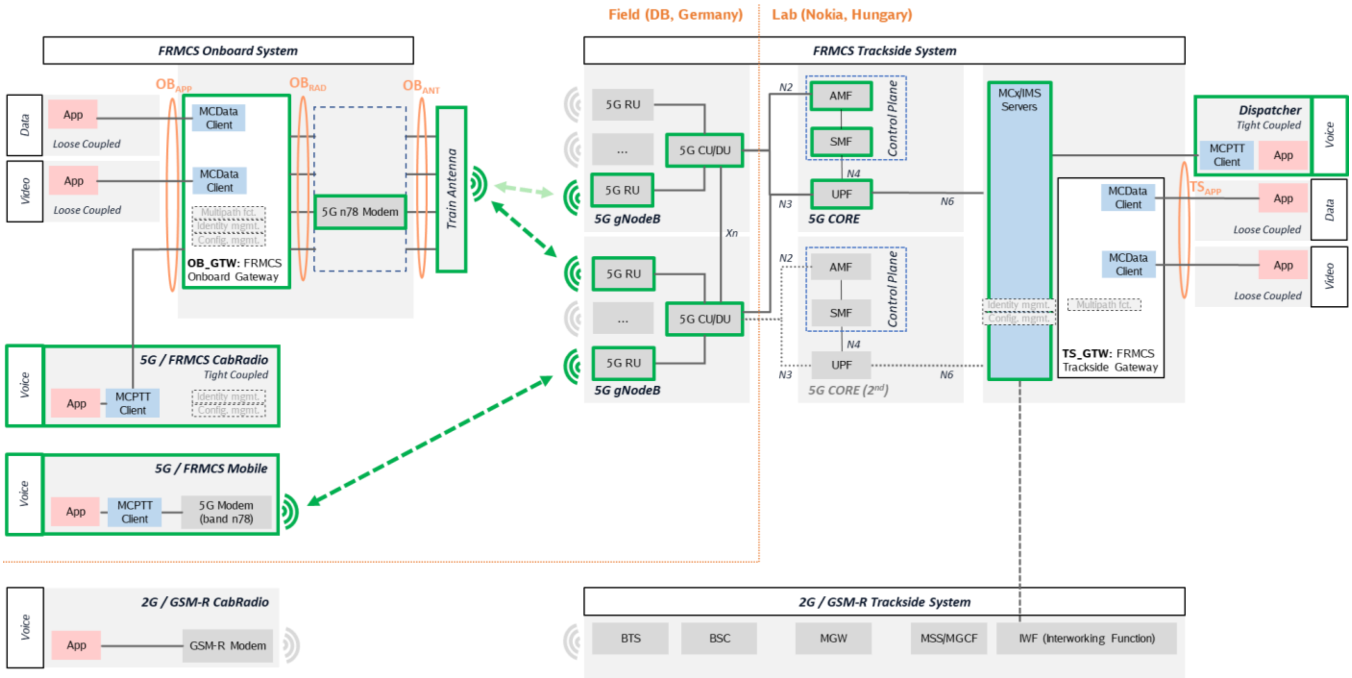


Figure 15: Set-up for test cases Voice_005 and Voice_010 (Testbed Germany) (Ref. 5.1)

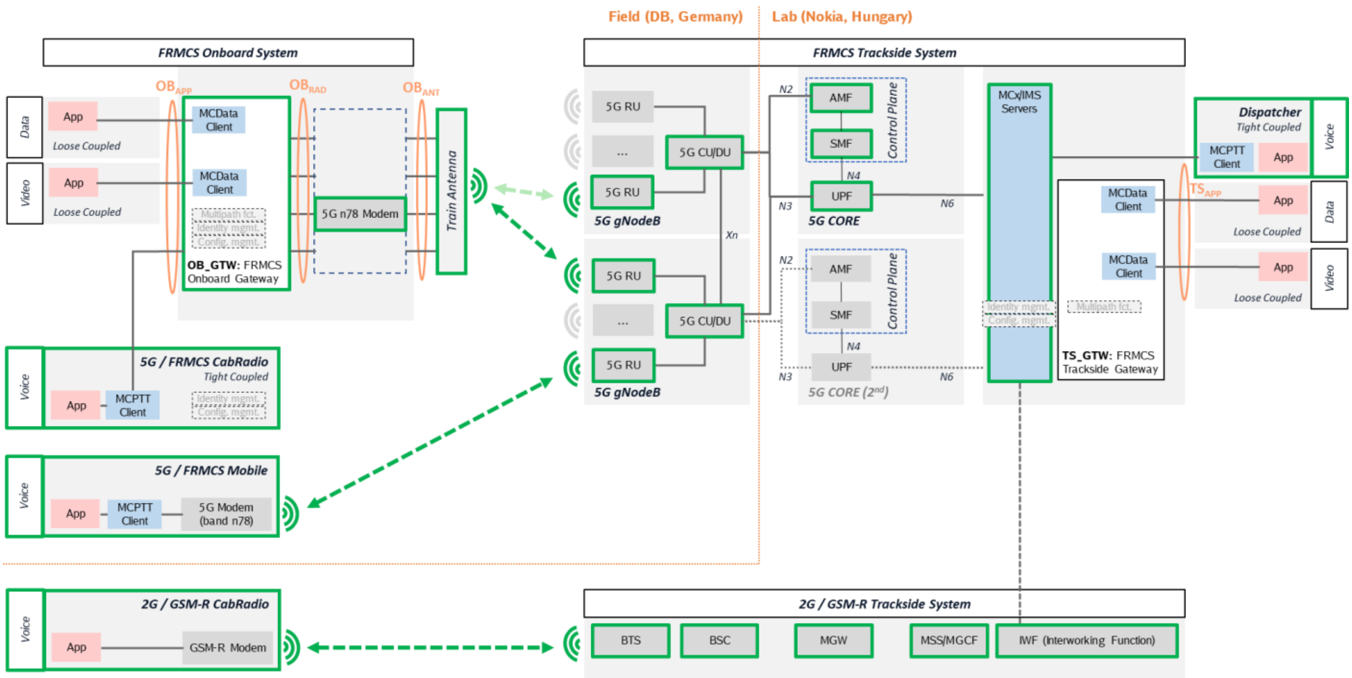


Figure 16: Set-up for test cases Voice_021 (Testbed Germany) (Ref. 5.1)

6.1.3.1 Observations/comments for voice group calls

In the scope of 5GRAIL in field as for lab, the voice group calls were tested using preconfigured groups and the participants involved in a group call were those subscribed in these preconfigured groups.

Specifications WGs are thinking to apply the Ad hoc Group Communications principle based on a specific criterion known at MCX Server level to create a dynamic affiliation in the groups. This dynamic approach once well defined in the standards needs to be tested in a future project.

As for the point-to-point calls, the notion of the controller responsible for the movement area of the train must be further tested, as there was only one dispatcher in the 5GRAIL configuration.

There was no indication for participants leaving a group call during field and lab testing. If Ad hoc Group Communications MCX building block is also used for group calls, there are on-going 3GPP activities for notification of leaving/joining participants of a group call to the authorised users. The controller and the group call initiator are considered as authorised users. This notification feature must be further tested, once the dynamic group affiliation is agreed.in the standards.

The interworking feature tested through Voice_021 has demonstrated that all codecs needed to be deactivated on the FRMCS device to hear properly the voice, except G711. Interworking is an on-going working item at ETSI specifications groups and the codec topics need to be further studied. The outcome needs to be validated by testing, since interworking feature implementation will be highly required during the migration period.

Referring to Voice_005, the multi-talker feature was successfully validated in field as in lab when the maximum number of simultaneous users has not been exceeded. What remains to be tested is what happens when the maximum number of simultaneous users is exceeded, mechanisms of queuing/priorities to be applied, which are also under discussion in specifications WGs and 3GPP. Another possibility is to change the maximum number of simultaneous users by an authorised user (e.g. controller) during the communication, these procedures need also to be completely specified and tested.

6.1.3.2 Performance measurements for voice group calls

The MCPTT KPI1 and KPI2, as defined in D1.3 §4.1 were used for field performance evaluation of voice group calls where all captured PTT requests for Voice_010 and Voice_021 were below 300ms, when referring to MCPTT KPI1. The mean value of KP1 is 75ms. With reference to KPI2, all captured PTT requests have been below the 1000 ms limit. The mean value of KPI2 is 678 ms, the maximum value was seen at 814 ms. Detailed results and graphs are presented in §9 [43] D5.1 chapter §6.5.4 Results and Observations.

6.1.4 REC - Railway emergency calls (Voice_011, Voice_012, Voice_022)

The purpose of the REC tests was to demonstrate that a Railway Emergency Call between train drivers and a train controller, responsible for the train movement area, can be established in both directions.

Thanks to Voice_012 test case, interworking has been successfully validated in field and lab for REC as well.

The set-up for these tests presenting the entities involved is the same as in Figure 15 with cab radio or dispatcher initiating group calls, since REC is also a group call and the same as in Figure 16 which represents group calls with interworking feature.

6.1.4.1 Observations/comments for REC

During the field testing as for lab, a simulation of the cab radio's position along the track was used to define if it was included in the targeted area of the REC. The REC implementation in 5GRAIL was extensively described in §9[37] D3.3 chapter Appendices §12.7 and in §9[45]D1.2 chapter §3.7, emphasizing the fact that a pre-standard approach was tested, validating the server-based affiliation instead of client-based, using a criterion, such as the originator's location to define the participants of a group, dynamically.

Moreover, there were two variants of FRMCS REC, a standalone REC alert and a combined REC alert with REC voice. In the combined REC alert and voice, the addressed group will be the same. In the scope of 5GRAIL, only REC voice was tested so further testing of alert which is a mandatory part of the REC is needed.

In between, within the FRMCS 3GPP activity, we have identified a solution which is the Ad Hoc Group Communication MCX feature, which was adopted, and tuned for the Railway Use. This feature is not completely standardized yet and hence not available, so it was not applicable to 5GRAIL.

As the interworking feature is under study by the ETSI, it has to be further investigated what is necessary for REC and other type of calls. Considering the REC case, the alert is not existing in GSM-R, so probably the interworking will only cover the voice part during the migration period.

The codec issue, where deactivation of all codecs except G711 was necessary, was also observed in REC calls with interworking feature, all the aspects about mixing FRMCs and GSM-R users in a call, need to be clearly handled by the specifications.

6.1.4.2 Performance measurements for REC calls

MCPTT KPI1 and KPI2 were also used for REC. KPI1 was satisfied in 98% of PTT requests, instead of the expected behaviour 99%, due to an outlier result below 300ms. The mean value of KPI1 is 81ms.

Higher access times occur likely due to an inter-gNB handover situation or a short coverage gap which leads to increased re-transmission attempts. Note that the 5G radio deployment along the utilized test track was well planned for the purpose of prototype testing but not optimized for official acceptance tests as on real operational lines.

KPI2 was with all PTT measurements below 1000ms. The mean value of KPI2 is 586 ms in the field trials (as compared to 436 ms in the lab trial conditions of WP3), the maximum value in the field trials was seen at 828 ms.

6.1.5 Combined Voice Calls (using MCPTT) and Video Uplink (using MCDATA) (Voice_017)

The purpose of this test was to demonstrate the FRMCS system behaviour while simultaneously using two applications, each requesting different MCX services – specifically, the MCPTT service for the voice application and the MCData service for the data application. Through this test case, the ability of the On-board architecture to handle in parallel two applications of different MCX type and implemented with different coupling mode (voice applications is tight-coupled and video is loose-coupled), using the resources of the same UE was validated. Moreover, the expected outcome of this test case was that each application maintains the standalone performance.

The combined scenario encompasses a MCPTT point-to-point call from driver (Cab Radio) to controller (Dispatcher) and an On-board to trackside MCData communication, using MCData IPCon. The latter one has been chosen to be a live video streaming application from Teleste that uses uplink resources of the 5G TDD band n78. Both applications are using the DSCP marking to differentiate QoS requirements. Voice application is configured as a GBR application with 5QI=2 and ARP=7, for normal usage and video is configured as a non-GBR application with 5QI=7, meaning that in case of degraded conditions, the voice application is prioritized to the video.

The following figure is presenting the entities in green involved in this combined scenario:

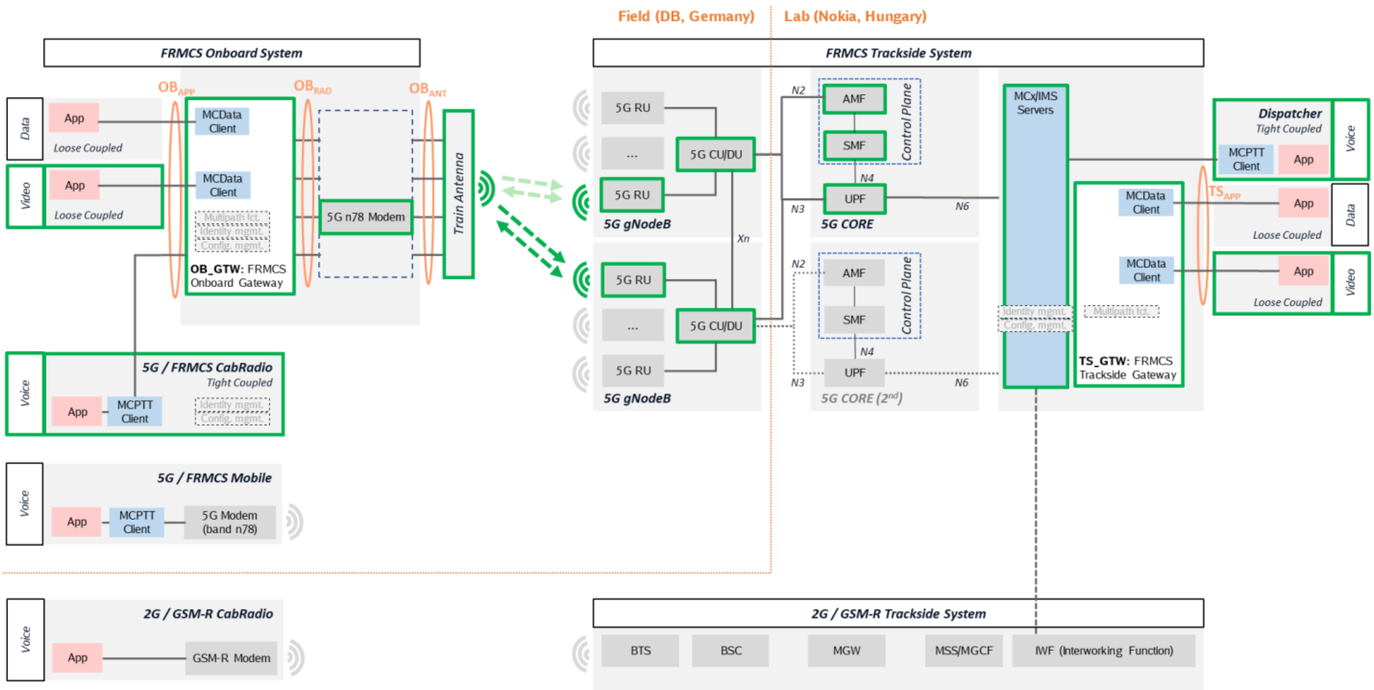


Figure 17: Set-up for combined scenario Voice_017 (Testbed Germany) (Ref. 5.1)

6.1.5.1 Observations/comments for combined scenario (Voice calls/Video uplink)

Field testing has confirmed the lab testing results for both applications, showing a good performance with voice. Voice communication between the users was established and functioned with clear and loud quality in both directions and it maintained without drops or within the quality even in mobility conditions, where due to some changing coverage conditions, the video frame rate was decreased giving degraded but still acceptable video quality.

6.2 ETCS and TCMS (using MCDATA) - Testbed in Germany

The ETCS and TCMS applications, both provided by CAF, were tested in the German testbed with the track and rolling stock infrastructure provided by DB Netz AG. Nokia has provided the 5G SA trackside network and Kontron the MCX system as well as the On-board connectivity using TOBA Gateway and 5G modem. The tests were performed in 5G band n78 TDD.

Both ETCS and TCMS applications have been implemented as simulations in the scope of 5GRAIL, using an On-board and trackside simulator each. Both applications were OBapp compliant. The simulators include the full protocol stack defined in the Subset 037 §9[24] and were flexible enough to configure any pattern which helps to “simulate” future increase of data in the ETCS applications, as well as to better evaluate the quality of the network.

The below figure represents the protocol stack of the ETCS application where the main changes come from the control plane between the application and the FRMCS Gateway (OBapp/WebSocket) and from the implementation and integration of the Ethernet protocol.

Figure 18: Evolution of the ETCS protocol stack for FRMCS (Ref. 5.1)

The ETCS and TCMS test cases repeated in field, as per §9[30] D1.1 Test plan, have been listed in the following, per category. The **FRMCS Principle/MCX feature** column highlights the FRMCS principle or MCX building block that has been validated by each test case:

- **ETCS simulation between onboard EVC and trackside RBC**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
ETCS_WP3-WP5_TC_001	Nominal communication between ETCS on board application and RBC [static]	- IP connectivity (IPcon) capability - IP connectivity - MCData IPcon point-to-point request - MCData IPcon point-to-point response - GRE Tunnel between clients directly
ETCS_WP3-WP5_TC_005	Nominal communication between ETCS on board application and RBC, including BTS handover (same 5G network) [dynamic]	
ETCS_WP3-WP5_TC_003	Increased data transferred in the ETCS communication [static & dynamic]	

- **Combined ETCS and TCMS simulations with prioritization regime**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
ETCS_WP3-WP5_TC_004	ETCS onboard combined with other data application [static & dynamic]	- IP connectivity (IPcon) capability - IP connectivity - MCData IPcon point-to-point request - MCData IPcon point-to-point response GRE Tunnel between clients directly

- **TCMS simulation between onboard MCG and trackside GCG**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
TCMS_TC_001 (TC_001a)	Nominal communication between MCG on board application and GCG [static]	- IP connectivity (IPcon) capability - IP connectivity - MCData IPcon point-to-point request - MCData IPcon point-to-point response GRE Tunnel between clients directly
TCMS_TC_001 (TC_001b)	Nominal communication between MCG on board application and GCG, including BTS handover (same 5G network) [dynamic]	

The following figure is presenting the entities in green involved in this combined scenario:

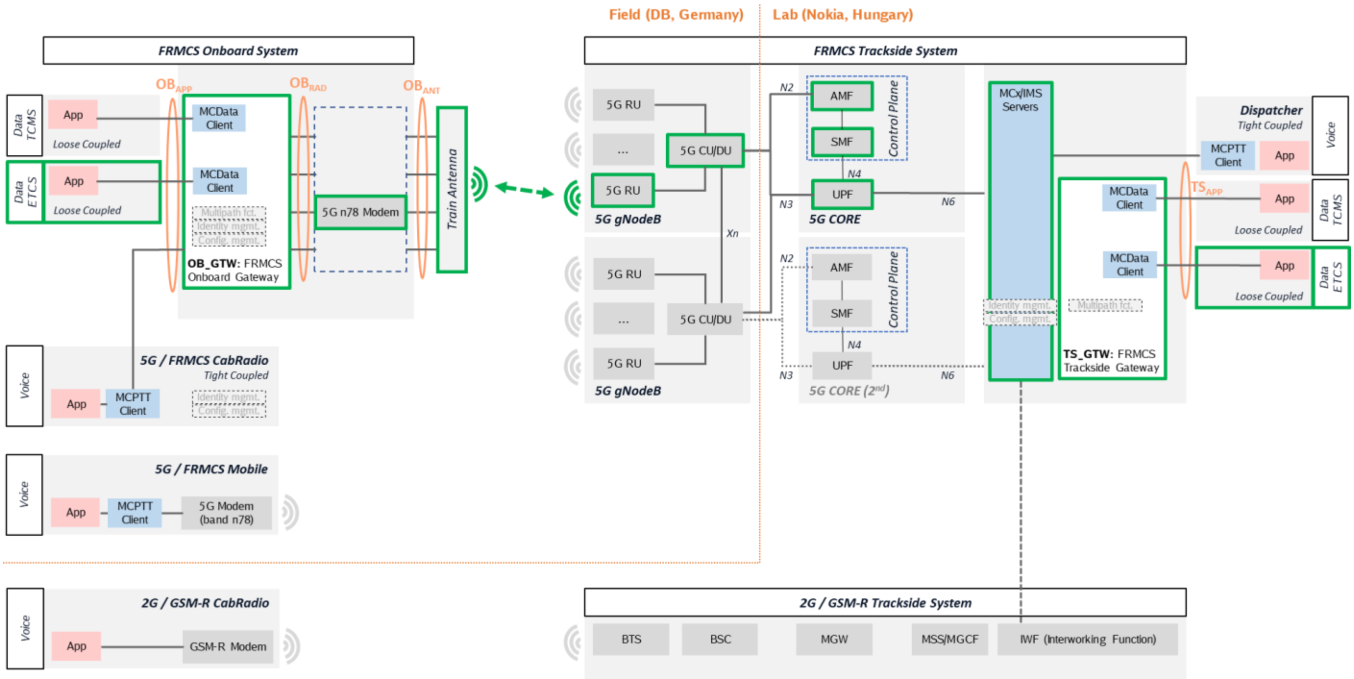


Figure 19: Set-up for test case ETCS_WP3-WP5_TC_001 (Testbed Germany) (Ref. D5.1)

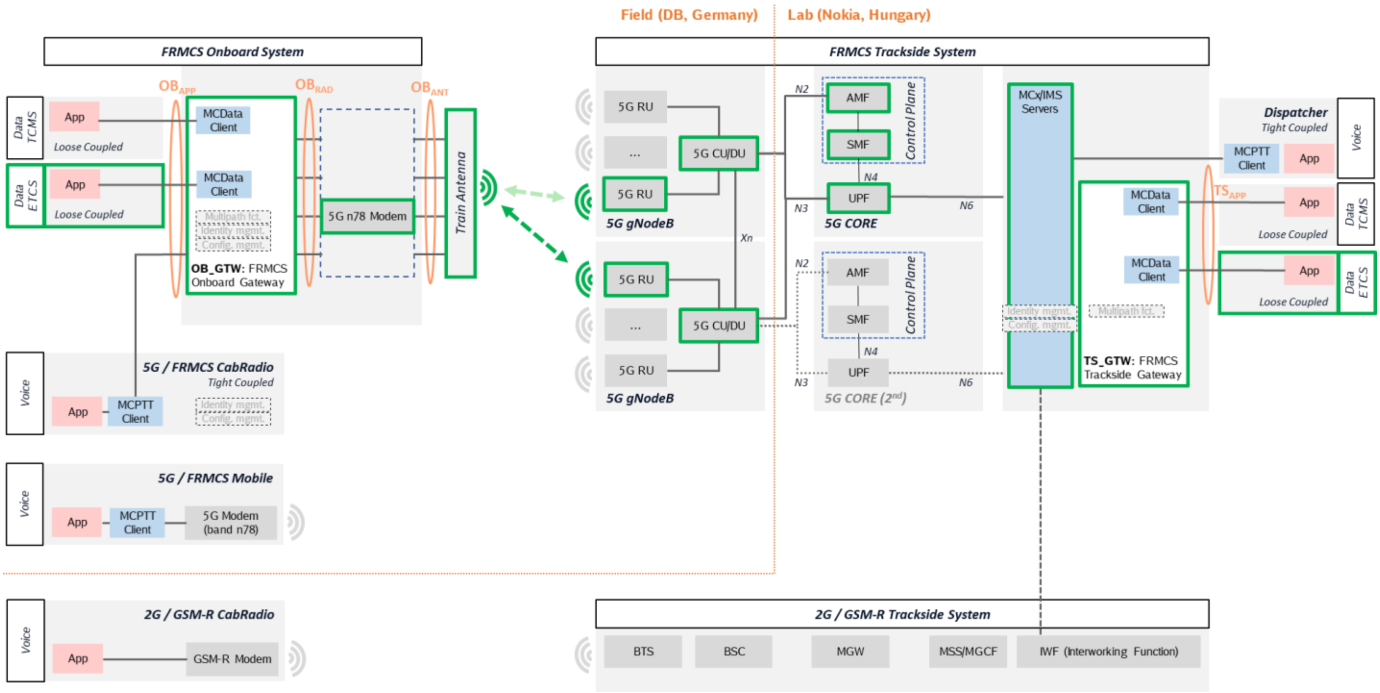


Figure 20: Set-up for test case ETCS_WP3-WP5_TC_005, with intra- and inter-gNodeB handover (Testbed Germany) (Ref. D5.1)

6.2.1 Observations/comments for ETCS application

A delay between the OBapp registration response and the session start command have been implemented in the application side to avoid the FRMCS GW to get stuck in trying state in field as explained in D1.2 chapter §3.1.4 and D2.4 chapter §4.

Wireshark traces have been obtained on the OBU as well as the RBC. The KPIs have been derived by analysing the TCP performance on Wireshark as explained in D1.3chapter 4.2.1.1.

6.2.2 Performance measurements for ETCS application

Static test results: It can be observed that the communication is very stable. The round-trip-time stays always below 120 ms. Compared to the lab test, a slight increase of about 10 ms in the RTT can be observed on the onboard side. This delay might come from the leased line link between the field test location in Germany and the trackside application location in Hungary.

Dynamic test results: An increase of about 20 ms can be observed in the RTT compared to static or lab values. during a specific frame of time were degraded conditions occurred (low coverage or interferences), but still the application was able to handle it. The usual nominal data transfer rate for ETCS simulations was set to 2.7 kbit/s, but in order to evaluate a future increase of data rate to 5 kbit/s, ETCS_WP3-WP5_TC_003 test was performed. The delay was increased however no retransmissions were necessary.

6.2.3 Combined ETCS and TCMS simulations (ETCS_WP3-WP5_TC_004)

The combined test case has been performed with data transfers of an ETCS simulation and of a TCMS simulation running in parallel, which again validates the parallel MCData applications handling by the On-board System. The QoS parameter 5QI was configured as 5QI=5 (ETCS) and 5QI=9 (TCMS), both using non-guaranteed bitrate (non-GBR) class, implemented through DSCP marking. The ETCS application, being more critical than the TCMS application was transmitted with high priority in order not to be affected by parallel data streams. The expected outcome of the test case was to maintain the ETCS (and TCMS) data communication without drops and with good quality, even in mobility conditions.

Both ETCS and TCMS applications are implemented as loose coupled applications using a MCData client embedded in the FRMCS Onboard Gateway (TOBA box) and FRMCS Trackside Gateway. The set-up of the test case, highlighting in green the entities involved in the tests, is presented below:

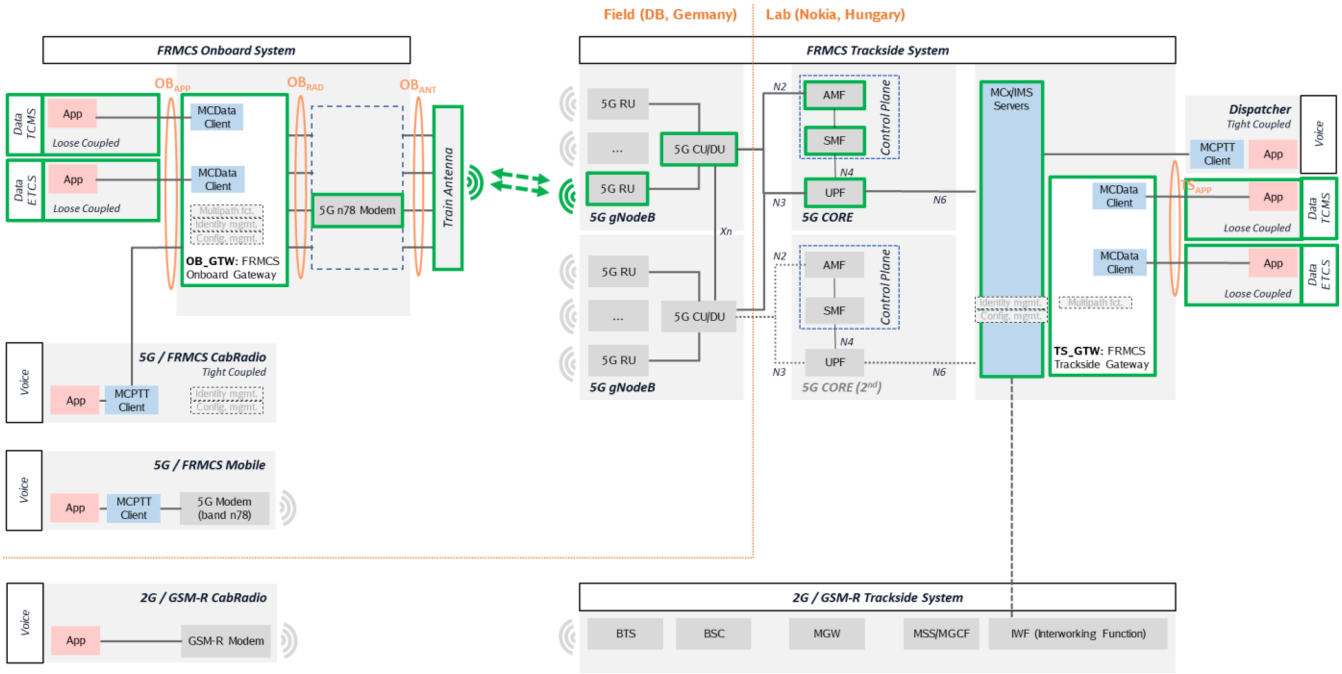


Figure 21: Set-up for test case ETCS_WP3-WP5_TC_004 (Testbed Germany) (Ref. D5.1)

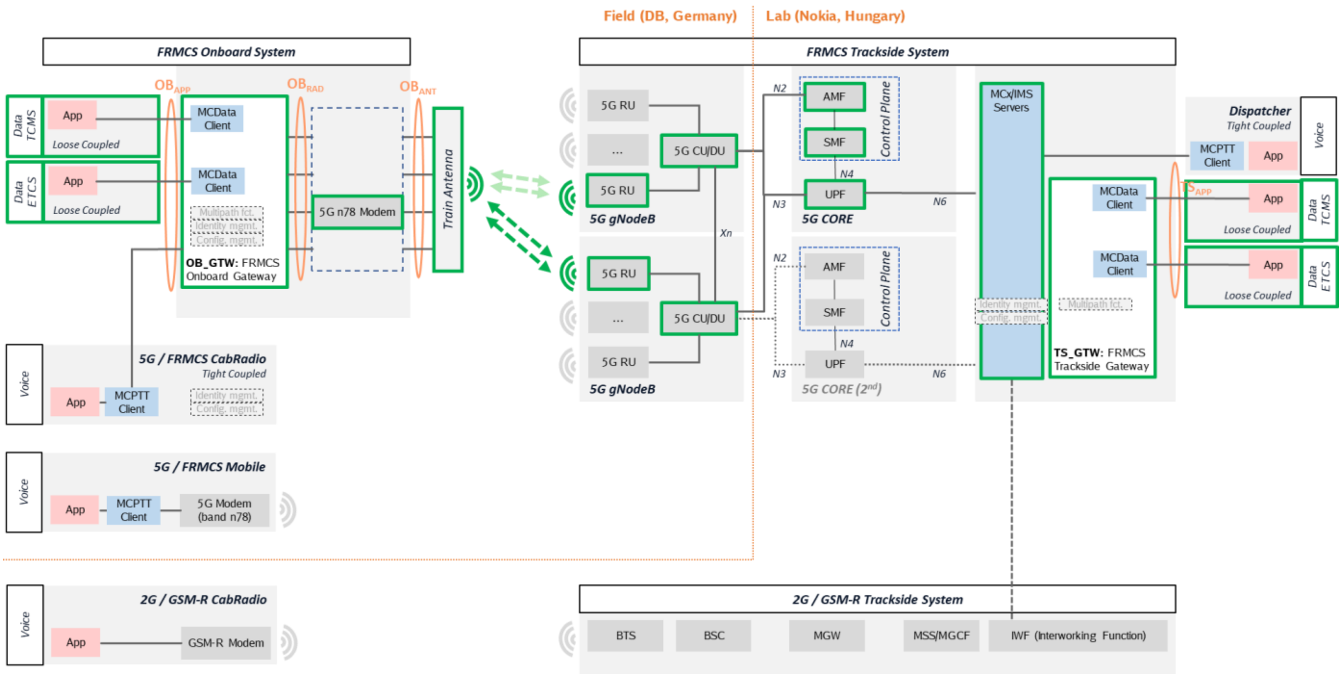


Figure 22: Set-up for test case ETCS_WP3-WP5_TC_004 with intra- and inter-gNodeB handover (Testbed Germany) (Ref. D5.1)

6.2.4 Observations/comments and performances of combined ETCS and TCMS test cases

The RTT delay was the KPI used for these test cases as well, derived from the TCP acknowledgements, based on Wireshark traces obtained on the OBU as well as the RBC part.

Static test results: It can be observed that the communication is as stable as the nominal test case in the lab, very low RTT and constant data rate.

Dynamic test results: The RTT and data rate values were good until the coverage was lost and the modem lost registration. At this point, the test was ended with about 5 minutes of execution. The coverage loss was due to some coverage outage areas within the track. The coverage study and the modem stability are key parameters for future project performance testing.

6.2.5 TCMS

The nominal data transfer test case for TCMS simulations is not a standard test. Data rates vary based on the vehicle subsystem information that shall be sent from/to the train. In the following case passenger count services have been selected with only small and not fixed data rates being transmitted.

TCMS is also implemented as loose coupled application and the following figure is presenting the entities involved in this test:

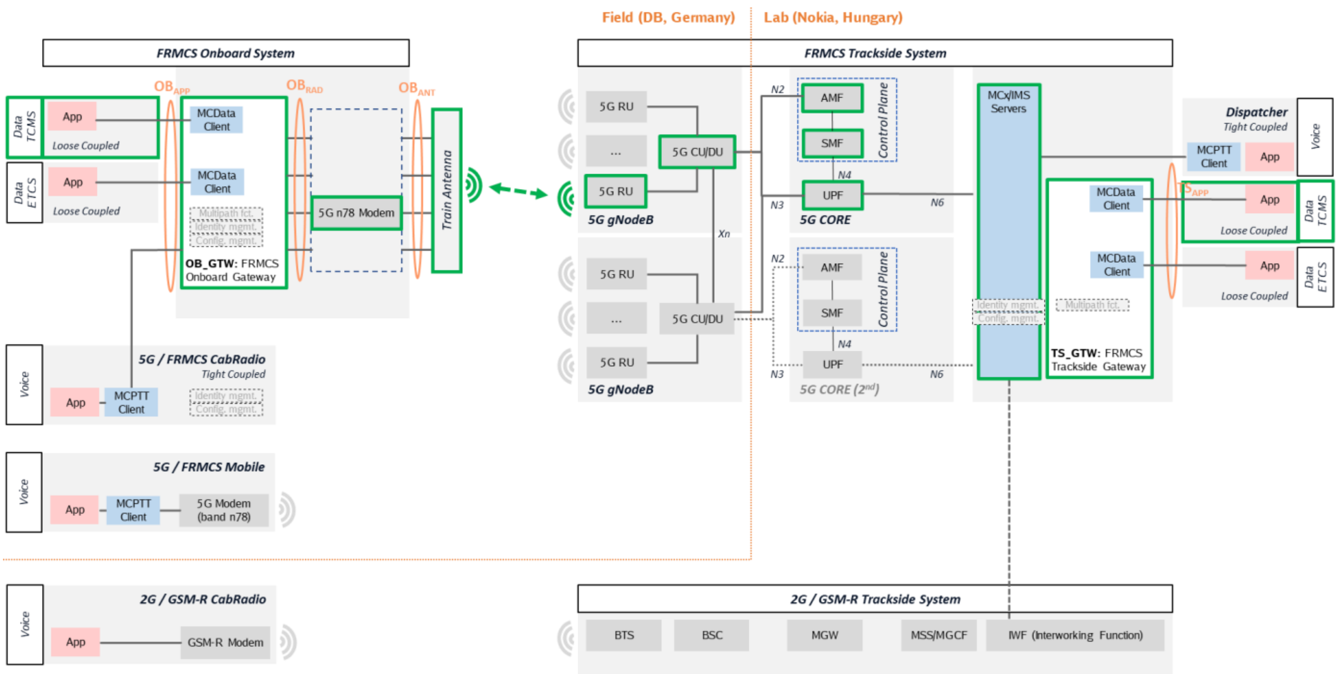


Figure 23: Set-up for test case TCMS_TC_001 (TC_001a) (Testbed Germany) (Ref. D5.1)

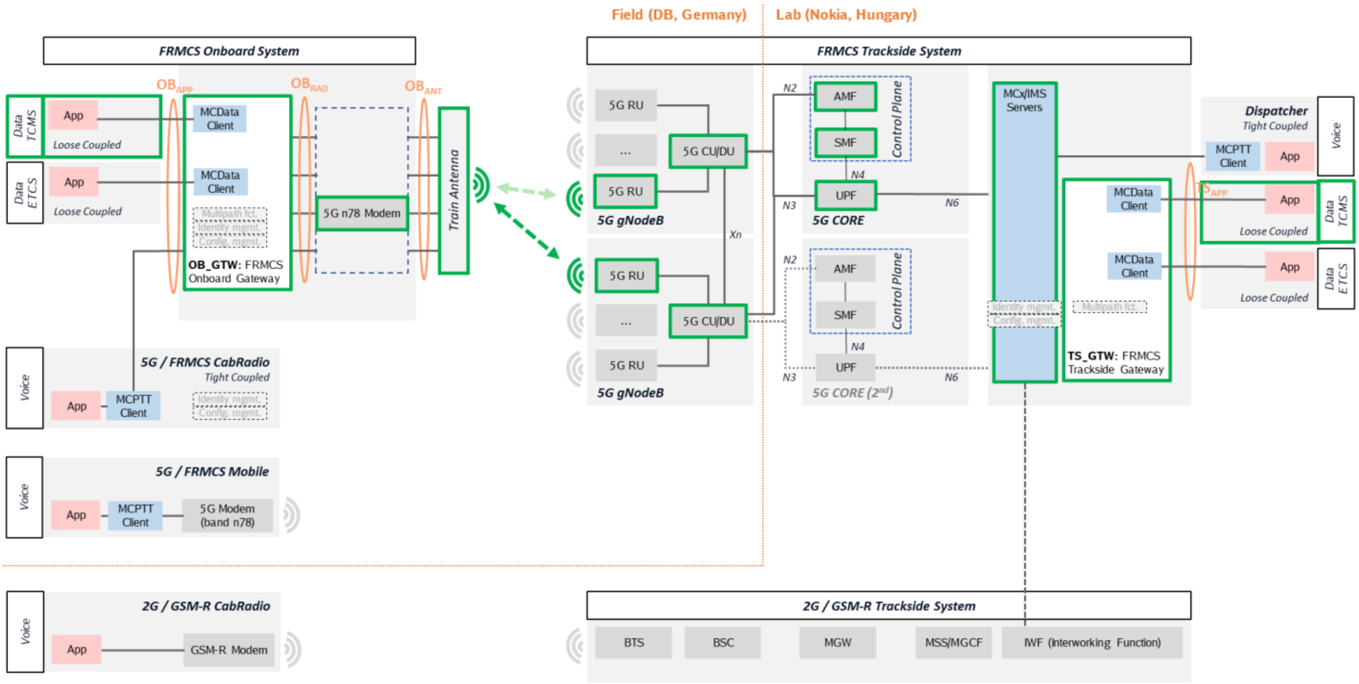


Figure 24: Set-up for test case TCMS_TC_001 (TC_001b), with intra- and inter-gNodeB handover (Testbed Germany) (Ref. D5.1)

6.2.5.1 Observations/comments/performances of TCMS

Due to the usage on an older version of TCMS, it was discovered that JSON information must be sent in a specific format to avoid parsing issues. KPI used is always the RTT based on Wireshark traces obtained on the TCMS on-board as well as the trackside.

Static test results: In the nominal as in the combined with ETCS test case, the achieved average RTT is 43ms.

Dynamic test results: Two dynamic tests have been performed. One for the nominal case and another for the combined with ETCS test case. In both cases, the RTT is in the range of 50 ms. Few times there are RTT peaks of some hundreds of milliseconds which are due to connection loss (e.g. handover situations with too low coverage for longer period or outage areas). In all these situations, the onboard modules have been capable to recover the connection. All the results can be retrieved in D5.1 chapter §7.6.4

6.3 Video and CCTV (using MCDATA) – Testbed in Germany

The Teleste S-VMX software is deployed on both On-board and trackside systems. The server on trackside continuously keeps active connection with the equipment in the train. This solution offers on-demand, real-time video streaming from any On-board camera. In the Teleste solution, the video data is transmitted as TCP stream to minimize the loss of video frames and ensure the best possible user experience. The following figure presents the On-board and trackside part of the CCTV video system:

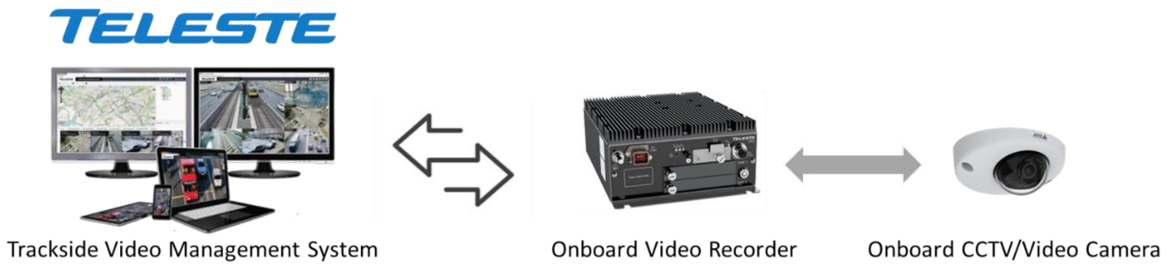


Figure 25: Trackside and onboard equipment of the CCTV video system (Testbed Germany) (Ref. D5.1)

The list of functional test cases is the following, also mentioning the FRMCS principles and MCX building blocks used:

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
Video_TC_001	Streaming of video from train to trackside [static]	MCData IPConn features
Video_TC_003	Streaming of video from train to trackside including BTS handover (same 5G network) [dynamic]	MCData IPConn features Intra/Inter gNodeB handover
CCTV_TC_001	CCTV offload from train to trackside [static & dynamic]	MCData IPConn features Intra/Inter gNodeB handover Bearer flex (multi-Access)

6.3.1 Streaming of video from train to trackside (Video_TC_001)

The purpose of this test case is to test live streaming of CCTV video from the On-board video management system (Train computer) into the trackside video management system in mobility and stationary mode.

The tests have been supported by DB Netz AG (providing the track and rolling stock infrastructure), by Nokia (providing the 5G SA trackside network) and Kontron (providing the MCX system as well as the onboard connectivity using TOBA Gateway and 5G modem). The tests have been performed in n78 band TDD.

The following figure is presenting the entities in green involved in this test case, considering the video applications as loose coupled applications using a MCData client, realized in the FRMCS On-board Gateway (TOBA box) and FRMCS Trackside Gateway.:

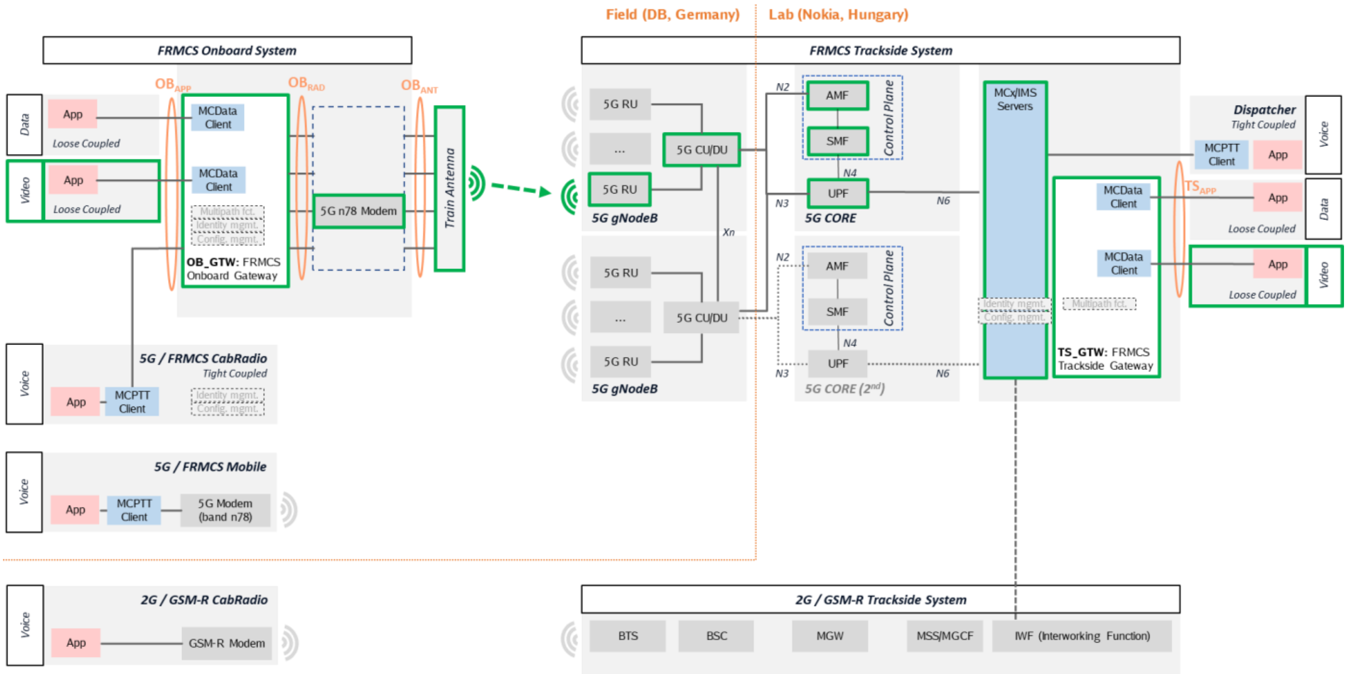


Figure 26: Set-up for test case Video_TC_001 (Testbed Germany) (Ref. D5.1)

Different Video resolutions and bit rate were tested:

- HD video (1280x720) with average bitrate at 2 Mbps
- SVGA video (800x600) with average bitrate at 1 Mbps
- VGA video (640x480) with average bitrate at 700 Kbps

The On-board application sends video data to the trackside application over TCP. The video over TCP is considered a better choice than over UDP for unstable network conditions where network degradations may occur. The experience and visual effects of the video over TCP in such scenarios is much better (especially for identification) than video over UDP. The video over TCP when network degradation occurs may jerk, be delayed or skip but picture is visible.

6.3.1.1 Performance measurements from video streaming (Video_TC_001)

- HD video (1280x720) with average bitrate at 2 Mbps

The Wireshark tool analyses of network dumps for RTP stream shows 14484 packets loss of expected 52821 (27.42%). Video framerate was dropped from time to time, picture jerks, stops and blinking were visible. The reason for this is coverage gaps; after short time the video was recovered to good quality and then again degradation occurred.

- SVGA video (800x600) with average bitrate at 1 Mbps

Detailed Wireshark tool analyses of network dumps for RTP stream shows 12 packets loss of 28896 expected (0.04%). Wireshark tool network data dumps analyses of video session shows brakes in the transmission, data were not received over the network in intervals, especially when video bit rate increases as of movements in the scene. On-board application was buffering the data and then was sending it immediately after the network becomes stable (increased bit-rate after brake). After some time of data transmission, the brake was happening again and the process continues in intervals.

- VGA video (640x480) with average bitrate at 700 Kbps

The Wireshark tool analyses of network dumps for RTP stream shows 0 packet loss of 21094 (0.00%). Wireshark tool network data dumps analyses of video session shows no brakes in the transmission, data were always received. During the test the visual effects of the video was good, no major jerks or picture blinking, frame rate was kept within expected rage. As the test was considered successful, this test setup and parameters were used for further testing.

6.3.2 Streaming of video from train to trackside including BTS handover (same 5G network) (Video_TC_003)

The purpose of this test case is to test live streaming of CCTV video from the onboard video management system (Train computer) into the trackside video management system in driving conditions with intra- and inter-gNB handover situations.

The following figure is presenting the entities in green involved in:

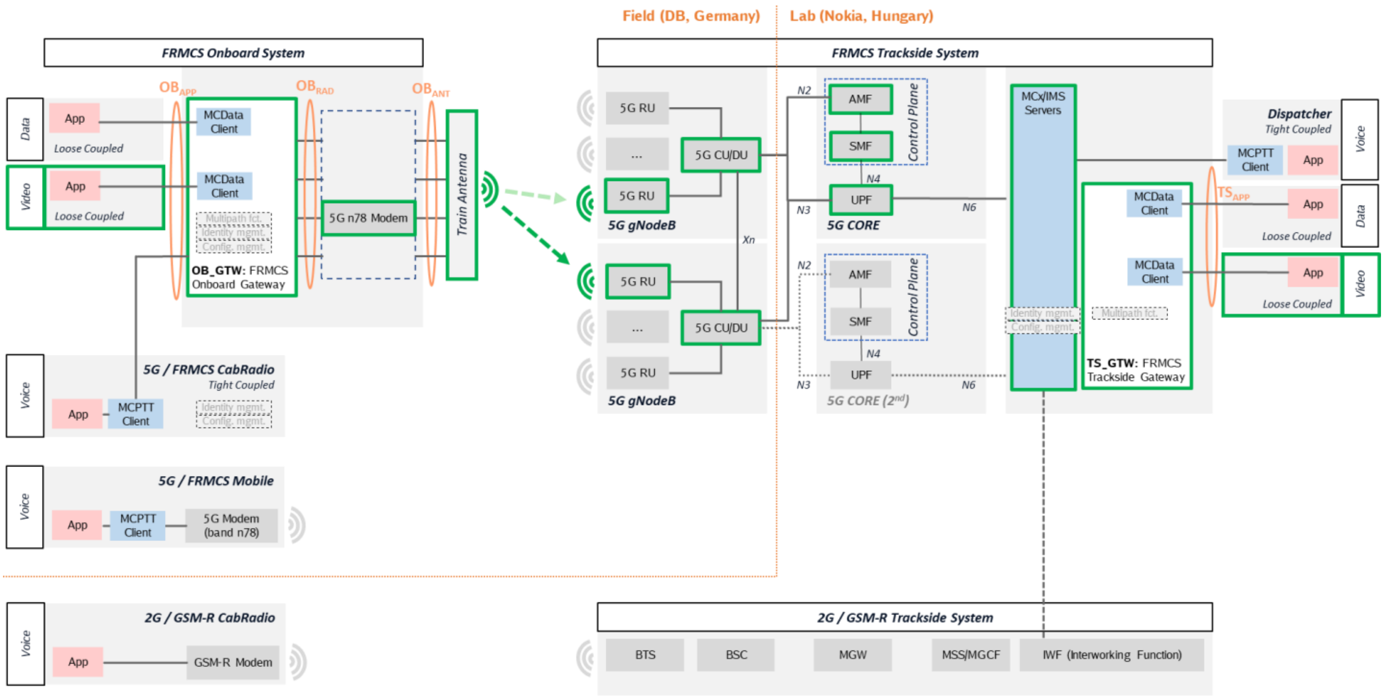


Figure 27: Set-up for the test case Video_TC_003 (Testbed Germany)

6.3.2.1 Performance measurements from video streaming mobility tests (Video_TC_003)

The test was executed with VGA video resolution and 700 kbps average bitrate with the train on the move. This configuration has been derived from stationary tests with different video qualities.

The experience and visual effects of the video over TCP is such scenarios is much better (especially for identification) then video over UDP. The video over TCP when network degradation occurs may jerk, be delayed or skip but still picture is visible, usually no artefacts on the video.

During the test the visual effects of the video was good, no major jerks or picture blinking, framerate was kept within expected rage. At one time for a short time during the drive the degradation occurred, small picture jerk and blink, video framerate and bitrate degraded. Onboard application was buffering the data and then was sending it immediately after the network becomes stable. Then the good quality was recovered and remain stable until network coverage was available.

6.3.3 CCTV offload from train to trackside (CCTV_TC_001)

In a CCTV offload system, FRMCS provides means for transferring video surveillance data between a mobile communication unit in the train and ground communication units located at the depot and at the stations and/or stops alongside the predetermined route of the train. Whenever the train approaches the stations and/or stops or arrives at the depot. FRMCS facilitates the communication between the mobile and ground communication unit using the 5G frequency available at stations or depots. FRMCS facilitates the communication between the mobile and ground communication unit outside of the depots or stops as well using other links / sub-bands with the frequency available along track. With this use case the bearer flexibility is demonstrated as multi access use case using two sub bands for track and station coverage. This use case is wished by railways, to considerable smoothing this operation, often done physically by hard drives swap.

In a CCTV offload situation, the time for data transmission may be limited (e.g. to the time that the train stands on a platform or slowly moves in the station area). Hence, it is important to achieve a stable and continuous data stream of sufficient quality.

The CCTV (offload) service is implemented in the FRCMS network as a loose coupled application using a MCData client which is realized in the FRMCS Onboard Gateway (TOBA box) and FRMCS Trackside Gateway. The tests were performed in n78 TDD band. The set-up of the test case is presented below with all the involved entities, highlighted in green:

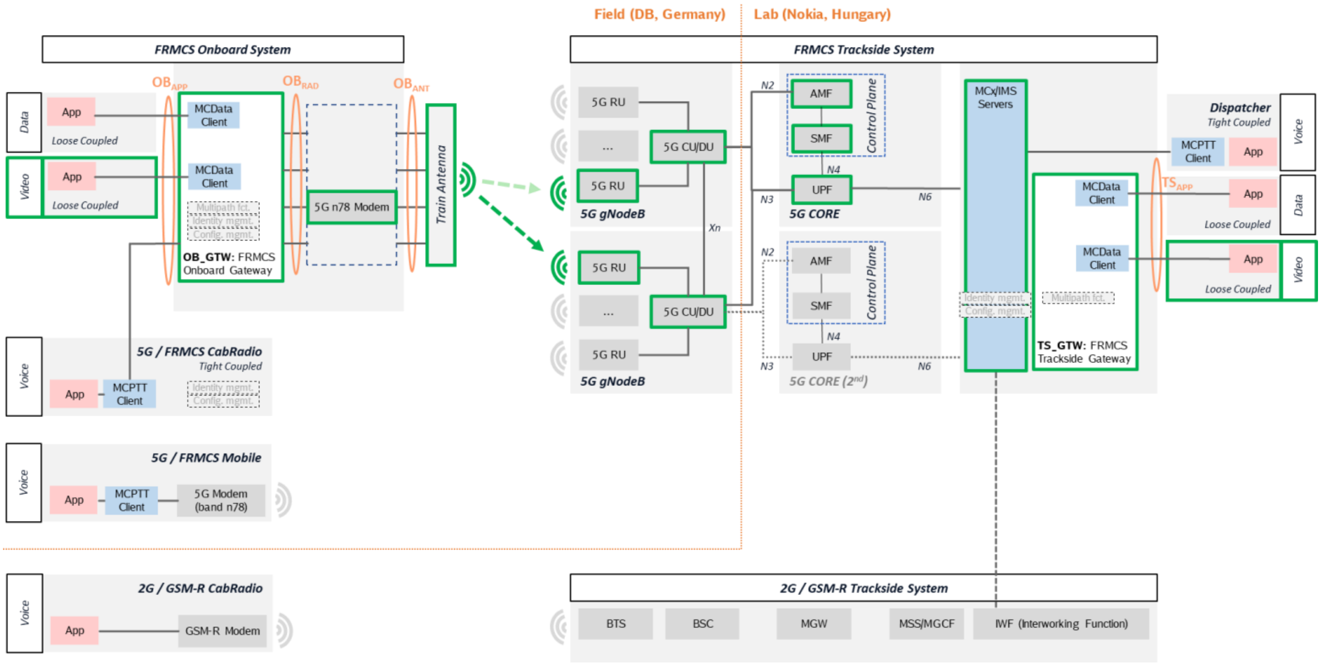


Figure 28: Set-up for the test case CCTV_TC_001 (Testbed Germany)

6.3.3.1 Performance measurements of CCTV offload

The test was executed with different conditions both in stationary mode and mobility mode (with velocity of max. 50 km/h), with:

- full offload speed, i.e., no rate limitation has been set on application level and
- limited offload speed, i.e., a specific data rate limitation has been set on application level.

The maximum achievable peak Rates in Uplink were up to 8 Mbps with TDD configuration 1/4, using 20 MHz bandwidth within 3700-3720 MHz in TDD band n78 but these results are only indicative, as the final FRMCS system at TDD band n101 will use 10 MHz bandwidth within 1900-1910 MHz. This observation is presented in the following figure:

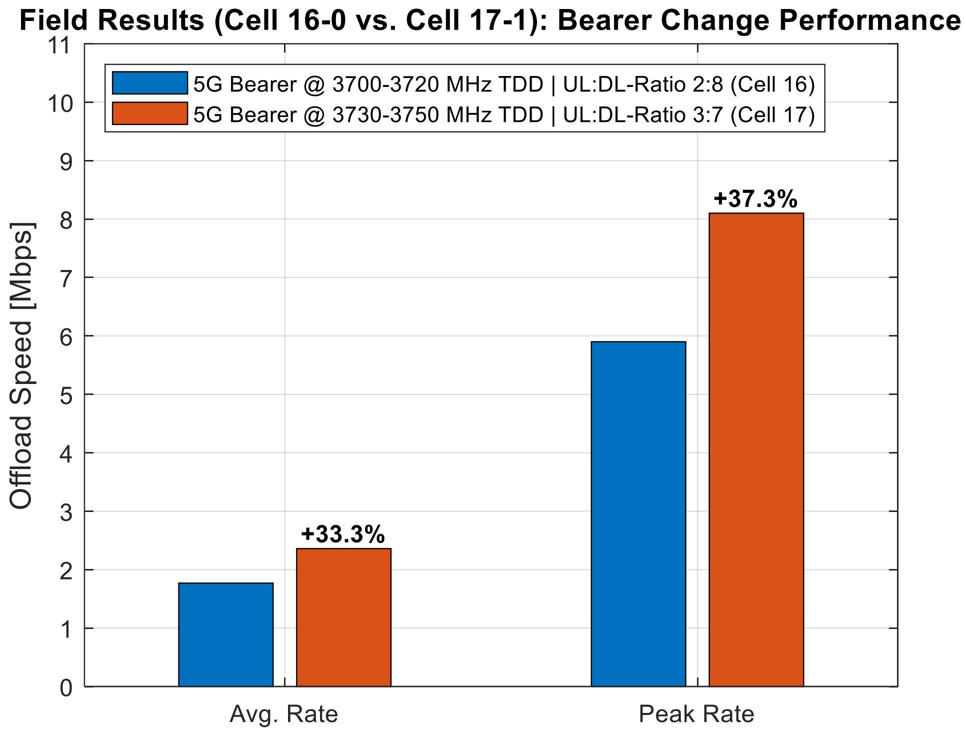


Figure 29: CCTV Offload – 5G Bearer Change in field (Testbed Germany) (Ref. D5.2)

- **Stationary Tests observations**

During the scenario for the stationary mode with 2 Mbps limit on the offload speed enabled, there can be seen less frequent breaks in the offload data transmission but interruptions are still available. The offload peak rate was just below 2 Mbps as expected by the applied limitation.

During the scenario for the stationary mode with 1 Mbps and 700 Kbps limit on the offload speed enabled, no breaks in the offload data transmission were seen, i.e., the offload service was working with continuous uplink stream. The offload speed was around 1 Mbps and 700Kbps as expected by the applied limitation.

- **Mobility Tests observations**

During the scenario for the drive mode, full offload speed enabled, there can be seen frequent breaks in the offload data transmission. The offload speed varied with the changing radio conditions while driving between the different radio cells along the track, reaching just over 8 Mbps uplink peak rate in good radio conditions.

During the scenario for the drive mode with 1 Mbps limit on the offload speed enabled, there are no breaks in the offload data transmission, i.e., the offload service was working with continuous uplink stream. The maximum offload speed was around 1 Mbps as expected by the applied limitation and it was also nearly constant over the full drive between the different radio cells along the track.

Detailed information about these results can be retrieved in D5.1 chapter §8.4.4

6.4 ETCS (using MCDATA) – Testbed in France

As previously mentioned ETCS application has been tested in both field testbeds. In France, the application provider was Alstom. For the ETCS testing, SNCF Reseau has provided the track and rolling stock infrastructure and coordinated the tests progress. Kontron has provided the 5G SA trackside network and the IMS/MCX system as well as the On-board connectivity using TOBA Gateway (TOBA-K) with 5G and 4G modems. The tests were performed in n39 band TDD with 5G ES3 protype modem in 31 dBm.

Many functional tests have been performed in the testbed in France, as listed in D1.1 Test plan chapter §6. Detailed results of these tests can be retrieved in D5.1 chapter §9. Due to the testbed context being nearby a commercial line in addition to the prototype level of end-to-end architecture, it was very difficult to have performance results, so for the purposes of this deliverable, selected test cases will be commented, where performance results based on RTT KPI were deduced.

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
ETCS_WP4-WP5_TC_003 (Procedure 1)	Nominal communication in ETCS level 2 (mobility conditions)	IP Conn Intra/inter gNodeB HO n39 (RMR band n101 TDD is sub-band of n39)

6.4.1 Nominal communication in ETCS level 2 (ETCS_WP4-WP5_TC_003 (Procedure 1)) – Performance measurements and observations

The following figure illustrates the entities involved in this test, as subpart of the global end-to-end architecture, as presented in chapter §5:

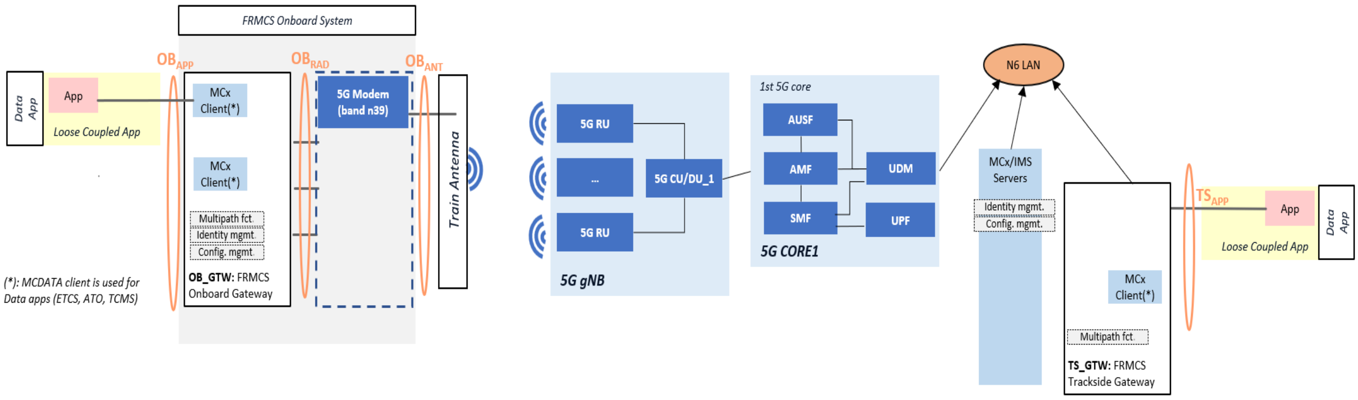


Figure 30: Set-up for test case ETCS_WP4-WP5_TC_003 (Testbed France) (Ref. D5.1)

The communication is established, there is no interruption (application data loss) until the loss of 5G signals. This test was passed in both static and dynamic conditions. Wireshark traces are saved and shows a consistent exchange.

The following KPIs have been measured for this test.

- Average round trip delay = 52.5 ms
- Standard deviation Round Trip Time = 35.5 ms
- The values are calculated on 681 samples.

As this test is the nominal case, those values will serve as comparison point for the following tests. Details are depicted in the following figure, where we can discuss some interesting observations.

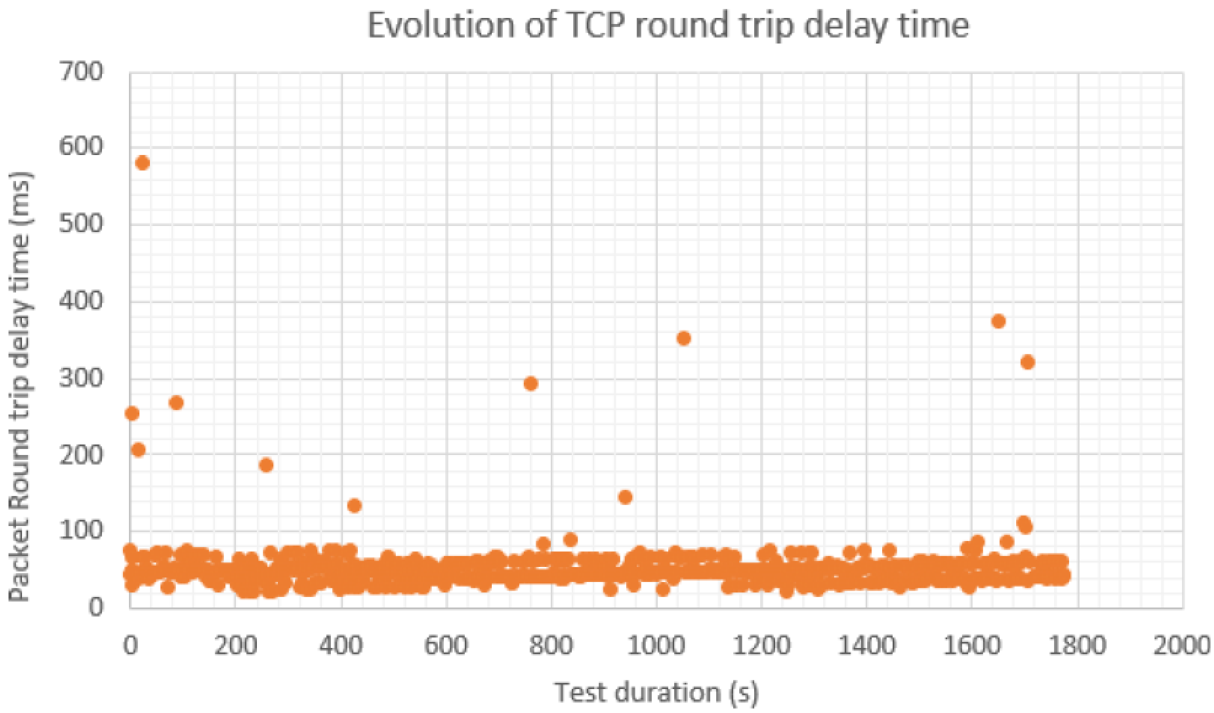


Figure 31 Round Trip Delay time observed with ETCS application field testing in Testbed France (mobility conditions). (Ref. D5.1)

The presence of some outliers can explain the TCP retransmissions. These refer to the lack of ACK for a sent segment, and consequently the timer has expired. In real environment conditions, TCP retransmissions are normal and expected if there are not too many. Usually, it should probably be less than 1% of the TCP segments that get retransmitted. In our case, we noticed 11 outliers out of 681 samples, which is far less than 1%.

6.5 ATO (using MCDATA) – Testbed in France

ATO application, implemented as a loose coupled MCDATA application, was provided by Alstom for field as for lab testing. For the ATO testing, SNCF Reseau has provided the track and rolling stock infrastructure and coordinated the tests progress. Kontron has provided the 5G SA trackside network and the IMS/MCX system as well as the On-board connectivity using TOBA Gateway (TOBA-K) with 5G and 4G modems. The tests were performed in n39 band TDD with 5G ES3 protype modem in 31 dBm.

The same reasons explained previously for the ETCS application in field testing in France, led us to select the test cases to comment in the purpose of this deliverable. These are the ones providing a performance evaluation based on the RTT KPI of the status report and are listed below:

- **ATO connectivity between onboard and trackside**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
ATO_TC_003	Nominal communication between the ATO-onboard and the ATO-Trackside applications	- IP Conn - Intra/inter gNodeB HO - n39 (RMR band n101 TDD is sub-band of n39)

- **Mobility Scenarios (Transitions on ETCS App. Simulator)**

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
ATO_TC_005	ATO in nominal conditions performing intra gNodeB HO	- IP Conn - Intra/inter gNodeB HO - n39 (RMR band n101 TDD is sub-band of n39)
ATO_TC_006	ATO in nominal conditions performing inter gNodeB HO	- IP Conn - Intra/inter gNodeB HO - n39 (RMR band n101 TDD is sub-band of n39)

- Combined ETCS and ATO simulations

Application_TC_ID	Test case Label	FRMCS Principles/MCX features
ATO_ETCS-TC_009	ETCS on board combined with ATO application	- IP Conn - Intra/inter gNodeB HO - n39 (RMR band n101 TDD is sub-band of n39) - OoS

6.5.1 ATO in nominal conditions (ATO_TC_003) – Performance measurements and observations

The following figure illustrates the entities involved in this test, as subpart of the global end-to-end architecture, as presented in chapter §5:

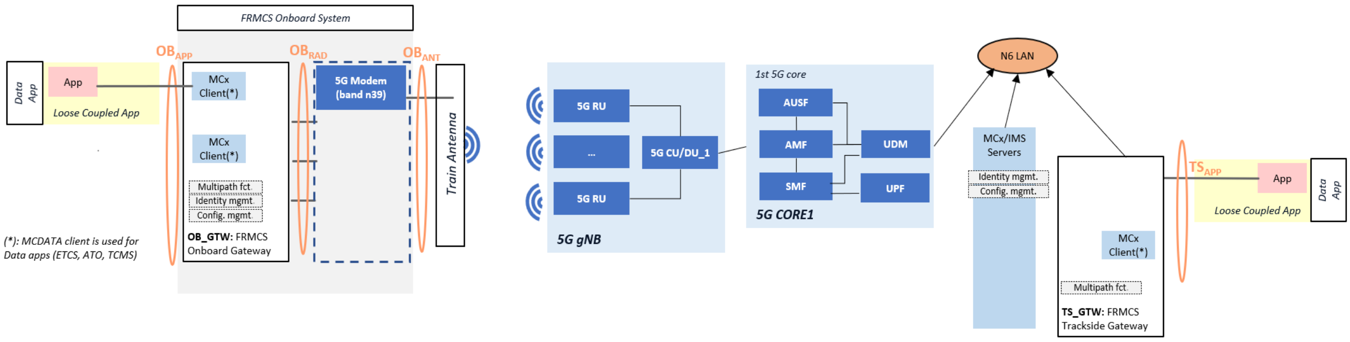


Figure 32: Set-up for test case ATO_TC_003 (Testbed France) (Ref. D5.1)

The following KPIs have been measured for this test, although the duration of the test was short with few captured values:

- Min-Max RTD: 26 ms – 110 ms
- Mean RTD: 71 ms
- Std deviation RTD: 28 ms

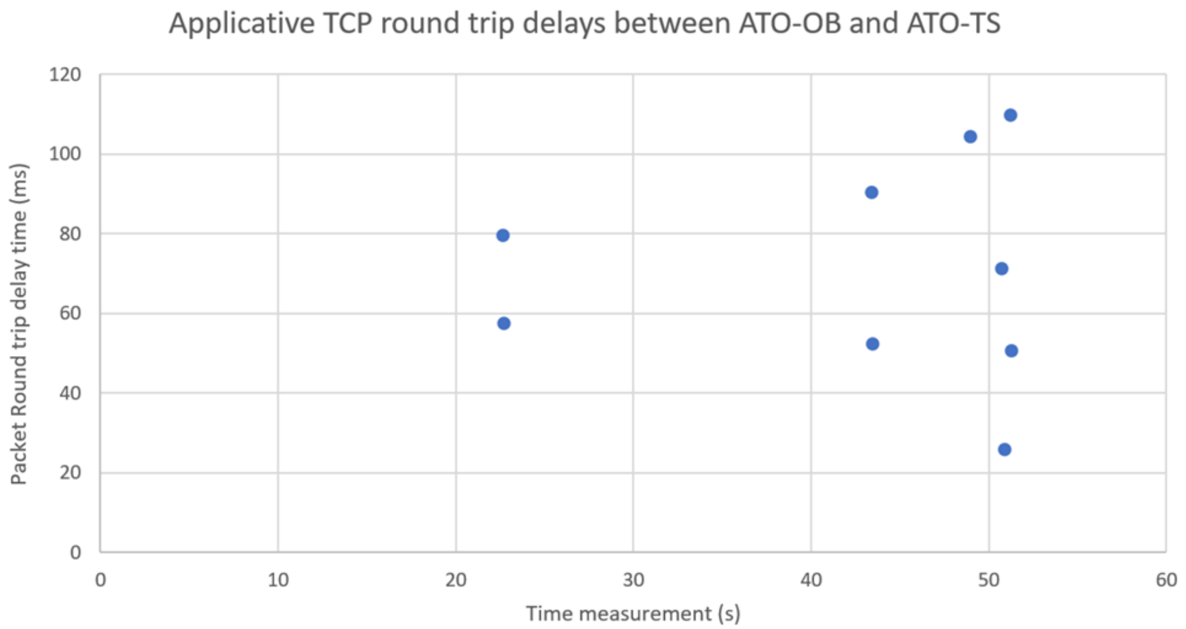


Figure 33 Round Trip Delay time observed with ATO application field testing ATO_TC_003 (Testbed France) (Ref. D5.1)

6.5.2 ATO in nominal conditions performing intra and inter gNodeB HO (ATO_TC_005, ATO_TC_006) – Performance measurements and observations.

The following figure illustrates the entities involved in this test, as subpart of the global end-to-end architecture, as presented in chapter §5:

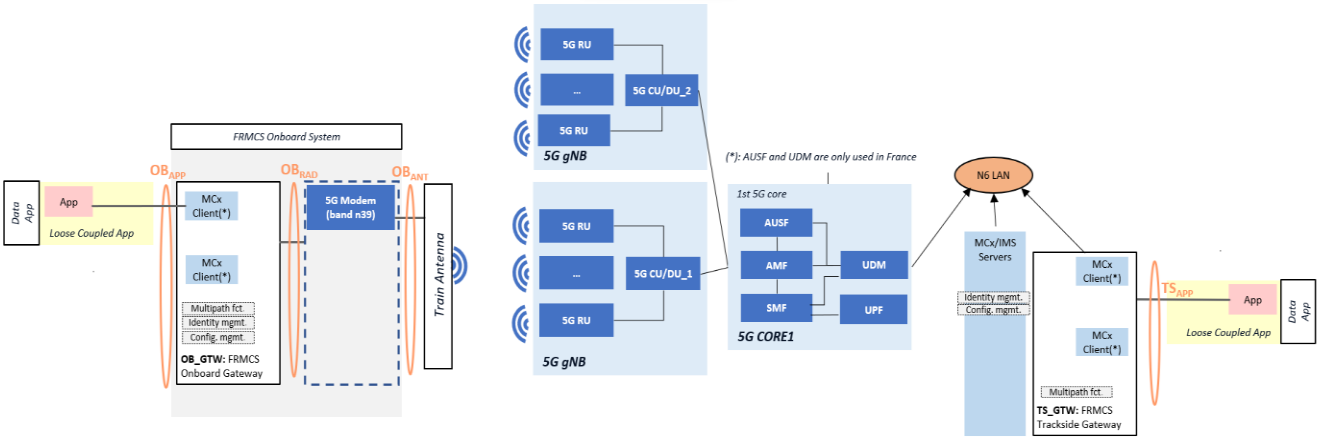


Figure 34: Set-up for test case ATO_TC_005 and ATO_TC_006 (Testbed France) (Ref. D5.1)

For this test a specific set-up is necessary because in case the inter-gNodeB handover happens under the same 5G core, where two ME1210 equipment is necessary because this equipment can only host one 5Gcore and one CU/DU on the same equipment. The 2gNodeB is switched off, so that the On-board GTW is connected to the 1st gNodeB.

The following KPIs have been measured for this test:

- Min-Max RTD: 57 ms – 142 ms
- Mean RTD: 89 ms
- Std deviation RTD: 21 ms

The evolution of the RTT delay of the status report during the whole test duration can be retrieved in the following figure:

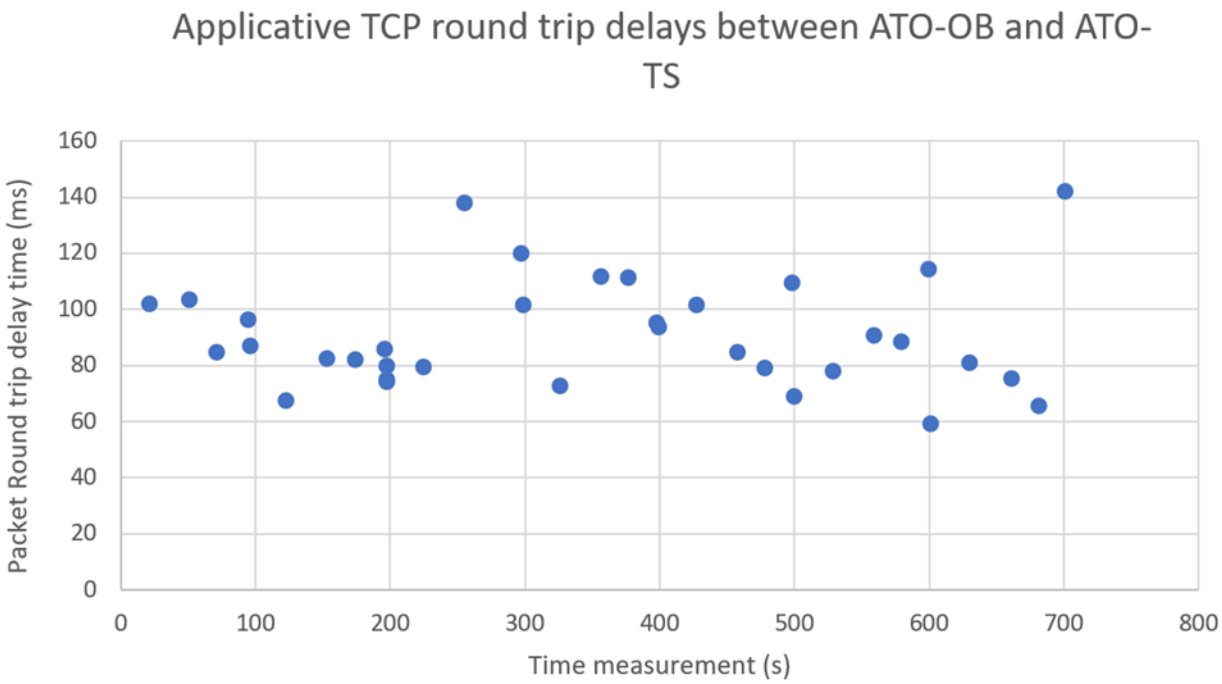


Figure 35 Round Trip Delay time observed with ATO application field testing ATO_TC_003 (Testbed France) (Ref. D5.1)

6.5.3 ETCS on board combined with ATO application (ATO_ETCS-TC_009) – Performance measurements and observations.

The following figure illustrates the entities involved in this test, as subpart of the global end-to-end architecture, as presented in chapter §5:

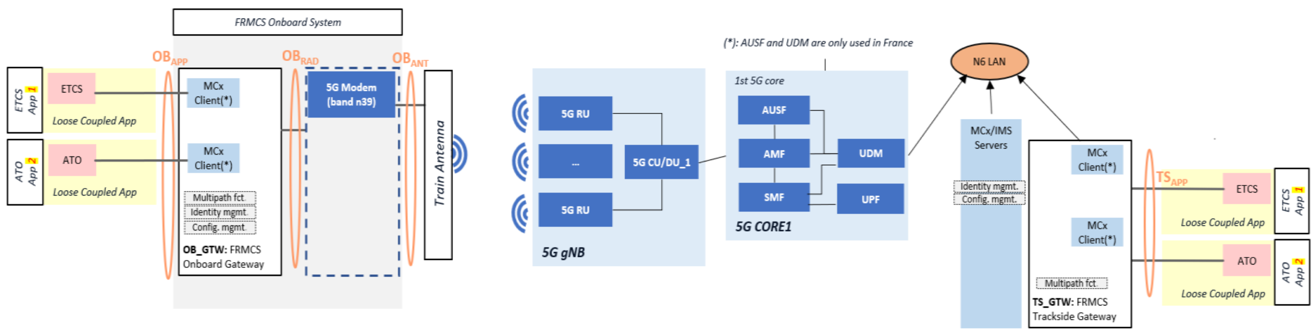


Figure 36: Set-up for test case ATO_ETCS - TC_009 (Testbed France) (Ref. D5.1)

The following KPIs have been measured for this test:

- Min-Max RTD: 56 ms – 299 ms
- Mean RTD: 95 ms

- Std deviation RTD: 50 ms

Further details can be observed in the following figure:

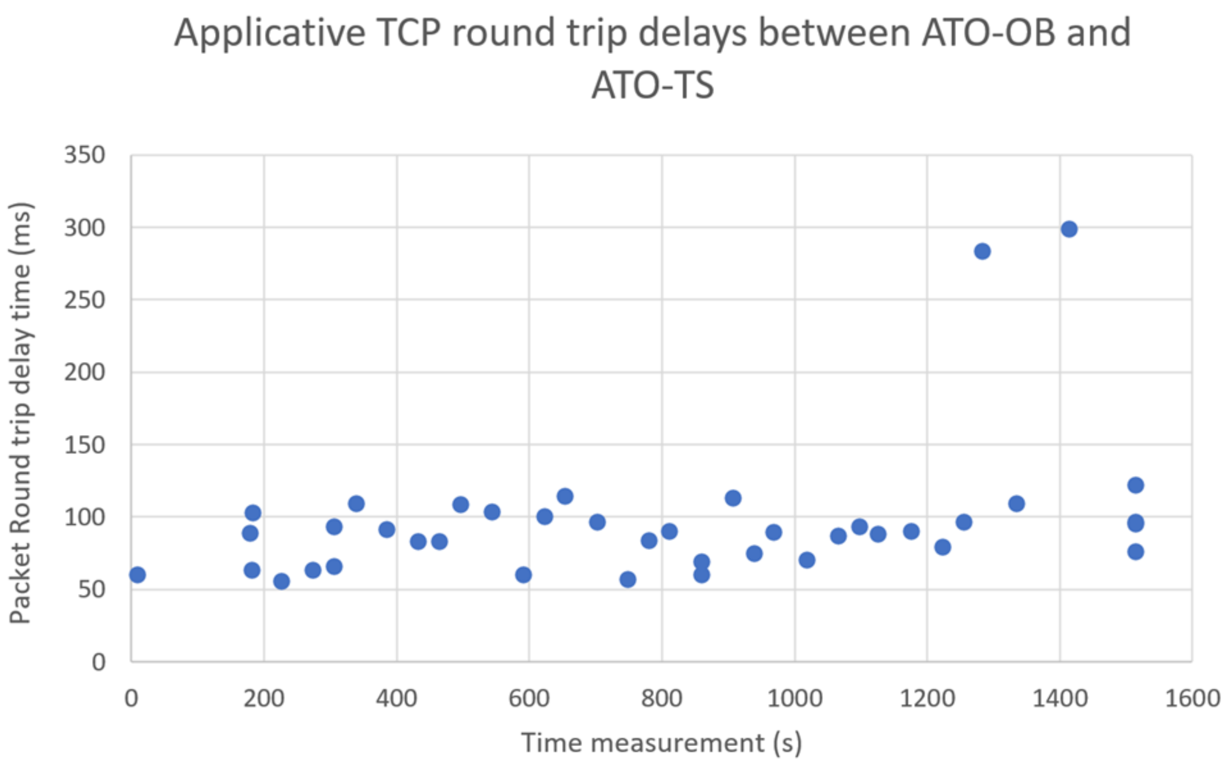


Figure 37 Round Trip Delay time observed with combined ETCS and ATO applications ATO_ETCS_TC_009 (Testbed France) (Ref. D5.1)

6.6 Remote Vision

Remote vision application is an application used by SNCF and provided by son partner Ektacom. For the Remote vision testing, SNCF Reseau has provided the track and rolling stock infrastructure and coordinated the tests progress. Kontron has provided the 5G SA trackside network and the IMS/MCX system as well as the On-board connectivity using TOBA Gateway (TOBA-K) with 5G modems. The tests were performed in n39 band TDD with 5G ES3 protype modem in 31 dBm.

6.6.1 Combined Remote Vision and ETCS in field conditions (RV_ETCS_WP5_TC_002) - Performance measurements and observations

The objective of the following test case is to validate that the remote vision application can coexist with other critical application without impact on the quality of them. For this, Remote Vision application which is a bandwidth demanding was tested with another heterogeneous critical app that is ETCS requiring low latency but also low bitrate.

Below are presented the QoS configurations of both applications:

Remote Vision:

- Comm_profile:5
- **5QI 7**
- Non-GBR
- Packet Delay Budget 100ms
- Error Rate 10-3

ETCS:

- Comm_profile:10
- **5QI 3**
- GBR
- Packet Delay Budget 50ms
- Error Rate 10-3
- Guaranteed Bit Rate 100 kb/s.
- Maximum Bit Rate 1 Mb/s

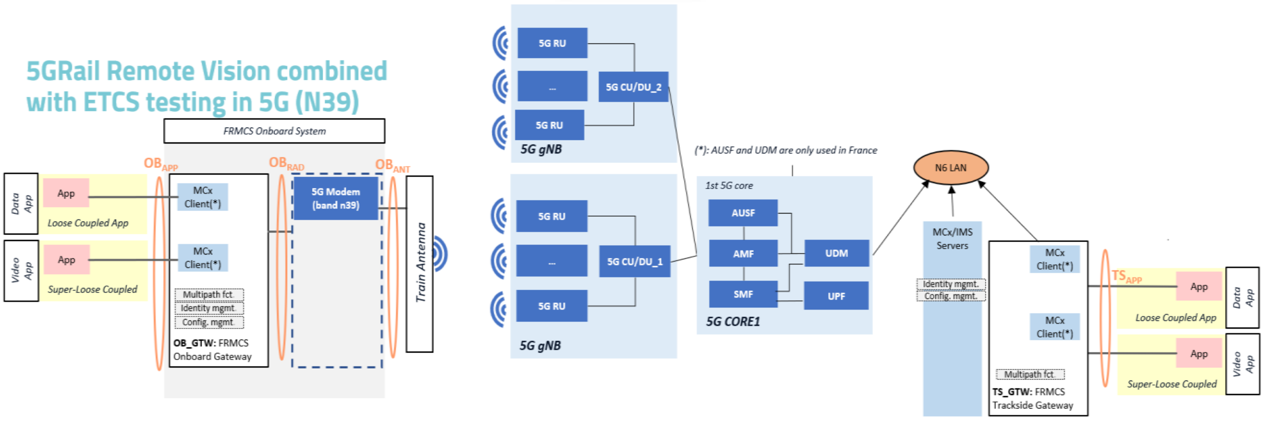


Figure 38: Set-up of Remote Vision combined with ETCS application in RV. (ETCS_WP5_TC_002) (Testbed France) (Ref. D5.1)

From ETCS perspective, the focus is rather on the latency and not on the bitrate, unlike the remote vision app. In this context, firstly, a test is executed in static condition with two different video data rates to establish a "baseline" for the subsequent runs in dynamic conditions (where the train will move along the tracks). The ETCS communication remains active, and no applicative data is lost. The following KPIs have been measured for this second baseline test:

- Average round trip delay = 48.3ms
- Standard deviation Round Trip Time = 216ms
- The values are calculated on 205 samples.

Then, the test is executed in dynamic conditions. The ETCS communication remains active, but we observed some data loss when approaching the Marin site (cf. Figure 9).

Interestingly, the following KPIs have been measured for this test:

- Average round trip delay = 67.06ms
- Standard deviation Round Trip Time = 230.13ms
- The values are calculated on 287 samples.

To analyze these results, in the following figure, we compare obtained results with nominal standalone ETCS application testing in dynamic conditions, elaborated in Section 9.3.4. We can see that the RTD for the ETCS when combined with the remote vision application remains in the same order of magnitude in both static and dynamic conditions compared to the baselines (normal conditions for ETCS in stand-alone or when combined in static conditions).

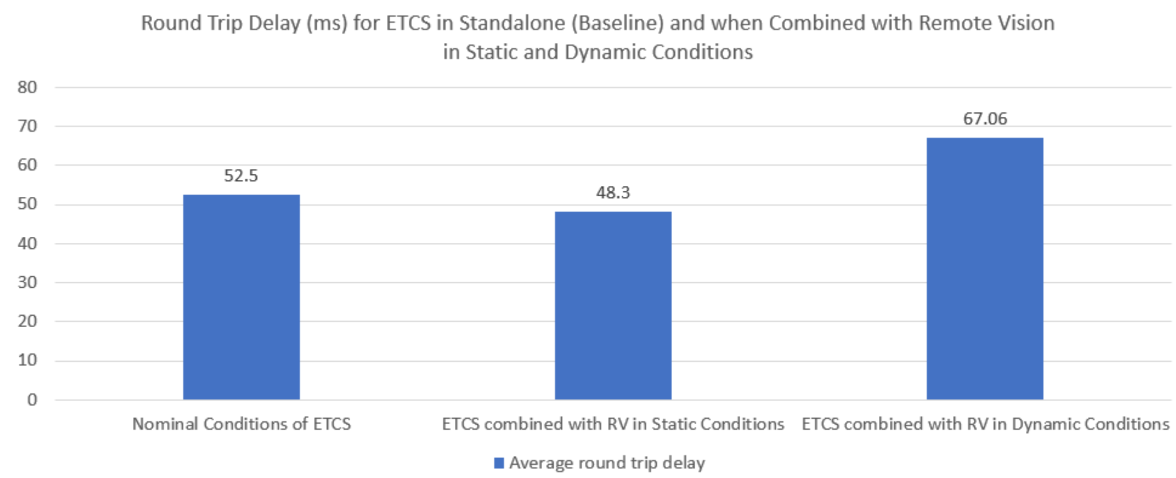


Figure 39: Average Round Trip Delay [ms] benchmarking for ETCS and Remote Vision (Testbed France)

As a bottom line: Tests results are satisfactory. The performance is only impacted by the network condition and the limited coverage knowing that it is not covering the whole train run journey.

7 Cross-border tested in field

Trains crossing the border is an essential requirement for FRMCS for the deployment allowing trains seamlessly travelling between the different countries, as currently with the GSM-R system. The implementation of the cross-border is mandatory for the FRMCS.

Border crossing for GSM-R is performed with service interruption for all services, voice including, except for ETCS. FRMCS 1st Edition aims to behave similar, at minimum. We do however aim to enhance the applications for which we can perform service continuity BX.

Border crossing has started to be specified during the preparation of the FRMCS V1 and the work continues during the FRMCS V2, since it is a particularly difficult topic as it is impacting all the strata, as presented in the figure below:

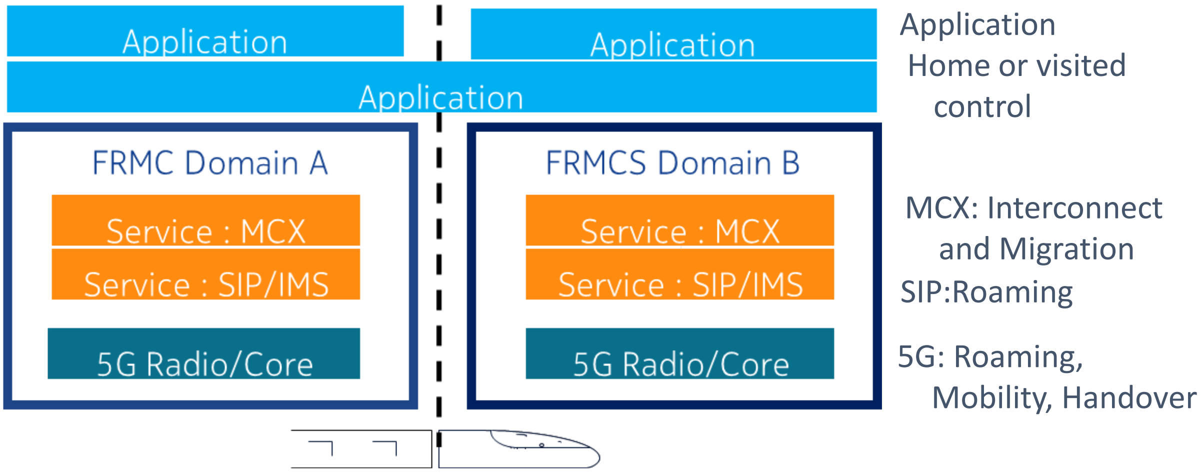


Figure 40: FRMCS strata impacted by Border Crossing (Ref. D3.3)

Moreover, some roaming functionalities were not developed in 5G SA (5G Standalone) ecosystem and were only existing in 5G NSA (non-Standalone) at the beginning of the 5GRAIL project (2020-2021).

Cross-border implementation in the scope of 5GRAIL was also a pre-standard one, with two different flavours tested:

In Kontron's lab, the multi-connectivity concept was used with the simultaneous usage of two 5G UEs by the On-Board FRMCS gateway of Kontron, achieving a seamless transition from the application point of view. In the same lab, the cross-border was also tested with the On-Board FRMCS gateway of Alstom applying the bearer flexibility with two 5G modems each one configured to a dedicated link and used by the application whenever operational with a given priority, preventing the application of any outage impact. This was important for railways as service continuity is only mandatory for ETCS application, where in case of voice, interruptions are accepted.

These two concepts were presented in the following figure:

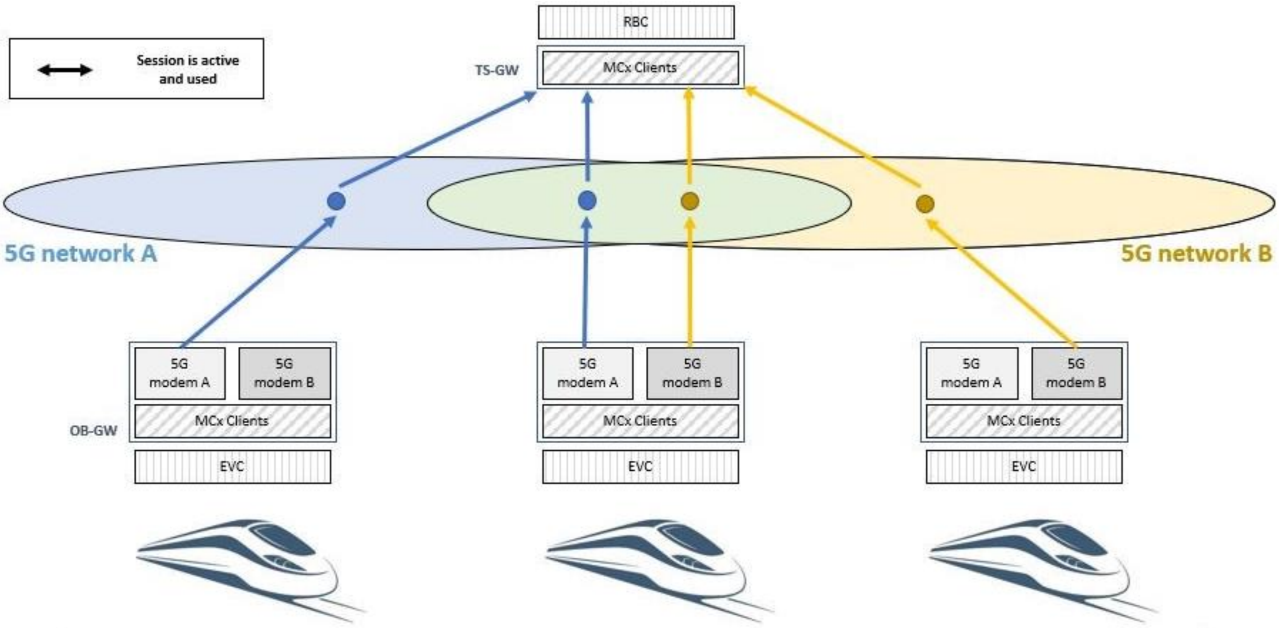


Figure 41: ETCS cross-border with TOBA-K (Ref. D1.2)

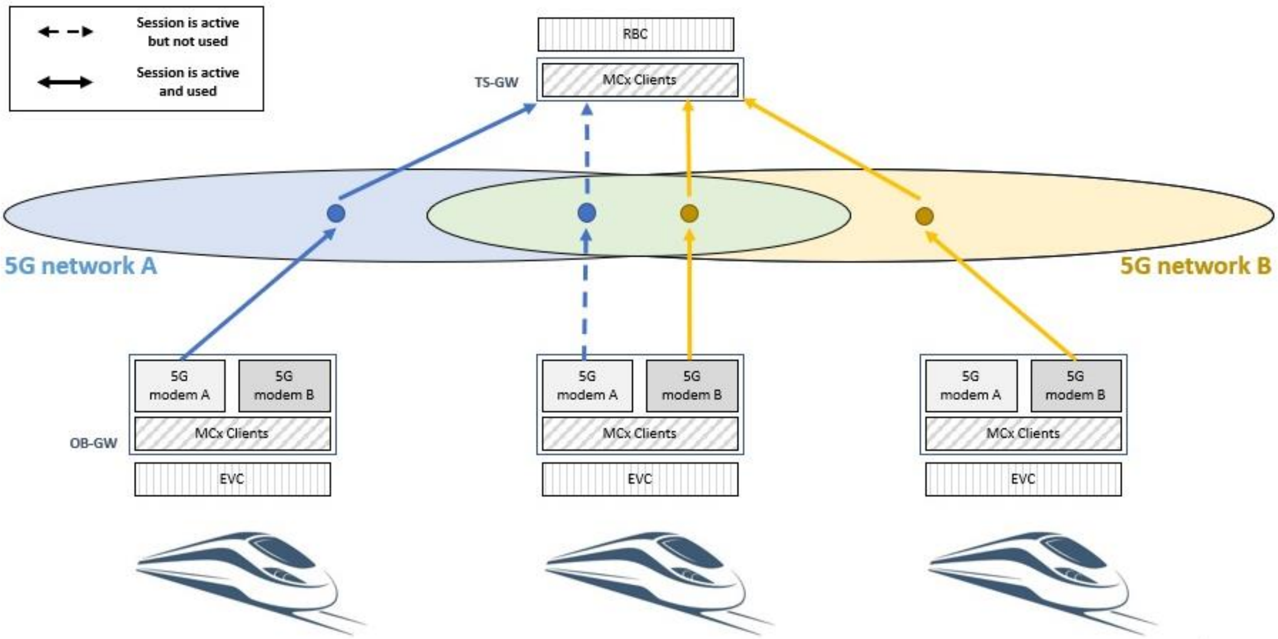


Figure 42: ETCS cross-border with TOBA-A (Ref. D1.2)

In Nokia's lab, Ng handover was configured using two 5G core systems by Inter Access and Mobility Management Function (AMF), where the active data session was seamlessly moved between the two cores without interruption. This concept is presented in the following figure:

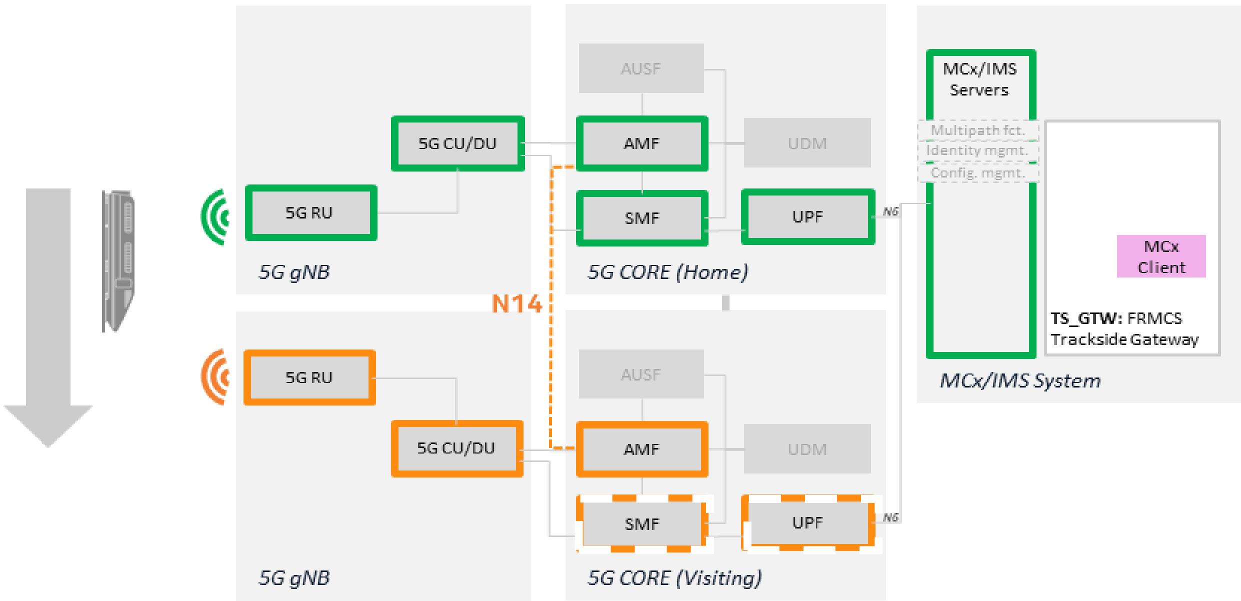


Figure 43: System overview for border crossing in WP3 lab (Ref. D3.3)

Another test case scenario of border-crossing particularly interesting for migration period is involving REC voice application in network transition between GSM-R and FRMCS. REC voice is initiated in the FRMCS network, the cab radio receives this REC thanks to the interworking feature. When the cab radio moves to the FRMCS coverage, by manually switching this cab radio leaves the GSM-R REC and joins the ongoing REC call on the FRMCS side, as presented in the following figure:

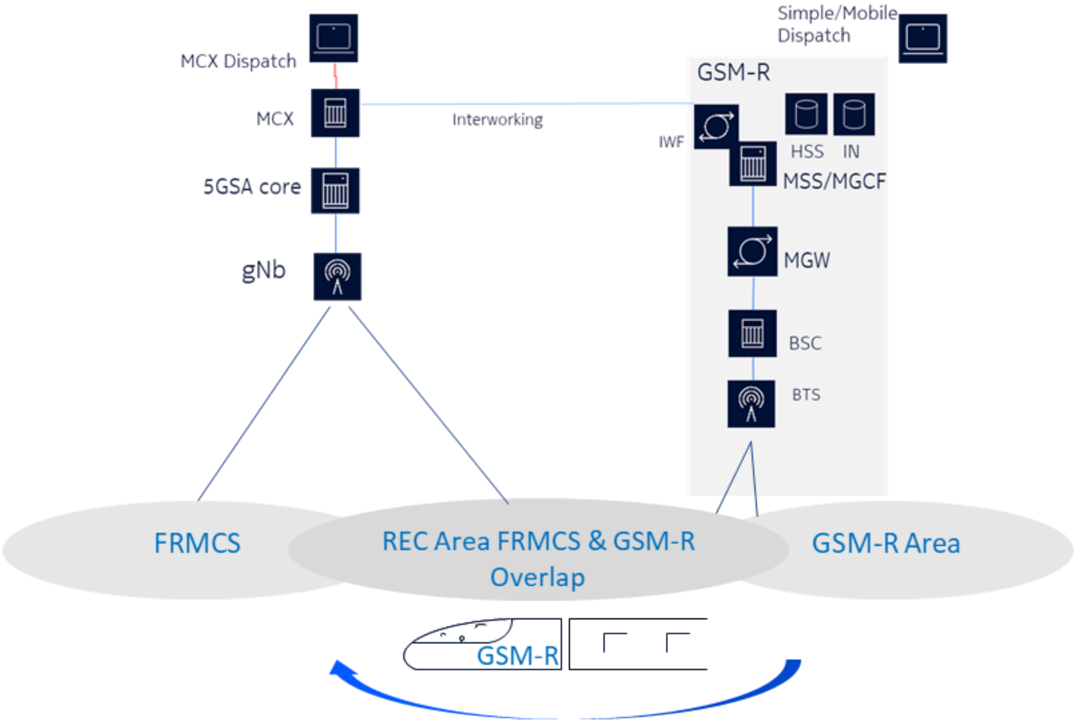


Figure 44: REC voice with GSM-R IWF for Border Crossing

The following table summarizes the different accomplished test cases which have validated steps towards FRMCS border-crossing scenarios that need to be enhanced in the future:

Application_TC_ID	Configuration	Description, Relevance for Border-Crossing & Status	FRMCS Principles/MCX features
Voice_015 (DE)	Cab radio and application provided by Siemens 5GS, MCX server, MSS, IWF and dispatcher provided by Nokia On-Board Gateway (TOBA-K) provided by Kontron n78 TDD band	Test Case Title: GSM-R to FRMCS system transition with service continuation BX Relevance: It is considered as a network transition GSM-R – FRMCS use case that will happen often during the migration period, either between countries or inside various regions of the same country. Status: Test performed in WP3 lab and field, in testbed in Germany.	**Interworking**: CAB radio connected to GSM-R receives the technology spanning REC call, initiated in the FRMCS system. **Network trigger:** Manual Switching of the Cab radio **Pre-configuration / Pre-affiliation of the MCX group call**: on the FRMCS side to allow the CAB radio to apply standard Late Join functionality.

ETCS_WP4-WP5_TC_003 (FR)	ETCS/ATO applications provided by Alstom. 5GS, MCX server, On-board (TOBA-K) and TS Gateway provided by Kontron. n39 TDD band with ES3 modem protype in 31dBm	Test Case Title: Communication in level 2 between ETCS onboard application and RBC – Test Procedure 3: RBC handover on a different 5G network: Cross-border use case BX Relevance: Early-stage assessment of border-crossing implementation with 2UEs, ensuring service continuity for ETCS application. Status: Test performed in WP4 lab and field, in testbed in France.	**Service continuity** required for ETCS/ATO: using 2UEs. **Multi-connectivity feature**: (5G to 5G or 5G to 4G and vice-versa): applied to border crossing. **Implementation with 2UEs:** Modem configuration with primary and secondary link (only one path active at the same time) or simultaneous connection to both networks (both paths active at the same time. Based on the MPTCP protocol)
Video_TC_004 (DE)	Video application provided by Teleste. Cab radio and application provided by Siemens. 5GS, MCX server, provided by Nokia. On-Board Gateway (TOBA-K) and TS provided by Kontron. n78 TDD band	Test Case Name: Cross-border with streaming of video/voice from train to trackside, using inter-gNodeB handover over AMF. BX Relevance: Assessment of control plane procedures in **Inter-gNB inter-AMF handover** as relevant part of an **5G SA Inter-Core cross-border scenario**, using NG/N14 interface. Hereby the transition occurs from the source 5G Core (AMF1) to the target 5G Core (AMF2). Notably, throughout this operation, session management remains within the source 5G Core (SMF1 and UPF1).Only one IP address is used, as if it was one PLMN, although there are two 5G cores implemented. PLMN2 was emulated, means it is treated as the same network. It is an important subfunction of an envisaged Inter-PLMN 5G Handover scenario. Status: Test performed in WP3 lab, but not performed in field (due to lack of stable specifications and readiness of field-equipment at the	**Inter-gNB inter-AMF handover over N14:** Evaluation of an important step of inter-PLMN 5GSA handover **Service continuity with 1UE**

		time of planning of the field test cases).	

Table 1: Border-crossing field test cases

7.1 Border-crossing investigations and future perspectives

Border crossing is part of the network transition specifications activity, encompassing Inter-FRMCS Domain transition as well as transition between GSM-R and FRMCS, that will be required during the migration period (2027 – 2035). It worth mentioning that both scenarios are valid inside a country or between countries.

There are two procedures that mainly intervene in border-crossing, as presented in the below figure:

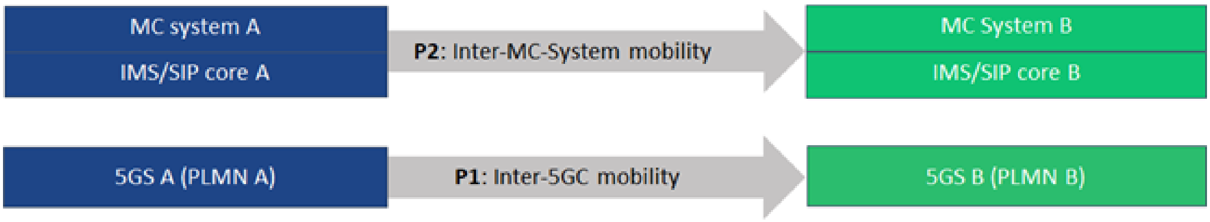


Figure 45: Procedures involved in border-crossing. (Ref. §9 [39])

Two solutions are envisaged for Inter-5GC mobility, as per 3GPP specifications approach:

- Inter-PLMN HO: Handing over the ongoing transport session (5G PDU session).
- Network Reselection: which consists of 1) dropping the ongoing transport session in PLMN A, 2) registering to PLMN B, 3) establishing a new transport session in PLMN B.

As per 3GPP specifications approach, there is a single solution for Inter-MC-System mobility, which is an ongoing specification and developing work in Rel.18 (there are no solution to date)

- MC Migration: which consists of 1) dropping of the ongoing service session, 2) registering the service user in the MC system B, 3) establishing a new service session to the MC system B.

The future projects testing will need to focus on the validation of available implementation of these two procedures. The MC migration is of particular interest for testing as 3GPP specifications are not even today available; therefore, the labs and field architecture set-up were limited to one MCX server.

Some topics closely related to border crossing, currently in the scope of specifications WGs are:

a) Triggering of network transition with potential information of target technology and target FRMCS transport domain

b) transfer of location information to tight coupled applications (e.g. voice)

c) usage of auxiliary function for network transition

d) behaviour of applications in border crossing conditions (e.g. service continuity is mandatory for ETCS but not for voice applications)

Once the FRMCS V2 specifications are in stable version, the performance of the implementation solutions needs to be tested to evaluate the performance of them during the MORANE 2 campaigns. In the meantime, the 2 active UEs shall be defined in FRMCS V2 for ETCS trains.

8 CONCLUSIONS

The purpose of D1.4, as defined in the GA was to analyse the observations and outcomes of field testing in the framework of WP5 in Germany and France. This is a complementary validation to the lab testing conclusions with the intention to improve FRMCS V1 specifications, and targeting the next step, which is FRMCS V2 specifications. This purpose was successfully achieved. For Railways it is important that any such concept is validated in field tests – 5GRAIL was a first such step, next step being MORANE-2 European trail for FRMCS. The field testing was also an opportunity to assess some ideas of performance methodology in real environment conditions, reminding that the performance methodology and the precise definitions of KPIs per application is a starting and complex activity for FRMCS. It was also delivering valuable lessons learnt on e.g. how to anticipate sites preparation, human resources planning in a multi-company collaboration, remote connexions, evaluate separately the behaviour of each equipment to ensure a successful result.

Field testing outcome of 5GRAIL is an important contributor for future FRMCS field testing projects with identified topics that need to be further tested, especially with an evolved version of specifications. A non-exhaustive list of them is proposed below:

- Recommendations of a radio environment suitable for FRMCS
- Evaluate impact of lack of coverage for some MCX procedures
- Location and positioning
- Border crossing (with a complete transport and service mobility implementation)
- Recommendations on trackside architecture
- Recommendations on QoS (considering dynamic QoS handling and high-speed trains impact)
- n101 band modem capabilities first evaluation

9 REFERENCES

id	DOCUMENT TITLE	REFERENCE, VERSIONS
[1]	FRMCS User Requirements Specification,	FU-7100
[2]	FRMCS Use cases	MG-7900
[3]	FRMCS Functional Requirement Specification (FRMCS FRS)	FU- 7120
[4]	System Requirements Specification (FRMCS SRS)	AT- 7800 v1.0
[5]	Study on Future Railway Mobile Communication System, Stage 1 (Release 16 & Release 17)	3GPP TR22.889 V17.4.0 3GPP TR22.889 V16.6.0
[6]	Technical Specification Group Services and System Aspects, Mission Critical Services over 5G System, Stage 2 (Release 17)	3GPP TS 23.289 V1.0.0
[7]	Technical Specification Group Services and System Mission Critical Services Common Requirements (MCCoRe) Stage 1 (Release 17)	3GPP TS 22.280 V17.4.0
[8]	Technical Specification Group Services and System Aspects Mission Critical Push to Talk (MCPTT) Stage 1(Release 17)	3GPP TS 22.179 V17.0.0
[9]	Technical Specification Group Services and System Aspects Mission Critical Data services Release 16	3GPP TS22.282 V16.4.0
[10]	Group Services and System Aspects Security of the Mission Critical (MC) service (Release 17)	3GPP TS 33.180 V17.2.0
[11]	Technical Specification Group Services and System Aspects System architecture for the 5G System (5GS) Stage 2(Release 17)	3GPP TS 23.501 V17.0.0
[12]	Technical Specification Group Services and System Aspects. Mobile Communication System for Railways Stage 1(Release 17)	3GPP TS22.289 V17.0.0

[13]	Technical Specification Group Services and System Service requirements for the 5G system Stage 1 (Release 18)	3GPP TSTS22.261 V18.2.0
[14]	ETSI- Study on FRMCS System Architecture	ETSI TR 103 459 V1.2.1 (2020-08)
[15]	ETSI-GSM-R/FRMCS Interworking	ETSI TR 103 768 V0.0.4 (2021-062)
[16]	D2.1 TOBA Architecture report	REV3 – 31/01/2023
[17]	D3.1 First Lab Integration and Architecture Description	13/09/2021 – v1 31/03/2022 – v2
[18]	D4.1 Second Lab Integration and Architecture Report	14/09/2021 – v1 25/03/2022 – v2
[19]	Grant Agreement number: 951725 — 5GRAIL — H2020-ICT-2018-20 / H2020-ICT-2019-3	
[20]	D3.2 First Lab Setup Report	28/02/2022 - v1 30/06/2022 – v2
[21]	D4.2 Second Lab Setup Report	25/02/2022 – v1
[22]	Functional Interface Specification	FIS – 7970
[23]	Form Fit Functional Interface Specification	FFFIS-7950
[24]	ERTMS/ETCS GSM-R Bearer Service Requirements	Subset 093 – v4.0.0
[25]	Radio Transmission FFFIS for EuroRadio	V13.0.0
[26]	Subset-037	v3.2.0
[27]	Functional architecture and information flows to support Mission Critical Push to Talk (MCPTT); Stage 2 - (Release 17)	3GPP TS 23.379 v17.8.0
[28]	Mission Critical Push To Talk (MCPTT) media plane control; Protocol specification	3GPP TS 24.380 v17.6.0

[29]	Subset 126 – Appendix A	Issue: 0.0.10
[30]	D1.1 Test plan	RV4
[31]	D4.3 Second Lab Test report	RV2
[32]	Technical Specification Group Services and System Mission Critical Services Common Requirements, Stage 2 (Release 17)	3GPP TS23.280 v17.9.0
[33]	Technical Specification Group Core Network and Terminals Mission Critical Data (MCData) signalling control Protocol specification (Release 17)	3GPP TS24.282 v17.9.0
[34]	Technical Specification Group Core Network and Terminals. Mission Critical Push To Talk (MCPTT) call control; Protocol specification (Release 17)	3GPP TS24.379 v17.11.0
[35]	Technical Specification Group Services and system Aspects; Policy and charging control framework for the 5G System (5GS) Stage 2 (Release 17)	3GPP TS23.503 v17.9.0
[36]	Cross-Working Group Work Item: Network Reselection Improvements (NRI) – 5GAA Automotive Association Technical Report	V1.0
[37]	D3.3 First Lab Test report	RV2
[38]	Ericsson White Paper	GFTL-22:000375 Uen March 2022
[39]	FRMCS Border Crossing.	5GRAIL Final Conference Presentation by Sara Akbarzadeh.
[40]	Procedures for the 5G System (5GS); Stage 2 (Release 17)	3GPP TS23.502 v17.11.0
[41]	D1.3 FRMCS Performance measurement methodology	RV1
[42]	D2.4 TOBA Test Report	RV1
[43]	D5.1 Test Results on Field Trials on FRMCS Functions and Performance	RV1

[44]	D5.2 Test results on Field Trials for Cross-Border Scenarios	RV1
[45]	D1.2 Test report conclusion from real-world environment	RV1

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