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Deliverable D4.3

Second Lab Test Report

5GRAIL

5G for future RAILway mobile communication system

D4.3 Second Lab Test Report V2

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0.1	12/04/2022	Draft Version
1.0	05/05/2023	Version 1 of D4.3 integrating comments from Consortium. Version submitted.
2.0	20/12/2023	Version 2 of D4.3 taking into account reviewers comments after 15/09/2023 project interim review. Following points have been taken into account (same order as remarks received from project reviewers): 1/ ATO end to end KPI related to delay has been added in section 3.2 2/ Reason why cross-border tests have been done with 2 UEs appears in section 4.4.2 3/ PIS tests explaination on KPI targets have been added, mentionning that the delivery time of a PIS message should be less than 7s, PIS being considered as a non-critical application. See chapter 5. 4/ Discussion on group calls management when interworking between GSM-R and FRMCS is inserted in 6.2 5/ Electronic air gap example of delay impact is added in 6.3.1.1 6/ ETCS KPIs have been added in chapter 4 with a general comment in section 4.1. ETCS KPI based on RTD. Graphs added for all tests. 7/ Objectives of “TOBA-K tests on 5G N39 band” are given in section 2.1 8/ Cross-border tests with ETCS have been updated with measurements. Dedicated section created, see 4.4 9/ Explaination on why two 5G networks could not be used with the TOBA-K cross-border tests is given in 4.4.2.24.4.2.2 10/ Update of multi-connectivity test with TOBA-K in section 4.4.2.2

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Executive Summary

The main purpose of this deliverable is to provide the reader with a report on the end to end tests defined by 5GRAIL WP1 team for WP4 lab experiments. The focus mostly dealt with some data applications that are of utmost importance for the future, namely ETCS and ATO, with the objective of achieving related FRMCS end to end communications when using on-board and trackside gateways prototypes and taking benefit from their features. Expected results from these tests were on one hand to be able to provide feedback on FRMCS v1 specifications in order to underline points of concerns and trigger enhancements, and, on the other hand, to perform some measurements that could give rough insights at this stage of the mock up where many prototypes stand at an early development phase.

Tests with ATO, ETCS and PIS FRMCS compliant applications were executed as expected by WP1 work package and are reflected in sections 3, 4 and 5 of this document. It includes tests with FRMCS gateway on N39 railways specific 5G band. These tests enabled to provide a good feedback on ways to improve procedures and timers whenever team faced integration issues. This was then a first valuable output for WP4 members and this is used to fuel D1.2 delivery [S25] “Test report conclusion from simulated/lab environments”. Besides, values of some KPIs are also given in these chapters in order to give insight on the measurements, keeping in mind that all bricks of WP4 labs have to be taken as prototypes.

Yet, as this report is also the last delivery the Work Package 4, it surely makes sense to mention and detail all other tasks we had to accomplish, with some suggestions for future works whenever we could. Namely, these activities dealt with TOBA performance evaluation, WP5 preparation and derisking (chapters 2 and 7), Cybersecurity topics (section 6.3) and optional tests we could run (chapter 6), looking for that our work could be useful for next FRMCS experimentations to come.

Finally, all Work Package members would like to stress the very good cooperation spirit that went along these past two years, pointing out that involved companies, sometimes competitors, have fully collaborated on shared actions. This clearly lead to a good team spirit that helped achieving major technical results, later recognized as a major innovative step ahead in the numerous meetings, advisory boards and conferences WP4 took part in.

Abbreviations and Acronyms

Abbreviation	Description
3GPP	3rd Generation Partnership Project
5G NSA	5G Non StandAlone
5G SA	5G StandAlone
ANSSI	Agence Nationale de la Sécurité des Systèmes d'Information
API	Application Programmable Interface
AS	Application Server
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATSSS	Access Traffic Steering, Switching and Splitting
BBU	Base Band Unit
BIOS	Basic Input Output System
BSC	Base Station Controller
BTS	Base Transceiver Station
CAM	Connected and Automated Mobility
CCS	Control Command and Signalling
CCTV	Closed Circuit TeleVision
CP	Control Plane
CPU	Central Processing Unit
CSCF	Call/Session Control Functions
CSFB	Circuit Switched Fall Back
DC	Direct Current
DMI	Desktop Management Interface
DMZ	Demilitarized Zone
DN	Domain Name
DNS	Domain Name System
DRCS	Data Radio Communication System

DSD	Driver Safety Device
E2E	End To End
EDOR	ETCS Data Only Radio
ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
EU	European Union
EVC	European Vital Computer
FDD	Frequency Division Duplexing
FFFIS	Form Fit Functional Interface Specification
FIS	Functional Interface Specification
FRMCS	Future Railway Mobile Communication System
FRS	Functional Requirements Specification
FW	Firewall
GA	Grant Agreement
GBR	Guaranteed Bit Rate
GCG	Ground Communication Gateway
GNSS	Global Navigation Satellite System
GoA	Grade of Automation
GRE	Generic Routing Encapsulation (RFC8086) -> Tunnel GRE
GTW or GW	GaTeWay or GateWay
HDMI	High Definition Multimedia Interface
HLR	Home Location Register
H2020	Horizon 2020 framework program
HSS	Home Subscriber System
HW	Hardware
IMPI	IP Multimedia Private Identity
IMPU	IMS Public User Identity
IMS	IP Multimedia Subsystem
IP	Internet Protocol

IWF	Inter Working Function
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LAN	Local Area Network
LED	Light Emitting Diode
LTE	Long Term Evolution
MCC	Mobile Country Code
MCG	Mobile Communication Gateway
MCPTT	Mission Critical Push To Talk
MCx	Mission Critical Voice/Data/Video
MGW	Media Gateway
MIMO	Multiple Input Multiple Output
MMI	Man Machine Interface
MNC	Mobile Network Code
MNO	Mobile Network Operator
MPTCP	MultiPath Transmission Control Protocol
MQTT	Message Queuing Telemetry Transport
N3IWF	Non-3GPP Inter Working Function
NR	New Radio
NSA	Non-Stand Alone (5G Core architecture)
OAM	Operation Administration Maintenance
OB	On Board
OB_GTW	On-Board Gateway
OBA	On-Board Application (e.g. ETCS on-board, ATO on-board)
OBU	On-Board Unit
OM	Operation & Maintenance
OMC	Operation & Maintenance Centre
OTA	Over The Air
OTT	Over The Top

PCB	Printed Circuit Board
PCRF	Policy and Charging Rules Function
PCU	Packet Control Unit
PDN	Packet Data Network
PIS	Passenger Information Service
PSS	Process Safety System
PTT	Push To Talk
QoS	Quality Of Service
RAM	Random Access Memory
RAN	Radio Access Network
RAT	Radio Access Technology
RBC	Remote Block Centre
REST	REpresentational State Transfer
RPC	Remote Procedure Call
RF	Radio Frequency
SA	Stand Alone (5G Core architecture)
SDWAN	Software-Defined Wide Area Network
S-CSCF	Servicing-CSCF (Correspondence IMPU - @ IP)
SIM	Subscriber Identity Module
SIP	Session Initiation Protocol
SMA	Subminiatures version A, type of coaxial RF connectors
SRS	System Requirements Specification
TCMS	Train Control Management System
TCN	Train Communication Network
TCU	TransCoder Unit
TFT	Traffic Flow Template
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
UP	User Plane
URLLC	Ultra-Reliable Low-Latency Communications (5G)
URS	User Requirements Specification
VPN	Virtual Private Network
WP1	Work Package 1
WP2	Work Package 2
WP3	Work Package 3
WP4	Work Package 4
WP5	Work Package 5

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1 INTRODUCTION

5Grail Work Package 4 activities lasted for about two years and the related lab was used for many purposes throughout the project. While appendix 10.1 will provide the reader with a detailed view of WP4 planning, it is worth summarizing the various WP4 tasks that had to be completed in order to get the full picture of this work package.

Firstly, WP4 team had to **put in place the lab in Montigny Kontron's headquarters**, France. This activity is described in delivery D4.1 [S20] and consisted in:

- Installing a 5G SA infrastructure (Core and Access) with 3 NR bands to be used (N8, N39, N78) knowing that N39 RU is a prototype that had to be designed and manufactured especially for this project,
- Integrating an IMS network with a MCx Application Server in order to provide MCDATA kind of service as well as MCPTT,
- Installing 4G infrastructure with band B38 for bearer-flex and an Wifi access point for convenience (to be used during some debugging activities),
- Connecting IMS/MCx network to a GSM-R network in order to test voice interworking function between FRMCS and GSM-R,
- Installing Alstom ETCS and ATO equipment, Alstom FRMCS On-Board Gateway, also known as TOBA-A, as well as Alstom Trackside Gateway, in a secured room and connect them to Kontron's equipment described above (it has to be underlined that specific 5G and 4G equipment were dedicated to TOBA-A to ease Alstom engineers activities),
- Setting-up a secure VPN between Alstom equipment and Alstom sites so that Alstom engineers could work remotely on their devices without any restriction (considering nowadays cybersecurity constraints, this task should not be overlooked),
- Coordinating with Thales engineers in order to connect, through another VPN, PIS equipment that stayed in Thales premises with Kontron's WP4 lab,
- Installing Kontron FRMCS On-Board Gateway, also known as TOBA-K, as well as Kontron Trackside Gateway,
- Installing all necessary tools (protocol analysers, radio conditions emulation…),
- Integrating voice oriented equipment (5G SA smartphones, Next Generation Dispatcher)
- Setting-up an ergonomic radio network with RF cables and attenuators in order to ease connections and hand-over scenarios,
- Engineer and manage the whole IP network so that all needs coming from the partners could be fulfilled.

Secondly, WP4 team was involved in an **integration activity of WP2 hardware and software deliveries** as WP4 lab could be seen as the place to put all pieces altogether in order to check their correct interconnection (as shown on Figure 1: WP4 lab as a place for WP2 deliveries integration):

- Obapp integration between FRMCS On-Board applications software's with TOBA-A and TOBA-K,
- TSapp integration between FRMCS Trackside applications software's with FRMCS Trackside Gateways delivered by Alstom and Kontron,

- Pre-check and validation of 5G modems provided by Thales before their integration inside TOBA (especially with the ES3 flavour that used N39 for the very first time),
- Validation of basic 5G TOBA radio behaviour, and especially the N39 version of it.

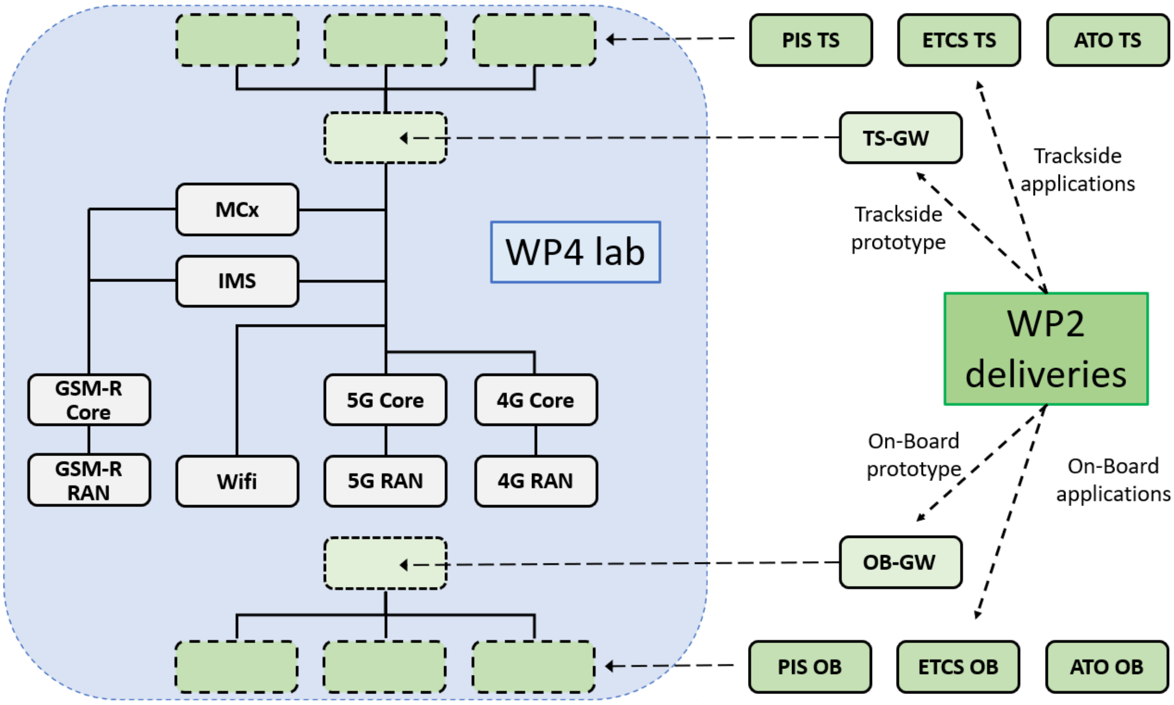


Figure 1: WP4 lab as a place for WP2 deliveries integration

Once these major steps had been achieved, WP4 was ready to **execute the test plan WP1 team had written for the second lab**. This core activity, also called Task 4.4, dealt with:

- ETCS, ATO and PIS end to end tests defined in D1.1 document [S22],
- Tests focusing on specific features (Multi-connectivity, QoS, Cross-Border scenario),
- Optional tests, that were considered in the 5GRAIL project grant agreement and that were mainly dealing with voice application and MCPTT,
- Optional tests that were introduced by WP4 team when they appeared to bring a plus to the project.

And last but not least, **WP4 had to prepare French WP5 activities** as a part of the lab was planned to be used for the field trials to be run with SNCF partner. In that perspective:

- The network had to be engineered for WP5 needs,
- A Remote Vision application had to be installed in the lab in order to derisk it,
- A VPN had to be established between Kontron's and SNCF's locations,
- The WP4 lab equipment move had to be carefully prepared in order to smooth this tricky step,
- Considering WP5 constraints (testing with trains had to be booked far in advance and cannot suffer planning changes), failover scenarios had to be considered in case of equipment failure,
- Continuity of service offered to WP2 teams should be guaranteed and planned.

Back to the delivery D4.3, it is reminded that 5GRail Grant Agreement defines its objective as follow:

"This document will provide a test report related to ETCS and ATO applications, PIS application as well as Voice application limited set as defined within WP1. It will provide as well a result of the tests related to the use cases described in the objectives of this WP. "
Even if the main task of this D4.3 deliverable is clearly to focus on the core test activity dealing with D1.1, it seems logical that it also reflects somehow the other parts of the important work that has been achieved by the team as it can be seen as a conclusion document for WP4 activities.

Having said that, and in order to ease the reading, here is an indication on document content and logic:

- Chapter 2 deals with some tests on TOBAs. These tests were done as soon as possible in order to evaluate basic performances knowing that the results could be useful later,
- Chapter 3 focuses on all tests done with ATO application,
- Chapter 4 is related to tests with ETCS,
- Chapter 54.3 gives details on PIS and its testing,
- Chapter 6 gathers all optional tests cases mainly linked with voice,
- and Chapter 7 sheds a light on WP5 preparation activities.

Some use cases and specific topics have been tested with several applications and, in order to have a quick access to them, they can be found in the following Table 1:

General Topic	Links in the document
QoS management	Sections 3.2.2, 3.2.3, 3.3.5, 3.3.6, 3.3.7, 4.2.5, 4.2.6, 4.3.7, 4.3.8, 5.2.7, 5.2.8, 5.2.9, 5.2.10 with global synthesis in chapter 8
Multiconnectivity	3.2.4, 3.2.5, 4.2.3, 4.2.4, 4.3.9, 4.4.2.2.1 with global synthesis in chapter 8
Cross-Border	4.2.5, 4.2.5, 4.2.6, 4.4.2.2.1, with global synthesis in chapter 8
Cybersecurity concerns	6.3 with conclusion in 6.3.3

Table 1: FRMCS important topics addressed in the document

Lastly, as this report is possibly targeted to a broad audience, a didactic approach has be chosen in each section. FRMCS concepts and technical details being explained when necessary in order to ease the reading and avoid as much as possible cross references between documents.

2 TOBA Performance Evaluation Tests

2.1 Introduction

Kontron's FRMCS On-Board Gateway version that supports 5G N39, also known as TOBA-K N39, has been received from WP2 around mid-September 2022. This TOBA is of course of top importance regarding 5GRail because it is the only TOBA of this project that will operate in a FRMCS band and also because it must be sent to WP5 for field tests.

Consequently, the very first task of WP4 was to evaluate the telecommunication performance of this gateway. In order to do that, we could tune some radio conditions such as:

- Attenuation level
- Fading and multipath profile
- Simulated Doppler effect reflecting train speed

The related tests appear in section 2.2. Some WP4 tests with TOBA in 5G band N8 were also scheduled by WP1 team and consequently, some basic tests were done in that band with TOBA-K and TOBA-A. These tests, that appear in section 2.3, only deal with throughput and latency measurement in a typical radio condition used for the tests.

Besides, it is reminded that N8 is using FDD mode whereas N39 is using TDD. Consequently, in N39, we had to choose a TDD pattern (number of uplink and downlink TS). In WP4 tests, we selected 2 uplink TS and 7 downlink TS. Reason is that in WP4, applications do not need huge data rates as described in PIS, ETCS and ATO dedicated chapters. WP5 France may use another configuration with 4 uplink TS for example, because Remote Vision application will be used during the tests.

<u>Note on the objectives of TOBA performance evaluation tests:</u>

The aim of these tests is to check the basic behaviour of the TOBA gateways. Focus is not on performance measurement because we are using early prototypes; one of 5Grail project objective is to develop prototypes, FRMCS gateways products being available later one, with performance assessmnet being the subject of other tests once industrial products will exist.

Yet, in order to ensure that WP4 tests could be run properly, we had to check the behaviour and stability of the TOBAs during basic scenarios. This was also of top importance considering WP5 tests. That's why if TOBA gateway appears reliable in terms of managing a HO, trafficking uplink or downlink… the related test could be considered as passed.

2.2 TOBA-K tests on 5G N39 band

2.2.1 TOBA-K HO intra gNodeB

<u>Notes on test execution:</u>

- In this test, we connect TOBA-K on a 5G N39 cell (Cell 1) and we start an iperf downlink session. The attenuation level in Cell 1 is adjusted so that pathloss reported to CD/DU is around 105 dB.
- There is also another 5G cell, Cell 2, which uses another RUs but which is on the same CU/DU.
- While the transfer is ongoing, by using a RF attenuator, we increase Cell 2 signal so that TOBA-K can now receive both RF signals. Note that attenuation level of Cell 2 remains high: it is adjusted so that pathloss level would be at 105 dB if TOBA was attached on it (see comment below).
- At one moment, attenuation of Cell 1 RF signal is increased so that an intra gNodeB HO will occur.

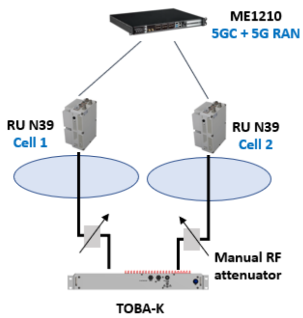


Figure 2: TOBA-K intra gNodeB HO test setup

<u>Comments:</u>

It is important to have a weak signal in Cell 2 when doing the HO from Cell 1 to Cell 2 as it reflects what may happen on field (as such HO will occur at cell edge). Path Loss of 105 dB is considered as a good level because of test 2.2.4 which shows that below this level, communication might be lost. We are consequently working in the worst case scenario.

<u>Conclusion:</u>

No issue was reported during this activity. Consequently, there was no restriction on tests implying intra gNodeB HO in WP4 or WP5.

2.2.2 TOBA-K HO inter gNodeB

<u>Notes on test execution:</u>

- This test is similar to 2.2.1 except that Cell 1 and Cell 2 are attached to different CU/DUs. Moving from Cell 1 to Cell 2 is then an inter-gNodeB HO.

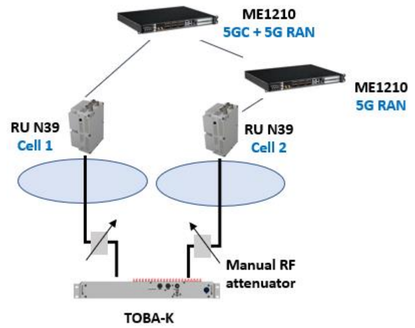


Figure 3: TOBA-K inter gNodeB HO test setup

Comments:

As in previous test, and for the same reasons, we aim at having RF conditions implying a Path Loss of 105 dB.

Conclusion :

No issue was reported during this activity. Consequently, there was no restriction on tests implying inter gNodeB HO in WP4 and WP5.

2.2.3 Total loss of radio. Reconnection

This test aims at checking TOBA-K behaviour when radio signal is completely cut for a while as this kind of situation might happen during WP5 field trials.

Notes on test execution:

- TOBA-K is attached on a 5G cell and launches a continuous ping. RF attenuation is adjusted so that Path Loss is around 105 dB.
- A continuous ping is launched from TOBA-K to P-CSCF.
- At one moment, RF signal is completely cut by increasing dramatically RF attenuation.
- This situation remains for a given period of time (**x** seconds)
- At date **t1** : Attenuation is then reduced to come back to the previous state.
- At date **t2**, ping traffic resumes. **t2-t1** is the duration modem needs to recover from the total loss of signal.
- Measurements are directly taken on TOBA-K console as ping command is horodated.

Comments:

- Test is done with several values of **x**. Considering what is to be expected on site, it was decided that **x** would be under 1 min, reflecting a temporary total loss that might encounter the train.

- Before and after the radio loss, RF signal is likely to be very low. That's the reason why a Path Loss of 105 dB is chosen (see test 2.2.4 to get an idea of this Path Loss level).

Conclusion:

Several values for the outage duration x were chosen : 10s, 30s and 1 min. Globally, in all the tests, recover value **t2-t1 is less than 35s**.

2.2.4 Iperf uplink test and Attenuation impact

This test helps to figure out what can be expect from TOBA-K N39 prototype in terms of uplink data rate according to the radio level it receives.

Notes on test execution:

- Iperf server service is started on a Trackside Gateway
- an Iperf session of 100 seconds is launched on TOBA-K
- In order to get a reference for attenuation level, which depends on many parameters (RF cables used, attenuators…), we can look at the CU/DU information that gives the Path Loss level for a specific UE, and we adjust attenuation in order to meet a specific Path Loss value.

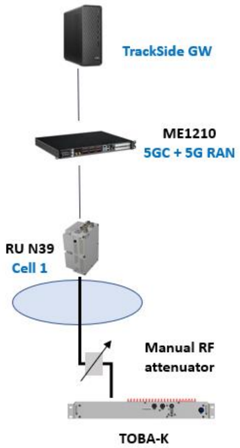


Figure 4: TOBA-K throughput performance evaluation test setup

Comments:

- Test is done with several values of Path Loss.

Conclusion:

Test result is shown on table below:

Path Loss (dB)	Uplink Data Rate (kb/s)	Jitter (ms)
66	2780	2.6
76	1200	6.7
86	880	9.1
96	830	9.2
106	660	12.4
115	Communication Lost	

Table 2: Uplink data rate according to Path Loss with TOBA-K on N39

We can see that communication might be lost when Path Loss is greater than 106 dB. In that case, with the TDD configuration chosen in WP4 (7 DL slots and 2 UL slots), we could reach a data rate of 660 kbits/s.

Note that more UL slots can be configured if needed. In WP4, data rates of applications remain low and 2 UL slots are enough. WP5 France could use different UL slots given the fact that they are using a remote vision application, quite demanding in UL bandwidth, once they have performed their first radio performance evaluation tests.

2.2.5 Iperf downlink test and Attenuation impact

This test helps to figure out what we can expect from TOBA-K N39 in terms of downlink link data rate according to the radio level it receives. Test setup is similar to the one of 2.2.4.

Notes on test execution:

- Iperf server service is started on TOBA-K
- an Iperf session of 100 seconds is launched on a Trackside Gateway
- In order to get a reference for attenuation level, which depends on many parameters (RF cables used, attenuators…), we can look at the CU/DU information that gives the Path Loss level for a specific UE, and we adjust attenuation in order to meet a specific Path Loss value.

Comments:

- Test is done with several values of Path Loss.

Conclusion:

Test result is shown on table below:

Path Loss (dB)	Downlink Data Rate (Mb/s)	Jitter (ms)
52	45,5	0,1
62	45,5	0,1
72	44,3	0,5
81	44	0,7
91	43,2	0,6
98	23,9	0,6
102	8,4	0,8
113	Communication Lost	

Table 3: Downlink data rate according to Path Loss with TOBA-K on N39

2.2.6 Iperf uplink with speed and fading impact

This test aims at checking simulated speed and fading impact on uplink data rate. For this test, we use a Vertex simulator tool.

Notes on test execution:

- The following RF propagation model is used on the Vertex:

Path	Fading Type	Relative Path Loss (dB)	Delay mode	Delay value (µs)
1	Rayleigh	4	Fixed	0
2	Rayleigh	3	Fixed	0.2
3	Rayleigh	0	Fixed	0.4
4	Rayleigh	2	Fixed	0.6
5	Rayleigh	3	Fixed	0.8
6	Rayleigh	5	Fixed	1.2
7	Rayleigh	7	Fixed	1.4
8	Rayleigh	5	Fixed	1.8
9	Rayleigh	6	Fixed	2.4
10	Rayleigh	9	Fixed	3
11	Rayleigh	11	Fixed	3.2
12	Rayleigh	10	Fixed	5

  It corresponds to the profile “TUx 12 tap” defined by 3GPP TS 05.05 in its section C3.3.
  We have chosen this profile as it corresponds to a rural area, knowing that WP5 tests in France will be run in such an environment and keeping in mind that WP4 activities must, as much as possible, contribute to WP5 derisking.
  We can see here that the tool simulates the existence of 12 paths for each emitted RF signal, each path having a fixed delay value and relative path loss with Rayleigh fading model.
- Test consists in launching Iperf client on TOBA-K while Iperf server runs on Trackside Gateway, objective being to record uplink throughput when changing simulated speed when path loss condition has been adjusted to 105 dB (measured at the CU/DU).
- Speed is changed from 10 to 50 km/h. For each speed value, an Iperf session of 100 seconds is launched. We do not consider higher train speeds as WP5 runs use this range.

Comments:

- Choice of "TUx 12 tap" profile looks relevant as WP5 tests will occur in urban area.
- Speed values remains under 50 km/h as WP5 test train is expected to run below this limit.
- Path Loss level corresponds to the limit beyond which modem might quickly loose connection (see test 2.2.4). So only worst case is considered.

Conclusion:

Idea behind this test was to check whether speed could have an impact on uplink data rate when speed remains low. Test result show no impact for the different speeds:

Path Loss (dB)	Fading Model	Speed (km/h)	Uplink Data Rate (kb/s)	Jitter (ms)
105	GSM TU 12 path	10	320	23.6
105	GSM TU 12 path	20	320	25.5
105	GSM TU 12 path	30	290	28.8
105	GSM TU 12 path	40	300	25.8
105	GSM TU 12 path	50	280	24.8

Table 4: Impact of speed on Uplink data rates

2.2.7 Iperf downlink test with speed and fading impact

This test is similar to previous test 2.2.6 but, this time, a downlink Iperf session is launched.

- Vertex is configured with the same RF propagation than the one used for test 2.2.6.
- Test consists in launching Iperf server on TOBA-K while Iperf client runs on Trackside Gateway, objective being to record downlink throughput when changing simulated speed when path loss condition has been adjusted to 105 dB (measured at the CU/DU).
- Speed is changed from 10 to 50 km/h. For each speed value, an Iperf session of 100 seconds is launched.

Conclusion:

Idea behind this test was to check whether speed could have an impact on downlink data rate when speed remains low. Test result show no impact for the different speeds:

Path Loss (dB)	Fading Model	Speed (km/h)	Downlink Data Rate (kb/s)	Jitter (ms)
105	GSM TU 12 path	10	7 700	1.9
105	GSM TU 12 path	20	7 560	2
105	GSM TU 12 path	30	7 610	2.1
105	GSM TU 12 path	40	7 310	1,7
105	GSM TU 12 path	50	7 510	1,5

Table 1: Impact of speed on Downlink data rates

2.2.8 RTD measurement and RF attenuation impact

Objective of this test is to check whether attenuation might have an impact on the round trip delay.

Notes on test execution:

- In this test, RF attenuator is used in order to lower little by little the radio level received by the TOBA-K.
- Round trip delay is measured by pinging the P-CSCF.

Comments:

Ping is done towards the P-CSCF as it is the entry point of many procedures where delay matters (IMS registration for instance).

Conclusion:

Test result show no impact of attenuation on RTD:

Path Loss (dB)	RTD (ms)
68	52
78	47
88	50
97	50
105	45

Table 2: Results of RTD measurement test with RF attenuation

2.3 TOBA-K and TOBA-A 5G tests on N8 band

Some other basic connectivity tests have been also achieved on N8 with TOBA-K and TOBA-A. They are less important as these FRMCS OB Gateways are not involved in WP5 activities. Yet, it was considered that these basic performances recording may be helpful at some point and were then done in that perspective.

Due to RF cabling constraints (TOBA-K and TOBA-A are not in the same room) and the fact that RF devices used to achieve the connections with RUs N8 are different for TOBA-A and TOBA-K, TOBA-A has a low Path Loss (65 dB) whereas attenuation on TOBA-K is higher and leads to a Path Loss next to 95 dB, which is acceptable as the overall objective of this section is not to compare TOBAs performances, but rather to get a benchmark that may be used later.

2.3.1 TOBA-K N8 tests

All these tests were done with RF attenuation corresponding to a Path Loss of 95 dB at CU/DU.

2.3.1.1 Iperf Uplink test

TOBA-K is connected to N8 RU on ME1210_1. An uplink iperf session is launched with a Trackside Gateway. Iperf session duration is set to 100s.

Measurements are shown on following Table:

Uplink Data Rate (Mb/s)	Jitter (ms)
4,24	1,9

Table 3: TOBA-K Iperf Uplink test results on 5G N8

2.3.1.2 Iperf Downlink test

TOBA-A is connected to N8 RU on ME1210_1. A downlink iperf session is launched with a Trackside Gateway. Iperf session duration is set to 100s.

Measurements are shown on following Table:

Downlink Data Rate (Mb/s)	Jitter (ms)
16.6	0.67

Table 4: TOBA-K Iperf Downlink test results on 5G N8

2.3.1.3 Round Trip delay test

TOBA-K is connected to N8 RU on ME1210_1. 150 pings were launched towards the P-CSCF. Measurements are shown on the following Table:

RTD min (ms)	RTD avg (ms)	RTD max (ms)
37	64	96

Table 5: TOBA-K Round Trip Delay test results on 5G N8

2.3.2 TOBA-A N8 tests

All these tests were done with RF attenuation corresponding to a Path Loss of 68 dB at CU/DU.

2.3.2.1 Iperf Uplink test

TOBA-A is connected to N8 RU on ME1210_1. An uplink iperf session is launched with a Trackside Gateway. Iperf session duration is set to 100s.

Measurements are shown on following Table:

Uplink Data Rate (Mb/s)	Jitter (ms)
21,5	0,43

Table 6: TOBA-A Iperf Uplink test results on 5G N8

2.3.2.2 Iperf Downlink test

TOBA-A is connected to N8 RU on ME1210_1. A downlink iperf session is launched with a Trackside Gateway. Iperf session duration is set to 100s.

Measurements are shown on following Table:

Downlink Data Rate (Mb/s)	Jitter (ms)
42,2	0,25

Table 7: TOBA-A Iperf Downlink test results on 5G N8

2.3.2.3 Round Trip delay test

TOBA-A is connected to N8 RU on ME1210_1. 112 pings were launched towards the P-CSCF. Measurements are shown on the following Table:

RTD min (ms)	RTD avg (ms)	RTD max (ms)
22	27	40

Table 8: TOBA-A Round Trip Delay test results on 5G N8

2.4 WP4 radio settings regarding WP5 expected conditions

WP5 team has provided WP4 with some RF surveys of the three sites that were to be used during the French field tests (“Rives”, “Marin”, “Bourbonnais”). Snapshot from the RF tool used during this survey is shown below:

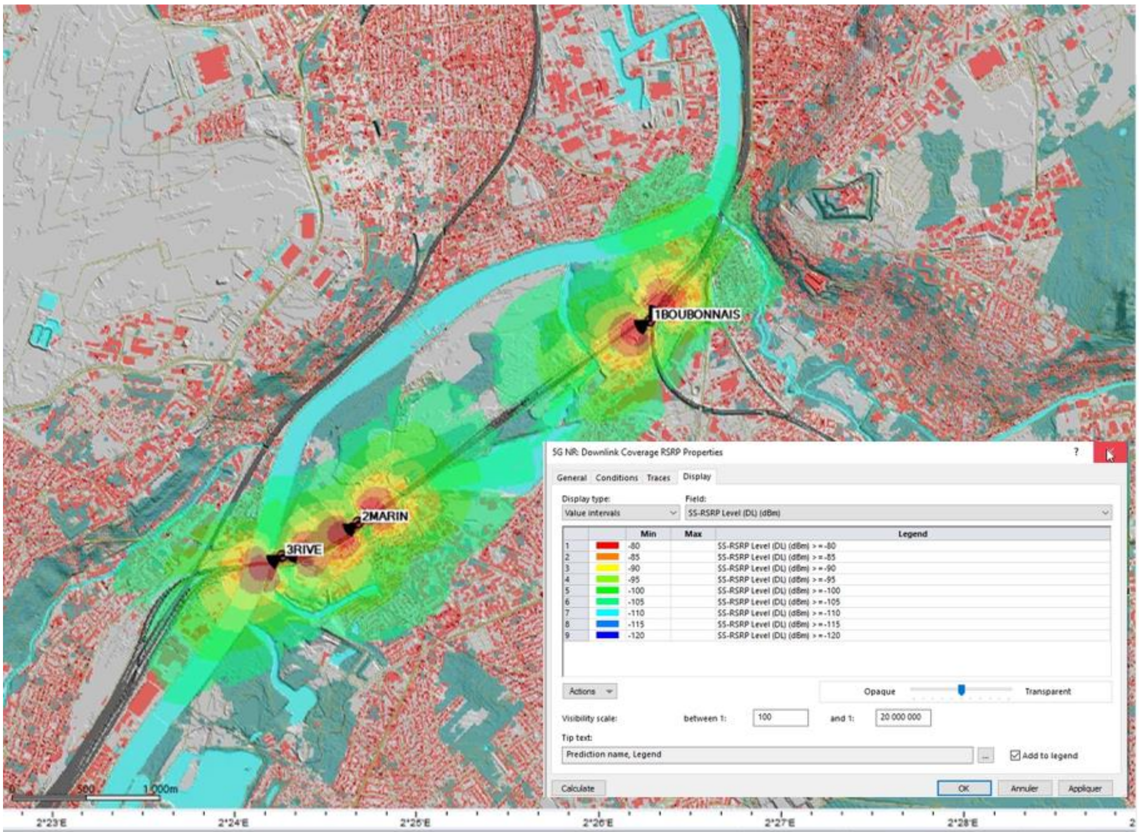


Figure 5: RF conditions analysis of WP5 French testing area

From this tool, RF engineers concluded that we should expect a path loss between TOBA and gNodeB around 70dB-80dB in areas with good radio propagation and around 100dB at cell edge. Adding attenuators in the setup, WP4 team was then able to adjust path loss accordingly for the different tests: in order to better match what we would face in WP5, path loss was set around 100dB for tests related to Handovers, around 70dB for all other tests.

Note: when gNodeB were installed in WP5 field area, first radio measurements were done with an ES3 N39 capable 5G Thales modem and path loss confirmed what had been predicted.

3 ATO Tests

3.1 Introduction to ATO tests

Automatic Train Operation (ATO) is a system that allows to automate the operation of trains. Grade of Automation (GoA) reflects the degree of automation: For example in Go3 the train does not need any driver on-board but a staff member is available to handle emergency situations, in Go4 the train is fully automatic. The ATO used in WP4 is GoA2 (Starting and stopping are automated using advanced train protection systems like ETCS).

ATO uses so called “Journey Profiles” that contains information about the driving behaviour of the train that must be taken into account. Journey Profiles are transmitted from the centralized ATO trackside system to the train and aim at informing about the optimal acceleration and breaking. On the other direction, On-Board ATO client responds with regular status reports.

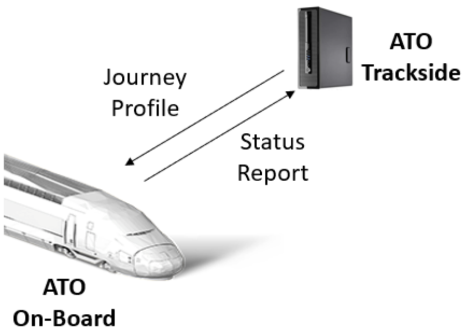


Figure 6: FRMCS ATO Application

The automation functions rely on up-to-date maps and segment profiles including geographical description of the relevant rail segments and environmental elements. At the beginning of the journey, the train obtains the latest version of all relevant maps and segment profiles (e.g. the track segment gradients, the track segment curvatures, the track segment maximum allowed speed, timing constraints etc.)., which will be crossed during the journey. Sometimes, relevant updates become available during the journey, for instance when destination is modified, which requires the download of further data.

It is required for the on-board part of the ATO (ATO-OB), which manages the automatic operation of the train, to exchange data with the ATO trackside part (ATO-TS) to retrieve this information about its journey. Two new software components have been developed and integrated into the ATO-OB and ATO-TS subsystems, respectively the OBApp and the TSApp, to be able to interface with the FRMCS systems and wirelessly communicate with each other.

We can see that ATO application is not a high bandwidth demanding one, needed data rates being roughly tens of kb/s.

3.2 ATO tests with TOBA-A

The following ATO tests have been done with TOBA-A:

Test Title	5G Band	OB-GW	Date
ATO in nominal and perfect lab conditions	N8	TOBA-A	02/12/2022
ATO in parallel with high uplink traffic generated by iPerf	N8	TOBA-A	27/01/2023
ATO in parallel with high downlink traffic generated by iPerf	N8	TOBA-A	27/01/2023
Bearer flexibility: 5G to 4G failover	N8	TOBA-A	27/01/2023
Bearer flexibility: 4G to 5G failover	N8	TOBA-A	27/01/2023

3.2.1 ATO in nominal and perfect lab conditions

- Objective of the test:

  This test aims at checking the good achievement of a FRMCS communication with ATO application using Alstom On-Board and Trackside Gateways.

- Test description:

  This test is described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.2. It consists in a basic ATO communication using FRMCS gateways and the 5G network.

- Test results and comments:

  Comments by Alstom

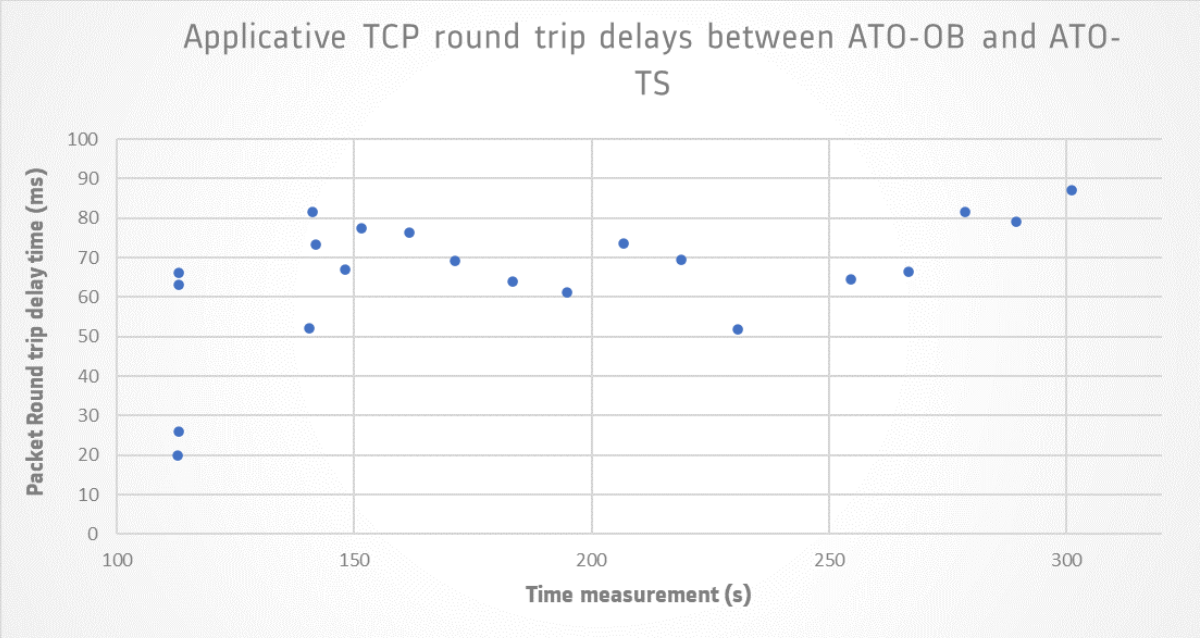
  At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

  The journey profile and segment profiles are properly received by the ATO-OB. Therefore, the requirements related to the trackside communication for the ATO to operate the train can be fulfilled using the FRMCS communication system.

  The following KPIs have been measured for this test:

  - (A) Handshake duration: 216ms
  - (B) Journey profile download duration: 3’618ms
  - (C) Segment profile download duration: 27’657ms
  - (D) Total time: 31’491ms

  An additional KPI was added in the post-analysis phase: the round trip delay of status report sent periodically from ATO-OB to ATO-TS. The following graph shows the values obtained for this test:



- (E) Status report RTD Mean: 65,26ms
- (F) Status report RTD Standard deviation: 16,77ms

As this test is the nominal case, those values will serve as comparison point for the following tests.

3.2.2 ATO in parallel with high uplink traffic generated by iPerf

- Objective of the test:
  This test aims at checking the good achievement of a FRMCS communication with ATO application using Alstom On-Board and Trackside Gateways when, at the same time, an high uplink traffic is done by another application on the TOBA-A.

- Test description:

  This test is described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.8.

- Test results and comments:

  Comments by Alstom

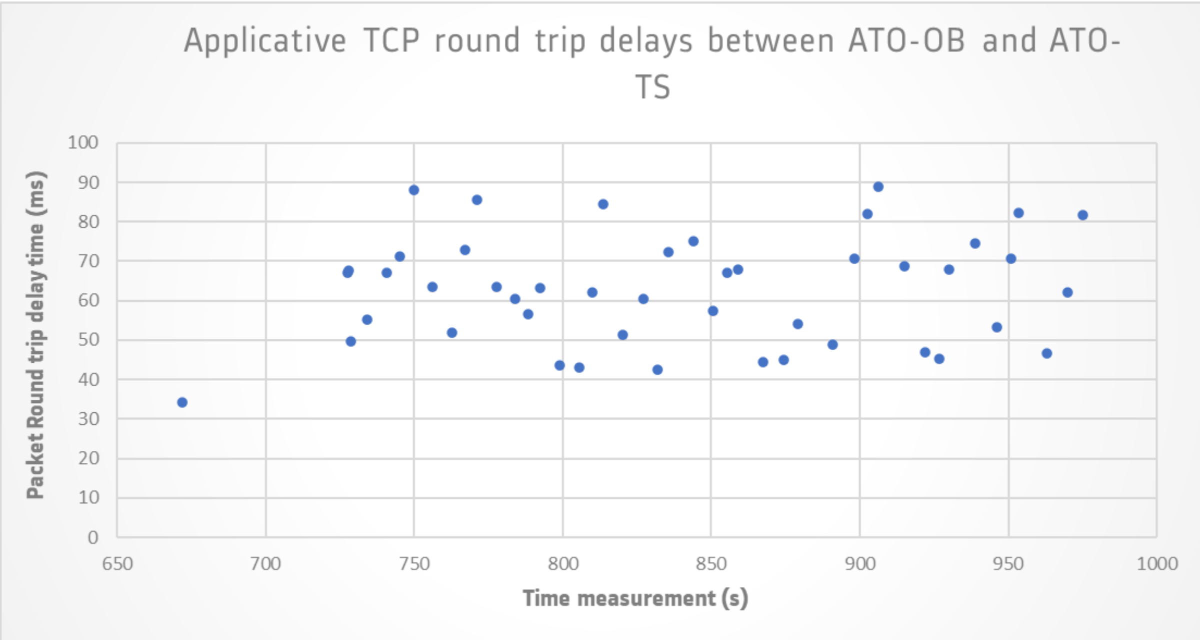
  At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

The journey profile and segment profiles are properly received by the ATO-OB. Therefore, the requirements related to the trackside communication for the ATO to operate the train can be fulfilled using the FRMCS communication system.

The following KPIs have been measured for this test:

- (A) Handshake duration: 353ms (+63.4 % wrt to nominal case)
- (B) Journey profile download duration: 116ms
- (C) Segment profile download duration: 68’637ms (+148.2 %)
- (D) Total time: 69’106ms (+119.4%)
  As expected, the high uplink traffic perturbates the ATO communication increasing the time needed to take all the information it needs to operate the train.

An additional KPI was added in the post-analysis phase: the round trip delay of status report sent periodically from ATO-OB to ATO-TS. The following graph shows the values obtained for this test:



- (E) Status report RTD Mean: 63,42ms
- (F) Status report RTD Standard deviation: 14,81ms

There is no impact compared with nominal conditions

3.2.3 ATO in parallel with high downlink traffic generated by iPerf

- Objective of the test:

This test aims at checking the good achievement of a FRMCS communication with ATO application using Alstom On-Board and Trackside Gateways when, at the same time, an high downlink traffic is done by another application on the TOBA-A.

- Test description:

This test is described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.9.

- Test results and comments:

Comments by Alstom

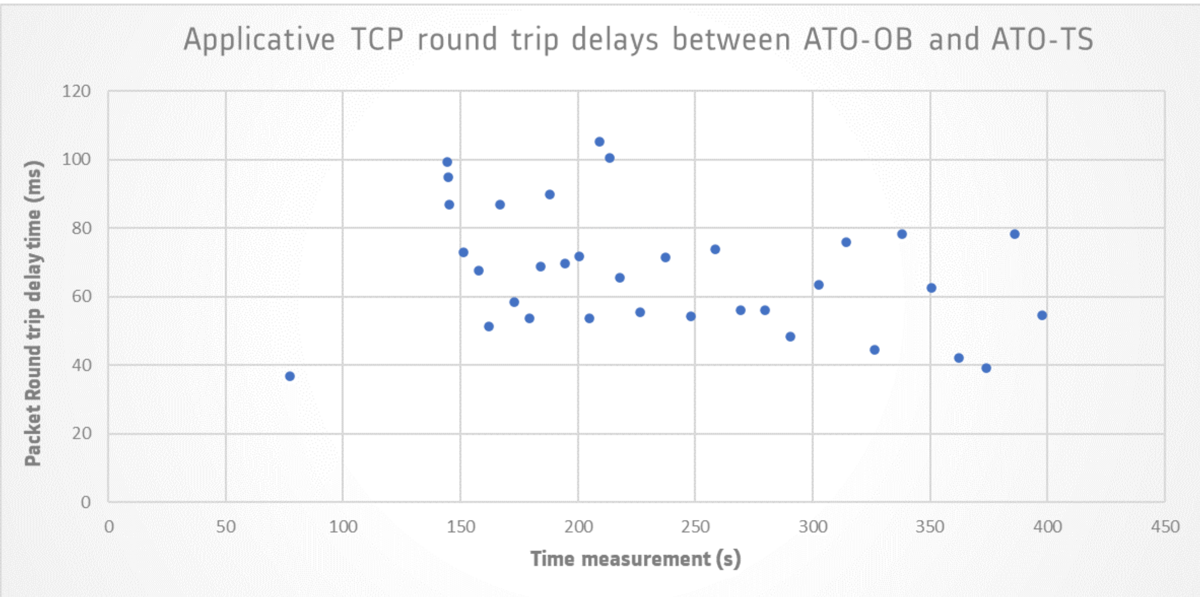
At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

The journey profile and segment profiles are properly received by the ATO-OB. Therefore, the requirements related to the trackside communication for the ATO to operate the train can be fulfilled using the FRMCS communication system.

The following KPIs have been measured for this test:

- (A) Handshake duration: 224ms (+3.7% wrt to nominal case)
- (B) Journey profile download duration: 212ms
- (C) Segment profile download duration: 468'686ms (+1589.3%)
- (D) Total time: 469'122ms (+1389.3%)
  As expected, the high downlink traffic perturbates the ATO communication increasing the time needed to take all the information it needs to operate the train.

An additional KPI was added in the post-analysis phase: the round trip delay of status report sent periodically from ATO-OB to ATO-TS. The following graph shows the values obtained for this test:



- (E) Status report RTD Mean: 67,26ms
- (F) Status report RTD Standard deviation: 18,06ms

3.2.4 Bearer flexibility: 5G to 4G failover

- Objective of the test:
  This test aims at checking the bearer flexibility feature that was available on TOBA-A in a failover mode. The objective is to run the ATO communication over a 5G connection only but as soon as a failure occurs on the 5G link (here, the radio link was cut), we expect TOBA-A to continue the same ATO communication over the 4G link as this one is available.

- Test description:

  This test is described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.6.1

- Specific Test configuration:
  TOBA-A configuration: one 5G modem and one 4G modem used for this test. The application profile used for ATO application is configured to use 5G modem as primary link and 4G modem as secondary link. Then, the 5G link is to be used as soon as it is available.
  Two MCdata-IPconn sessions are established (one per link) and TOBA-A/TS_GTW-A select the one to be used thanks to a monitoring signal and according to the configured priority.
  To simulate the failure of the 5G link, the radio wire was disconnected (optical fiber between RRH and BBU)

- Test results and comments:

  Comments by Alstom

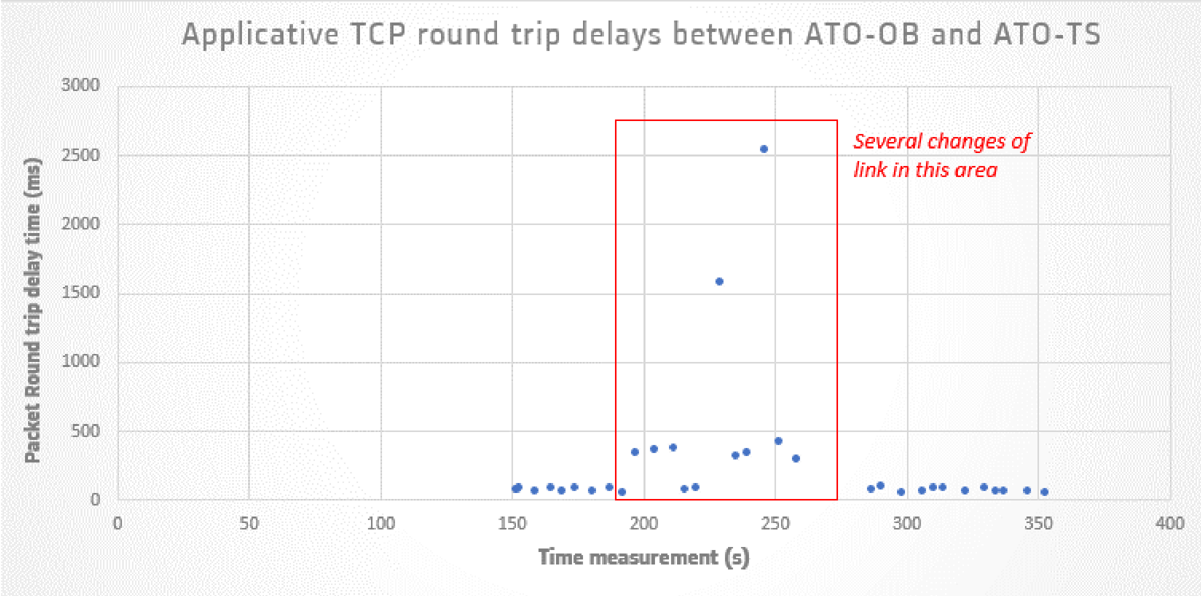
  At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

  The journey profile is properly received by the ATO-OB.

  The following KPIs have been measured for this test:

  - (A) Handshake duration: 303ms (+40.28% wrt to nominal case)
  - (B) Journey profile download duration: 102ms

  An additional KPI was added in the post-analysis phase: the round trip delay of status report sent periodically from ATO-OB to ATO-TS. The following graph shows the values obtained for this test:



- (E) Status report RTD Mean: 69,52ms if we do not consider the high values obtained during link switch
  The switch between links may increase the RTD obtained for regular status period during the transition period.

3.2.5 Bearer flexibility: 4G to 5G failover

- Objective of the test:
  This test aims at checking the bearer flexibility feature that was available on TOBA-A in a failover mode. The objective is to run the ATO communication over a 4G connection only but as soon as a failure occurs on the 4G link (here, the radio link was cut), we expect TOBA-A to continue the same ATO communication over the 5G link as this one is available.

- Test description:

  This test is described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.6.2

- Specific Test configuration:
  TOBA-A configuration: one 5G modem and one 4G modem used for this test. The application profile used for ATO application is configured to use 5G modem as primary link and 4G modem as secondary link. Then, the 5G link is to be used as soon as it is available.
  Two MCdata-IPconn sessions are established (one per link) and TOBA-A/TS_GTW-A select the one to be used thanks to a monitoring signal and according to the configured priority.
  To simulate the failure of the 5G link, the radio wire was disconnected (optical fiber between RRH and BBU)

- Test results and comments:

  Comments by Alstom

At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

The journey profile is properly received by the ATO-OB.

The following KPIs have been measured for this test:

- (A) Handshake duration: 303ms (+40.28% wrt to nominal case)
- (B) Journey profile download duration: 102ms

3.3 ATO tests with TOBA-K

The following table gives the list of ATO tests that have been executed with TOBA-K:

Test Title	5G Band	OB-GW	Date
ATO in nominal and perfect lab conditions	N39	TOBA-K	26/09/2022
ATO in degraded conditions, fading & varying speed	N39	TOBA-K	26/09/2022
ATO in nominal and perfect lab conditions with intra gNodeB HO	N39	TOBA-K	22/11/2022
ATO in nominal and perfect lab conditions with inter gNodeB HO	N39	TOBA-K	22/11/2022
ATO in parallel with high uplink traffic generated by iPerf	N39	TOBA-K	17/02/2023
ATO in parallel with high downlink traffic generated by iPerf	N39	TOBA-K	17/02/2023
ETCS onboard combined with ATO application	N39	TOBA-K	17/02/2023

Table 9: List of ATO tests cases executed with TOBA-K

3.3.1 ATO in nominal and perfect lab conditions

- Objective of the test:
  This test aims at checking the good achievement of a FRMCS communication with ATO application using Kontron On-Board and Trackside Gateways.

- Test description:

  This test is fully described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.2.

  This is a basic test of ATO connection over FRMCS.

- Test results and comments:

  Test is passed.

  Comments by Alstom

At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

The journey profile and segment profiles are properly received by the ATO-OB. Therefore, the requirements related to the trackside communication for the ATO to operate the train can be fulfilled using the FRMCS communication system.

The following KPIs have been measured for this test:

- (A) Handshake duration: 216ms
- (B) Journey profile download duration: 3618ms
- (C) Segment profile download duration: 27’657ms
- (D) Total time: 31’491ms

As this test is the nominal case, those values will serve as comparison point for the following tests.

Comments by Kontron

This test enabled us to test the Obapp and Tsapp interface between Kontron’s gateways and Alstom ATO FRMCS applications. Working on this test enabled Kontron’s engineers to understand link between IMS/MCx Registration durations and Obapp timers (as reported in [S25]). This test was also important in terms of WP5 activities derisking.

It should be also noticed that this test was the very first FRMCS end to end test ever done (ATO FRMCS application with FRMCS gateways over a 5G SA network using N39 band).

3.3.2 ATO in degraded conditions, fading & varying speed

- Objective of the test:
  This test aims at checking the good achievement of a FRMCS communication with ATO application using Kontron On-Board and Trackside Gateways when some perturbations are introduced with the Vertex tool.

- Test description:

  This test is fully described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.5.

  This is a basic test of ATO connection over FRMCS using radio propagation profile already used in section 2.2.6. The simulated speed was set to 50km/h. This set-up has been chosen to reflect as much as possible the expected conditions of WP5 France test run (urban area and limited speed as the train is not expected to run faster than 50 km/h).

- Test results and comments:

  Test is passed.

Comments by Alstom

At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

The journey profile and segment profiles are properly received by the ATO-OB. Therefore, the requirements related to the trackside communication for the ATO to operate the train can be fulfilled using the FRMCS communication system.

The following KPIs have been measured for this test:

- (A) Handshake duration: 227ms (+5.09%)
- (B) Journey profile download duration: 204ms
- (C) Segment profile download duration: 32’440ms (+17.24%)
- (D) Total time: 32’871ms (+4.38%)
  As expected, the fading slightly perturbates the ATO communication increasing the time needed to take all the information it needs to operate the train.

Comments by Kontron

We have not noticed any issue compared to the nominal test case 3.3.2. Consequently, we do not expect that WP5 conditions will prevent the ATO communication to be done successfully.

3.3.3 ATO in nominal and perfect lab conditions with intra gNodeB HO

- Objective of the test:
  This test aims at checking the good achievement of a FRMCS communication with ATO application using Kontron On-Board and Trackside Gateways when some intra gNodeB HO are done.

- Test description:

  This test is fully described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.3.

  This is a basic test of ATO connection over FRMCS where regularly, using RF signal attenuators, we trigger intra gNodeB HO. This test is important in terms of derisking because in WP5 tests runs several RUs may be used and intra gNodeB HO will occur.

- Test results and comments:

  Test is passed.

  Comments by Alstom

At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

The journey profile and segment profiles are properly received by the ATO-OB. Therefore, the requirements related to the trackside communication for the ATO to operate the train can be fulfilled using the FRMCS communication system.

The following KPIs have been measured for this test:

- (A) Handshake duration: 424ms (+96.3%)
- (B) Journey profile download duration: 212ms
- (C) Segment profile download duration: 27'895ms (+0.8%)
- (D) Total time: 28'531ms (+2.7%)
  Slight perturbations for the ATO communication increasing the time needed to take all the information it needs to operate the train.

Comments by Kontron

We have not noticed any issue compared to the nominal test case 3.3.2. Consequently, we do not expect that intra gNodeB HO will affect ATO communication during WP5 activities.

3.3.4 ATO in nominal and perfect lab conditions with inter gNodeB HO

- Objective of the test:
  This test aims at checking the good achievement of a FRMCS communication with ATO application using Kontron On-Board and Trackside Gateways when some inter gNodeB HO are done.

- Test description:

  This test is fully described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.4.

  This is a basic test of ATO connection over FRMCS where regularly, using RF signal attenuators, we trigger inter gNodeB HO.

- Test results and comments:

  Test is passed.

  Comments by Alstom

  At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

The journey profile and segment profiles are properly received by the ATO-OB. Therefore, the requirements related to the trackside communication for the ATO to operate the train can be fulfilled using the FRMCS communication system.

The following KPIs have been measured for this test:

- (A) Handshake duration: 229ms (+6.02%)
- (B) Journey profile download duration: 220ms
- (C) Segment profile download duration: 30’291ms (+9.51%)
- (D) Total time: 30’740ms (-2.39%)
  Slight perturbations for the ATO communication increasing the time needed to take all the information it needs to operate the train.

Comments by Kontron

We have not noticed any issue compared to the nominal test case 3.3.2.

3.3.5 ATO in parallel with high uplink traffic generated by iPerf

- Objective of the test:
  This test aims at checking the good achievement of a FRMCS communication with ATO application using Kontron On-Board and Trackside Gateways when, at the same time, an high uplink traffic is done by another application on the TOBA-K.

- Test description:

  This test is described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.8.

- Test results and comments:

  Comments by Alstom

  At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

  The journey profile is properly received by the ATO-OB.

  The following KPIs have been measured for this test:

  - (A) Handshake duration: 217ms
  - (B) Journey profile download duration: 229ms

  Comments by Kontron

  We have not noticed any issue compared to the nominal test case 3.3.2.

3.3.6 ATO in parallel with high downlink traffic generated by iPerf

- Objective of the test:
  This test aims at checking the good achievement of a FRMCS communication with ATO application using Kontron On-Board and Trackside Gateways when, at the same time, an high downlink traffic is done by another application on the TOBA-K.

- Test description:

  This test is described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.9.

- Test results and comments:

  Comments by Alstom

  At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

  The journey profile is properly received by the ATO-OB.

  The following KPIs have been measured for this test:

  - (A) Handshake duration: 111ms
  - (B) Journey profile download duration: 501ms

  Comments by Kontron

  We have not noticed any issue compared to the nominal test case 3.3.2.

3.3.7 ETCS onboard combined with ATO application

- Objective of the test:
  This test aims at checking the good achievement of a FRMCS communication with ATO application using Kontron On-Board and Trackside Gateways when, at the same time, an ETCS communication is also running on the TOBA-K.

- Test description:

  This test is described in D1.1 v3 [S22] WP1 test plan, chapter 8.3.7.

- Test results and comments:

  Comments by Alstom

  At the ATO application level, the logs are checked to be sure there are no errors, the local binding is established, and finally the end-to-end communication is established.

The journey profile is properly received by the ATO-OB.

The following KPIs have been measured for this test:

- (A) Handshake duration: 111ms
- (B) Journey profile download duration: 501ms

Comments by Kontron

We have not noticed any issue compared to the nominal test case 3.3.2.

3.4 Conclusion on ATO tests

The ATO-OB and ATO-TS applications have been upgraded to allow the integration with the FRMCS communication system. We were then able to test the communication between the ATO subsystems in a more realistic environment and highlighted that the ATO still needs some robustification against edge cases where the communication availability is not ideal.

Apart from the test of the application itself, activities with ATO prototypes enabled us to introduce the decoupling concept between applications and bearers, which is managed by the FRMCS gateways. Regarding this, bearer flexibility and failover tests, where applications do not suffer any outage, were particularly interesting. ATO tests were also used to validate the use of DSCP as a QoS discriminator within the 5G network, knowing that PCF function was not yet available in the 5G SA ecosystem we installed.

4 ETCS Tests

4.1 Introduction to ETCS tests

The ETCS (European Train Control System) application is a signaling component necessary for railway operations. It is important to be sure that the ETCS information can be received and transmitted to trackside signaling system. A new application has been developed to be able to be interfaced with the FRMCS on-board system (Obapp interface) in order to communicate with the ground system via the FRMCS infrastructure. The ETCS application is part of the European Vital Computer installed in the train.

The figures below show the test environment architecture and test bench of ALSTOM in Kontron laboratory:

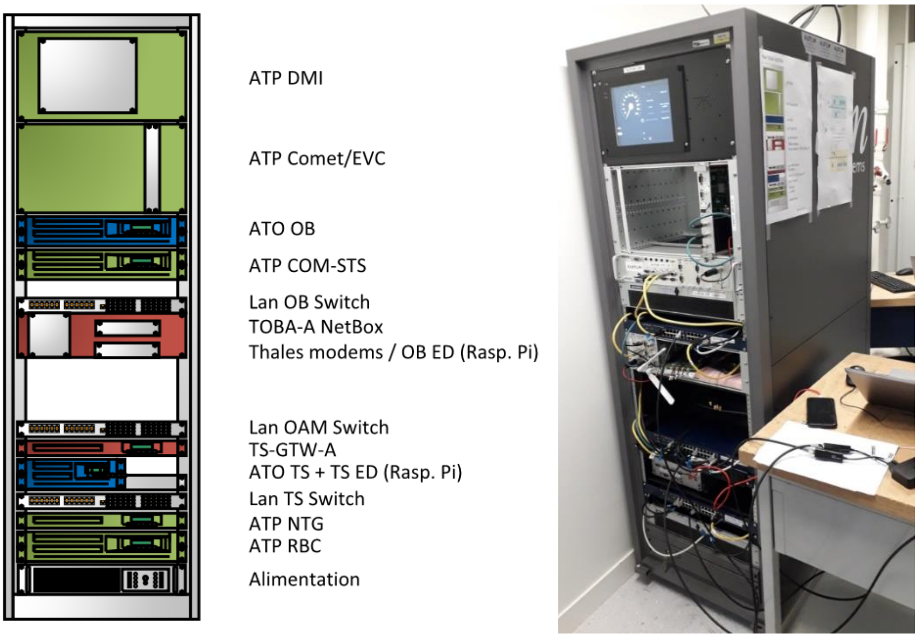


Figure 7: ALSTOM test bench used during WP4 located in Kontron laboratory (Scheme on the left side, photo on the right side)

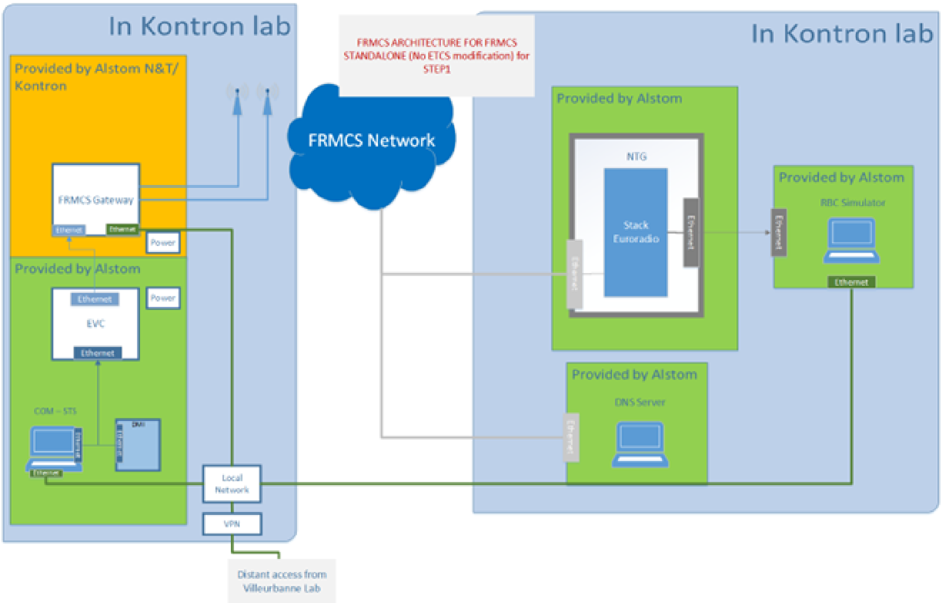


Figure 8: Scheme of the test environment architecture in Kontron laboratory

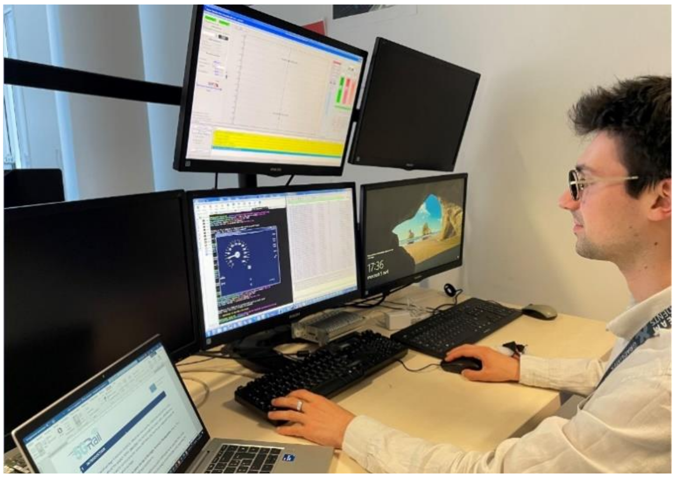


Figure 9: Remote testing in ALSTOM Villeurbanne

<u>Note on ETCS KPIs:</u>

For the time being, there is no standardized KPI nor target values for ETCS over FRMCS. However, we can infer from GSM-R experience that for this critical application, following indicators are important:

- Duration for an ETCS packet to be sent from On-Board application to the RBC (and vice-versa). This leads to measure and get interest in Round Trip Delay from application point of view.
- Loss of ETCS packets during communication. Knowing that ETCS communication can suffer the loss of some ETCS packets from time to time but consecutive loss of some ETCS packets might lead to the ETCS communication reset, with high impact on service.

In the next tests, we are then focusing on the RTD that should stand, by comparison with GSM-R current expectations, below xxx ms. Besides, for each test, if the ETCS communication is dropped due to loss of ETCS packets, test is failed. Any drop of ETCS packet is also mentioned.

4.2 ETCS tests with TOBA-A

The following table gives information about ETCS tests executed with TOBA-A:

Test Title	5G Band	OB-GW	Date
Communication in level 2 between ETCS onboard application and RBC	N8	TOBA-A	23/11/2022
RBC handover on the same 5G network	N8	TOBA-A	16/12/2022
Redundancy use case: OB GW going from 4G to 5G coverage with on-going ETCS call continuation	N8	TOBA-A	23/12/2022
Redundancy use case: OB GW going from 5G to 4G coverage with on-going ETCS call continuation	N8	TOBA-A	23/12/222
ETCS and iperf UDP test. ETCS on 5G, iperf UDP on 4G. TOBA moves from 4G/5G area to 5G only area. Iperf & ETCS traffic continue on 5G	N8	TOBA-A	16/02/2023
ETCS and iperf UDP test. ETCS and iperf UDP on 5G. TOBA moves from 5G only area to 4G/5G area. ETCS traffic continue on 5G and UDP iperf on 4G	N8	TOBA-A	16/02/2023

4.2.1 Communication in level 2 between ETCS onboard application and RBC

- **Objective of the test:**
  The purpose of this test is to verify that the end-to-end communication in Level 2 between the ETCS application (OnBoard) and the RBC application (Trackside) is working through the 5G network using the FRMCS gateways.
  Thanks to this first test we can check the correct behaviour of the ETCS Application and the TOBA.

- **Test description:**
  See Communication in level 2 between ETCS onboard application and RBC, nominal communication in Level 2 (8.2.2.3.3) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  For this test the ETCS on board application and RBC are on the same 5G network.
  The ETCS App and the TOBA-A are installed and correctly configured.

The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
The ETCS App receives the connection status "Connected".
A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
Check data exchange between ETCS App and RBC.
After a while, send a session end and check that the session is correctly close.

- **Test results and comments:**

Test is passed.

Comments by Alstom

At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

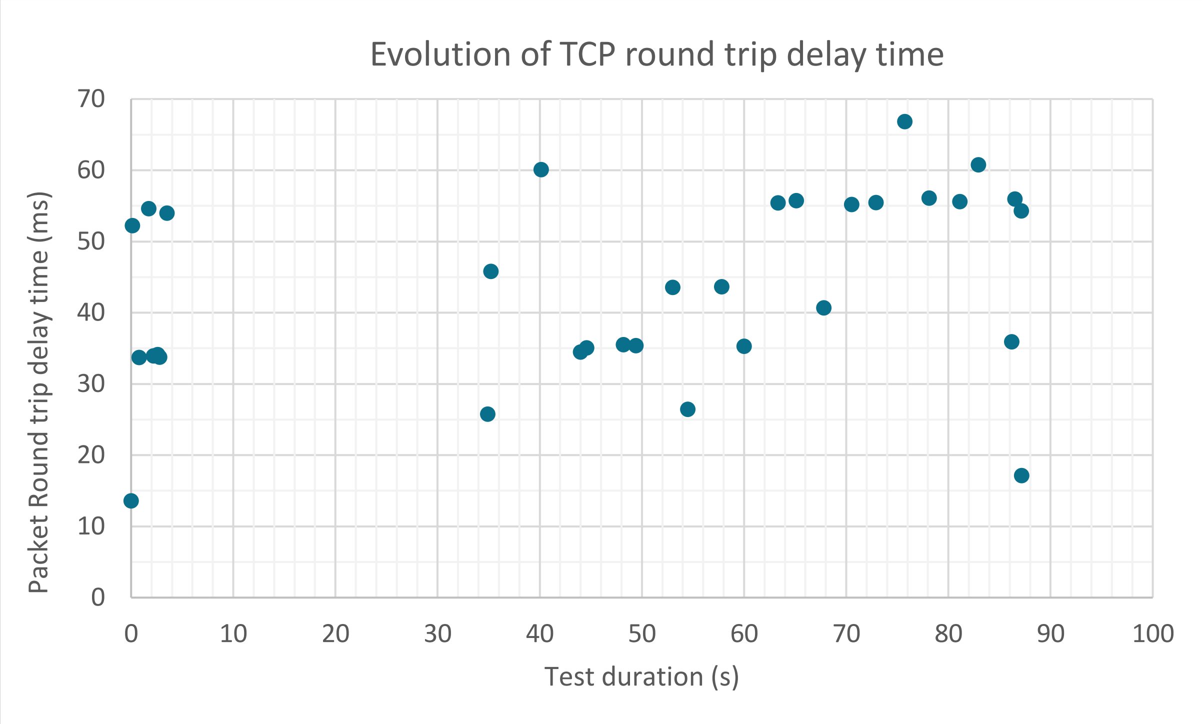
Session start
Session status
Data exchanges between ETCS App IP and RBC IP
Session end

- Traces and logs recorded during the test:

Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time = 43.62ms
Standard deviation Round Trip Time = 13.4ms
Value calculated on 32 samples.



Following traces have been recorded:
5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82233_TOBAA

4.2.2 RBC handover on the same 5G network

- **Objective of the test:**
  Once end-to-end communication is up and running, it is necessary to ensure that handovers between RBCs are working.
  During a handover there are 2 communication sessions in parallel and one session must be able to be closed while keeping the other open.
  The test is performed with TOBA-A (on n8 5G band).

- **Test description:**
  See Communication in level 2 between ETCS onboard application and RBC, RBC Handover on the same 5G network (8.2.2.3.4) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**

  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status “Connected”.
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC1.

A second connection request for Level 2 communication is done by simulating the train crossing a beacon with packet 131.
Check data exchange between ETCS App and RBC2.
Simulate a second balise to close the communication session with RBC1.

For this test the ETCS on board application, RBC1 and RBC2 are on the same 5G network.
The ETCS App and the TOBA-A are installed and correctly configured.

- **Test results and comments:**

Test is passed.

Comments by Alstom

At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

Session start
Session status
Data exchanges between ETCS App IP and RBCs IP
Session end

The communication is established from the first connection request. There is no interruption of communication throughout the duration of the test. The simultaneous ETCS App communication with RBC 1 and RBC2 is working properly. The session 1 is closed without any impact on the session 2.

- Traces and logs recorded during the test:

Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

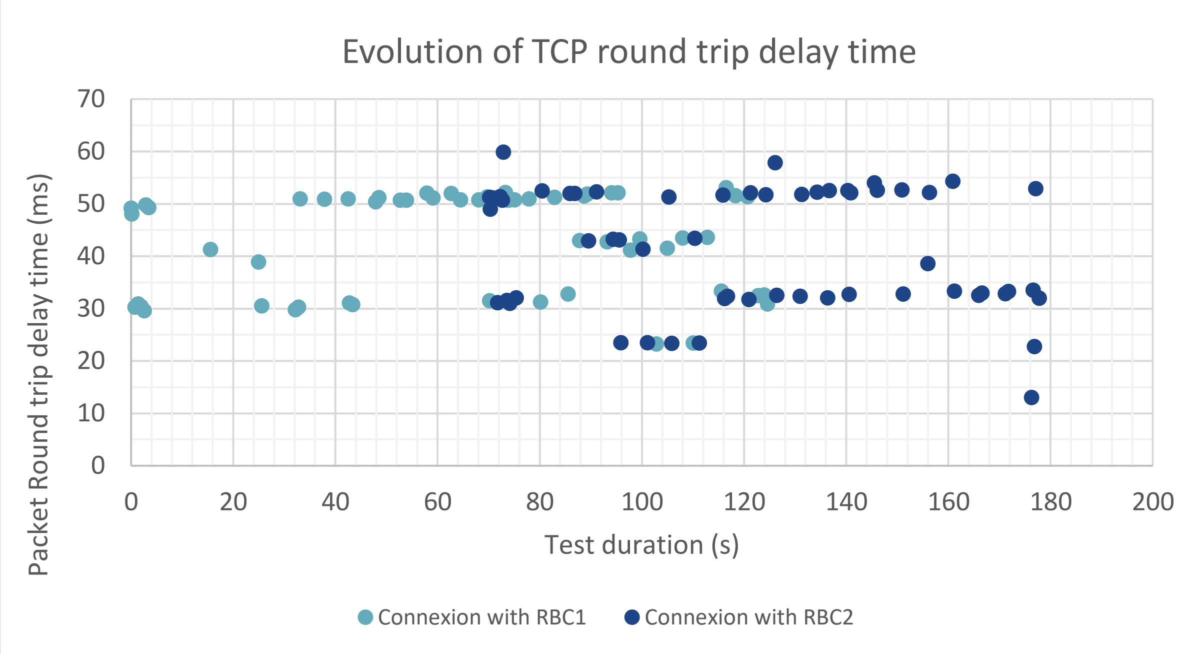
Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time :

- for the connexion with RBC1 = 42.9ms
- for the connexion with RBC2 = 41.47ms

Standard deviation Round Trip Time = 10.52ms

The value calculated on 113 samples



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82234_TOBAA

4.2.3 Redundancy use case: OB GW going from 4G to 5G coverage with on-going ETCS call continuation

- **Objective of the test:**
  This test verifies that the OnBoard Gateway handle a bearer change from 4G to 5G without impact on the ETCS App communication.

- **Test description:**
  Refer to Redundancy use case: OB-GW going from 4G to 5G coverage (8.2.2.7.2) in [S22] (5GRAIL Deliverable D1.1 version 4).

  The ETCS App and the TOBA-A are installed and correctly configured.
  The TOBA-A is connected to 4G (b38 band)
  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status “Registered”.
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC1.
  Switch on the 5G cell and progressively attenuate the 4G

- **Specific Test configuration:**

TOBA-A configuration: one 5G modem and one 4G modem used for this test. The application profile used for ETCS application is configured to use 5G modem as primary link and 4G modem as secondary link. Then, the 5G link is to be used as soon as it is available.
Two MCdata-IPconn sessions are established (one per link) and TOBA-A/TS_GTW-A select the one to be used thanks to a monitoring signal and according to the configured priority.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no impact on the ongoing communication.

  The tcpdump log are captured to be sure there is no impact on the application data due to the changeover with comparison to the nominal conditions.

- Traces and logs recorded during the test:

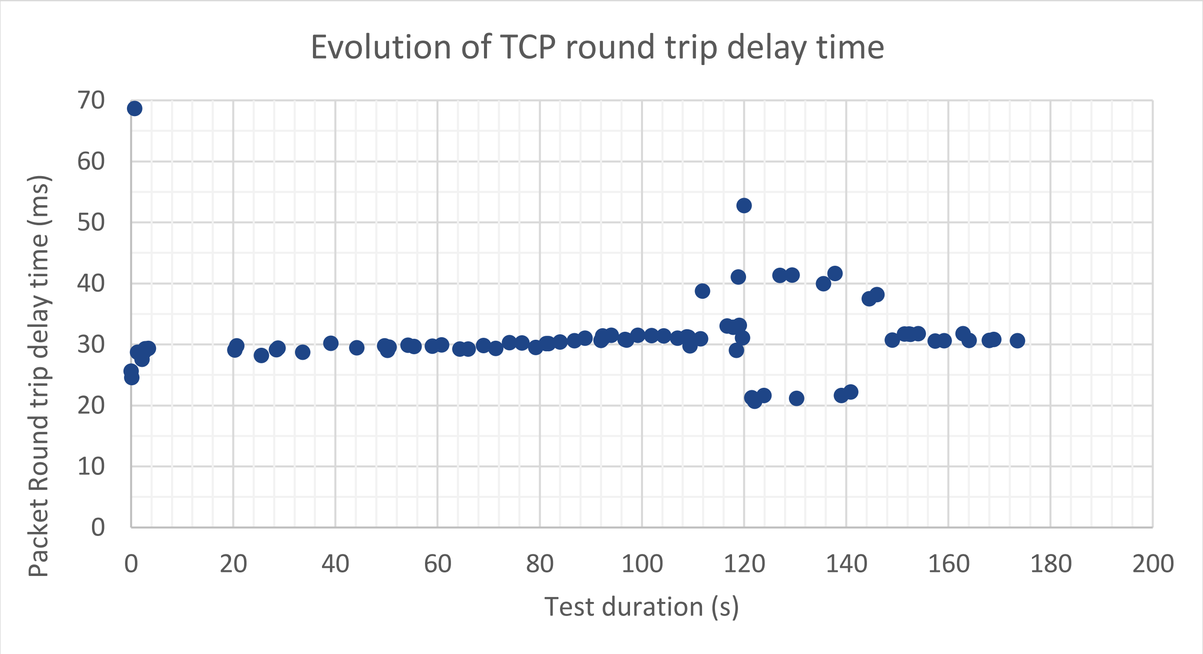
Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time = 31.23ms

Standard deviation Round Trip Time = 6.4ms

The value calculated on 81 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_822371_TOBAA

4.2.4 Redundancy use case: OB GW going from 5G to 4G coverage with on-going ETCS call continuation

- **Objective of the test:**
  This test verifies that the OnBoard Gateway handle a bearer change from 5G to 4G without any impact on the ETCS Application communication.

- **Test description:**
  Refer to Redundancy use case: OB-GW going from 5G to 4G coverage (8.2.2.7.1) in [S22] (5GRAIL Deliverable D1.1 version 4).

  The ETCS App and the TOBA-A are installed and correctly configured.
  The TOBA is connected to 5G (N8 band)
  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status "Registered".
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC1.
  Switch on the 4G cell and progressively attenuate the 5G

- **Specific Test configuration:**
  TOBA-A configuration: one 5G modem and one 4G modem used for this test. The application profile used for ETCS application is configured to use 5G modem as primary link and 4G modem as secondary link. Then, the 5G link is to be used as soon as it is available.
  Two MCdata-IPconn sessions are established (one per link) and TOBA-A/TS_GTW-A select the one to be used thanks to a monitoring signal and according to the configured priority.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no impact on the ongoing communication.

  The tcpdump log are captured to be sure there is no impact on the application data due to the changeover with comparison to the nominal conditions.

- <u>Traces and logs recorded during the test:</u>

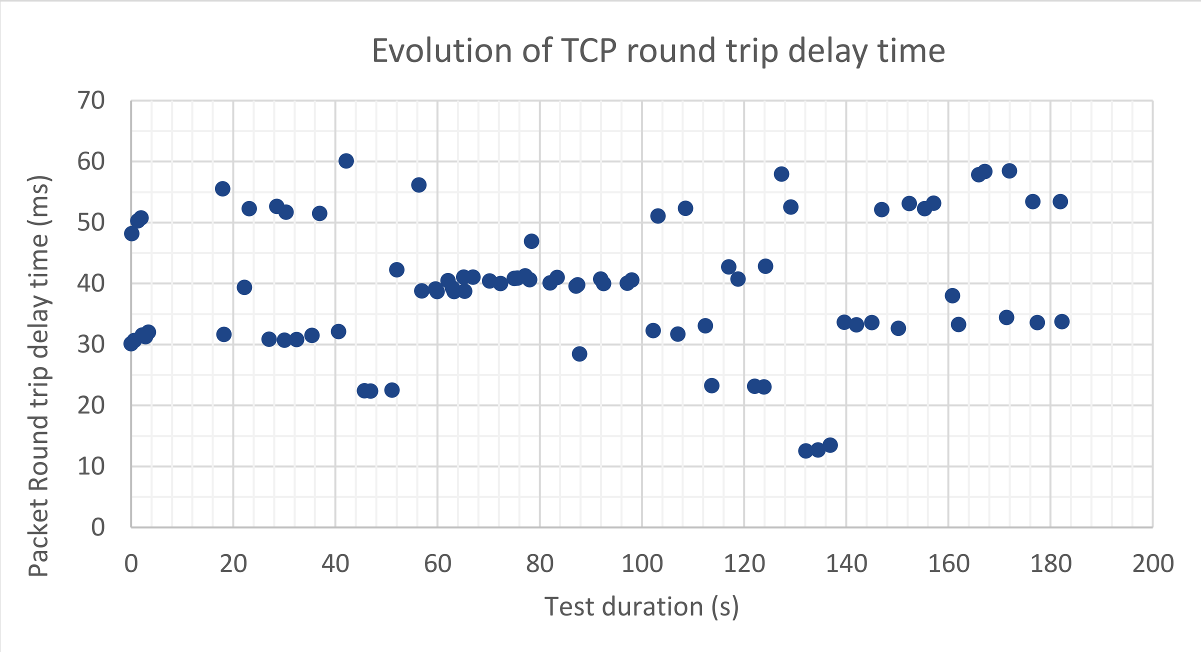
Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time = 39.58ms

Standard deviation Round Trip Time = 10.95ms

The value calculated on 85 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_822372_TOBAA

4.2.5 ETCS and iperf UDP test. ETCS on 5G, iperf UDP on 4G. TOBA moves from 4G/5G area to 5G only area. Iperf & ETCS traffic continue on 5G

- **<u>Objective of the test:</u>**
  This test verifies that the OnBoard Gateway can handle a transition from aggregated networks (4G and 5G) to a 5G only area without any impact on the ETCS Application communication.

- **Test description:**

  Refer to Aggregation use case: ON-GW is moving from an aggregated coverage (5G+4G) to a place with 5G only coverage with the ETCS call still going on (8.2.2.3.7.4) in [S22] (5GRAIL Deliverable D1.1 version 4).

  The ETCS App and the TOBA-A are installed and correctly configured.
  The TOBA is connected to 4G (b38 band) and 5G (n8 band)
  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status "connected".
  iPerf UDP simulator (disturbing flow) is started and generates data load.
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC1.
  Progressively attenuate the 4G signal.

- **Specific Test configuration:**

  TOBA-A configuration : two modems (5G and 4G) are used. The application profile used for ETCS is configured to use 5G modem as primary link, the application profile used for iPerf (disturbing flow) is configured to use 4G modem as primary link.
  Comm_profile used for ETCS session is 10, according to D2.1. Comm_profile used for iPerf is 6 (low priority)

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no impact on the ongoing communication.

  The tcpdump log are captured to be sure there is no impact on the application data due to the changeover with comparison to the nominal conditions.

- Traces and logs recorded during the test:

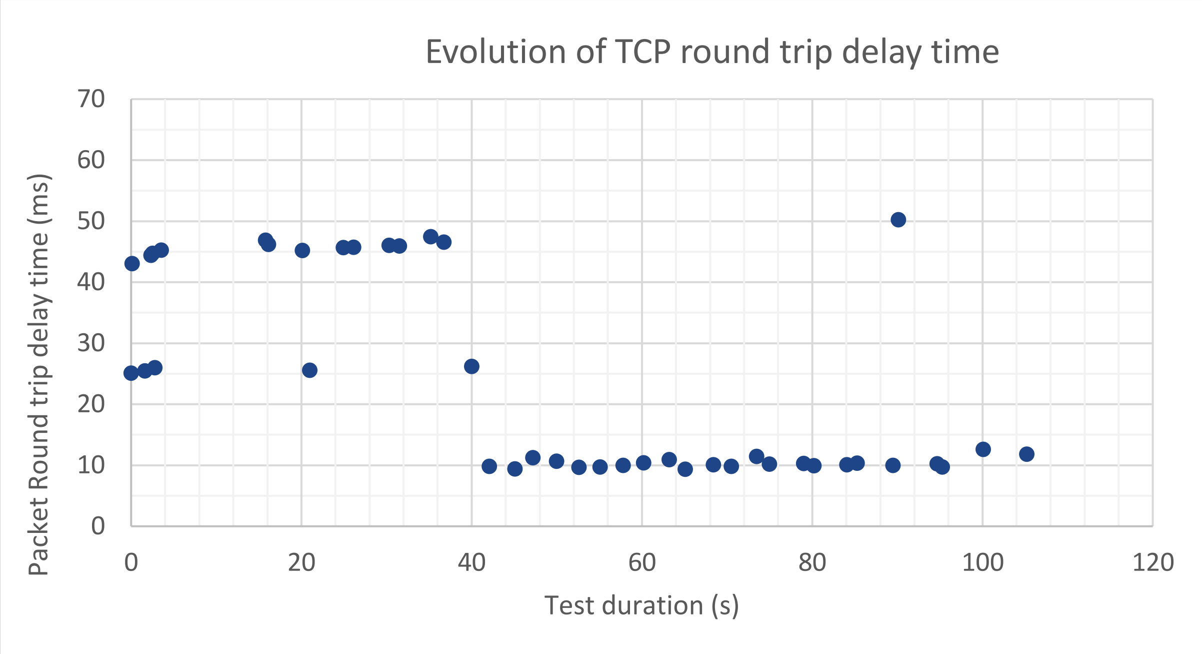
  Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

  Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

  Average Round Trip Time = 25.55ms

  Standard deviation Round Trip Time = 19.07ms

  The value calculated on 43 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_aggregation4G5Gto5G_TOBAA

4.2.6 ETCS and iperf UDP test. ETCS and iperf UDP on 5G. TOBA moves from 5G only area to 4G/5G area. ETCS traffic continue on 5G and UDP iperf on 4G

- **Objective of the test:**
  This test verifies that the OnBoard Gateway can handle a transition from 5G only to an aggregated networks (4G and 5G) area without any impact on the ETCS Application communication.

- **Test description:**
  Refer to Aggregation use case: ON-GW under 5G coverage moves to a location of simultaneous coverage from an aggregated coverage (5G+4G). ETCS call is using simultaneously both bearers (8.2.2.3.7.3) in [S22] (5GRAIL Deliverable D1.1 version 4).
  The ETCS App and the TOBA-A are installed and correctly configured.
  The TOBA is initially connected to 5G (n8 band).
  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.

The ETCS App receives the connection status “connected”.
iPerf UDP simulator is started and generates data load.
A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
Check data exchange between ETCS App and RBC1.
Enable, then progressively amplify the 4G signal.

- **Specific Test configuration:**

  TOBA-A configuration : two modems (5G and 4G) are used. The application profile used for ETCS is configured to use 5G modem as primary link, the application profile used for iPerf (disturbing flow) is configured to use 4G modem as primary link.
  Comm_profile used for ETCS session is 10, according to D2.1. Comm_profile used for iPerf is 6 (low priority)

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no impact on the ongoing communication.

  The tcpdump log are captured to be sure there is no impact on the application data due to the changeover with comparison to the nominal conditions.

- Traces and logs recorded during the test:

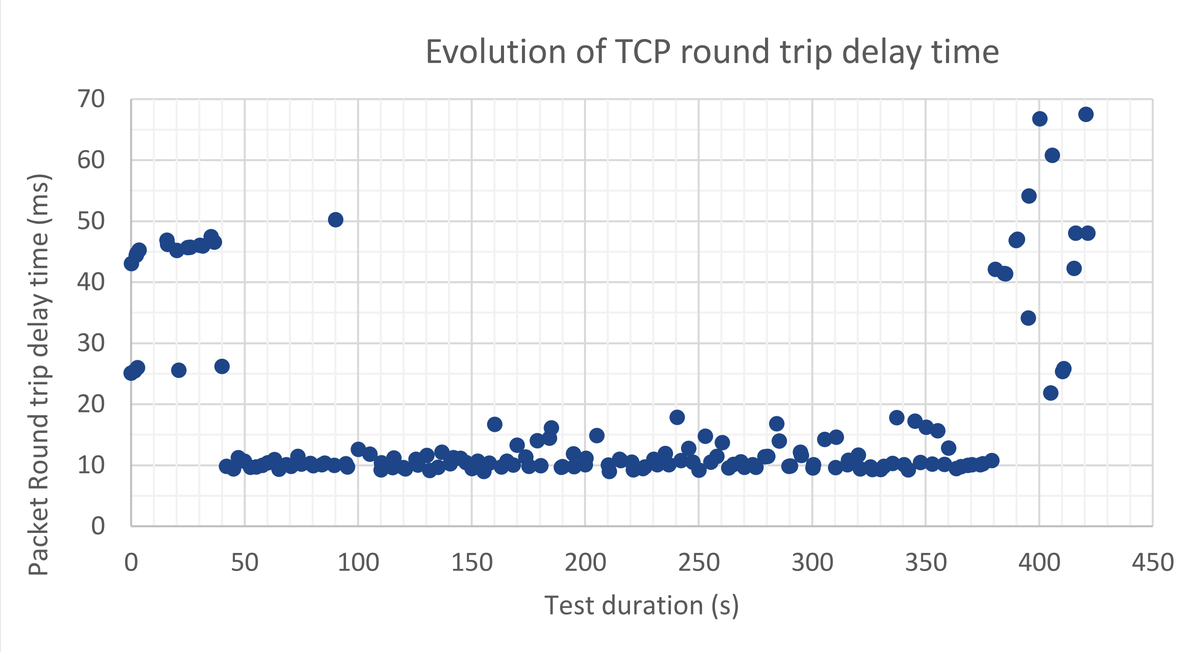
Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time = 18.24ms

Standard deviation Round Trip Time = 15.34ms

The value calculated on 163 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_aggregation5Gto4G5G_TOBAA

4.3 ETCS tests with TOBA-K

The following table gives information about ETCS tests executed with TOBA-K:

Test Title	5G Band	OB-GW	Date
Communication in level 2 between ETCS onboard application and RBC	N39	TOBA-K	06/01/2023
RBC handover on the same 5G network	N39	TOBA-K	06/01/2023
RBC and gNodeB handover on the same 5G network	N39	TOBA-K	10/01/2023
Communication in level 2 between ETCS onboard application and RBC using Vertex tool with fading and varying speed	N39	TOBA-K	13/01/2023
RBC handover on the same 5G network using Vertex tool with fading and varying speed	N39	TOBA-K	13/01/2023
RBC and gNodeB handover on the same 5G network using Vertex tool with fading and varying speed	N39	TOBA-K	13/01/2023
Combined Remote Vision and ETCS in nominal lab conditions	N39	TOBA-K	25/01/2023

Combined Remote Vision and ETCS in degraded conditions (with Vertex)	N39	TOBA-K	25/01/2023
Aggregation use case: OB GW under overlapping 4G and 5G coverage is performing ETCS call using simultaneously both bearers. It moves under 4G only coverage and on-going call still continues.	N39	TOBA-K	17/02/2023
Multiconnectivity in a border crossing scenario_Scenario 1 (TOBA-K in 4G/5G area moves to 4G only area than 4G/5G area than 5G only area)	N39	TOBA-K	03/03/2023

4.3.1 Communication in level 2 between ETCS onboard application and RBC

- **Objective of the test:**
  The purpose of this test is to verify that the end-to-end communication in Level 2 between the ETCS application (OnBoard) and the RBC application (Trackside) is working through the 5G network using the FRMCS gateways.
  Thanks to this first test we can check the correct behaviour of the ETCS Application and the TOBA.

- **Test description:**
  See Communication in level 2 between ETCS onboard application and RBC, nominal communication in Level 2 (8.2.2.3.3) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  For this test the ETCS on board application and RBC are on the same 5G network.
  The ETCS App and the TOBA-K are installed and correctly configured.
  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status “Connected”.
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC.
  After a while, send a session end and check that the session is correctly close.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  In a first place, the test shows a mismatch between the TOBA-K and ETCS application URI message used during the websocket session establishment. The TOBAK software was modified to be compatible.

A second modification had been implemented in TOBA-K to allow answering quicker to websocket "register request" when the network is not available.

At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

Session start
Session status
Data exchanges between ETCS App IP and RBC IP
Session end

- Traces and logs recorded during the test:

Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

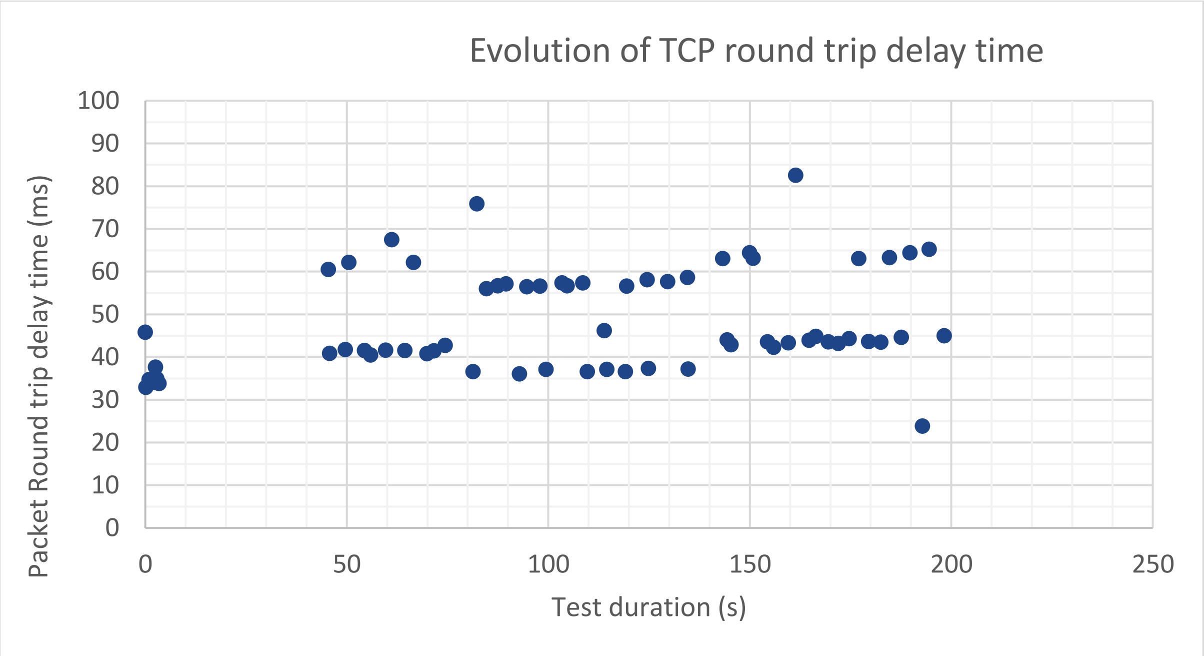
Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time = 46.7ms

Standard deviation Round Trip Time = 14.3ms

2 packets were delayed and involved retries TCP increasing the RTT value (3,53sec and 1,45sec). These 2 retries had no impact on the exchange of ETCS data and were not be taken into account to calculate the average RTT value and to make the charts.

The values are calculated from 67 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82233_TOBAK

4.3.2 RBC handover on the same 5G network

- **Objective of the test:**

  Once end-to-end communication is up and running, it is necessary to ensure that handovers between RBCs are working.
  During a handover there are 2 communication sessions in parallel and one session must be able to be closed while keeping the other open.
  The test is performed with TOBA-K (on n39 5G band).

- **Test description:**

  See Communication in level 2 between ETCS onboard application and RBC, RBC Handover on the same 5G network (8.2.2.3.4) in [S22] (5GRAIL Deliverable D1.1 version 4).

  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status "Connected".
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC1.
  A second connection request for Level 2 communication is done by simulating the train crossing a balise with packet 131.
  Check data exchange between ETCS App and RBC2.
  Simulate a second balise to close the communication session with RBC1.

- **Specific Test configuration:**

  For this test the ETCS on board application, RBC1 and RBC2 are on the same 5G network.
  The ETCS App and the TOBA are installed and correctly configured.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  In the first place, the ETCS application has been modified to patch an erroneous session end message sent while closing the RBC1 session. The test is passed with the new version of ETCS application.

  At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

Session start
Session status
Data exchanges between ETCS App IP and RBCs IP
Session end

The communication is established from the first connection request. There is no interruption of communication throughout the duration of the test. The simultaneous ETCS App communication with RBC 1 and RBC2 is working properly. The session 1 is closed without any impact on the session 2.

- Traces and logs recorded during the test:

Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

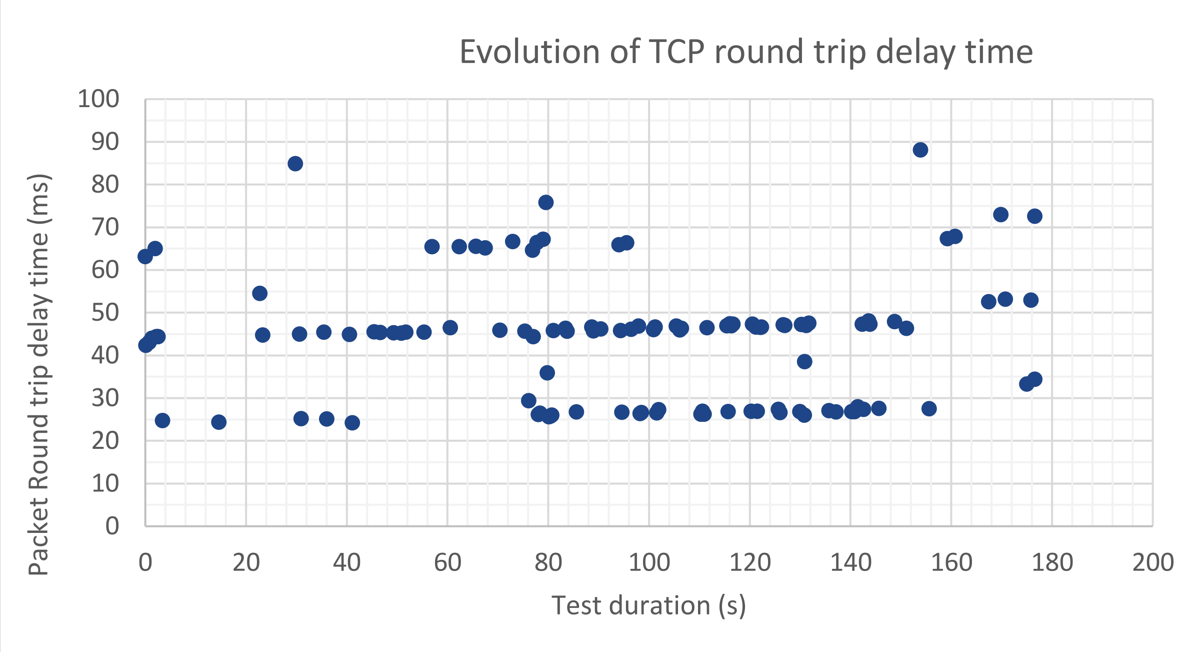
Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time = 44.15

Standard deviation Round Trip Time = 14.23

The value is calculated 117 samples.

(2 retries TCP increase this RTT value. This explains a higher value of standard deviation value. These 2 retries had no impact on the exchange of ETCS data)



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82234_TOBAK

4.3.3 RBC and gNodeB handover on the same 5G network

- **Objective of the test:**
  On the field, an RBC handover is likely to occur at the same time as a BTS handover. This test verifies that there is no communication break in this case.

- **Test description:**
  See RBC and gNodeB Handover on the same 5G network (8.2.2.3.6) in [S22] (5GRAIL Deliverable D1.1 version 4).

  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status "Connected".
  BTS handover are trigged every 5 seconds in a loop (roughly 20 handovers during the test).
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC1.
  A second connection request for Level 2 communication is done by simulating the train crossing a balise with packet 131.
  Check data exchange between ETCS App and RBC2.
  Simulate a second balise to close the communication session with RBC1.

- **Specific Test configuration:**
  For this test the ETCS on board application, RBC1 and RBC2 are on the same 5G network.
  The ETCS App and the TOBA are installed and correctly configured.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

  A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

  Session start
  Session status
  Data exchanges between ETCS App IP and RBCs IP
  Session end

  The communication is established from the first connection request. There is no interruption of communication throughout the duration of the test even if the BTS is changing every 5 seconds.

- Traces and logs recorded during the test:

Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

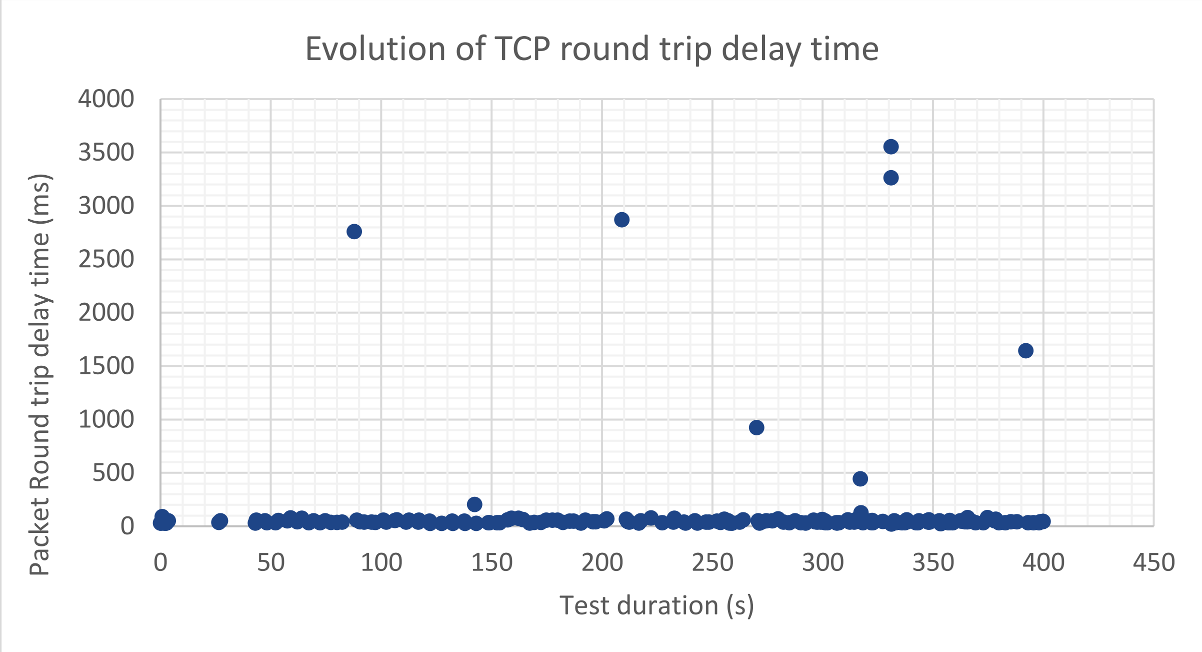
Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

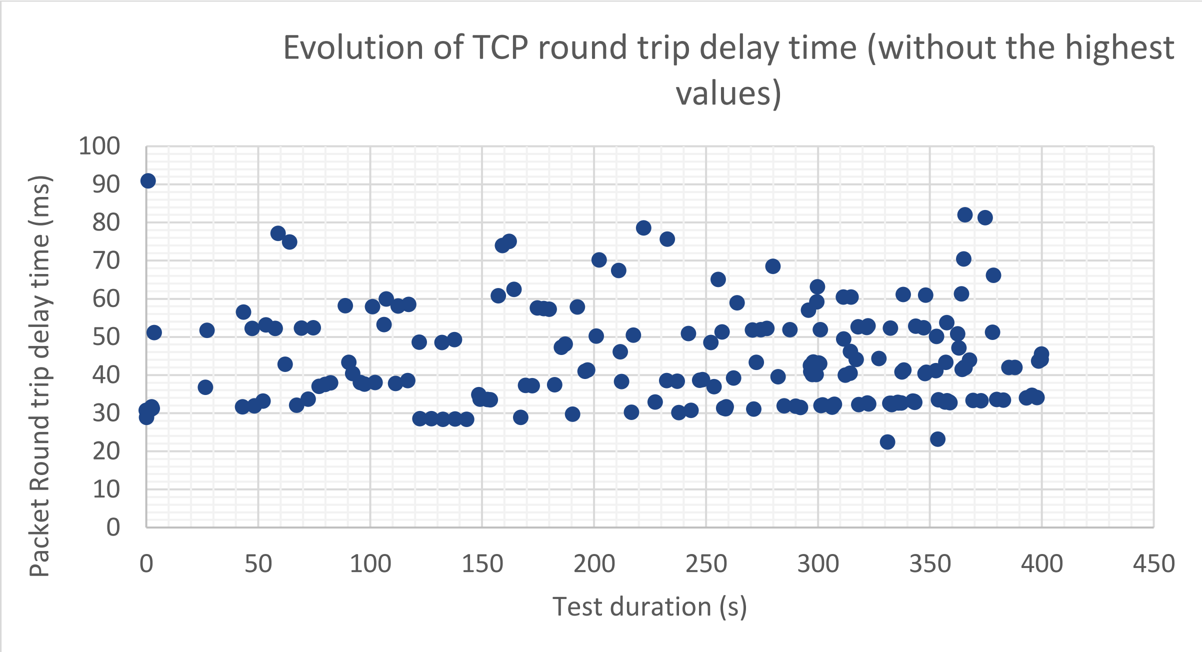
Average Round Trip Time = 121.3 ms

Standard deviation Round Trip Time = 450.7 ms

The value is calculated samples.

(Some retries TCP increase this RTT value. This explains a higher value of standard deviation value. These retries had no impact on the exchange of ETCS data)





Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82236_TOBAK

4.3.4 Communication in level 2 between ETCS onboard application and RBC using Vertex tool with fading and varying speed

- **Objective of the test:**
  The purpose of this test is to verify that the end-to-end communication in Level 2 between the ETCS application (OnBoard) and the RBC application (Trackside) is working while using Vertex tool that simulates degraded 5G network quality of signals.

- **Test description:**
  See Communication in level 2 using Vertex tool with fading and varying speed (8.2.2.4.1) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  For this test the network quality of signal is degraded using the Vertex tool.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

  A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

  Session start
  Session status
  Data exchanges between ETCS App IP and RBC IP
  Session end

- Traces and logs recorded during the test:

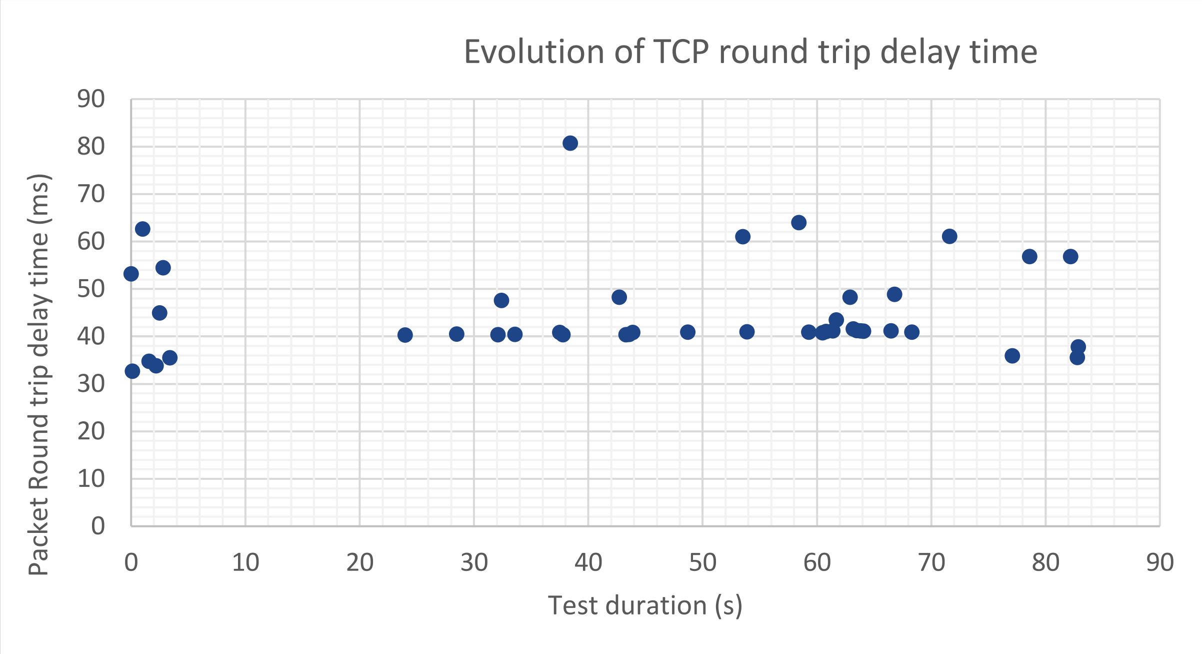
  Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

  Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

  Average Round Trip Time = 45.02ms

  Standard deviation Round Trip Time = 9.77ms

  The value is calculated with 43 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82241_Level2_Vertex_TOBAK

4.3.5 RBC handover on the same 5G network using Vertex tool with fading and varying speed

- **Objective of the test:**
  Once end-to-end communication is up and running, it is necessary to ensure that handovers between RBCs are working.
  During a handover there are 2 communication sessions in parallel and one session must be able to be closed while keeping the other open.
  The test is performed with TOBA-K (on n39 5G band). Vertex tool that simulates degraded 5G network quality of signals.

- **Test description:**
  See RBC handover on the same 5G network using Vertex tool with fading and varying speed (8.2.2.4.2) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  For this test the ETCS on board application, RBC1 and RBC2 are on the same 5G network.
  The ETCS App and the TOBA are installed and correctly configured.
  For this test the network quality of signal is degraded using the Vertex tool.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

  A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

  Session start
  Session status
  Data exchanges between ETCS App IP and RBCs IP
  Session end

  The communication is established from the first connection request. There is no interruption of communication throughout the duration of the test. The simultaneous ETCS App communication with RBC 1 and RBC2 is working properly. The session 1 is closed without any impact on the session 2.

- Traces and logs recorded during the test:

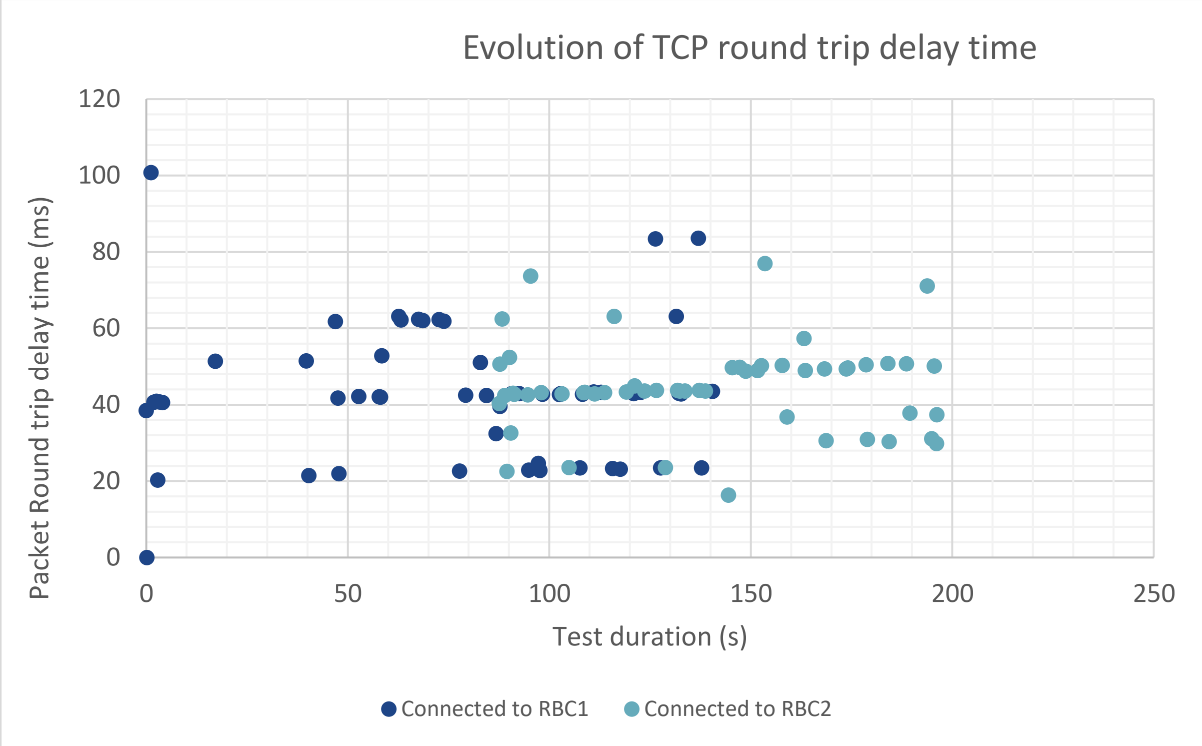
Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time (not taking the data impacted by TCP retry into account):

- for the connexion with RBC1 = 43.9ms
- for the connexion with RBC2 = 44.57ms

The value is calculated with 109 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82242_RBC_handover_Vertex_TOBAK

4.3.6 RBC and gNodeB handover on the same 5G network using Vertex tool with fading and varying speed

- **Objective of the test:**
  On the field, an RBC handover is likely to occur at the same time as a BTS handover. This test verifies that there is no communication break in this case. This test is similar to 4.3.3 with the Vertex tool added to simulates degraded 5G network quality of signals.

- **Test description:**
  See RBC and gNodeB handover on the same 5G network using Vertex tool with fading and varying speed (8.2.2.4.3) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  For this test the ETCS on board application, RBC1 and RBC2 are on the same 5G network.
  The ETCS App and TOBA-K are installed and correctly configured.
  For this test the network quality of signal is degraded using the Vertex tool.

- <u>**Test results and comments:**</u>

  Test is passed.

  <u>**Comments by Alstom**</u>

  At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

  A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

  Session start
  Session status
  Data exchanges between ETCS App IP and RBCs IP
  Session end

  The communication is established from the first connection request. There is no interruption of communication throughout the duration of the test even if the BTS is changing every 5 seconds.

- <u>Traces and logs recorded during the test:</u>

  Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

  Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

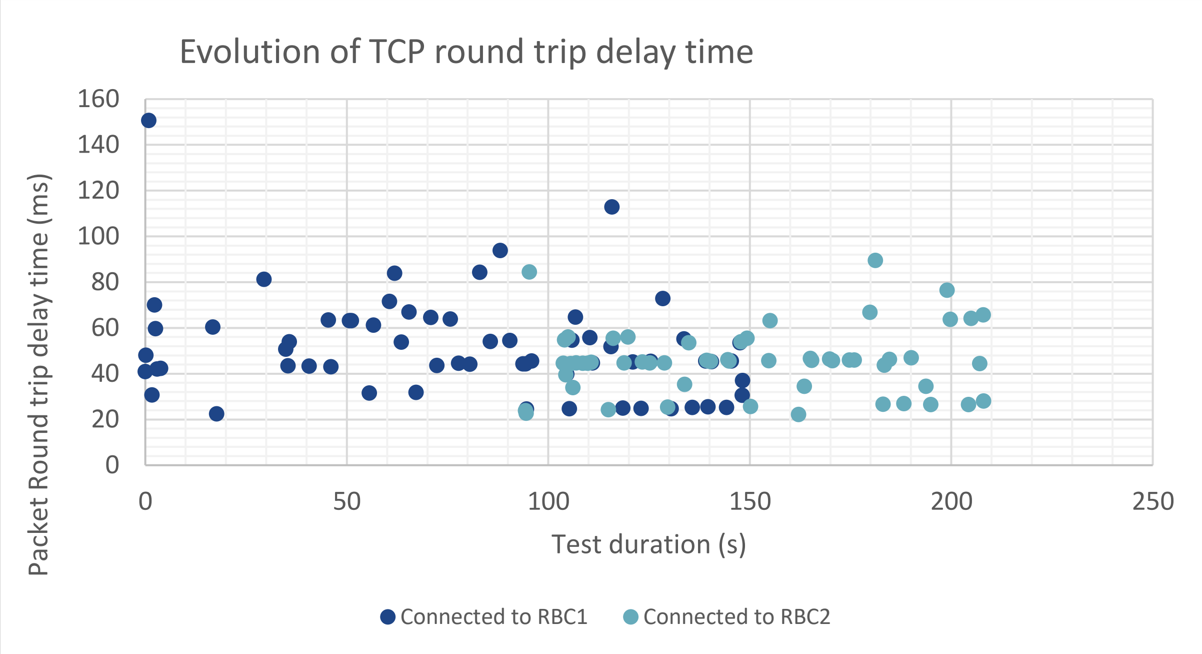
  Average Round Trip Time

  (not taking the data impacted by TCP retry into account):

- for the connexion with RBC1 = 51.7ms
- for the connexion with RBC2 = 54.52ms

Standard deviation Round Trip Time = 19.56ms

The value is calculated with 120 samples



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82243_RBC_BTS_handover_Vertex_TOBAK

4.3.7 Combined Remote Vision and ETCS in nominal lab conditions

- **Objective of the test:**
  The purpose of this test is to verify that there is no impact on the ETCS Application communication when the onboard gateway is also used for Remote vision communication.

- **Test description:**
  See Remote control of engines in parallel with ETCS application in lab nominal conditions (11.2) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  A Remote vision communication is started at the beginning of the test and remains active.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

Session start
Session status
Data exchanges between ETCS App IP and RBC IP
Session end

- Traces and logs recorded during the test:

Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

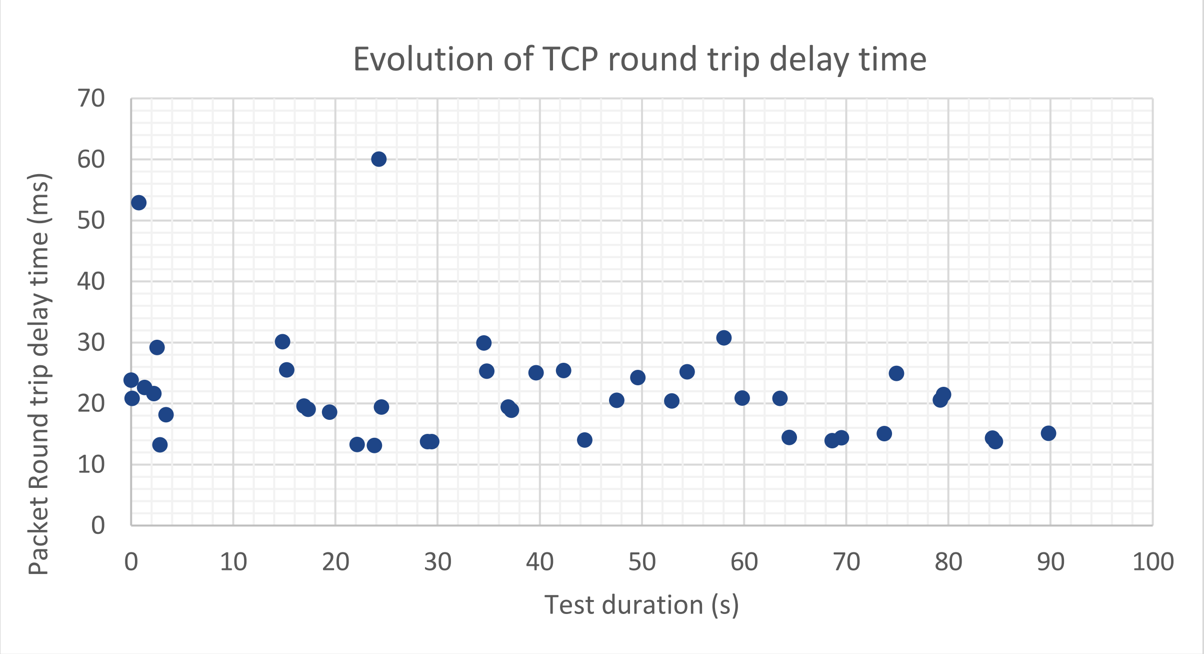
Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time = 12.82

Standard deviation Round Trip Time = 9.31

The value is calculated with 43 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_112_TOBAK

4.3.8 Combined Remote Vision and ETCS in degraded conditions (with Vertex)

- **Objective of the test:**
  The purpose of this test is to verify that there is no impact on the ETCS Application communication when the onboard gateway is also used for Remote vision communication. This test is similar to 4.3.7 with the Vertex tool added to simulates degraded 5G network quality of signals.

- **Test description:**
  See Remote control of engines in parallel with ETCS application in degraded radio conditions using Vertex emulator (11.3) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  A Remote vision communication is started at the beginning of the test and remains active.
  For this test the network quality of signal is degraded using the Vertex tool.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no errors, and the communication is established.

  A tcp dump spy is set up between EVC and TOBA and the content of the following frames are checked:

  Session start
  Session status
  Data exchanges between ETCS App IP and RBC IP
  Session end

- Traces and logs recorded during the test:

  Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

  Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

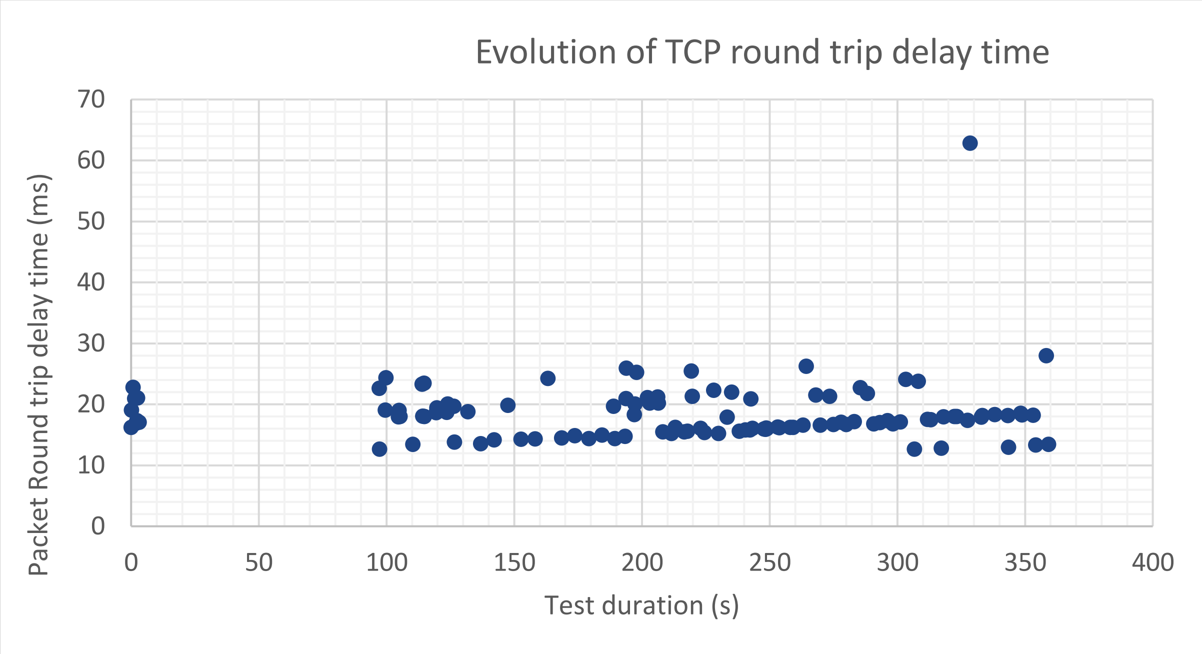
  Round trip delay is calculated from EVC side between the TCP ETCS App packets sending and their respective TCP ACK received from NTG.

Note: the analyse exclude TCP keep alive packet sent due to inactivity on the link

Average Round Trip Time = 18.51ms

Standard deviation Round Trip Time = 5.29ms

The value is calculated with 113 samples.



Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_113_TOBAK

4.3.9 Aggregation use case: OB GW under overlapping 4G and 5G coverage is performing ETCS call using simultaneously both bearers. It moves under 4G only coverage and on-going call still continues.

- **<u>Objective of the test:</u>**
  This test verifies that the OnBoard Gateway can handle a transition from aggregated networks (4G and 5G) to a 4G only area without any impact on the ETCS Application communication.

- **<u>Test description:</u>**
  See Aggregation use case: OB–GW is moving from an aggregated coverage (5G+4G) to a place with 5G only coverage with ETCS call still on-going (8.2.2.3.7.4) in [S22] (5GRAIL Deliverable D1.1 version 4), test case having to be adapted with the crossing towards a 4G

only area due to a limitation on WP2 TOBA-K feature at the time of the test. Test 8.2.2.3.7.4 being targeted for WP5.

The ETCS App and the TOBA are installed and correctly configured.
The TOBA is connected to 4G (b38 band) and 5G (n39 band)
The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
The ETCS App receives the connection status "connected".
A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
Check data exchange between ETCS App and RBC1.
Progressively attenuate the 5G signal.

- **Specific Test configuration:**
  The network is configured to allow ETCS communication data to use both bearers simultaneously.

- **Test results and comments:**

  Test is passed.

  Comments by Alstom

  At the ETCS App level, the application logs are checked to be sure there are no impact on the ongoing communication.

  The tcpdump log are captured to be sure there is no impact on the application data due to the changeover with comparison to the nominal conditions.

- Traces and logs recorded during the test:

  Following traces have been recorded:

  5GRAIL_WP4_Alstom_D4_3_ETCS_TC_822374_aggregation4G5Gto4G_TOBAK

4.4 WP4 Border Crossing tests

4.4.1 Border crossing challenges in FRMCS

In FRMCS, a border crossing scenario starts with a transition from the 5G network of Railway Operator A to the 5G network of Railway Operator B. This transition can be achieved with Local Break Out (UPF to be used for data traffic will then be located in 5G network B) or Home Routed scenarios (UPF to be used will stay in 5G network A).

Yet, FRMCS communication is not only a 5G communication: in order to achieve the railway application (ETCS, ATO, PIS…) communication: Firstly IMS registration must have been completed, followed by MCx service authentication and authorization. Secondly, a MCx communication should have been established.

When train reaches Railway Operator B network, many questions arises about the way the Railway Application communication communication should be maintained, when necessary.

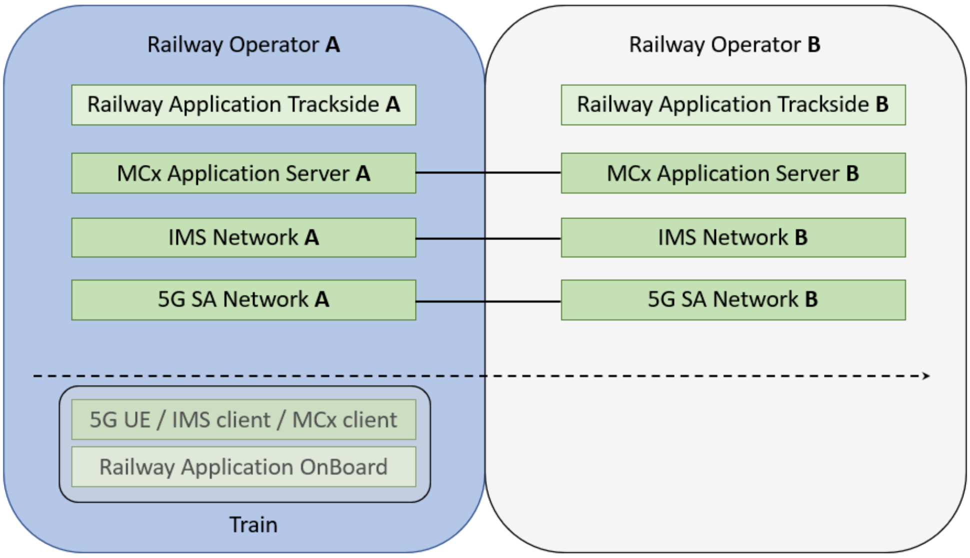


Figure 10: FRMCS Cross-Border model with one 5G UE

Some challenges are the following:

a/ **If the UE does not keep the same IP address after the transition**, then it must register again on IMS network A or IMS network B, this is time consuming.

b/ **In order to keep the same IP address as before the transition**, the 5G transition must be Home Routed. But Home Routing may not be optimum when train travels for a long journey in network B. For example, a train moving from Barcelona to Brussels will then always be attached to Spanish 5G network, which might not be optimal at all in terms of latency.

c/ **If Local Break Out is used**, it is clear that the train must at least perform an IMS Registration, preferably on IMS Network B (in order to avoid being anchored to its home network, for latency reasons). MCx communication is broken during that process and must be re-established after IMS registration (with impact on OBAPP side). This means that we can not ensure service continuity if this telecommunication outage does not fit with Railways Application needs.

Consequently, we understand that after the 5G network transition, a delay is needed to resume the Railway Application traffic when using one 5G UE. To give an idea on that, in WP4 lab, it takes at least 1s to only perform a REGISTER from OB-GW with PUBLISH sent to MCx AS. In live networks, when distance matters and with possible IMS roaming procedures, it might be higher. Then, MCx communication and Obapp service restoration must be done. The overall procedure looks challenging for a critical data communication continuity.

Note that at the time this document is written, **FRMCS specifications have not yet defined the way border crossing should be achieved**.

4.4.2 Border crossing tests in WP4

When WP4 lab was set-up in 2021, LBO and HR were not available in 5G SA features of any manufacturers, knowing that public operators focused primarly on 5G NSA (ie 5G RAN connected to a 4G Core). WP4 then focused on another solution consisting in using 2 5G UEs during the transition and considered the test with a critical railway application: ETCS. **It is important to notice that 2 GSM-R modems are already used in ETCS current border crossing scenarios**, which consequently fuels the interest of WP4 testings with the 2 5G UE approach.

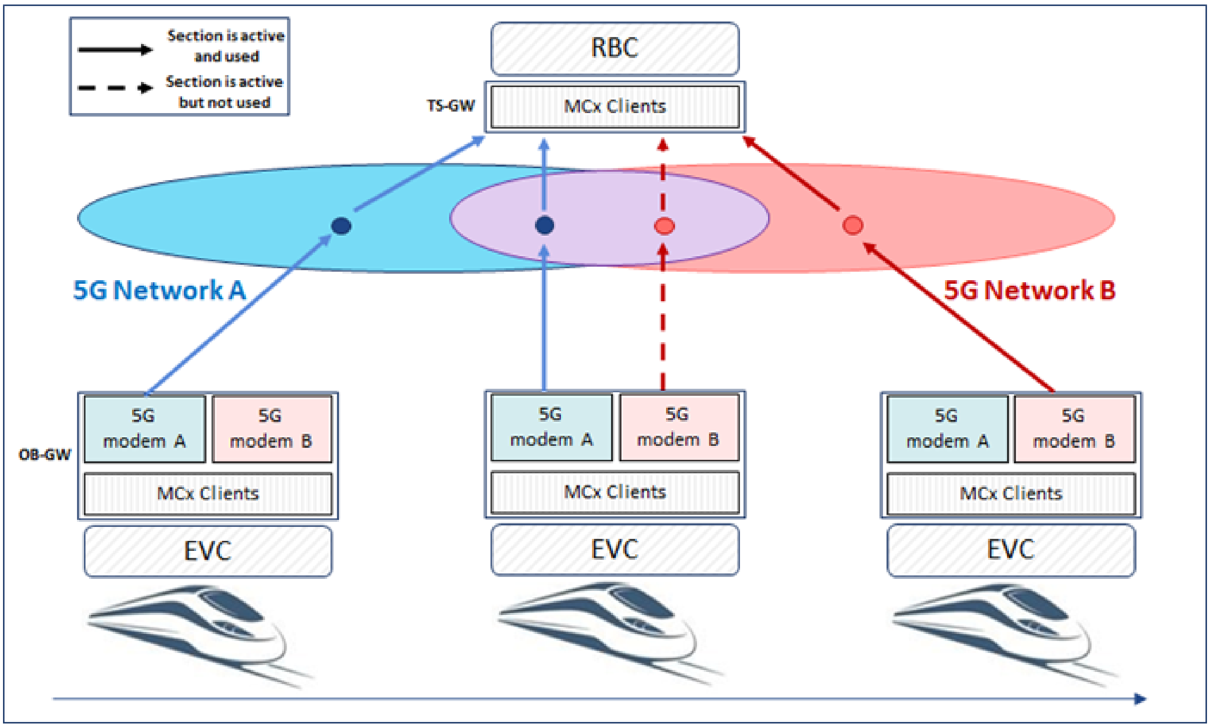
FRMCS gateways however brings a serious plus in the setup, compare to GSM-R, as we can then envision the use of some new features for a better network transition, namely multiconnectivity (being able to use two bearers at the same time) and bearer flexibility (ability to use several bearers and being able to jump from one to another). Besides, we had the chance of having two flavours of FRMCS gateways (Kontron and Alstom implementations) with two different approaches on this border crossing topic:

- TOBA-A : Bearer flexibility with only one path active at the same time (Primary and Secondary link)
- TOBA-K: Multiconnectivity with both paths active at the same time. Based on the MPTCP protocol.

Following sections give some information on these tests.

4.4.2.1 WP4 Border crossing tests with TOBA-A

- **Objective of the test:**
  The cross-border scenario is a crucial scenario for railways: we must ensure the continuity of ETCS communication when the train moves from one network to another. The experiment consist in putting two 5G N8 modems in TOBA-A and move from one 5G network to another with an overlapping zone.
  5G modem A is configured to attach only on first network while 5G modem B can only use network B. In the overlapping zone, modem B will attach to the second 5G network. A priority rule is also added so that whenever modem A is attached, it must be used (preferred or primary link). The test scenario looks like this:



- **Test description:**
  Refer to RBC handover on a different 5G network: Cross-border use case (8.2.2.3.5) in [S22] (5GRAIL Deliverable D1.1 version 4).

  The ETCS App and the TOBA-A are installed and correctly configured.
  The TOBA is connected to the first 5G network (N8 band).
  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status "connected".
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC1.
  Switch off the Network1 and switch on the Network2

- **Specific Test configuration:**
  Two 5G networks are used (Network 1 and Network2, the train is going from Network 1 to Network 2)
  TOBA-A configuration: two 5G modems are used for this test. The application profile used for ETCS application is configured to use 5G modem 1 (to be attached to Network 1) as primary link and 5G modem 2 (to be attached to network 2) as secondary link. Then, the modem 1 link is to be used as long as it is available.

- **Test results and comments:**

  Test is passed.

- **Comments by Alstom**

At the ETCS App level, the application logs are checked to be sure there are no impact on the ongoing communication.

The tcpdump log are captured to be sure there is no impact on the application data due to the cross-border.

- **Analysis of the logs and Conclusion:**

This chapter aims at giving additional details about cross-border scenario performed with ETCS application and TOBA-A using two 5G modems and two different 5G networks (named "blue" network and "red" network in the description below), and relying on the multipath function of TOBA-A to switch from a first 5G network to the second 5G network.

Especially, it illustrates the impact of border crossing in terms of RTT (round trip time) for ETCS applicative data, which is the main KPI used by ETCS to qualify the FRMCS communication.

The scatter plot below displays all the RTT for the applicative frames sent from EVC side (on-board) to RBC side (trackside) through FRMCS sessions established between TOBA-A and TS-GTW-A. The abscissa corresponds to the time where the TCP ACK of the packet is received (which is considered to compute the RTT). The first plot shows the full picture of the test, the second plot is a zoom around the key moments of the border-crossing, i.e. the change of network to carry the applicative data.

Initial conditions:

T0 of the graphic below corresponds to the initiation of the "end to end" TCP connection between EVC and RBC. It means that the FRMCS session has already been requested to TOBA-A through OBapp API, and TOBA-A has already sent a notification to the ETCS applications (both OB and TS) to notify the availability of the underlying session.

From TOBA-A point of view, two tunnels has been established in parallel to transport the applicative data :

- Tunnel 0xdbb168db through 5G modem 1, connected to 5G network A ("Blue" 5G network)
- Tunnel 0x17754811 through 5G modem 2, connected to 5G network B ("Red" 5G network)

There is a primary/backup policy configured for the two modems. Modem 1 ("Blue" network) is the primary link, Modem 2 ("Red "network) is the backup link. At T0, TOBA-A is under coverage of both networks (Blue and Red) and the two tunnels 0xdbb168db and 0x17754811 are working. **But all the ETCS applicative data is carried by tunnel 0xdbb168db**.

Steps of the border-crossing:

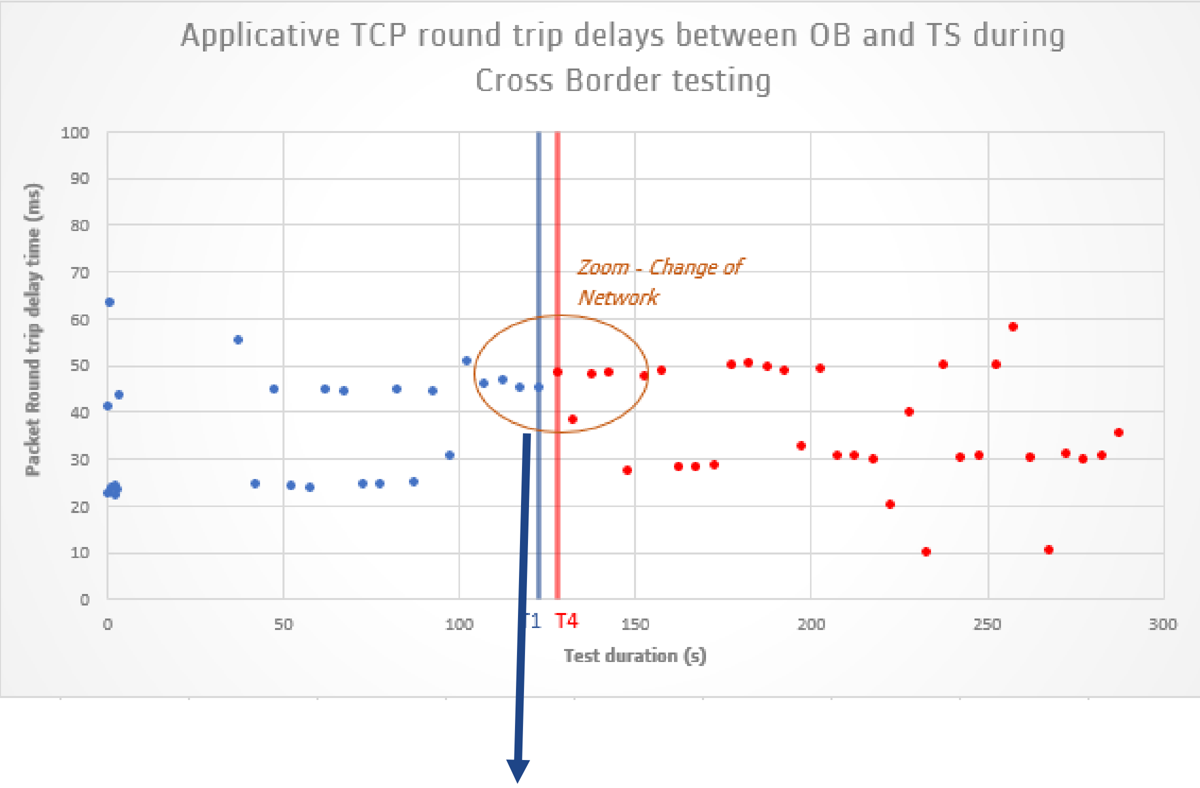
In the two graphics below, blue points correspond to applicative frames carried on the blue network (tunnel 0xdbb168db for TOBA-A point of view), red points correspond to applicative frames carried on the red network (tunnel 0x17754811 for TOBA-A point of view).

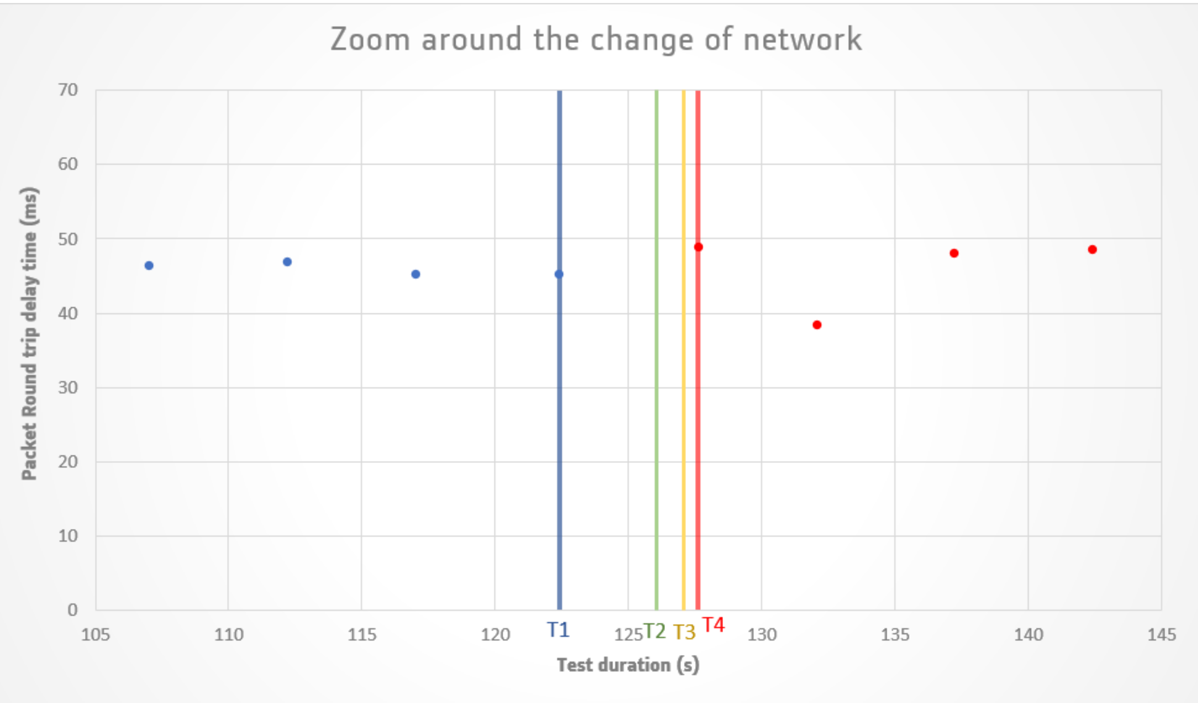
T1 = 122.40s: last ETCS frames carried on the blue network by TOBA-A. RTT=45.3ms

T2 = **126.05s** (only visible on the second graphic): TOBA-A loss the connection to network A.

T3 = **127.05s** (only visible on the second graphic): TOBA-A decides to switch the applicative data to tunnel 0x17754811 (red network).

T4 = 127.61s: first ETCS frames carried on the red network. RTT=48.8ms





Conclusion:

The change of network made by TOBA-A to carry ETCS applicative data has strictly no impact on the RTT seen by the application. The RTT just before and just after the transition is approximately the same (48.8ms vs 45.3ms).

It can be explained with the zoomed picture, the full transition from network A to network B occurs between T2 and T3 but there is no attempt of ETCS frames sending between T2 and T3, meaning that the change of network was fully done by TOBA-A between two consecutive frames. Hence, when the next applicative frame occurs (i.e. T4-45.3ms), the change of network has already been done and the frame is normally transported.

- Traces and logs recorded during the test:

  Following traces have been recorded:

  5GRAIL_WP4_Alstom_D4_3_ETCS_TC_82235_TOBAA

4.4.2.2 WP4 Border crossing tests with TOBA-K

The border crossing tests with TOBA-K have been executed on 1900 MHz band with the ES3 modem inside. This modem is a tailor designed one and suitable for live tests, meaning that it must be used with a 31 dBm power set. **This constraint implied that WP2 team could only put one modem in TOBA-K, because of heating constraints**. Consequently, as only one 5G modem was in the TOBA-K, the crossborder tests used one 5G and one 4G network (TOBA-K also embarks a 4G modem). This is not a critical issue as when using 2 UEs for crossborder, the objective of the test is to look at the transition between the bearers, 5G roaming procedures being not used.

The first test (section 4.4.2.2.1), that existed in the version 1 of this document, was an early attempt to demonstrate the concept of multiconnectivity applied to cross-border. Due to time constraints (most of WP4 lab having to move to field for WP5 trials), and as explained in the section, this test was not fully successful. WP2 team continued to work on the scenario and improved the prototype so that some tests could be added in the version 2 of this document (cf section 4.4.2.2.2).

4.4.2.2.1 MULTICONNECTIVITY IN A BORDER CROSSING SCENARIO_SCENARIO 1 (TOBA-K IN 4G/5G AREA MOVES TO 4G ONLY AREA THAN 4G/5G AREA THAN 5G ONLY AREA)

- **Objective of the test:**
  The objective of the test is to ensure the continuity of ETCS communication when the train moves from one network to another.

- **Test description:**
  - Scenario 1: TOBA-K in 4G/5G area moves to 4G only area then 4G/5G area then 5G only area (see Figure 11: Cross border with TobaK – scenario 1)
  - See section 8.2.2.3.7.4 in [S22] (5GRAIL Deliverable D1.1 version 4).
  - The ETCS App and the Toba are installed and correctly configured.
  - The Toba is connected to 4G (b38 band) and 5G (n39 band)
  - The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  - The ETCS App receives the connection status “connected”.
  - A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  - Check data exchange between ETCS App and RBC1.

  - Progressively attenuate the 5G until no more signal is received.
  - Wait 2 minutes.
  - Check data exchange between ETCS App and RBC1.

  - Enable, then progressively amplify the 5G signal.
  - Wait 2 minutes.
  - Check data exchange between ETCS App and RBC1.

  - Progressively attenuate the 4G until no more signal is received.
  - Wait 2 minutes.
  - Check data exchange between ETCS App and RBC1.

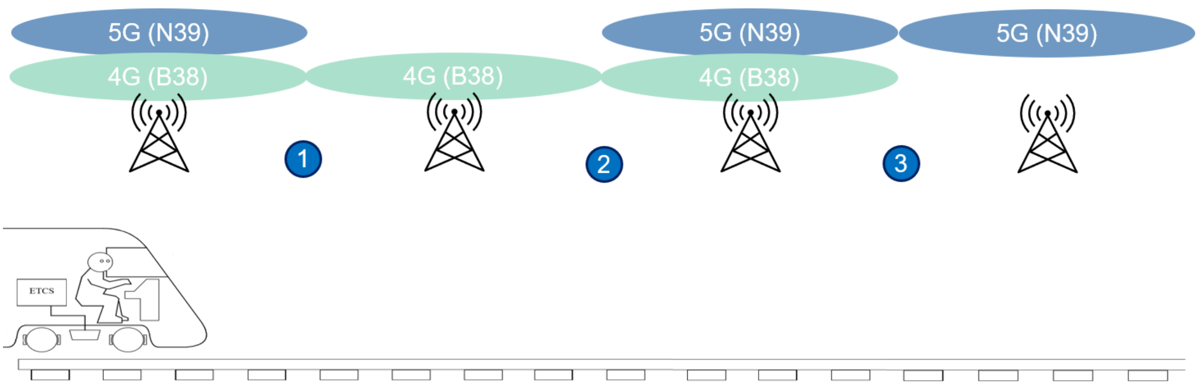


Figure 11: Cross border with TobaK – scenario 1

- Scenario 2: TOBA-K in 4G/5G area moves to 5G only area then 4G/5G area then 4G only area (see Figure 12: Cross border with TobaK – scenario 2)
  See section 8.2.2.3.7.4 in [S22] (5GRAIL Deliverable D1.1 version 4).
  The ETCS App and the Toba are installed and correctly configured.
  The Toba is connected to 4G (b38 band) and 5G (n39 band)
  The ETCS onboard and trackside equipment are powered on: the WebSocket connection is open and working.
  The ETCS App receives the connection status "connected".
  A new connection request for Level 2 communication is done via the DMI: connection to the RBC1.
  Check data exchange between ETCS App and RBC1.

  Progressively attenuate the 4G until no more signal is received.
  Wait 2 minutes.
  Check data exchange between ETCS App and RBC1.

  Enable, then progressively amplify the 4G signal.
  Wait 2 minutes.
  Check data exchange between ETCS App and RBC1.

  Progressively attenuate the 5G until no more signal is received.
  Wait 2 minutes.
  Check data exchange between ETCS App and RBC1.

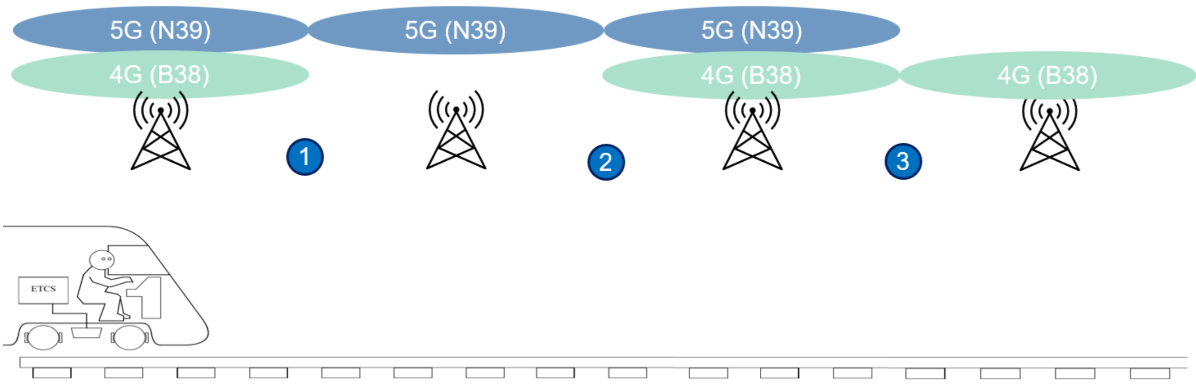


Figure 12: Cross border with TobaK – scenario 2

- **Specific Test configuration:**
  The network is configured to allow ETCS communication data to use both bearers simultaneously.

- **Test results and comments:**

Scenario 1 is failed. The communication is lost during the transition number 3 (from 4G/5G to 5G). Data packets sent from the RBC are no longer received by ETCS onboard application from the moment the 4G bearer is stopped in transition 3.

Scenario 2 is passed.

- **Comments by Alstom :**

The initial state in this test with a 5G/4G bearer aggregated is not realistic compared to on field test conditions but it due to some current constraints on TOBA-K. A more representative scenario would be to start the test with 5G or 4G bearer only, as the aggregated bearer state only happens where the border crossing takes place.

- **Comments by Kontron :**

While scenario 2 is passed, scenario 1 was still failing when closing WP4 activities (WP4 must close because of WP5 having to start, which demand many equipment to be moved as explained in 7.3). However, WP2 team was still working on it in order to deliver it in the field tests.

- **Traces and logs recorded during the test:**

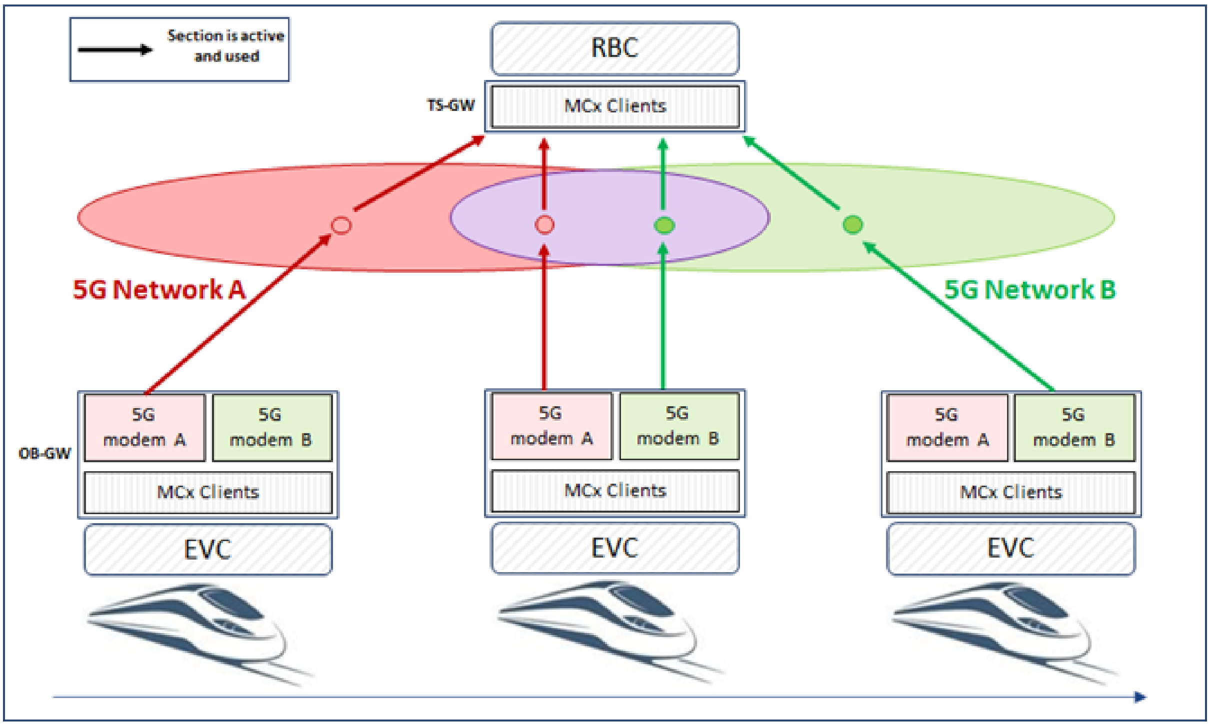
Following traces have been recorded:

5GRAIL_WP4_Alstom_D4_3_ETCS_TC_4.3.10_crossborder_TobaK.zip

4.4.2.2.2 CROSSBORDER TEST WITH TOBA-K : GOING FROM 5G ONLY AREA TO 5G+4G THEN 4G ONLY

- **Objective of the test:**

The objective of the test is to check the performance of the communication when the TOBA-K, used with a 5G UE and a 4G UE, moves from a 5G only area zone to a 5G+4G zone, then to a 4G only zone.



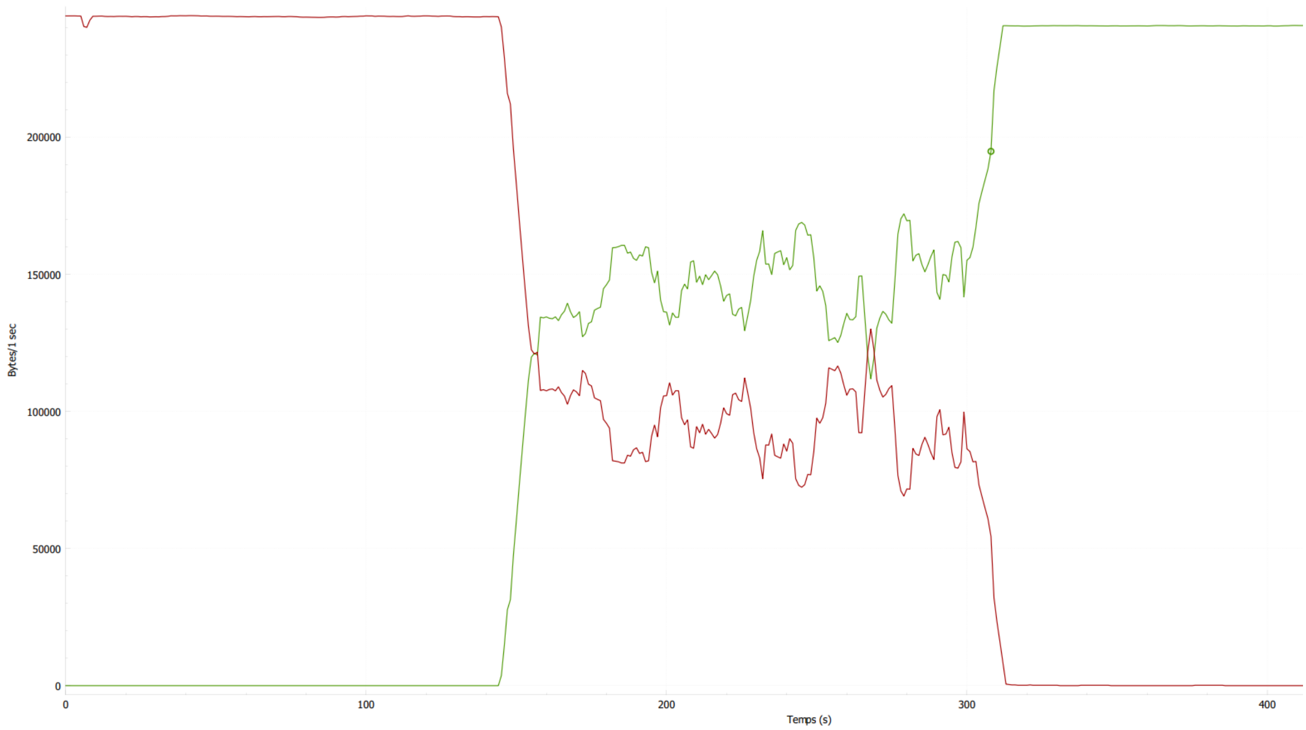
- **Test description:**

Scenario 1: TOBA-K is trafficking on a 5G only area with the application requiring a constant data rate set at 240 kB/s uplink. 4G signal is then added little by little with the RF attenuator. Then later on, the 5G signal is switched sown little by little with another RF attenuator.

- **Test results and comments:**

Following graph has been extracted from the measurements done on 4G and 5G modems.

Red graph shows the data rate on 5G modem while green one shows the one on 4G modem:



We can see that:

- During the first phase, traffic is only on the 5G UE with constant data rate,
- When TOBA-K enters the overlapping 4G+5G zone, the traffic on 5G decreases. Traffic is now shared by MPTCP protocol over the two available paths.
- In the last phase, traffic goes only over 4G.

Interesting points to note:

- When traffic is shared between 4G and 5G, the aggregation of the two flows equals the desired traffic (ie, there is no capacity reduction when using both paths).
- When 5G traffic decreases, 4G traffic increases at the same path. **There is no service outage, the available user data rate remains always the same and there is no interruption of the critical flow**. At the end of the transition, all the traffic is supported by the 4G UE. From critical

railway application point of view, **service continuity has been ensured** during the border crossing.

- **Traces and logs recorded during the test:**

  Following traces have been recorded:

  5GRAIL_WP4_Kontron_ 5G_5Gand4G_4G_crossborder_TobaK.zip

4.5 Conclusion on ETCS tests

Thanks to WP4 tests, we can confirm that the ETCS application in a 5GRail context is able to exchange data with trackside equipment. In a first step, the communication compatibility between the ETCS application and the TOBA has been verified. Sharing the results of the integration tests with WP2 team has resulted in improvements of the equipment software. Then, end to end ETCS communications were verified in both nominal and degraded tests. Minor improvement remains to be done in order to pass the border crossing scenario test as scheduled in WP5. These test results give us confidence on future WP5 field tests. Thanks to WP4 tests, we expect a quick integration of onboard equipment on train and be more efficient in the constrained planning of WP5.

The ETCS test activities were also fruitful as we managed to test features around bearer flexibility, knowing that TOBA-A and TOBA-K use different approaches. Thus, aggregation of bearers (test 4.3.9) and failover scenarios (already seen with ATO) will provide the reader with a good picture of the new capabilities brought by FRMCS OB Gateway. Besides, multiple applications handling were also well tested with ETCS being combined with ATO (in the previous chapter), intense IP traffic and also Remote Vision. In terms of crossborder use cases, it was interesting to test the possible use of two modems thanks to TOBA-A software readiness (test 4.4.2.1) but also the changing of bearers while maintaining the communication (test 4.4.2.2.1). So globally, this chapter shed a light on numerous FRMCS features that bring more flexibility compared to the previous GSM-R system.

5 PIS Tests

5.1 Introduction to PIS tests

A Passenger Information System (PIS) is a system that delivers real-time Transit information to passengers in public areas of the facilities (e.g. concourse, platforms, station entrances,…) as well as through digital channels (web pages, mobile apps, …).

This system publishes visual operator service information, such as station information, train schedules, weather, other useful information in real-time to station or third parties. It also delivers infotainment and advertising content to passengers on different type of devices and locations (e.g. large displays, Led displays, Kiosks…).

We can highlight some common use cases:

- Institutional information (network and the facilities the operator control, the ticket cards or prices, …)
- Public Safety (e.g. Covid messages, etc…)
- Emergencies and warnings (e.g. Do not leave your baggage unattended, Fire alerts etc…) are considers as high priority messages to be delivered to passengers
- News feeds and weather feeds (e.g. scrolling news message from CNN, local area forecast, etc …)
- Promoting events by changing Station names with the event name. (e.g. instead of destination being the usual name would be JO Paris 2024 ,…)

Overall, the PIS is an essential component of modern railway infrastructure, which helps to enhance the passenger experience, improve safety, and increase operational efficiency.

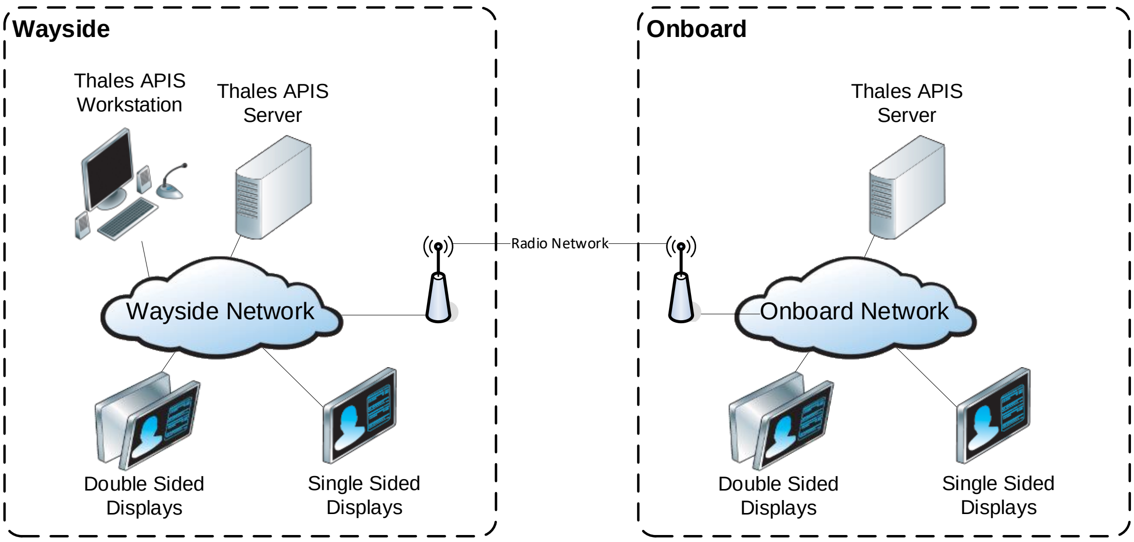


Figure 13: PIS system overview

The 5G network performance for PIS application is an opportunity to improve the delay for real-time information delivery to passenger, especially for high priority messages such as train evacuation needed in case of emergency.

5.2 PIS tests with TOBA-A

The following table gives information about PIS tests executed with TOBA-A:

Test Title	5G Band	OB-GW	Date
On-board PIS logs downloaded on the fly in normal conditions	N8	TOBA-A	11/10/2022
Send text message with a normal priority to trains	N8	TOBA-A	11/10/2022
Send text message with a high priority to trains	N8	TOBA-A	11/10/2022
Open a “trackside to on-board” management session with a high priority	N8	TOBA-A	11/10/2022
Check connection to FRMCS services	N8	TOBA-A	11/10/2022
Display train location information	N8	TOBA-A	11/10/2022
Send text message with a normal priority in degraded conditions – 5G radio link is overloaded	N8	TOBA-A	30/11/2022
Send text message with a high priority in degraded conditions – 5G radio link is overloaded	N8	TOBA-A	30/11/2022
On-board PIS logs downloaded on the fly in degraded conditions	N8	TOBA-A	30/11/2022
Offloading of the on-board logs with 5G overloaded com_profile 6 (auto-accept mode)	N8	TOBA-A	30/11/2022

PIS application was only tested with Alstom flavour of FRMCS gateways because PIS was not targeted to be used in WP5 and consequently not with TOBA-K.

5.2.1 On-board PIS logs downloaded on the fly in normal conditions

- **Objective of the test:**
  The purpose of this test is to validate the ability to send on the fly the on-board PIS logs to trackside equipment in normal conditions, without 5G radio link overload.

- **Test description:**

  See TC_021 PIS Loose test case scenarios (9.6.2.21) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**

  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.
  On trackside, loose mode is set to "auto_accept".
  On on-board side, loose mode is set to "auto_reject"

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  Thales PIS application is registered with three originator id at the same time. We realized that there was a need for a timer between REGISTER messages to avoid issue on FRMCS gateway SIP registration.

  In our test case, we have configure the following sequence: msg.ts.pis is registering, then one second later mgt.ts.pis and again one second later log.ts.pis.

  A minimum timer needs to be defined for FRMCS GW to avoid inconsistency between local registration and SIP registration.

  Comments by Alstom

  Same comment than Thales on the multiple registrations (3 applications). The OB_GTW supports it, but it triggers 3 SIP registrations and MCX authentication in the same time and that was not correctly supported by the SIP core/MCX server. Sequential registrations (every 1 second) solved the issue but it implies a loss of time and a better improvement would be that the SIP core/MCX server support multiple registrations in a short time.

- Traces and logs recorded during the test:

  Following traces have been recorded:

  5GRAIL_WP4_Thales_D4_3_PIS_TC_021_OB_GW_Alstom.pcapng

  5GRAIL_WP4_Thales_D4_3_PIS_TC_021_TS_GW_Alstom.pcapng

  5GRail_WP4_Thales_D4_3_PIS_TC_021_logs.txt

  5GRAIL_WP4_Alstom_D4.3_PIS_test1.pcap

5.2.2 Send text message with a normal priority to trains

- **Objective of the test:**
  The purpose of this test is to validate that the Passenger Information Controller is able to send text messages to trains.

- **Test description:**
  See TC_013 PIS Loose test case scenarios (9.6.2.13) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.
  On trackside, loose mode is set to “auto_reject”.
  On on-board side, loose mode is set to “auto_accept”

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  As a reminder, PIS application is not critical and the application delay requirement is less than 7 seconds.

  Following KPI has been measured during this test:

  Message received in 4,75 s when session not opened.

  Message received in 2,64 s when session is already opened.

  Comments by Alstom

  No comment, successful test.

- Traces and logs recorded during the test:

  Following traces have been recorded:

  5GRail_WP4_Thales_D4_3_PIS_all_TC_TS_messages_logs_11102022.txt

  5GRAIL_WP4_Thales_D4_3_PIS_TC_013_TS_GW_Alstom.pcapng

5GRAIL_WP4_Thales_D4_3_PIS_TC013_OB__GW_Alstom.pcapng

5GRAIL_WP4_Alstom_D4.3_PIS_test2.zip

5.2.3 Send text message with a high priority to trains

- **Objective of the test:**
  The purpose of this test is to validate that the Passenger Information Controller is able to send text messages with a high priority to trains.

- **Test description:**

  See TC_014 PIS Loose test case scenarios (9.6.2.14) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.
  On trackside, loose mode is set to “auto_reject”.
  On on-board side, loose mode is set to “auto_accept”

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  As a reminder, PIS application is not critical and the application delay requirement is less than 7 seconds.

  Following KPI has been measured during this test:

  Message received in 5.05 s when session not opened.

  Message received in 2.75 s when session is already opened.

  Comments by Alstom

  No improvement compared with test 2 but it was expected (no disturbing flow in parallel)

- Traces and logs recorded during the test:

  Following traces have been recorded:

5GRAIL_WP4_Thales_D4_3_PIS_TC014_TS_GW_Alstom.pcapng

5GRAIL_WP4_Thales_D4_3_PIS_TC014_OB_GW_Alstom.pcapng

5GRail_WP4_Thales_D4_3_PIS_all_TC_TS_messages_logs_11102022.txt

5GRAIL_WP4_Alstom_D4.3_PIS_test3.pcap

5.2.4 Open a "trackside to on-board" management session with a high priority

- **Objective of the test:**
  The purpose of this test is to validate the ability to open a "trackside to on-board" management session with a critical priority during a significant time (e.g., 15 minutes) for PIS O&M operations.
  The connection shall be resilient even with non-optimal radio conditions.

- **Test description:**
  See TC_019 PIS Loose test case scenarios (9.6.2.19) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.
  On trackside, loose mode is set to "auto_reject".
  On on-board side, loose mode is set to "auto_accept"

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  For maintenance purpose, trackside is able to open a management session from Trackside to on-board system.

  Comments by Alstom

  No comment, successful test.

- Traces and logs recorded during the test:

Following traces have been recorded:

5GRAIL_WP4_Thales_D4_3_PIS_TC019_TS_GW_Alstom.pcapng

5GRAIL_WP4_Thales_D4_3_PIS_TC019_OB_GW_Alstom.pcapng

5GRail_WP4_Thales_D4_3_PIS_TC_019_020_messages_logs_11102022.txt

5GRAIL_WP4_Alstom_D4.3_PIS_test4.pcap

5.2.5 Check connection to FRMCS services

- **Objective of the test:**
  The purpose of this test is to validate the ability to verify the connection status is correct between PIS on-board application and FRMCS services.

- **Test description:**
  See TC_020 PIS Loose test case scenarios (9.6.2.20) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  This is an useful feature that's helping application to get FRMCS gateway network status. Error 503 seen once for SIP registration.

  Comments by Alstom

  No particular comment, successful test. The "Error 503" mentioned in Thales comments was related to the SIP PUBLISH message (for MCdata authorization), but it is hidden to the application (there is a decoupling between SIP exchanges with the SIP core/MCx server, and OBapp/TSapp exchanges between application and FRMCS gateway)

- Traces and logs recorded during the test:

  Following traces have been recorded:

  5GRAIL_WP4_Thales_D4_3_PIS_TC020_OB_GW_Alstom.pcapng

5GRAIL_WP4_Thales_D4_3_PIS_TC020_TS_GW_Alstom.pcapng

5GRAIL_WP4_Thales_D4_3_PIS_TC_019_020_messages_logs_11102022.txt

5GRAIL_WP4_Alstom_D4.3_PIS_test5.pcap

5.2.6 Display train location information

- **Objective of the test:**
  The purpose of this test is to validate the ability to synchronize the "secondary" on-board Train Mission Database with "primary" trackside database to provide accurate information to the passengers in the train about the location of the train.

- **Test description:**
  See TC_017 PIS Loose test case scenarios (9.6.2.17) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  Train mission has been sent successfully to on-board and displayed.

  Comments by Alstom

  No particular comment, successful test

- Traces and logs recorded during the test:

  Following traces have been recorded:

  5GRAIL_WP4_Thales_D4_3_PIS_TC017_OB_GW_Alstom.pcapng

  5GRAIL_WP4_Thales_D4_3_PIS_TC017_TS_GW_Alstom.pcapng

  5GRail_WP4_Thales_D4_3_PIS_TC_017_messages_logs_11102022.txt

  5GRAIL_WP4_Alstom_D4.3_PIS_test6.pcap

5.2.7 Send text message with a normal priority in degraded conditions – 5G radio link is overloaded

- **Objective of the test:**
  The purpose of this test is to validate that the Passenger Information Controller is able to send text messages to trains in degraded conditions.
  5G radio link overload is considered as degraded conditions scenario.

- **Test description:**
  See TC_015 PIS Loose test case scenarios (9.6.2.15) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.

  Iperf load of 20 Mbps is applied with comm_profile = 6
  PIS application is used with comm_profile = 7

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  An issue at FRMCS gateway has been identified due to a QOS management. It was solved later thanks to a new delivery of FRMCS GW.

  Following KPI results have been recorded:

  Message received in 6.90s (session not open)
  Message received in 5.67s (session already open)

  5G overloaded is impacting message time delivery (increase of around 2s) but still respected the maximum delay allowed for PIS end to end messages (less than 7 seconds)

  Timer needs to be fine tuning between session start and session status between application and FRMCS Gateway

  Comments by Alstom

  After modification of FRMCS GW to internally manage the priority (before the QoS on radio level), the test behaviour was correct as expected. The Iperf session was established with comm_profile less prioritized than PIS session. We notice that the low rate (PIS) is OK.

- Traces and logs recorded during the test:

Following traces have been recorded:

5GRAIL_WP4_Thales_D4_3_PIS_TC015_TS_GW_Alstom.pcapng

5GRAIL_WP4_Thales_D4_3_PIS_TC015_OB_GW_Alstom.pcapng

5GRail_WP4_Thales_D4_3_PIS_TC_019_020_messages_logs_30112022.txt

5GRAIL_WP4_Alstom_D4.3_PIS_test7.zip

5.2.8 Send text message with a high priority in degraded conditions – 5G radio link is overloaded

- **Objective of the test:**
  The purpose of this test is to validate that the Passenger Information Controller is able to send high priority text messages to trains in degraded conditions.
  5G radio link overload is considered as degraded conditions scenario.

- **Test description:**
  See TC_016 PIS Loose test case scenarios (9.6.2.16) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.
  On trackside, loose mode is set to "auto_reject".
  On on-board side, loose mode is set to "auto_accept"

  Iperf load of 20 Mbps is applied with comm_profile = 6
  PIS application is used with comm_profile = 8

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  An issue at FRMCS gateway has been identified due to a QOS management. It was solved later thanks to a new delivery of FRMCS GW.

  Following KPI results have been recorded:

  Message received in 6.97s (session not open)
  Message received in 5.53s (session already open)

5G overloaded is impacting message time delivery (increase of around 2s) but still respected the maximum delay allowed for PIS end to end messages (less than 7 seconds).

Timer needs to be fine tuning between session start and session status between application and FRMCS Gateway

Comments by Alstom

Modification of FRMCS GW to internally manage the priority (before the QoS on radio level). Then, the test behaviour was correct as expected.

The Iperf session was established with comm_profile less prioritized than PIS session.

We notice that the low rate (PIS) is OK.

- Traces and logs recorded during the test:

  Following traces have been recorded:

  5GRAIL_WP4_Thales_D4_3_PIS_TC016_TS_GW_Alstom.pcapng

  5GRAIL_WP4_Thales_D4_3_PIS_TC016_OB_GW_Alstom.pcapng

  5GRail_WP4_Thales_D4_3_PIS_TC_019_020_messages_logs_30112022.txt

  5GRAIL_WP4_Alstom_D4.3_PIS_test8.pcap

5.2.9 On-board PIS logs downloaded on the fly in degraded conditions

- **Objective of the test:**
  The purpose of this test is to validate the ability to send on the fly the on-board PIS logs to trackside in degraded conditions.
  5G radio link overload is considered as degraded conditions scenario.

- **Test description:**
  See TC_018 PIS Loose test case scenarios (9.6.2.18) in [S22] (5GRAIL Deliverable D1.1 version 4).

- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.
  On trackside, loose mode is set to “auto_accept”.

On on-board side, loose mode is set to “auto_reject”

Iperf load of 20 Mbps is applied with comm_profile = 6
PIS application is used with comm_profile = 7 (instead of 6, as defined in QoS PIS table, section 9.6.1.1 of [S22]).

- **Test results and comments:**

Test is passed.

Comments by Thales

An issue at FRMCS gateway has been identified due to a QOS management. It was solved later thanks to a new delivery of FRMCS GW.

Comm_profile 7 has been tested to ensure that QOS priority is working on FRMCS GW.

No packet loss. No specific KPI to be recorded for this test as there is no requirements for the moment on that service.

Comments by Alstom

Modification of FRMCS GW to internally manage the priority (before the QoS on radio level). Then, the test behaviour was correct as expected.

- Traces and logs recorded during the test:

Following traces have been recorded:

5GRAIL_WP4_Thales_D4_3_PIS_TC018_TS_GW_Alstom.pcapng

5GRAIL_WP4_Thales_D4_3_PIS_TC018_OB_GW_Alstom.pcapng

5GRAIL_WP4_Thales_D4_3_PIS_TC018_offloading_messages_20221130.txt

5GRAIL_WP4_Alstom_D4.3_PIS_test9.zip

5.2.10 Offloading of the on-board logs with 5G overloaded com_profile 6 (auto-accept mode)

- **Objective of the test:**
The purpose of this test is to validate the ability to send on the fly the on-board PIS logs to trackside in degraded conditions.
5G radio link overload is considered as degraded conditions scenario.

- **Test description:**
  See TC_018 PIS Loose test case scenarios (9.6.2.18) in [S22] (5GRAIL Deliverable D1.1 version 4).
- **Specific Test configuration:**
  FRMCS on-board Gateway is a TOBA-A delivered by Alstom. It uses an ES1 Thales modem operating in 5G N8.
  On trackside, loose mode is set to "auto_accept".
  On on-board side, loose mode is set to "auto_reject"

  Iperf load of 20 Mbps is applied with comm_profile = 6
  PIS application is used with comm_profile = 6

- **Test results and comments:**

  Test is passed.

  Comments by Thales

  An issue at FRMCS gateway has been identified due to a QOS management. It was solved later thanks to a new delivery of FRMCS GW.

  In the context of the prototype, QOS for the offloading on-board logs is not significant due to low data rate and low messages occurrence. In real train operation, this can be more logs to be downloaded at given time and QOS could be useful.

  No packet loss. No specific KPI to be recorded for this test as there is no requirements for the moment on that service.

  Comments by Alstom

  Modification of FRMCS GW to internally manage the priority (before the QoS on radio level). Then, the test behaviour was correct as expected.

- Traces and logs recorded during the test:

  Following traces have been recorded:

  5GRAIL_WP4_Thales_D4_3_PIS_TC018_TS_GW_Alstom_com_6.pcapng

  5GRAIL_WP4_Thales_D4_3_PIS_TC018_OB_GW_Alstom_com_6.pcapng

  5GRAIL_WP4_Thales_D4_3_PIS_TC018_offloading_messages_20221130.txt

5.3 Conclusion on PIS tests

Thales PIS application prototype is now compliant with FRMCS specifications V1 in terms of OBapp and TSapp interface.

The application has been tested with Alstom and Kontron Gateway over Wifi, 5G (n8 band) and 4G technologies.

The virtual session IP address principle has been validated successfully with Thales PIS and Alstom FRMCS gateway.

QOS proposal has been made and tested successfully for PIS application usage with Alstom GW over 5G Kontron infrastructure. In fact, 5G QI mapping has been done with DSCP value defined in D2.1 specification document.

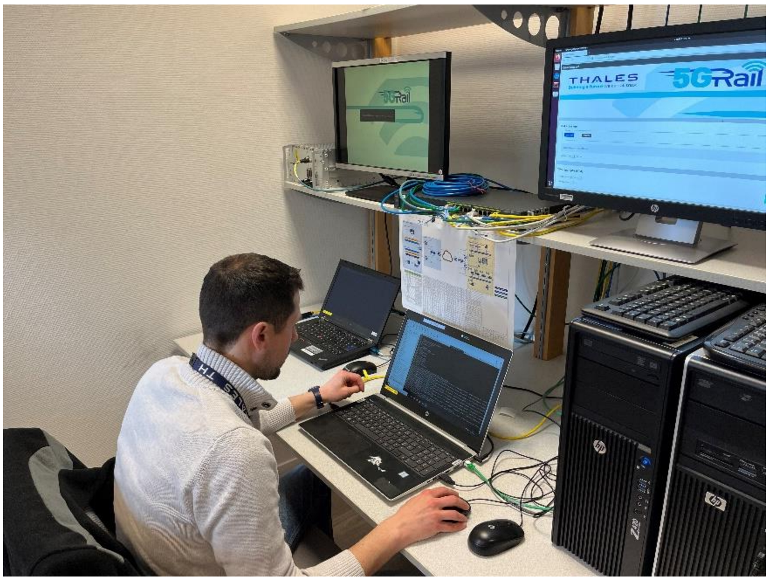


Figure 14: Thales engineer working remotely on PIS WP4 set-up

6 WP4 Optional Tests

6.1 MCPTT and MCDATA Tests

Voice tests with MCPTT were optional in WP4. However, Kontron having a MCPTT solution and some experience on it, we took the opportunity to run few tests related to that service in order to contribute to technical exchanges.

6.1.1 Introduction

For MCPTT testing, we could use:

- An MCx dispatcher directly connected to the N6 LAN, this dispatcher hosts a MCx User Agent,
- Two smartphones SONIM XP8 that can connect on the Wifi network, with an android version of the Kontron MCPTT client,
- A XP10 smartphone that can connect on the N8 band and on which the Kontron MCPTT client has been installed.

Globally, we have then the following set-up for the MCPTT tests:

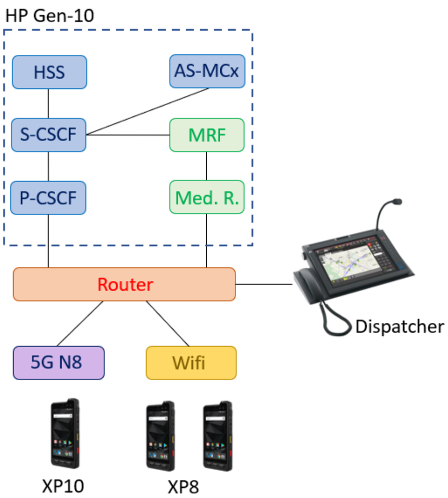


Figure 15: MCPTT test set-up

Some tests (6.1.2.1, 6.1.2.2 and 6.1.2.3) enabled us to measure some KPIs in order to give rough ideas on their values. Other tests are more informative about what can be done with MCx solutions and illustrate some use cases. Reading of [S26] chapter 6.15 is interesting regarding MCPTT KPIs.

6.1.2 MCx tests

The following MCPTT and MCDATA tests have been done:

Test Title	Section
A smartphone user initiates an Emergency Group Call	6.1.2.1
A smartphone user request access to speak during a Group Call	6.1.2.2
Dispatcher sends a SDS to a smartphone	6.1.2.3
MCPTT point to point call from Dispatcher to smartphone with floor control	6.1.2.4
MCPTT point to point call from Dispatcher to smartphone without floor control	6.1.2.5
MCPTT group call from Dispatcher to smartphones with floor control	6.1.2.6
MCPTT emergency call from Dispatcher to smartphones already in call	6.1.2.7
MCPTT dynamic group call from Dispatcher	6.1.2.8
MCPTT priority management when accessing floor	6.1.2.9
Smartphone sends a SDS to a group of users	6.1.2.10

6.1.2.1 Smartphone initiates an Emergency group Call

- **Objective of the test:**
  The purpose of this test is to launch an emergency Group Call from a smartphone and measure the time needed to establish such a call. Smartphone is connected on 5G N8 band.

- **Test description:**
  The three smartphones are connected (Two on Wifi and the other one on 5G SA N8 network).
  Dispatcher console is opened and in service.
  The smartphone connected on 5G launches an emergency group call.

- **Specific Test configuration:**
  The objective is to measure time needed for this emergency group call to be established, knowing that the call is automatically answered by all participants. In order to do this measurement, and because we do not have currently a 5G SA mobile with tracing capabilities, we take traces at the P-CSCF level. Round-trip delay between smartphone and P-CSCF is then added to get a rough idea on the KPI value.

- **Test results and comments:**

  Call is established successfully. Test is passed.

  Comments by Kontron

This test is linked to the KPI "End-to-end MCPTT Access time" defined in 3GPP TS22.179. In the call flow below, it refers to the time needed between the *INVITE* message, sent by the caller, and the *200 OK* message it receives when the call is established. It gives an idea on the time needed to set up an Emergency Group Call with the current set-up.

Measurements:

From the trace, time between packet 123 and 56, KPI is roughly 700ms. It is related to KPI defined in [S26] section 8.15.3 under the name "End-to-end MCPTT Access Time" with a target of less than 1000ms.

- **Traces and logs recorded during the test:**

  Following traces have been recorded:

  5GRAIL_WP4_Kontron_D4_3_MCPTT_Emergency Call from Smartphone.pcapng

6.1.2.2 A smartphone user request access to speak during a Group Call

- **Objective of the test:**
  The purpose of this test is to launch a Group Call from dispatcher where all smartphones are involved. Dispatcher gets the floor first and after a while, the smartphone using 5G SA N8 requests the floor.

- **Test description:**
  The three smartphones are connected (Two on Wifi and the other one on 5G SA N8 network).
  Dispatcher console is opened and in-service. Dispatcher is launching a group call with PTT function and all smartphones join.
  The smartphone connected on 5G launches requests the floor.

- **Specific Test configuration:**
  The objective is to measure time needed for this floor request to be granted. In order to do this measurement, and because we do not have currently a 5G SA mobile with tracing capabilities, we take traces at the P-CSCF level. Round-trip delay between smartphone and P-CSCF is then added to get a rough idea on the KPI value.

- **Test results and comments:**

  Group call is established successfully and after floor request, floor is actually given to the smartphone using 5G N8. Test is passed.

  Comments by Kontron

This test is linked to the KPI "MCPTT Access time" defined in 3GPP TS22.179. In the call flow below, it refers to the time needed between the *Floor Request* message, sent by the initiator, and the *Floor Granted* message it receives when the floor is actually given. It gives an idea on the time needed to really get the ability to talk after deciding to.

Figure 16: Sequence flow when floor is requested

Measurements :

From the trace below, RTCP messages are screened and time measurement is done between Floor granted and Floor request messages. <u>KPI is roughly 50ms</u>. It is related what is defined in [S26] section 8.15.3 under the name "MCPTT Access Time" with an expected target of less than 300ms.

- <u>**Traces and logs recorded during the test:**</u>

  Following trace has been recorded:

  5GRAIL_WP4_Kontron_D4_3_MCPTT_ A smartphone user request access to speak during a Group Call.pcapng

6.1.2.3 Dispatcher sends a SDS to a smartphone

- <u>**Objective of the test:**</u>
  The purpose of this test is to send a short message from the dispatcher to the smartphone using 5G N8 and measure the time needed to receive such SDS.

Figure 17: MCx dispatcher and smartphones used in WP4 lab

- **Test description:**
  The smartphone is connected on 5G SA N8 network.
  Dispatcher console is opened and in service.
  The dispatcher sends a short message to the smartphone (less than 50 characters).

- **Specific Test configuration:**
  The objective is to measure time needed for this SDS to be delivered. In order to do this measurement, we take traces at the P-CSCF level. Half round-trip delay between smartphone and P-CSCF, plus half round-trip delay between Dispatcher and P-CSCF is then added to get a rough idea on the KPI value.

- **Test results and comments:**

  SDS is delivered successfully. Test is passed.

  Comments by Kontron

  This tests gives a rough idea on the time needed for SDS delivery. SDS is conveyed using SIP MESSAGE METHOD.

  Measurements :

  In the trace below, we measure the time between packets 69 and 77 (SIP MESSAGE). KPI is roughly 50ms.

- **Traces and logs recorded during the test:**

  Following traces have been recorded:

  5GRAIL_WP4_Kontron_D4_3_ Dispatcher sends a SDS to a smartphone.pcapng

6.1.2.4 MCPTT point to point call from Dispatcher to smartphone with floor control

- **Objective of the test:**
  The purpose of this test is to initiate a point to point call from Dispatcher to the smartphone using 5G N8. This call should be with the PTT function.

- **Test description:**
  The smartphone is connected on 5G SA N8 network.
  Dispatcher console is opened and in service.
  The dispatcher launches a MCPTT point to point call to the smartphone.

- **Specific Test configuration:**
  None.

- **Test results and comments:**

  Call is achieved successfully. Test is passed.

  Comments by Kontron

  No specific KPI recorded for this test. Idea of this test is to show what is feasible with current MCx specifications.

- **Traces and logs recorded during the test:**

  Following traces has been recorded:

  5GRAIL_WP4_Kontron_D4_3_ MCPTT point to point call from Dispatcher to smartphone with floor control.pcapng

6.1.2.5 MCPTT point to point call from Dispatcher to smartphone without floor control

- **Objective of the test:**
  The purpose of this test is to initiate a point to point call from Dispatcher to the smartphone using 5G N8. This call should be without the PTT function, showing then that MCPTT calls can be with or without Floor Control.

- **Test description:**
  The smartphone is connected on 5G SA N8 network.
  Dispatcher console is opened and in service.
  The dispatcher launches a MCPTT point to point call to the smartphone, without PTT function.

- **Specific Test configuration:**
  None.

- **Test results and comments:**

  Call is achieved successfully. Test is passed.

  Comments by Kontron

  No specific KPI recorded for this test. Idea of this test is to show what is feasible with current MCx specifications.

- Traces and logs recorded during the test:

  Following traces has been recorded:

  5GRAIL_WP4_Kontron_D4_3_ MCPTT point to point call from Dispatcher to smartphone without floor control.pcapng

6.1.2.6 MCPTT group call from Dispatcher to smartphones with floor control

- **Objective of the test:**
  The purpose of this test is to initiate a group call from Dispatcher to the smartphones using 5G N8 and Wifi. This call should be with the PTT function.

- **Test description:**
  The XP10 smartphone is connected on 5G SA N8 network. XP8 smartphones are connected on Wifi.
  Dispatcher console is opened and in service.
  The dispatcher launches a MCPTT group call to the smartphones, with PTT function.

- **Specific Test configuration:**
  None.

- **Test results and comments:**

  Call is achieved successfully. Test is passed.

  Comments by Kontron

  No specific KPI recorded for this test. Idea of this test is to show what is feasible with current MCx specifications.

- Traces and logs recorded during the test:

  Following traces has been recorded:

5GRAIL_WP4_Kontron_D4_3_ MCPTT group call from Dispatcher to smartphones with floor control.pcapng

6.1.2.7 MCPTT emergency call from Dispatcher to smartphones already in call

- **Objective of the test:**
  The purpose of this test is to initiate an emergency group call from Dispatcher to smartphones that are already participating in a MCx communication.

- **Test description:**
  XP8 smartphones are connected on Wifi.
  Dispatcher console is opened and in service.
  The two smartphone are involved in a point to point MCx call.
  The dispatcher launches a MCPTT group call to the smartphones, with PTT function.

- **Specific Test configuration:**
  None.

- **Test results and comments:**

  Emergency call is notified on the smartphones that automatically join the call, leaving the other ongoing one pending. Test is passed.

  Comments by Kontron

  No specific KPI recorded for this test. Idea of this test is to show what is feasible with current MCx specifications. Note that there is no pre-emption mechanism and that behaviour is linked to MCx client software implementation. Previous call is just put aside for the duration of the emergency call. Priorities of calls (defined in MCx specifications) are used to set up which call should be active.

- Traces and logs recorded during the test:

  Following traces has been recorded:

  5GRAIL_WP4_Kontron_D4_3_ MCPTT emergency call from Dispatcher to smartphones already in call.pcapng

6.1.2.8 MCPTT dynamic group call from Dispatcher

- **Objective of the test:**
  The purpose of this test is to initiate a group call from Dispatcher to smartphones that are in a specific area.

- **Test description:**
  XP8 smartphones are connected on Wifi with GPS location reported to AS MCx.
  Dispatcher console is opened and in service.
  The dispatcher launches a MCPTT group call to the smartphones using the map.

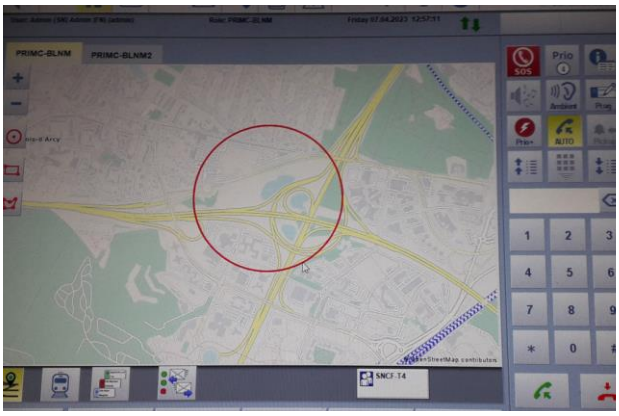


Figure 18: Dispatcher ability to select a zone for a Group Call

- **Specific Test configuration:**
  In order to run the test, smartphones send fake GPS positions in order to get one smartphone out of the zone.

- **Test results and comments:**

  Group call is notified on the smartphones that are in the area. Test is passed.

  Comments by Kontron

  No specific KPI recorded for this test. Idea of this test is to show what is feasible with current MCx specifications.

- **Traces and logs recorded during the test:**

  Following traces has been recorded:

  5GRAIL_WP4_Kontron_D4_3_ MCPTT dynamic group call from Dispatcher.pcapng

6.1.2.9 MCPTT priority management when accessing floor

- **Objective of the test:**
  The purpose of this test priority management of users wanting to access floor during a MCPTT group call.

- **Test description:**

The XP10 smartphone is connected on 5G SA N8 network. XP8 smartphones are on Wi-Fi.
Dispatcher console is opened and in service.
The dispatcher launches a MCPTT group call with floor control.
Dispatcher talks and do not release the floor.
XP10 requests the floor but its priority does not allow it to grab the token. Floor is not granted.
XP8 requests the floor knowing that its priority does actually allow it to grab the token. Floor is granted.

- **Specific Test configuration:**
  None

- **Test results and comments:**

  Test is passed.

  Comments by Kontron

  No specific KPI recorded for this test. Idea of this test is to show what is feasible with current MCx specifications.

- **Traces and logs recorded during the test:**

  Following traces have been recorded:

  5GRAIL_WP4_Kontron_D4_3_ MCPTT priority management when accessing floor.pcapng

6.1.2.10 Smartphone sends a SDS to a group of users

- **Objective of the test:**
  The purpose of this test is to send a short message from the dispatcher to the smartphones (group SDS).

- **Test description:**
  The XP10 smartphone is connected on 5G SA N8 network. XP8 smartphones are on Wi-Fi.
  Dispatcher console is opened and in service.
  The dispatcher sends a short message to the smartphones (less than 50 characters).

- **Specific Test configuration:**
  None

- **Test results and comments:**

  SDS is delivered successfully. Test is passed.

Comments by Kontron

No specific KPI recorded for this test. Idea of this test is to show what is feasible with current MCx specifications.

- **Traces and logs recorded during the test:**

Following traces have been recorded:

5GRAIL_WP4_Kontron_D4_3_ Dispatcher sends a SDS to a group of users.pcapng

6.2 Interworking with GSM-R

MCX/GSM-R interworking will be required whatever the network due to transition period for migration of the whole networks, and indeed for migration of the pending part within trains. In order to facilitate the migration between GSM-R and FRMCS system, some decision have been recently taken by UIC and ETSI. The FRMCS (on-board side) system should as far as possible be developed independently of GSM-R. Thus, in this context, the service migration functionality should be part of the Application layer and not part of the FRMCS Service layer. Reader can benefit from the reading of 3GPP TS 23.283 "Mission Critical Communication Interworking with Land Mobile Radio Systems" (R17) [S28] in order to get more details on this interconnection.

The basic idea is to connect GSM-R core network to the SIP Core of FRMCS system. Then, typically when group calls occur, groups of MCX users and Group of GSM-R users will have to communicate together within common calls. The more the migration of users from GSM-R to FRMCS will advance, the more the usage of MCX will take importance. Currently, specifications are not ready for this interface, which naturally prevents development efforts on that topic. Yet, we were able to test basic interconnection for voice service and point to point calls.
Among these optional tests, interworking with GSM-R group calls could not be tested as the token management between MCx and GSM-R users is yet not defined in the ETSI specification TR 103 768 [S29]. WP3, whose focus is on voice tests, could not test floor control yet for the same reasons.

At the end, following tests were performed:

Test Title	5G Band	Date
Point to Point Voice Call from a GSM-R user to a MCx user	N8	02/02/2023
Point to Point Voice Call from a MCx user to a GSM-R user	N8	02/02/2023

6.2.1.1 Point to Point Voice Call from a GSM-R user to a MCx user

- Objective of the test:
  This test aims at checking that a GSM-R user can call a MCx user.

- Test description:
  GSM-R handset is attached on the GSM-R network and call the phone number corresponding to the MCx user which is registered on FRMCS side.

- Specific Test configuration:
  Translation is configured in GSM-R core network and a SIP connection is available towards S-CSCF of the FRMCS SIP Core (no IBCF/TrGW function implemented). GSM-R Media Gateway is linked to the MRF via a common user plane IP network.

- Test results and comments:
  Call is successful and voice communication is normal.

- Traces and logs recorded during the test:

  5GRAIL_WP4_Kontron_D4.3_6.2.1.1.zip

6.2.1.2 Point to Point Voice Call from a MCx user to a GSM-R user

- Objective of the test:
  This test aims at checking that a MCx user can call a GSM-R user.

- Test description:
  GSM-R handset is attached on the GSM-R network. MCx user calls the phone number corresponding to the GSM-R user.

- Specific Test configuration:
  Translation is configured in S-CSCF and a SIP connection is available towards R4 GSM-R MSC (direct link with no IBCF/TrGW function implemented for the time being). GSM-R Media Gateway is linked to the MRF via a common user plane IP network.

- Test results and comments:
  Call is successful and voice communication is normal.

- Traces and logs recorded during the test:

  5GRAIL_WP4_Kontron_D4.3_6.2.1.2.zip

6.3 Activities linked with cybersecurity

As explained in appendices 10.1 “10.1Work Package 4 content and planning of activities”, Task 4.3 has been skipped under a consortium agreement in order to ensure a faster delivery of 5G N39 modem.

However, Kontron and Alstom proposed to fill partially the gap by introducing some new experiments and suggestions regarding cybersecurity. This section deals with these topics.

6.3.1 Electronic Air Gap device introduction

The Electronic Air Gap function is a very interesting concept that helps providing security in some telecommunication architectures. The basic idea of it is to have an equipment with two sides, called gates, with a typical connection between them. In fact, as shown on Figure 19: Electronic Air Gap device architecture, whenever a packet reaches Gate A on a logical slot, the upper layers of the OSI model (4-7) will be extracted from it, transferred to Gate B that will build new layers 1-3. Slots are paired one to one and configured with rules. For example, these rules will stipulate that any packet coming on Gate A with destination IP x.x.x.x and destination port y will be handled by Slot 1, and so automatically passed (after deconstructing) to Slot 1 of Gate B.

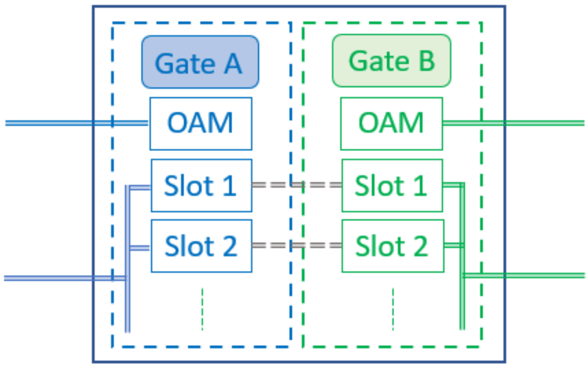


Figure 19: Electronic Air Gap device architecture

When doing this, there is a kind of protection related to the cyber attacks targeting low level layers. Yet, the interest is also to be found in the fact that Gates A and B are managed by separated OAM parts with no connection between them.

Thus, supposing that a hacker managed to get control of side A for example, there is no possibility for him to reach the operating system on side B. And this is precisely the interest of the whole equipment: whereas some attacks can progress hop by hop through routers, electronic air gap device sets a clear wall that will stop any spreading. Consequently, it fits quite well protection needs between a critical zone that needs top security, and another one that is not managed by the same bodies or which is prone to more kind of attacks because the technologies it uses.

For example, let’s consider the case of Figure 20: Electronic air gap example of use case where an electronic air gap device is inserted between a critical OAM LAN and a non critical one. User A may need to connect to a device that does not belong to the critical part and thus, there is a need for an interconnect device (here, the electronic air gap). On the contrary, user B is not allowed to do any connection towards critical LAN and this restriction comes from configuration on Gate B and Gate A.

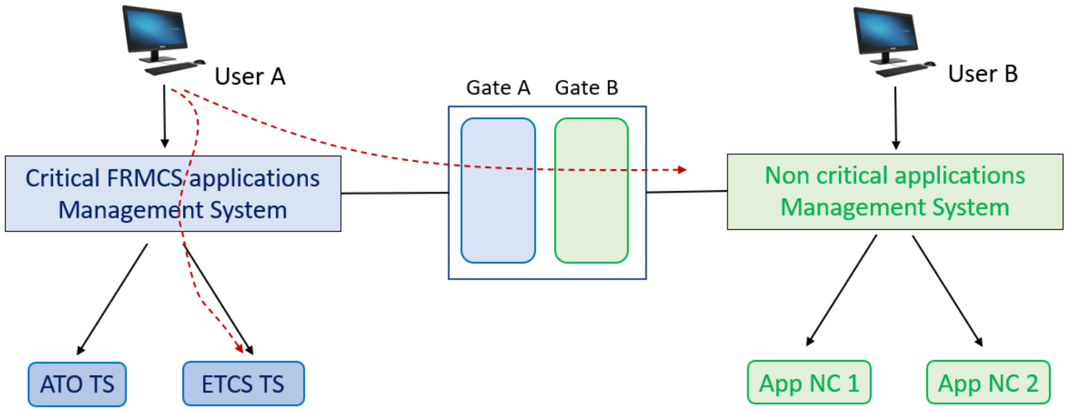


Figure 20: Electronic air gap example of use case

Suppose that a hacker manages to get into user's B PC. He will be able to connect and modify whatever he can on that PC, on non-critical application 1 and non-critical application 2. He may even manage to hack Gate B of the electronic air gap device. But, he will never be able to connect onto Gate A because, unlike firewalls and routers, sides A and B do not belong to the same system.

In WP4 lab, we installed a SCE XN electronic air gap device from SecLab company.

Figure 21: Sec XN Seclab equipment

We chose to illustrate another use case with that equipment by installing another IMS network next to the N6 LAN (see Figure 22). Idea is to reflect the following use case: A user is in the critical zone (FRMCS on the left) but needs to access some non-critical services that stands in another network of the railway operator (green part on the right). An interconnection point is needed and in this case, we put an electronic air gap device because in doing so, there is a physical isolation of critical and non-critical networks, including OAM part: Let's assume for instance, that OAM B is hacked because of an attack coming from OAM non critical zone, there is no way for hackers to go further in the critical zone.

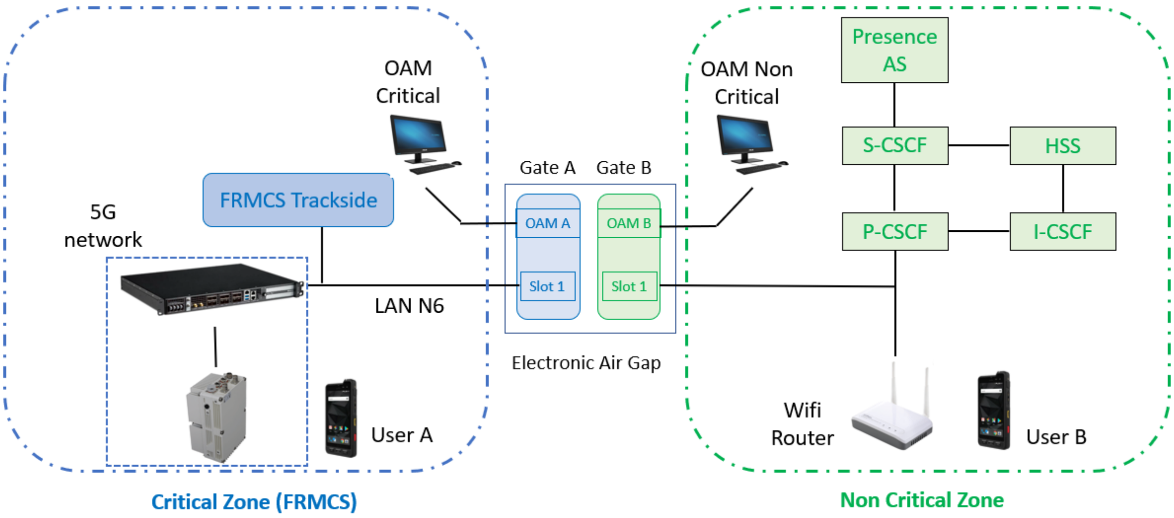


Figure 22: Electronic Air Gap device and non-critical IMS network inserted in WP4 lab

Having set-up Sec-Xn device, we put an IMS network on simulated non-critical zone (P-CSCF, I-CSCF, S-CSCF, HSS and a presence Server). User B, in the non-critical zone, reaches its services thanks to a Wifi router. User A moves to the critical zone and, using for instance 5G SA connection, wants to connect its IMS client in order to access the non-critical services.

Following basic tests have been done with that configuration:

Test Title	5G Band	Date
User A, in critical zone; registers on non critical IMS	N8	14/02/2023
User A, in critical zone, launches a voice call to User B in non critical zone	N8	14/02/2023
User A, in critical zone, launches a video call to User B in non critical zone	N8	14/02/2023
User A, in critical zone, sends a message to User B in non critical zone	N8	14/02/2023

6.3.1.1 User A, in critical zone; registers on non critical IMS

- **Objective of the test:**
  The purpose of this test is to launch the registration process from critical zone.

- **Test description:**
  The XP10 smartphone is connected on 5G SA N8 network.
  User opens its IMS client (Boghe software).

- **Test results and comments:**

  Registration is achieved and third party registration to Presence Server is done. User B can then see that User A is reachable.

  Comments by Kontron

SecXn equipment obviously introduce some delay compare to the use of a router with firewall. This is due to constructing/deconstructing process between the Gates. If we want to assess the delay that is introduced, we must compare with the duration of the same procedure executed in the green zone. For this registration test, **comparing with the registration in the non-critical zone shows that the electronic air gap has added a delay of 82 ms**. It shows that the device might have an impact on real time application.

- **Traces and logs recorded during the test:**

  Following traces have been recorded:

  5GRAIL_WP4_Kontron_D4_3_ 6.3.1.1.pcapng

  5GRAIL_WP4_Kontron_D4_3_ 6.3.1.1_Green zone.pcapng

6.3.1.2 User A, in critical zone, launches a voice call to User B in non critical zone

- **Objective of the test:**
  The purpose of this test is to launch a voice call from critical zone.

- **Test description:**
  The XP10 smartphone is connected on 5G SA N8 network.
  A XP8 is on IMS non-critical zone.
  Users open their IMS client (Boghe software). Once registration is achieved, 5G user launches a voice call to the Wifi user in non-critical zone.

- **Test results and comments:**

  The call is successful and the communication is normally established.

  Comments by Kontron

  SecXn equipment obviously introduce some delay compare to the use of a router with firewall. This is due to constructing/deconstructing process between the Gates. However, we have not noticed any impact on call setup or voice call quality.

- **Traces and logs recorded during the test:**

  Following traces have been recorded:

  5GRAIL_WP4_Kontron_D4_3_ 6.3.1.2.pcapng

6.3.1.3 User A, in critical zone, launches a video call to User B in non critical zone

- **Objective of the test:**

The purpose of this test is to launch a video call from critical zone.

- **Test description:**
  The XP10 smartphone is connected on 5G SA N8 network.
  A XP8 is on IMS non-critical zone.
  Users open their IMS client (Boghe software). Once registration is achieved, 5G user launches a video call to the Wifi user in non-critical zone.

- **Test results and comments:**

  The call is successful and the communication is normally established.

  Comments by Kontron

  SecXn equipment obviously introduce some delay compare to the use of a router with firewall. This is due to constructing/deconstructing process between the Gates. However, in our case, we have not noticed any impact on call set-up time nor in the quality of the video stream.

- **Traces and logs recorded during the test:**

  Following traces have been recorded:

  5GRAIL_WP4_Kontron_D4_3_ 6.3.1.3.pcapng

6.3.1.4 User A, in critical zone, sends a message to User B in non critical zone

- **Objective of the test:**
  The purpose of this test is to send a short message from critical zone.

- **Test description:**
  The XP10 smartphone is connected on 5G SA N8 network.
  A XP8 is on IMS non-critical zone.
  Users open their IMS client (Boghe software). Once registration is achieved, 5G user sends a message to the Wifi user in non-critical zone.

- **Test results and comments:**

  The message is well received. Test is passed.

  Comments by Kontron

  SecXn equipment obviously introduce some delay compare to the use of a router with firewall. This is due to constructing/deconstructing process between the Gates. However, in our case, we have not noticed any impact on call message delivery time.

- **Traces and logs recorded during the test:**

Following traces have been recorded:

5GRAIL_WP4_Kontron_D4_3_ 6.3.1.4.pcapng

6.3.2 Tests with TLS

Alstom proposed to enhanced initial test cases with two additional ones related to security (end to end and on Obapp interface). Following tests, described in next sections, have been done with TOBA-A and ATO as a demonstrator:

Test Title	5G Band	OB-GW	Date
TLS for Local Binding	N8	TOBA-A	02/02/2023
TLS for end to end ATO applicative session	N8	TOBA-A	02/02/2023

6.3.2.1 TLS for Local Binding

- Objective of the test:
  This test aims at checking the use of secured Websocket (i.e. Websocket over TLS) for OBapp API, instead of unsecured WebSocket.

- Test description:

  This test is similar to the one described in 3.2.1 excepted that the Websocket API between ATO-OB and TOBA-A is over TLS (instead of over plain TCP).

  Same for Websocket API between ATO-TS and TS_GTW-A.

- Specific Test configuration:
  Certificates were generated by an offline PKI (based on EJBCA) and manually pushed on the involved devices (ATO-OB, ATO-TS, TOBA-A and TS_GTW-A). The root certificate (certificate authority which has signed the used client/server certificates) was also pushed on the same devices.
  For example:
  - ATO-OB contains:
    - ATO-OB client certificate (signed by the certificate authority),
    - the root certificate (certificate of the CA)
    - ATO-OB private key.
  - TOBA-A contains:

- TOBA-A server certificate (signed by the certificate authority),
- the root certificate (certificate of the CA)
- TOBA-A private key.

- Test results and comments:

  Comments by Alstom

  The TLS handshake was working well and the subsequent OBapp API exchanges are OK.

  The following KPIs have been measured for this test:

  (A) Handshake duration: 222ms
  (B) Journey profile download duration: 638ms
  (C) Segment profile download duration: NA – SP not received by ATO-OB
  (D) Total time: NA

- Traces and logs recorded during the test:

  5GRAIL_WP4_Alstom_D4.3_TLSlocalbinding_ATO.zip

6.3.2.2 TLS for end to end ATO applicative session

- Objective of the test:
  This test aims at using end to end (E2E) TLS for the full applicative session between ATO-OB and ATO-TS.

- Test description:

  This test is similar to the one described in 3.2.1 excepted that the applicative TCP connection between ATO-OB and ATO-TS is over TLS.

- Specific Test configuration:
  Certificates used for the TLS connection between ATO-OB and ATO-TS are managed by an online PKI (based on EJBCA) on a virtual machine, hosted on the same device than ATO-TS. A "flat-IP" session is statically established by the TOBA-A to allow ATO-OB to reach the PKI which is in the trackside network.
- The TLS usage follows Subset-137.

- Test results and comments:

  Comments by Alstom

  The TLS handshake was working well and the subsequent applicative message are OK.

The following KPIs have been measured for this test:

(A) Handshake duration: 333ms
(B) Journey profile download duration: 624ms
(C) Segment profile download duration: 16’620ms
(D) Total time: 17’577ms

- Traces and logs recorded during the test:

5GRAIL_WP4_Alstom_D4.3_E2ETLS_ATO.zip

6.3.3 Conclusion

There is obviously a wide range of solutions in order to make FRMCS secured. Among topics discussed briefly in this chapter, use of PDCP over 5G NR air interface, use of SecureBoot for hardware equipment, 802.1x security in the WAN, use of Ipsec tunnels provided by Secured Gateways, MCx encryption and security mechanisms, PKI servers etc, are obviously points of interests.

For further experimentations, WP4 team would also like to mention the possible interest in adding SBCs (Session Borders Controllers) in the setup (see appendices 10.4.2 for more information about this device). SBCs often offers cybersecurity features like protection against DDOS attack and topology hiding. Besides, it normally embeds RTP proxy function with transcoding capability and manages transversal NAT. The latter is important because, even if the use of NAT is always interesting in IP networks, it brings some constraints when used with SIP protocol.

7 WP4 activities linked with WP5 preparation

7.1 Introduction

WP3 and WP4 teams had to consider that their equipment will be reused by WP5 after their test period. Indeed, part of WP4 setup was planned to be used by WP5 France whereas WP3 would provide much of WP5 Germany infrastructure. Consequently, WP5 preparation was also a concern for WP4 members and, as this report is the final one on WP4 activities, it is worth mentioning related work around that. Besides, several tests, among them some not in the initial plan of WP4, were carried out in a WP5 derisking perspective, for example the ones linked with the Remote Vision application.

7.2 Remote Vision application

SNCF provided WP4 with a remote vision system they wanted to be integrated in the lab. Remote Vision application consists in:

- A rugged camera that will be ultimately installed in front of the train engine during WP5 activity,
- A trackside Remote Vision server with a screen in order to display whet is recorded by the camera.

Data video between camera and server is obviously mostly an uplink traffic. Data rate is tuned automatically according to the bandwidth but it is supposed that several hundreds of kb/s are available in the uplink direction in order to have a good quality.

Remote Vision application is foreseen to be used when remotely slowly operating a train, for instance in a shunting zone or when entering a maintenance area. Additional details on what is expected from Remote Vision and associated KPIs will be given in WP5 deliverables.

In terms of integration, it should be noted that Remote Vision softwares were not Obapp/Tsapp compatible, that is to say that the version we received was not FRMCS ready. However, it was very interesting to test it because it enabled us to use what WP2 calls “flat IP mode of connection with FRMCS gateways”. To simplify, in that case, FRMCS gateways are simply considered as routers by OB and TS applications, but a preestablished IPconn connection should exist between the FRMCS GWs so that the IP flow could be routed across FRMCS system.

In a WP5 derisking perspective, following tests were done with remote vision in addition to ETCS tests of sections 4.3.7 and 4.3.8:

Test Title	5G Band	OB-GW	Date
Remote vision in nominal lab conditions	N39	TOBA-K	09/12/2023
Cross border scenario with Remote Vision	N39	TOBA-K	09/12/2023

7.2.1 Remote vision in nominal lab conditions

- Objective of the test:
  This test aims checking the good behaviour of Remote Vision application with TOBA-K in N39, as expected to be used during WP5 trials.

- Test description:

  An Ipconn connection is configured on OB and TS Gateways. Once established, the Remote Vision application is started on both sides.

- Test results and comments:
  A path loss of 68dB was measured during this test. Remote Vision application is working and a measurement is achieved to measure latency: camera is filming a stopwatch. OB and TS screen are then taken in the same picture shot (see Figure 23: OB to TS delay measurement by taking a picture of screens connected to the OB camera and the TS (Camera is filming a stopwatch) which enables a rough measurement (around 460ms delay).
  Note that for WP5 activity, this method cannot be used and then, Remote Vision provider is expected to deliver a measurement tool. Besides, data rate can be adjusted in uplink if needed by putting more UL TS in the 5G TDMA frame. In WP4 we used only 2 TS in uplink but we checked the use of 4 TS, which improved the quality of the video.

- Traces and logs recorded during the test:

  5GRAIL_WP4_Kontron_D4.3_721.zip

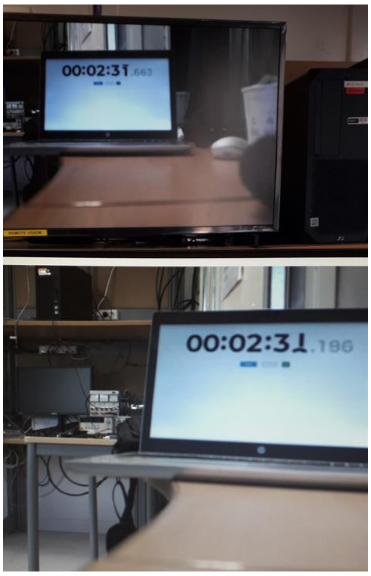


Figure 23: OB to TS delay measurement by taking a picture of screens connected to the OB camera and the TS (Camera is filming a stopwatch)

7.2.2 Cross border scenario with Remote Vision

- Objective of the test:
  This test aims checking the good behaviour of Remote Vision application with TOBA-K in N39, when TOBA-K moves from one 5G core to another one.

- Test description:

  An Ipconn connection is configured on OB and TS Gateways. Once established, the Remote Vision application is started on both sides. Then TOBA-K experiences a 5G cell change that implies a change of 5G SA core (cross border scenario).

- Test results and comments:
  Remote Vision application is still working after TOBA-K gets a new IP address on the new core.

- Traces and logs recorded during the test:

  5GRAIL_WP4_Kontron_D4.3_722.zip

7.3 WP4 network evolution to address WP5 needs

In order to optimize investment, it was agreed at the beginning of the project that part of WP4 lab will be reused in WP5 France. Some equipment, mostly RAN part, had to be sent to WP5 test area in Vigneux sur Seine, near Paris, while being still connected to the trackside functions that were to stay in Montigny.

In order to achieve that, a dedicated link was set-up between the two sites, it consisted in an ethernet connection with a Service Level Agreement matching WP5 constraints. As we will see, the choice of this level 2 connection proved to be very useful and that's why we are mentioning it because this design may be used in the future by other projects. So globally, the network configuration we had to build is the one depicted on Figure 24: WP5 network is using parts of WP4.

The benefits of this network structure are the following:

- ME1210 1 and 2, that are moved in WP5 location (Vigneux sur Seine), can still be managed from Montigny thanks to the transport of OAM LAN on the VPN,
- A N2/N3 link was created so that the 5G Core on ME1210_2 could manage a 5G RAN that would stay in Montigny (on ME1210_3). This enabled N39 tests to be still possible in Montigny by a support team that would help WP5 engineers if needed.
- N6 connection between 5G Core and Trackside equipment that were to stay in Montigny was also carried on the VPN.

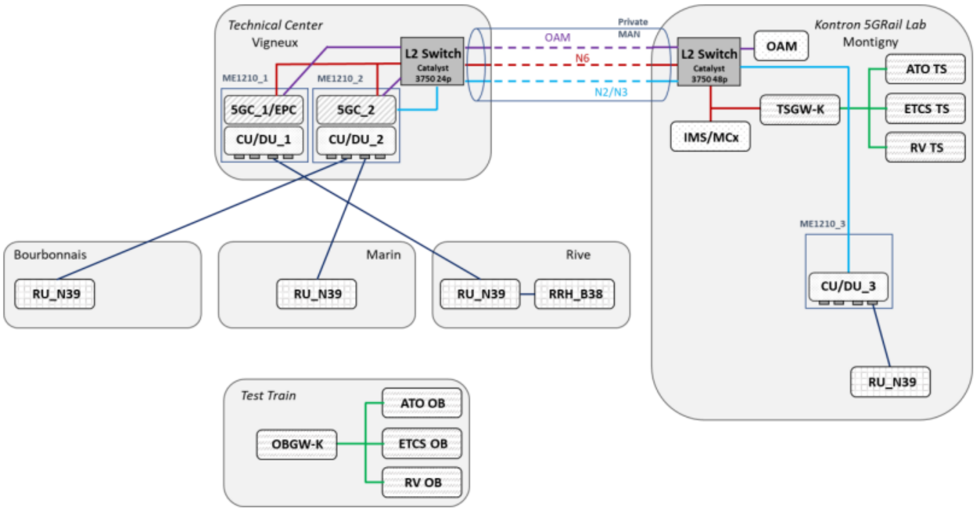


Figure 24: WP5 network is using parts of WP4

In order to achieve that, a switch has been wisely inserted in the WP4 lab as shown on the following pictures:

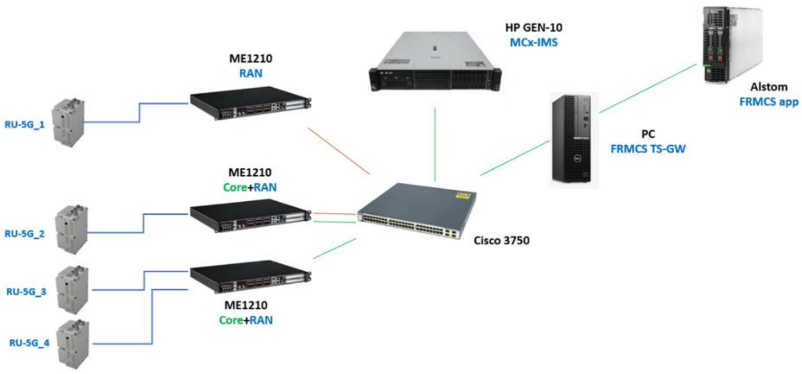


Figure 25: Step 1 / WP4 Initial set-up

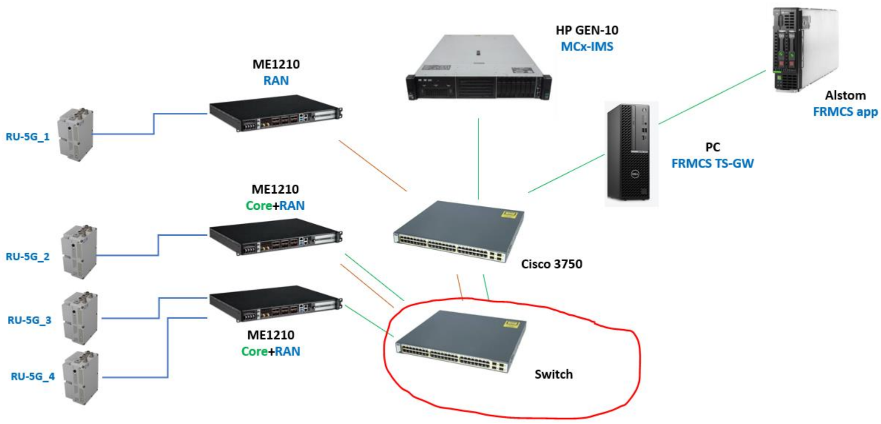


Figure 26: Step 2 / Insertion of a switch to aggregate devices intended to move

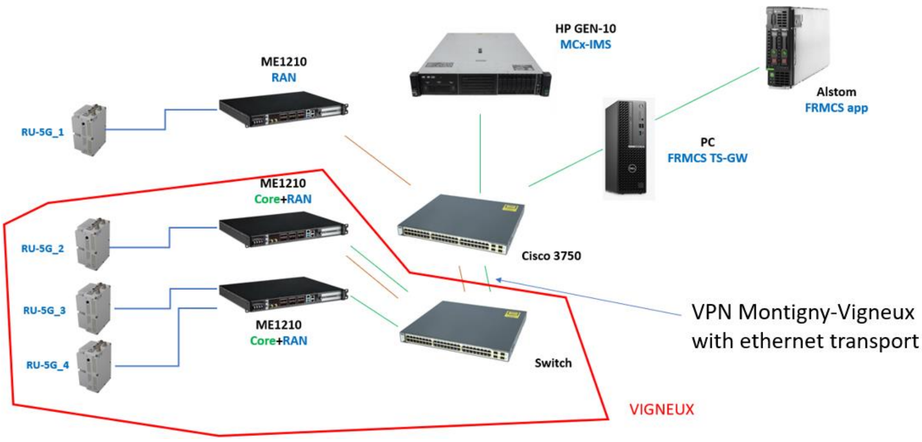


Figure 27: Step 3 / Devices are moved including the switch. VPN carries Switch-Router traffic

This design enabled us to prestage all WP5 configuration in advance in Montigny (step 2). Moving of equipment was just a matter of half a day and, when all devices were powered on again, all network was back in service automatically.

8 CONCLUSION

When starting the Work Package 4 at the end of 2020, team faced immediately several issues: at that time, 5G SA equipment were not widespread and only basic features were available, Local Break Out or Home Routing roaming (cf appendices 10.3), that demand huge development efforts, were not in portfolios (still the same nowadays), QoS related PCF function neither. Besides, we had uncertainties around design of N39 capable RUs and modems and FRMCS specifications were not released yet. Not to mention the pandemic Covid situation that jeopardized plannings and forecasts.

However, little by little, all the lab integration efforts, particularly on OBapp and TSapp interfaces, lead to the very first FRMCS end-to-end call using ATO and FRMCS Gateways over 5G SA network, in March 2022. This was a major achievement quickly disseminated to the FRMCS community. Later, other FRMCS calls were performed on N39 band with ATO, PIS, Remote Vision and ETCS applications. The time has then come to look at tests defined by WP1 team in order to address several topics:

QoS management

Services brought by FRMCS can be linked with a specific QoS according to the needs of the connected applications. For instance, ETCS is a very critical application that demands priority over RV for instance. WP4 had no PCF function but QoS could be statically assigned using DSCP method. This enabled to check that critical flows could be protected, with a chosen 5QI, when a concurrent and less important flows exists.

Multi-path usage

Besides, FRMCS OB Gateways are able to handle multiple bearers at the same time. This enables for instance the ability to use one specific bearer with top priority, and a possible failover to another one. This kind of test was performed in WP4 with ETCS application and a service continuity could be achieved. Multiple bearer tests were also done with the same application using two bearers at the same time thanks to the MPTCP protocol.

Crossborder scenarios

Albeit crossborder scenarios are not yet defined in FRMCS specifications, which is understandable considering the complexity of 5G, IMS and MCx roaming, WP4 was able to simulate few scenario believed to be interesting for the next steps:

- Roaming of a flat IP application (Remote Vision) was first tested in the lab. While not very complex (because Obapp interface is not involved there), it implies that TOBA must manage change of IP address and maintain the IPConn MCDATA connection during the network change to ensure the continuity of service.
- Test case with two modems was also tested with TOBA-A and ETCS, reflecting what can currently occur in GSM-R network for this application. Continuity of service being then achieved by the second modem connecting onto the visited network and its RBC. ETCS On-board application changing the target RBC it communicates with according to orders it receives from beacons. This scenario was quite interesting as it suggests crossborders scenario

may be different depending on applications (to be confirmed when FRMCS specifications on these topics will be released).

- Finally, testing of a crossborder scenario implying a FRMCS application connected in loose coupling (ie Obapp is used and an MCx client inside TOBA is used) was done at the end of WP4 test phase due to WP2 late delivery. Test used TOBA-K with two modems, each one being able to connect to a network. Using MPTCP feature, it was possible to maintain service while passing from one network to another one (with a transition phase were the two networks are available) even if some limitations must be corrected by WP2 for WP5 trials tests on the same topic.

Cybersecurity and other optional tests

Having the possibility to test optional tests cases and scenarios, WP4 proposed few interesting cybersecurity tests cases about TLS and the use of an electronic air gap device. Some tests of interworking function between GSM-R and FRMCS for MCPTT service, which is also a quite important topic considering FRMCS and GSM-R coexistence, were also done, as well as MCx tests in order to give some ideas on few KPIs values.

Globally and as expected, WP4 team was also able to provide an important feedback on FRMCS specifications and engineering, as to be reflected in WP1 delivery D1.2 [S25] whereas tests performance measurements have of course to be taken with care considering the early prototypes state of the art, but can anyway already give some possible insights.

To conclude, WP4 members want to emphasize on the very good partnership and team spirit that was established among all participants. Thanks to the work package, we believe a major step forward has been achieved on the way towards FRMCS realization as lab experiments could not only stimulate discussions on FRMCS specifications, but also created a clear momentum among all partners. For instance, industrials could design and test their prototypes in the lab, foreseeing then solutions, components and products they will use in the future to address their customer's needs. Besides, 5GRAIL WP4 stand as a place for a global acceleration on FRMCS as it created exchanges opportunities for all stakeholders through conferences, advisory boards and lab visits. We must also underline the technical ramp up that this project definitely boosted as engineers had to develop new critical skills on various subjects like 5G SA, IMS-MCx and of course FRMCS protocols. Numerous achievements have already been recorded so far but many efforts are still to be made in this exciting and challenging journey that will make FRMCS real; they should bring robustness to existing prototypes, fine tune parameters, focus on cybersecurity essential requirements and much more, but WP4 is already proud to have contributed and paved the way toward this ultimate goal. Finally, we want to insist again on the human factor as WP4 was not only a question of prototypes and technical devices: People commitment, which was outstanding, is definitely the key factor for the success of such projects and partners deep involvement has consequently to be underlined.

9 REFERENCES

Document Title	Reference, version
[S1] Radio-frequency connectors –Part 16: Sectional specification – RF coaxial connectors with inner diameter of outer conductor 7 mm (0,276 in) with screw coupling – Characteristics impedance 50 Ω (75 Ω) (type N)	IEC 61169-16
[S2] Management Information Base for Network Management of TCP/IP-based internet: MIB-II	RFC 1213
[S3] MC Services Security aspects (useful to understand MCx authentication and authorization)	3GPP TS33.180
[S4] Mission Critical Data (MCData) signalling control; Protocol specification	3GPP TS 24.282
[S5] Mission Critical Data (MCData) media plane control; Protocol specification	3GPP TS 24.582
[S6] UIC – FRMCS Use cases	UIC MG-7900, Version 2.0.0
[S7] 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on Future Railway Mobile Communication System	3GPP TR 22.889
[S8] UIC – FRMCS Principle Architecture	UIC MG-7904 Version 0.3.0 (Draft)
[S9] UIC – FRMCS – Telecom On-board system – Functional Requirement Specification	UIC TOBA FRS-7510 Version 0.2.0
[S10] Common functional architecture and information flows to support mission critical communication services	3GPP TS 23.280 Stage 2

[S11]	3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Functional architecture and information flows to support Mission Critical Data (MCData)	3GPP TS 23.282 V17.6.0, Stage 2 (Release 17) – 04/2021
[S12]	Rail Telecommunications (RT); Future Rail Mobile Communication System (FRMCS); Study on system architecture	ETSI TR 103.459 V1.2.1, 08/2020
[S13]	UIC – FRMCS – User Requirements Specification	FU-7100 Version 5.0.0
[S14]	UIC – FRMCS – Functional Requirements Specification	FU-7120 Version 0.3.0
[S15]	UIC FRMCS On-Board System Requirements Specification (TOBA SRS)	TOBA-7530
[S16]	UIC FRMCS Functional Interface Specification (FRMCS FIS)	
[S17]	UIC FRMCS Form-Fit Functional Interfaces (FRMCS FFFIS)	
[S18]	UIC FRMCS System Requirements Specification (FRMCS SRS)	AT-7800
[S19]	TOBA Architecture Report	D2.1
[S20]	Second Lab Integration and Architecture Report	D4.1
[S21]	Second Lab Test Setup Report	D4.2
[S22]	Test Plan	D1.1
[S23]	TOBA Integration Report	D2.2
[S24]	Roaming Guidelines	GSMA NG.113 Version 6.0

[S25] Test report conclusion from simulated/lab environments	D1.2
[S26] Technical Specification Group Services and System Aspects; Mission Critical Push To Talk (MCPTT)	3GPP TS 22.179 Stage 1
[S27] 5Grail Grant Agreement	H2020-CP-IA-2017
[S28] Mission Critical Communication Interworking with Land Mobile Radio Systems	3GPP TS 23.283 Release 17
[S29] Rail Telecommunications (RT); Future Rail Mobile Communication System (FRMCS); Interworking study with legacy systems	ETSI TR 103 768 V1.1.1

10 APPENDICES

10.1 Work Package 4 content and planning of activities

Grant agreement document [S27] defined the tasks of WP4 work package as follow:

Task 4.1 - Preparation and setup of the integrated End to End Lab infrastructure

Task 4.2 - ETCS and ATO application integration over 5G infrastructure

Task 4.3 - Cybersecurity end to end integration for safe applications over 5G infrastructure

Task 4.4 - Lab test execution and recommendations

Task 4.1 was about lab setup, choice of all necessary equipment, setting of VPNs between partners… It is reflected in delivery D4.1 [S20].

Task 4.2 was about integration of the FRMCS prototypes into WP4 lab so that we could ensure an end to end functionality. This par, including related integration tests, is reflected in delivery D4.2 [S21].

Task 4.3 was initially leaded by Thales, a partner which also provides 5G modems to WP2. In order to cope with this crucial part, it was agreed by the consortium that Thales will no longer fulfil Task 4.3 that was about Cybersecurity topics. However, Kontron and Alstom decided to bridge partially the gap by proposing some tests and equipment linked with their expertise on that domain. It is reflected in part 6.3 of this document.

Task 4.4 was about execution of all tests defined in D1.1 WP1 document. Delivery D4.3 deals with the report of this activity.

On top of that, WP4 team had the duty of preparing and derisking WP5 as explained in chapter 7. Overall, In terms of planning, work package activities can be summarized as follow:

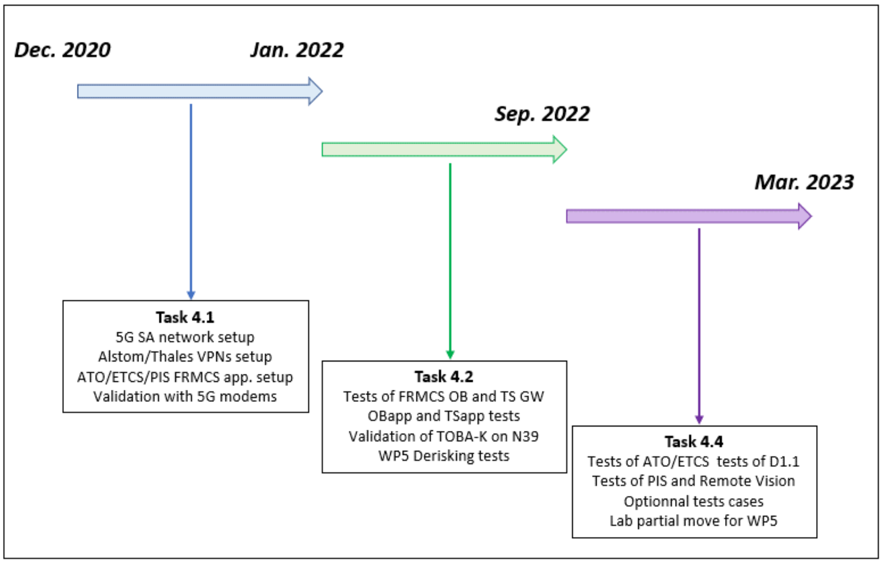


Figure 28: WP4 activities

10.2 List of tests cases that have been executed within Task 4.4

The following tables provide the list of all tests performed during WP4 task 4.4:

Test Title	Type	Status	5G Band	OB-GW	Section
TOBA-K HO intra gNodeB	TOBA eval.	Passed	N39	TOBA-K	2.2.1
TOBA-K HO inter gNodeB	TOBA eval.	Passed	N39	TOBA-K	2.2.2
Total loss of radio. Reconnection.	TOBA eval.	Passed	N39	TOBA-K	2.2.3
Ipfer uplink test and attenuation impact	TOBA eval.	Passed	N39	TOBA-K	2.2.4
Ipfer downlink test and attenuation impact	TOBA eval.	Passed	N39	TOBA-K	2.2.5
Iperf uplink with speed and fading impact	TOBA eval.	Passed	N39	TOBA-K	2.2.6
Iperf downlink test with speed and fading impact	TOBA eval.	Passed	N39	TOBA-K	2.2.7
RTD measurement and RF attenuation impact	TOBA eval.	Passed	N39	TOBA-K	2.2.8
Iperf Uplink Test	TOBA eval.	Passed	N8	TOBA-K	2.3.1.1
Iperf Downlink Test	TOBA eval.	Passed	N8	TOBA-K	2.3.1.2
Round Trip delay test	TOBA eval.	Passed	N8	TOBA-K	2.3.1.3
Iperf Uplink Test	TOBA eval.	Passed	N8	TOBA-A	2.3.2.1
Iperf Downlink Test	TOBA eval.	Passed	N8	TOBA-A	2.3.2.2
Round Trip delay test	TOBA eval.	Passed	N8	TOBA-A	2.3.2.3
ATO in nominal and perfect lab conditions	ATO	Passed	N8	TOBA-A	3.2.1

ATO in parallel with high uplink traffic generated by iPerf	ATO	Passed	N8	TOBA-A	3.2.2
ATO in parallel with high downlink traffic generated by iPerf	ATO	Passed	N8	TOBA-A	3.2.3
Bearer flexibility: 5G to 4G failover	ATO	Passed	N8	TOBA-A	3.2.4
Bearer flexibility: 4G to 5G failover	ATO	Passed	N8	TOBA-A	3.2.5
ATO in nominal and perfect lab conditions	ATO	Passed	N39	TOBA-K	3.3.1
ATO in degraded conditions, fading & varying speed	ATO	Passed	N39	TOBA-K	3.3.2
ATO in nominal and perfect lab conditions with intra gNodeB HO	ATO	Passed	N39	TOBA-K	3.3.3
ATO in nominal and perfect lab conditions with inter gNodeB HO	ATO	Passed	N39	TOBA-K	3.3.4
ATO in parallel with high uplink traffic generated by iPerf	ATO	Passed	N39	TOBA-K	3.3.5
ATO in parallel with high downlink traffic generated by iPerf	ATO	Passed	N39	TOBA-K	3.3.6
ETCS onboard combined with ATO application	ATO	Passed	N39	TOBA-K	3.3.7
Communication in level 2 between ETCS onboard application and RBC	ETCS	Passed	N8	TOBA-A	4.2.1
RBC handover on the same 5G network	ETCS	Passed	N8	TOBA-A	4.2.2
Redundancy use case: OB GW going from 4G to 5G coverage with on-going ETCS call continuation	ETCS	Passed	N8	TOBA-A	4.2.3
Redundancy use case: OB GW going from 5G to 4G coverage with on-going ETCS call continuation	ETCS	Passed	N8	TOBA-A	4.2.4
ETCS Crossborder test using two 5G modems	ETCS	Passed	N8	TOBA-A	4.2.5
ETCS and iperf UDP test. ETCS on 5G, iperf UDP on 4G. TOBA moves from 4G/5G area to 5G only area. Iperf & ETCS traffic continue on 5G	ETCS	Passed	N8	TOBA-A	4.2.5
ETCS and iperf UDP test. ETCS and iperf UDP on 5G. TOBA moves from 5G only	ETCS	Passed	N8	TOBA-A	4.2.6

area to 4G/5G area. ETCS traffic continue on 5G and UDP iperf on 4G					
Communication in level 2 between ETCS onboard application and RBC	ETCS	Passed	N39	TOBA-K	4.3.1
RBC handover on the same 5G network	ETCS	Passed	N39	TOBA-K	4.3.2
RBC and gNodeB handover on the same 5G network	ETCS	Passed	N39	TOBA-K	4.3.3
Communication in level 2 between ETCS onboard application and RBC using Vertex tool with fading and varying speed	ETCS	Passed	N39	TOBA-K	4.3.4
RBC handover on the same 5G network using Vertex tool with fading and varying speed	ETCS	Passed	N39	TOBA-K	4.3.5
RBC and gNodeB handover on the same 5G network using Vertex tool with fading and varying speed	ETCS	Passed	N39	TOBA-K	4.3.6
Combined Remote Vision and ETCS in nominal lab conditions	ETCS	Passed	N39	TOBA-K	4.3.7
Combined Remote Vision and ETCS in degraded conditions (with Vertex)	ETCS	Passed	N39	TOBA-K	4.3.8
Aggregation use case: OB GW under overlapping 4G and 5G coverage is performing ETCS call using simultaneously both bearers. It moves under 4G only coverage and on-going call still continues.	ETCS	Passed	N39	TOBA-K	4.3.9
Multiconnectivity in a border crossing scenario_Scenario 1 (TOBA-K in 4G/5G area moves to 4G only area than 4G/5G area than 5G only area)	ETCS	Passed	N39	TOBA-K	4.4.2.2.1
On-board PIS logs downloaded on the fly in normal conditions	PIS	Passed	N8	TOBA-A	5.2.1
Send text message with a normal priority to trains	PIS	Passed	N8	TOBA-A	5.2.2
Send text message with a high priority to trains	PIS	Passed	N8	TOBA-A	5.2.3
Open a “trackside to on-board” management session with a high priority	PIS	Passed	N8	TOBA-A	5.2.4
Check connection to FRMCS services	PIS	Passed	N8	TOBA-A	5.2.5
Display train location information	PIS	Passed	N8	TOBA-A	5.2.6

Send text message with a normal priority in degraded conditions – 5G radio link is overloaded	PIS	Passed	N8	TOBA-A	5.2.7
Send text message with a high priority in degraded conditions – 5G radio link is overloaded	PIS	Passed	N8	TOBA-A	5.2.8
On-board PIS logs downloaded on the fly in degraded conditions	PIS	Passed	N8	TOBA-A	5.2.9
Offloading of the on-board logs with 5G overloaded com_profile 6 (auto-accept mode)	PIS	Passed	N8	TOBA-A	5.2.10
Smartphone initiates an Emergency group Call	MCx	Passed	N8	NA	6.1.2.1
A smartphone user requests access to speak during a Group Call	MCx	Passed	N8	NA	6.1.2.2
Dispatcher sends a SDS to a smartphone	MCx	Passed	N8	NA	6.1.2.3
MCPTT point to point call from Dispatcher to smartphone with floor control	MCx	Passed	N8	NA	6.1.2.4
MCPTT point to point call from Dispatcher to smartphone without floor control	MCx	Passed	N8	NA	6.1.2.5
MCPTT group call from Dispatcher to smartphones with floor control	MCx	Passed	N8	NA	6.1.2.6
MCPTT emergency call from Dispatcher to smartphones already in call	MCx	Passed	N8	NA	6.1.2.7
MCPTT dynamic group call from Dispatcher	MCx	Passed	N8	NA	6.1.2.8
MCPTT priority management when accessing floor	MCx	Passed	N8	NA	6.1.2.9
Smartphone sends a SDS to a group of users	MCx	Passed	N8	NA	6.1.2.10
Point to Point Voice Call from a GSM-R user to a MCx user	Interco. GSM-R	Passed	N8	NA	6.2.1.1
Point to Point Voice Call from a MCx user to a GSM-R user	Interco. GSM-R	Passed	N8	NA	6.2.1.2
User A, in critical zone; registers on non critical IMS	Cyber	Passed	N8	NA	6.3.1.1

User A, in critical zone, launches a voice call to User B in non critical zone	Cyber	Passed	N8	NA	?
User A, in critical zone, launches a video call to User B in non critical zone	Cyber	Passed	N8	NA	?
User A, in critical zone, sends a message to User B in non critical zone	Cyber	Passed	N8	NA	?
TLS for Local Binding	Cyber	Passed	N8	TOBA-A	6.3.2.1
TLS for end to end ATO applicative session	Cyber	Passed	N8	TOBA-A	6.3.2.2
Remote vision in nominal lab conditions	Remote Vision	Passed	N39	TOBA-K	7.2.1
Crossborder scenario with Remote Vision	Remote Vision	Passed	N39	TOBA-K	7.2.2

10.3 Roaming in 5G

Document [S24] and 3GPP TS 23.501 provides lots of information about architecture models that can be used for 5G roaming. There are two basic ones: Local Break Out (LBO) and Home Routed (HR).

- In Local Break Out, roamer uses a visited network UPF to access a Data Network, which clearly appears on Figure 29: LBO in 5G below copied from [S24]

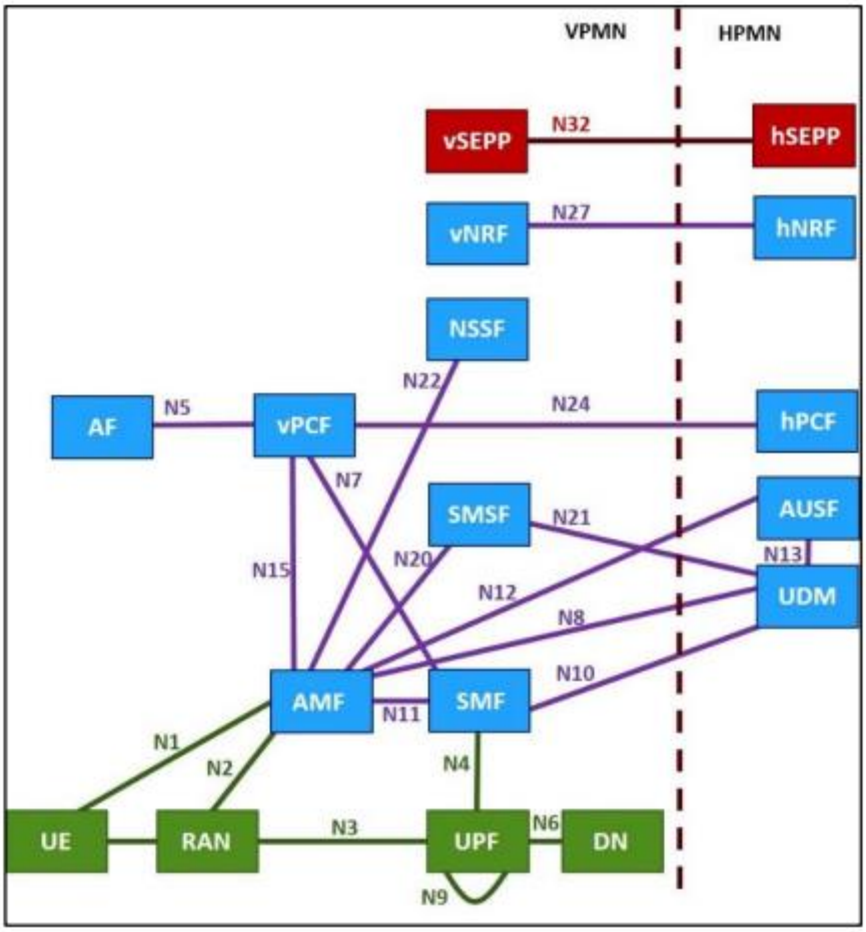


Figure 29: LBO in 5G

Classically, some functions from the visited network (AMF, SMF) will interact with functions of the home network in order to authenticate the user. Security Edge Protection Proxies (SEPP) are used to carry all data between networks in a secured way.

- In Home Routed, roamer uses a home network UPF to access a Data Network, as shown on Figure 30: Home Routed architecture in 5GFigure 29: LBO in 5Galso from [S24] :

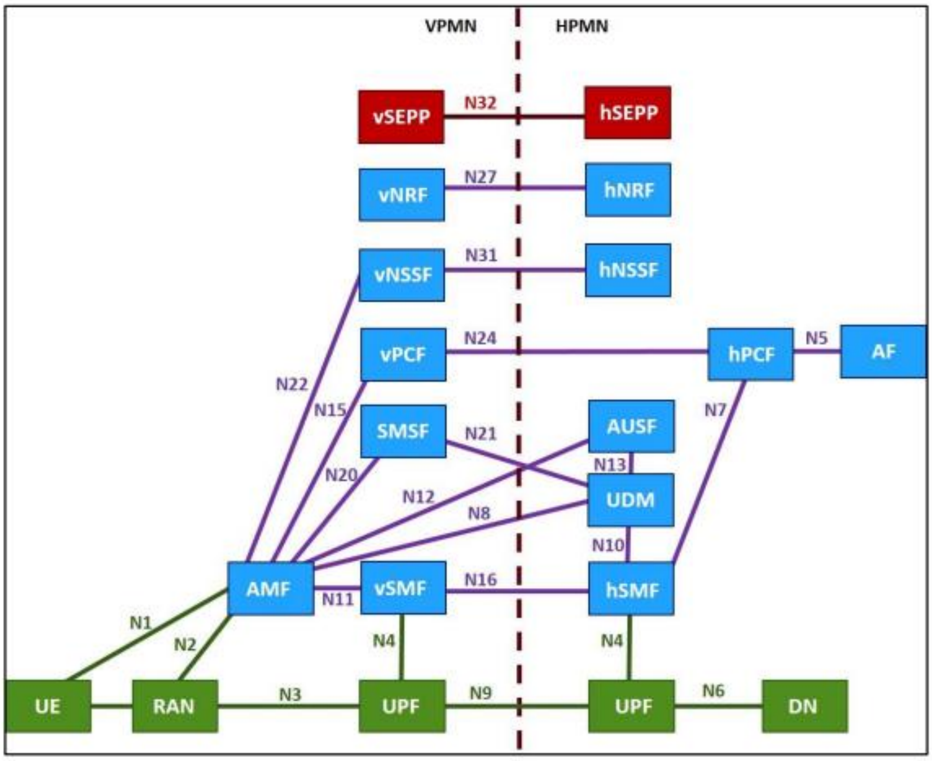


Figure 30: Home Routed architecture in 5G

As we can see, Home Routed architecture is much more complex as, compared to LBO, some home network functions are in charge of selecting home UPF resource for the session, this UPF having to be linked to a vUPF.

At the time 5Grail project started, 5G SA ecosystem was not as developed as it starts to be nowadays, ie more than 2 years later. Next FRMCS initiative will for sure be able to take into account these new possibilities, depending also on FRMCS specifications choices and outcomes on that matter.

10.4 Session Border Controllers

Whenever an IMS or a SIP core is used, Session Border Controllers (SBC) devices can be considered as they can bring many important features. Indeed, SBC is a device that is typically placed at the border between two different networks, such as between a service provider's network and a customer's network, to control and monitor the flow of voice and data traffic. Consequently, they are very important regarding cybersecurity as explained below.

10.4.1 Access and Interconnect SBCs

As regards signalling, IMS network uses P-CSCF as an entry point for IMS users. P-CSCF IP address is communicated to them, most of the time during IP address allocation. All requests are then sent to P-CSCF which plays its basic role of proxy. As regards user plane, the same entry point to the IMS network should also exists and is handle by what is called Media Router (MR). MR is also responsible for transcoding if needed, ie whenever different codecs are supported, therefore used, by end users. P-CSCF and MR are hosted in the SBC equipment, which is called Access-SBC (S-SBC) in that case.

IMS networks may also be interconnected to each other’s and, in that case, Interconnection Border Control Function (IBCF) and Transition Gateway (TrGW) are to be used on each side as entry points for signalling and user plane. These two functions are hosted in what is called an Interconnect-SBC (I-SBC).

A-SBC and I-SBC can provide various IP engineering services such as hosting a firewall or tackling with Network Address Translations issues linked with the SIP protocol. They can also provide the network with some useful cybersecurity features.

10.4.2 SBC and cybersecurity

As main entry point to the IMS core network, SBC is a critical device and the best place to put cybersecurity tools in order to protect what stands behind.

The first protection that is commonly implemented on SBC is the so called “topology hiding” feature that consists in removing some information elements of some SIP messages and that gives information about all IMS nodes that were involved in the handling of the SIP method.

Another very useful protection is the ability of the SBC to fight Distributed Deny Of Service (DDOS) attacks thanks to the use of proprietary algorithms.

Grant agreement
No 951725