Deliverable D3.3

First Lab Test Report

5GRail

5G for future RAILway mobile communication system

D3.3 First Lab Test Report Rev 2

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Executive Summary

This document covers the report on the end-to-end tests defined by 5GRail WP1 team for WP3 lab experiments in the Nokia Budapest lab. The focus was on operational, critical voice (incl. REC - Railway Emergency Calls) and specific data applications that are of high importance for the future, namely ETCS/TCMS and Video/CCTV, 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 in an 5G SA environment. Beside functional testing various handover and performance test were done covering setups for bearer flexibility and several aspects related to border crossing as well.

Results from these tests provide feedback on FRMCS v1 specifications incl. 3GPP and ETSI in order to underline points of concern and trigger enhancements, and additionally, rough insights at this stage in 5GRail where many prototypes or 5G SA Infrastructure stand at an early development phase.

Application Testing

Tests with Voice, ETCS, TCMS, CCTV /Video FRMCS compliant applications were executed as expected by WP1 work package and are reflected in chapter 4 until 7 of this document. It includes tests with FRMCS gateway on N78 and N8 bands; near to the railways specific 5G RMR band. These tests allowed feedback on ways to improve procedures and timers whenever team faced integration issues. This was then a first valuable output for the 5GRail project and this is used as input to D1.2 delivery [S25] “Test report conclusion from simulated/lab environments”.

Performance measurements

Besides application and functional testing various performance measurements have been done, based on application level (like ETCS or video performance, or MCX KPI for voice) as well on specific handover performance for the different radio configurations and bands used, under normal mode but also using train velocity emulation for degrade mode. Some comparison with GSM-R was also done to demonstrate the 5G capabilities. Overall keeping in mind that some products or functions of WP3 labs have to be taken as prototypes.

5G deployment and Border Crossing

Already in WP1 when defining the test cases, restrictions, and limitations of the system under test had to be considered. One of the main challenges was to find solutions at the early stage of 5G SA technology or testing based on the restrictions still existing in 5G SA technology in the market, ecosystem and products, leading to limited maturity of aspects related to Roaming, Handover or Interconnection. For example, an existing 5G SA solution was enhanced to achieve some of the important aspects of smooth border crossing scenarios (Inter core Handover),

Due to the early stage of 5G SA at 5GRail time frame some limits and reduced functionality are impacting the products, either on mobile or on infrastructure (core, radio). One example is the capability of the 5G SA with its service-based architecture to provide a comparable mobility and roaming feature set that e.g. 4G or 5G NSA provides, as most initial 5G SA deployments focussed on rather enterprise and campus environment without the need of mobility. This has impact on some of the test cases especially related to border crossing, as described in an introduction chapter on specific generic test characteristics to be considered. However, the existing 5G SA solution could be enhanced to verify important building blocks for a smooth border crossing scenario, namely Inter AMF/Core and Ng based Radio (refer to chapter 2.)

Mission Critical Service

Additionally, the ongoing evolution of the MCX 3GPP standards during 5GRail timeline had to be considered, e.g. with the ongoing standardization of Railway Emergency Communication, or the further standard tasks on MCX interconnection and migration use cases e.g. for border crossing.

WP5 Field support

During WP3 activities several tasks have already been started on support of the WP5 field. Especially due to the benefits of having the remote configuration of the radio at the field, with a core network (and radio) at the Budapest lab allowed to support activities in parallel in WP3 and WP5, helping to avoid delays on WP5 planning when lab test requested more time, or evaluating field results in specific lab setup.

COVID measures

Several challenges due to COVID and setup of remote test support as well as challenges due to the high number of interoperability configurations due to various partner needed to be addressed in the WP3 work, leading to the final extension of the activities. However, all Work Package members would like to emphasize 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 led 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 WP3 took part in. These experiences surely would help to setup and execute future projects like the envisaged Morane 2.0 project.

Abbreviations and Acronyms

Abbreviation	Description
3GPP	3rd Generation Partnership Project
5GC	5G Core
5G NSA	5G Non StandAlone
5G SA	5G StandAlone
AMF	Access and Mobility Management Function
API	Application Programmable Interface
APN	Access Point Name
AS	Application Server
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATSSS	Access Traffic Steering, Switching and Splitting
AUSF	Authentication Server Function
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
COTS	Commercial Off The Shelf
CP	Control Plane
CPU	Central Processing Unit
CSCF	Call/Session Control Functions
CSFB	Circuit Switched Fall Back
CU	Centralized Unit
DC	Direct Current

DMI	Driver Machine Interface
DN	Domain Name
DNS	Domain Name System
DRCS	Data Radio Communication System
DSCP	Differentiated Services Code Point
DSD	Driver Safety Device
DU	Distributed Unit
eMLPP	Enhanced Multi-Level Precedence and Pre-emption service
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
GCapp	Group Communication App (on smartphone)
GCG	Ground Communication Gateway
GDCP	Graphical Driver's Control Panel
GNSS	Global Navigation Satellite System
GoA	Grade of Automation
GRE	Generic Routing Encapsulation (RFC8086) -> Tunnel GRE
GTW or GW	GaTeWay or GateWay

HMI	Human Machine Interface
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, with X=PTT (Push-To-Talk forVoice) or X=Video or X=Data
MGW	Media Gateway
MIMO	Multiple Input Multiple Output
MMI	Man Machine Interface
MNC	Mobile Network Code
MNO	Mobile Network Operator
Mock/MOC journey	Here: Emulated trip with defined GPOS coordinates
MPTCP	MultiPath Transmission Control Protocol
MQTT	Message Queuing Telemetry Transport
N3IWF	Non-3GPP Inter Working Function

N8 or n8	3GPP frequency band 900 MHz FDD
N78 or n78	3GPP frequency band 3.7 GHz TDD
NG	Next Generation
NR	New Radio
NSA	Non-Stand Alone (5G Core architecture)
NTG	Network Transmission Gateway
NTP	Network Time Protocol
OAM	Operation Administration Maintenance
OB	On Board
OB_GW	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
PCC	Policy and Charging Control
P-CSCF	Proxy - Call Session Control Function
PCRF	Policy and Charging Rules Function
PCU	Packet Control Unit
PDN	Packet Data Network
PIS	Passenger Information Service
PKI	Public Key Infrastructure
PLMN	Public Land Mobile Network
PPDR	Public Protection and Disaster Relief
PSS	Process Safety System
PTT	Push To Talk
QCI	QoS Class Identifier

5QI	5G QoS Identifier
QoS	Quality Of Service
RAM	Random Access Memory
RAN	Radio Access Network
RAT	Radio Access Technology
RBC	Remote Block Centre
REC	Railway Emergency Call
REST	REpresentational State Transfer
RF	Radio Frequency
RPC	Remote Procedure Call
RRH	Remote Radio Head
RTCP	Real-Time Transport Control Protocol
SA	Stand Alone (5G Core architecture)
SDWAN	Software-Defined Wide Area Network
S-CSCF	Servicing-CSCF (Correspondence IMPU - @ IP)
SDP	Session Description Protocol
SIM	Subscriber Identity Module
SIP	Session Initiation Protocol
SMA	Subminiatures version A, type of coaxial RF connectors
SMF	Session Management Function
SRS	System Requirements Specification
TC	Test case
TCMS	Train Control Management System
TCP	Transmission Control Protocol
TCN	Train Communication Network
TCU	TransCoder Unit
TDD	Time Division Duplex
TFT	Traffic Flow Template
TLS	Transport Layer Security

TOBA	Telecom On-Board Architecture
TS	Track Side
TS_GW	TrackSide Gateway
TSE	Track Side Entity (e.g. RBC, KMC, ATO trackside)
TSI	Technical Specification for Interoperability
UDM	Unified Data Management
UE	User Equipment
UP	User Plane
UPF	User Plane Function
URLLC	Ultra-Reliable Low-Latency Communications (5G)
URS	User Requirements Specification
VMS	Video Management System
VoNR	Voice over New Radio
VoLTE	Voice over LTE
VPN	Virtual Private Network
WP1	Work Package 1
WP2	Work Package 2
WP3	Work Package 3
WP4	Work Package 4
WP5	Work Package 5

Definitions

Term	Definition
Application	Provides a solution for a specific communication need that is necessary for railway operations. In the context of this document, an application is interfacing with the FRMCS on-board system, through the OB_{APP} reference point, to receive and transmit information to ground systems, (for example, ETCS, DSD, CCTV, passenger announcements, etc.).
Application Coupled mode	It defines if an application is aware of the services used in the FRMCS service layer.
Application Service	Application part responsible of the UP management
Communication Services	Services enabling the exchange of information between two or more applications
Communication service availability	Percentage value of the amount of time the end-to-end communication service is delivered according to an agreed QoS, divided by the amount of time the system is expected to deliver the end-to-end service according to the specification in a specific area.
Communication service reliability	Ability of the communication service to perform as required for a given time interval, under given conditions.
Control Plane	The control plane carries signalling traffic between the network entities.
Data communication	Exchange of information in the form of data, including video (excluding voice communication).
End-to-End	Including all FRMCS ecosystem elements
End-to-end latency	The time that takes to transfer a given piece of information unidirectional from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination.
Interworking	Interworking is the function that enables two different networks to communicate with each other, enabling services to be delivered across them
iPerf	Open source tool used to evaluate network performances in a client-server architecture, available in different operating systems.
NG interface	The NG interface is a logical interface between an NG-RAN and 5GC. There are two interfaces under NG interface: NG-C for control plane and NG-U for user plane.
Priority service	A service that requires priority treatment based on operator policies.
QCI (or 5QI)	A scalar that is used as a reference to a specific packet forwarding behaviour (e.g. packet loss rate, packet delay budget) to be provided to a SDF. This may be implemented in the access network by the QCI referencing node specific parameters that control packet forwarding treatment (e.g. scheduling weights,

	admission thresholds, queue management thresholds, link layer protocol configuration, etc.), that have been pre-configured by the operator at a specific node(s) (e.g. eNodeB)
Reliability	In the context of network layer packet transmissions, percentage value of the amount of sent network layer packets successfully delivered to a given system entity within the time constraint required by the targeted service, divided by the total number of sent network layer packets.
Service continuity	The uninterrupted user experience of a service that is using an active communication when a UE undergoes an access change without, as far as possible, the user noticing the change.
Transport Domain	A Transport Domain is the administrative realm of the Transport Stratum. The Transport Stratum comprises one or more access technologies controlled by a core network. A Transport Domain is uniquely identified by the PLMN-ID.
User Equipment	An equipment that allows a user access to network services via 3GPP and/or non-3GPP accesses.
User plane	The user plane (sometimes called data plane or bearer plane), carries the user/application traffic.
Voice Communication	Exchange of information in the form of voice requiring corresponding QoS treatment, regardless of the transmission method.

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1 INTRODUCTION

5GRail work package 3 activities lasted for about two years and the related lab was used for many purposes throughout the project. Appendix 12.1 provides the detailed view of the WP3 planning, a high level overview is depicted below:

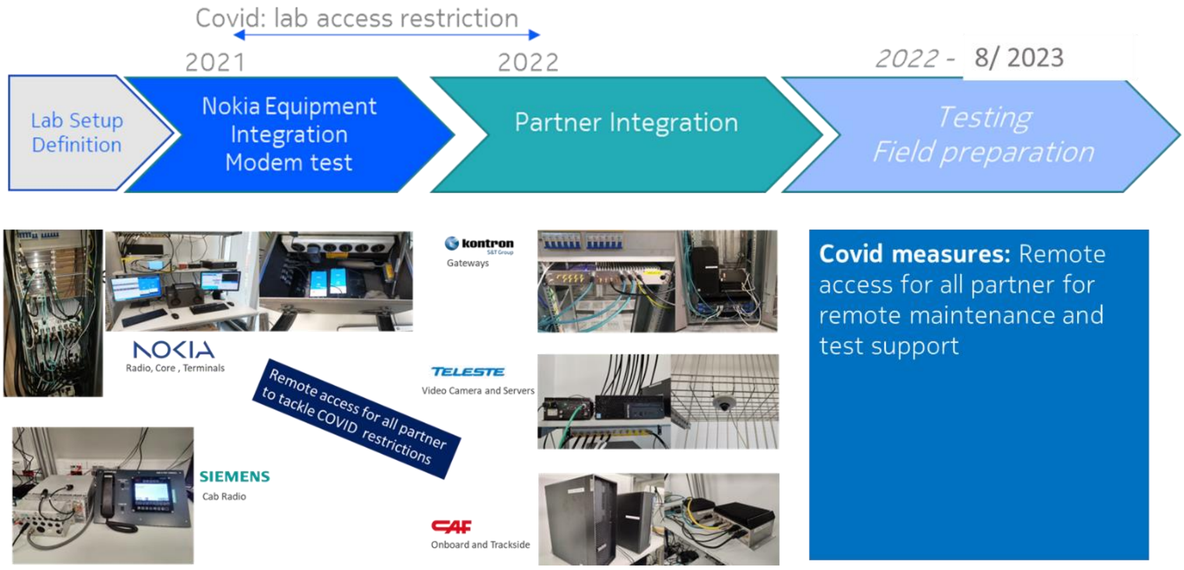


Figure 1: WP3 High Level Planning Status

As the first integration phase the WP3 team had to put in place the lab in Budapest Nokia's premises, Hungary. This activity is described in delivery D3.1 [S20] and consisted in:

- Installing a 5G SA infrastructure (Core , MCX Server & Dispatcher, Radio Access) with 3 NR bands to be used (N8, N78, GSM-R) …,
- Provide GSM-R IWF function and interconnect FRMCS/MCX system with GSM-R test system
- Provide Devices, Monitoring Equipment,
- Engineer and manage the whole IP network so that all needs coming from the partners could be fulfilled.
- Provide secure Remote Access for partners to mitigate restrictions due to COVID,
- Finally the remote setup towards the BSS radio installation at the WP5 field had to be setup

Secondly, WP3 team was involved in the integration activity of applications in the laboratory infrastructure, both for onboard and trackside. Thus as WP3 lab could be seen as the place to put all pieces altogether in order to check their correct interconnection:

- OBapp integration between FRMCS On-Board applications with the Onboard GW,
- TSapp integration between FRMCS Trackside applications with FRMCS Trackside Gateway,

- Setting up Voice end to ends setup with Nokia devices, MCX server and Dispatcher together with Siemens CAB Radio

Once these major steps had been achieved, WP3 was to execute the test plan WP1 team had written for the first lab in D1.1 [S22] – to some extend even during the WP3 phase. This activity covered:

- Voice tests including railway relevant use cases as train to/from dispatcher/controller calls, or Railway Emergency Calls (which received the award by the EU as a key innovation ([Innovation Radar > Discover great EU-funded innovations (europa.eu)]))
- Data ETCS and TCMS tests
- CCTV/video end to end tests
- Mission critical related test as Functional Alias, Location handling, Authentication & Authorization, multi talker control
- Tests focusing on specific 5G related features (Bearer Flexibility, QoS incl. higher train speed emulation, different handover schemes, Cross-Border scenarios)

And last but not least, WP3 had to prepare German WP5 activities as the trackside setup of the lab will be remotely connected to the WP5 field trial to be run with partner DB. In that perspective:

- The network had to be engineered for WP5 needs
- Monitoring on both sides using centralized NTO server for aligning e.g. of Wireshark traces
- A VPN had to be established between Nokia's and DB's locations, following DB and Nokia security policies
- The WP3 onboard lab equipment removal had to be carefully prepared in order pave the way of WP5
- Considering WP5 constraints (testing with trains had to be booked far in advance and can not suffer planning changes), failover scenarios had to be considered in case of equipment failure,

According 5GRail Grant Agreement the objectives of WP 3 and the D3-3 scope are defined as follows:

"The lab testing reports outlines and details the different lab test phases for each application. It documents the work done and details the achieved results for the integration of prototypes into the 5G infrastructure and the validation of the communication capabilities in the lab environment in line with the lab test strategy document elaborated in WP1. It covers Voice, TCMS, ETCS, CCTV/Video test results, as well as cross-border testing."

To document the achievements the delivery D3-3 is organized as follows:

- Chapter 2 gives some introduction on general aspects of some of the executed tests, explaining the concepts of 5GRail tests on Border Crossing, Bearer Flexibility, Railway Emergency Call, GSM-R Interworking and QoS. Note that some background information (e.g. on Border Crossing results in other H2020 CAM projects) are described in the Annex 12
- Chapter 3 deals with an update of the integration done after the publication of D3.2 (handover tests, modem tests, train speed emulation/fading tests, IWF tests, bearer flexibility and border crossing integration tasks.)
- The following chapter deal with the end to end application tests, describing the test case, test results as well as pointing to the gathered result documentation (e.g.log files)
    - Chapter 4 focuses on all executed Voice tests
    - Chapter 5 is related to tests with the ETCS application,

- Chapter 6 gives details on TCMS and its testing,
- Chapter 7 is related to Video tests
- Chapter 8 informs on WP5 related preparation activities.
- Chapter 9 provides a summary and overview of the performance related measurements done

2 Generic Information on specific tests

The following chapter describes in more detail the concepts behind some of the solutions defined in WP3 to realize the required tests for border crossing, bearer flexibility and voice related REC, GSM-R IWF and QoS. It explains the capabilities as well as constraints of the components of the 5GRail test environment of WP3.

2.1 Bearer flexibility

According to UIC FRMCS specification FRMCS should provide two mechanisms to achieve Bearer Flexibility Multi Access (refer to [S18], chapter 12.3.1): FRMCS Multi Access and FRMCS Multipath

Where FRMCS Multipath enables the (sequential or simultaneous) use of multiple UEs on the same or different transport domains, FRMCS Multi Access enables the (sequential or simultaneous) use of multiple radio access technologies on a single UE and a single (FRMCS) Transport Domain.

For 5GRail WP3 addresses the concept of FRMCS Multi Access (in contrast to WP4 focussing on Multipath approach). The use case is to utilize a second "access" with higher bandwidth to demonstrate a video archive upload from a train reaching the station (see chapter 7.2.6).

Multi access capabilities by the 5G SA transport domain standardized in 3GPP defines the functionality required to serve different access using the ATSSS (Access Traffic Steering, Switching & Splitting). It is important to understand that in current 3GPP Rel. 17/18 the solution is limited to serve a 3GPP and a non 3GPP (e.g. WiFi) access, but activities have been started for 3GPP Rel. 19 to evaluate enhancements of the ATSSS model to serve (at least) two different 3GPP access types as well. In Annex 12.8 we explain in more detail the concepts of ATSSS.

However, the support of multi access by the UE and infrastructure during 5GRail does not allow to demonstrate ATSSS, instead a solution based on two sub bands on the N78 band was selected to demonstrate the behaviour of relying on an (high performant) second Uplink for the test case CCTV_TC_002 "CCTV offload from train to trackside with bearer-flex". The following figure depicts the schematic setup:

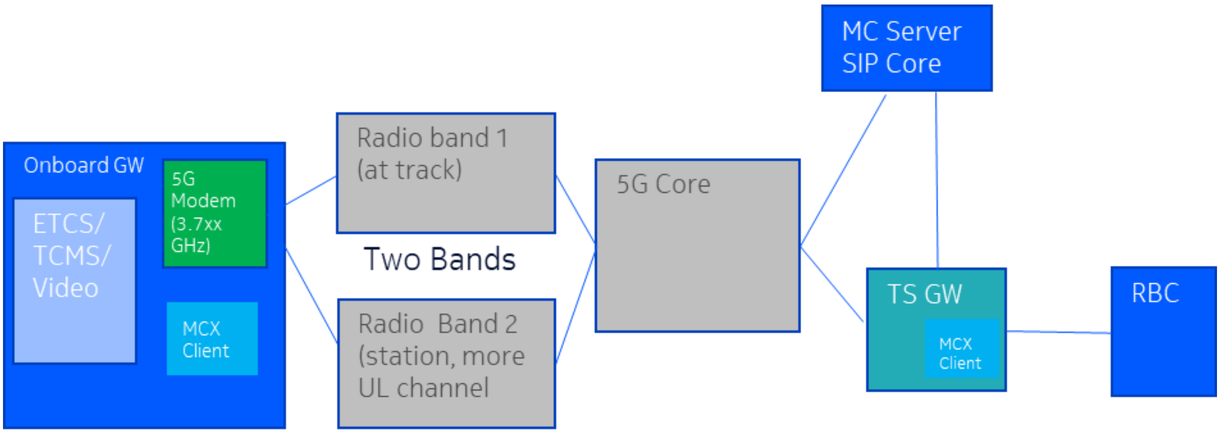


Figure 2: Schematic overview on Bearer Flexibility

Higher throughput of the second sub band was achieved by using TDD Frame Structure with higher number of UL channels. It is worth to mention that by this approach additional performance evaluation of different TDD frame structures related to uplink could be achieved – a result important for FRMCS in general.

Additionally, handover between different TDD bands with different TDD frame structure can be seen as a building block for border crossing, as with different TDD frame structures deployed by operators this aspect get's an important factor (depending on the availability of different TDD subbands, e.g. not yet defined for RMR n101 band).

2.2 Border crossing

Trains crossing the border is an essential requirement for FRMCS for the deployment of a Pan Europe Single Rail Domain, allowing trains seamlessly travelling between the different countries. This is already a guiding principle for GSM-R which lead to the inclusion of GSM-R in the EU legal frame of Technical Specifications for Interoperability.

When it comes to FRMCS the different Strata of the FRMCS architecture are impacted and involved in Border Crossing scenarios:

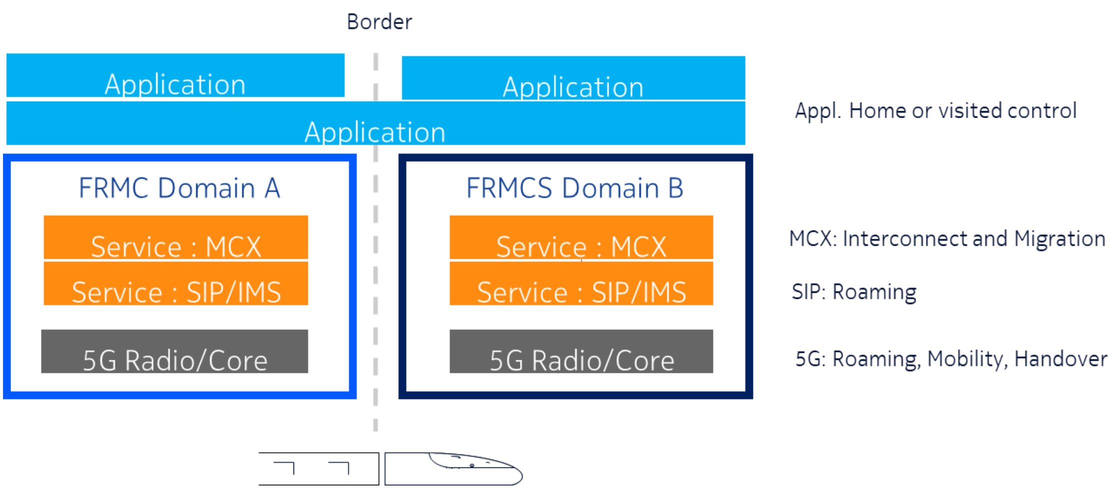


Figure 3: FRMCS Strata impacted by Border Crossing

The following topics are to be considered:

- On 5G Radio / Core measures for roaming and cell reselection or Inter PLMN to be considered
- On Session layer we have SIP roaming as the base to allow session handling between different countries, supporting MCX interworking and interconnection
- MCX lay interconnection and migration is under further standardization in 3GPP (e.g. TS 23.280 / Rel. 18 , refer to Annex 12.6) to allow border crossing in a MCX environment:
  - Interconnection
    Communication between MC systems whereby MC service users obtaining MC service from one MC system can communicate with MC service users who are obtaining MC service from one or more other MC systems. Interconnections between FRMCS domains is required.

- Migration
  MC service user is able to obtain MC services from a partner MC system e.g., the MCX of the roaming PLMN. Therefore, User Profile data is migrated and then accessible to partner network to migrate, especially in cross border scenarios

When it comes to the 5G NSA/SA evaluations different steps have been analysed and tested in the 5G CAM projects on potential improvements towards seamless service continuity support on 5G level with a focus on automotive requirements for border crossing between CSP network, mainly differentiating the following scenarios related to Network Reselection Improvements (refer to [S26]):

Scenario in 5G CAM projects	**Description**
Scenario 1 / Basic	UE roaming with new registration
Scenario 2	UE roaming with AMF relocation (idle mode mobility)
Scenario 3	(Inter PLMN) Handover, relying on NG/N2 based handover

Scenario 1 is typically taking up to several minutes as no specific support is provided, and new search and registration phase as part of the roaming procedure is needed after loosing the coverage with a new session setup (IP address change).

In scenario 2 the improved idle mode mobility (with redirect function from source to target frequency and PLMN) allows to reduce interruption time to about 1 second, with same IP address kept.

Scenario 3 is the most demanding solution offering interruption time as low as 0,1 seconds with same IP Address as context is transferred.

One of the corner stone of Scenario 3 with Inter PLMN handover is the NG/N2 handover as a solution where the handover is not managed via interconnection of the gNb involved (X2 handover) but is realized via the core network. Note: NG/N2 can be realized within on core network, or between two core networks. In an Inter PLMN Handover scenario this requires the exchange of session information between home and visited PLMN requires roaming interfaces between AMF (N14), as well as handling of SMF/UPF anchor transmission.

Annex 12.5 gives some more details on the evaluations in the Horizon 2020 CAM projects.

It should be noted that for concrete test setups in the initial phase of those projects the 5G system was based on 5G NSA (means relying on LTE core network) where functionality as Roaming is available since years (see following simplified figure on 5G NSA and SA difference):

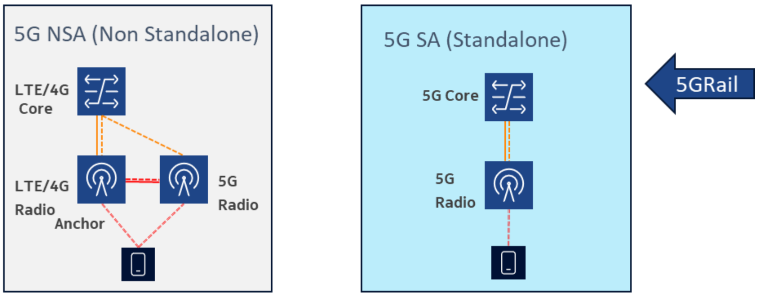


Figure 4: 5G NSA vs. 5G SA

Some scenarios are expected to be easier realized in FRMCS compared to CAM projects for the automotive sector, due to the stronger interconnection measures between railway operators. It is important to understand that – in contrast to railway – CAM services rely on public operator networks, and thus for automotive sector the cooperation of mobile operator between networks is required, which is expected to be more challenge compared to the cooperation models typically done in railway (where already in GSM-R close cooperation between railways are in place to achieve seamless interworking ad roaming across Europe (refer to GSM-R ENIR project [S27].

5G Rail implications:

For 5GRail the limits of the available infrastructure on Roaming and Handover capabilities in a 5G SA environment led to the solution to identify some of the building blocks defined above to derive benefits of the concepts for FRMCS.

Hint: the initially planned test case on Home Routing for TCMS services (refer to WP3 D3-2 delivery) could not been further tested due to the mentioned restrictions in 5G SA on roaming support (refer to Annex 12.4).

Instead, important building blocks of the 5G Inter PLMN and service continuity concepts have been analysed and tested using a Video Streaming application.

The following picture shows the overall architecture used to verify the border crossing functionality by emulating a second PLMN as roaming interfaces are not supported:

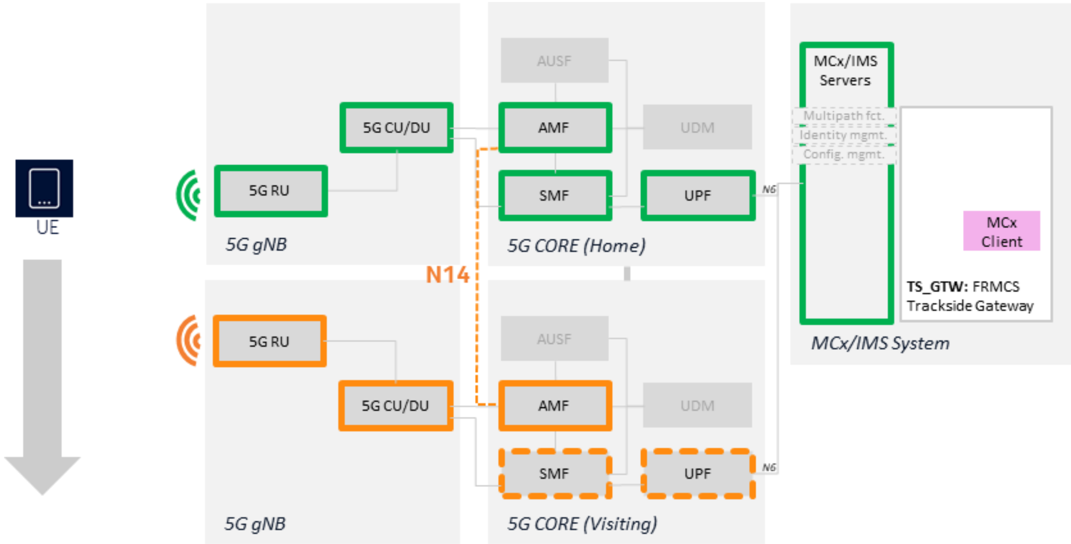


Figure 5: System overview for border crossing

Note:

- As the roaming interfaces are missing, the two core system are treated as same PLMN (means the UDM/AUSF of the second visited PLMN is not used
- The realization of Inter AMF handover/connectivity as NG handover is tested by the capability of the N14 based interconnection of two AMF in Nokia core
- Note: UPF (or SMF) change was not realized in the test setup.

The Inter gNB NG/N2 Handover as a main building block for seamless Inter PLMN Handover scenario is depicted in following figure:

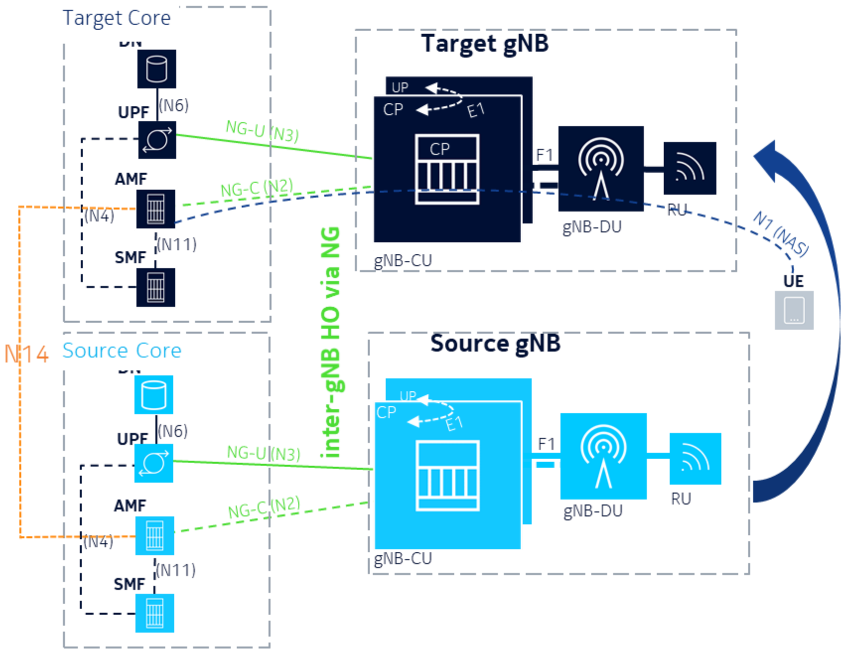


Figure 6: Inter gNB handover via NG/N2

Note: the picture shows the target situation with two core/AMF configuration. An intermediate step (using two RAN but one Core) has been executed to first evaluate NG handover mechanisms on the radio side.

2.3 Railway Emergency Call

The Railway Emergency Call (REC) for FRMCS V1 is an open topic, where the result of intensive evaluations was summarized be defining 4 potential options for further evaluation for V2. Based on that the WP3 realization for 5Grail can be seen as "Pre-Standard".

In the FIS v1 [S16] the REC has been analysed and described as potential implementation options based on current or upcoming 3GPP MCX building blocks. One of the findings during that activity was to identify Gaps of current 3GPP MCX standards.

The following options have been discussed (refer also to the Annex 12.7 where some more details are described):

- Option 1: Client based approach using rule-based affiliation done by the client
- Option 2: Server based approach. Server sends message to the clients based on rules that trigger the clients to perform an affiliation to the emergency group
  - Option 2A: Client Aware solution – continuous affiliation
  - Option 2B: Client Aware solution – affiliation at setup
- Option 3: User regroup method: Server determines the clients, but a client to perform the active re-group
- Option 4: Adhoc group method (AHGC) with Server based area definition and user determination without required affiliation (Target for 3GPP Rel-18)

It should be noted that the dynamic identification of the Area – based on the originator location – and the further identification and affiliation of impacted clients according to their location, is a new concept in MCX standards which up to now more focused on "controller based Emergency Call use cases defined by the Public Safety / PPDR market.

For this reason, 5Grail considered to evaluate and test a server based option (option 2A was selected). Note that today's discussion points rather to the realization of the (newly standardized) Option 4 (Ad Hoc Group) under standardization in 3GPP Rel. 18.

However, the role and requirement on the server-based area calculation is comparable with Option 2, by these valuable results could been derived from 5Grail test cases.

The Concept of Solution 2A can be described as follows:

- The MCX Server determines the affiliation of the clients by internal rules that trigger the clients to perform an affiliation to a specific group.
- The step to affiliate the client is performed continuously as the mobiles are updating their location independent if a call setup is performed.
- The standard MCPTT emergency group call is used as base procedure.

Please refer to the Annex 12.7 where the realized message flows are described.

The following figure shows how the specific 5Grail setup realizes the test cases for REC based on option 2:

1 CAB Radio, 1 Smartphone, 1 Dispatcher.

1. Emergency Group defined in MCX Server related to Area 1 -> GPS Coordinates define the Area 1
2. Pre/ defined Fixed configuration for Smartphone and Dispatcher for Group Area 1 . They do affiliation on their own
3. CAB radio with GPS Fake for Area 1
4. CAB radio sends continuous location report : first out of Area, second in Area
5. Dynamic group affiliation for CAB Radio when in Area 1
6. CAB Radio : Setup of MCX Emergency Call for Group Area 1 -> MCX invites also Dispatcher, Smartphone

- Termination by Dispatcher or CAB

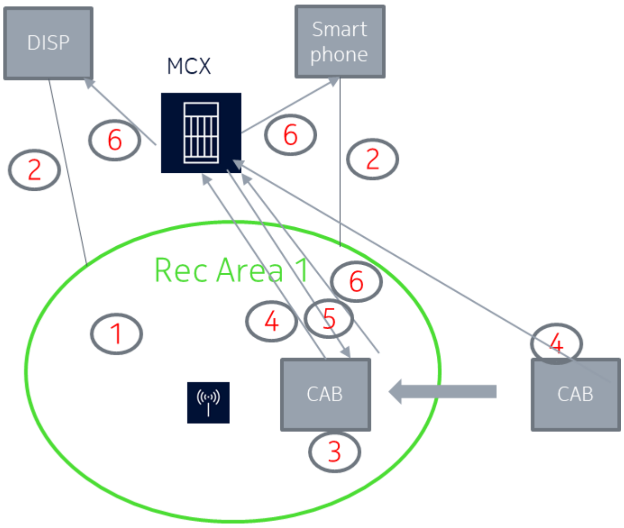


Figure 7: CAB Radio initiated REC

A second test case uses the Controller initiated REC in a similar setup:

1 CAB Radio, 1 Smartphone, 1 Dispatcher.

1. Emergency Group defined related to Area 1 -> GPS Coordinates define the Area 1
2. Fixed configuration for Smartphone and Dispatcher for Group Area 1 . They do affiliation on their own
3. CAB radio with GPS Fake for Area 1
4. CAB radio sends location report in the Area 1
5. Dynamic group affiliation for CAB Radio
6. Dispatcher: Setup of MCX Emergency Call for Group Area 1 -> MCX invites also CAB radio , Smartphone

- Termination by Dispatcher

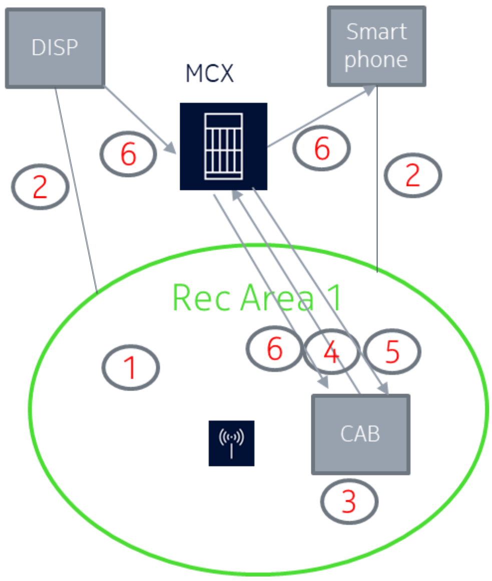
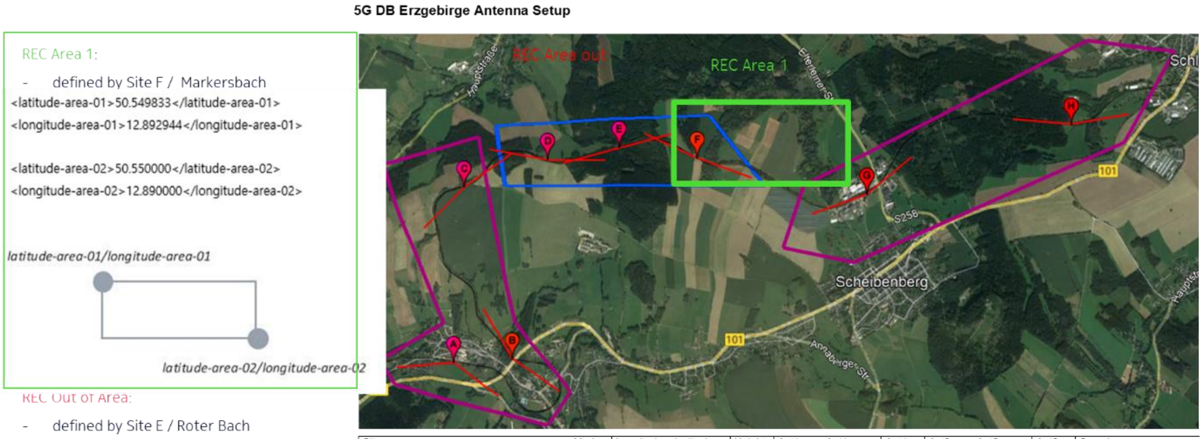


Figure 8: Dispatcher initiated REC

Note that the GPS location handling in the lab needs to be emulated. The Area definition of the lab setup however is aligned with WP5 real coordinates. In 5Grail the definition of an Area is done based on a Rectangle definition.



Site name		Marker	Longitude [WGS84]	Latitude [WGS84]	Height [m]	Ant1 Azimuth	Ant1 Height [m]	Ant1 Tilt	Ant2 Azimuth	Ant2 Height [m]	Ant2 Tilt	Search Google Earth
Markersbach-Bf		A	12,861389	50,534444	486	265	10	1 down	125	10	1 down	50.534444°,12.861389°
Markersbach-obere-Schleife		B	12,867222	50,535278	523	125	10	1 down	330	10	2 up	50.535278°,12.867222°
Markersbach-BUE-Emmlerweg		C	12,862083	50,548111	575	225	10	2 down	55	10	1 down	50.548111°,12.862083°
Hilligweg	(km 13,6)	D	12,872333	50,550222	597	280	10	1 down	90	10	1 down	50.550222°,12.872333°
Roter Bach	(km 12,9)	E	12,881111	50,550972	624	255	10	1 down	75	10	1 down	50.550972°,12.881111°
Markersbach_	(km 12,1)	F	12,892944	50,549833	624	295	10	1 down	110	10	1 down	50.549833°,12.892944°
Scheibenberg-Bf		G	12,910861	50,547528	626	250	17	1 down	50	17	1 down	50.547528°,12.910861°
Schlettau West	(km 8,62)	H	12,935583	50,552889	598	275	10	1 down	80	10	1 down	50.552889°,12.935583°

Figure 9: WP5 Network Layout

The test cases for late join / leave) have been defined as optional and not been implemented following the dynamic calculation method of the server. However, the existing MCX functionality of Late Join (based on preconfigured groups) have been used to verify the test case for GSM-R Interworking and transition (see chapter 2.4).

2.4 GSM-R Interworking

GSM-R – FRMCS Interworking is an important functionality during the transition phase where both technologies will be supported at the same time. The standardization in ETSI (refer to [S29] are still ongoing, thus the realized implementation is realized as pre standard functionality.

However, one important use case is the triggering of a Railway Emergency Call in a specific area for both technologies by the infrastructure to ensure that trains with either GSM-R or FRMCS capabilities can be reached. The principal realization in 5GRail was to automatically trigger a Railway Emergency Call on the GSM-R network when in the FRMCS system a corresponding REC is established by the CAB radio. for this the following setup was used for 5GRail:

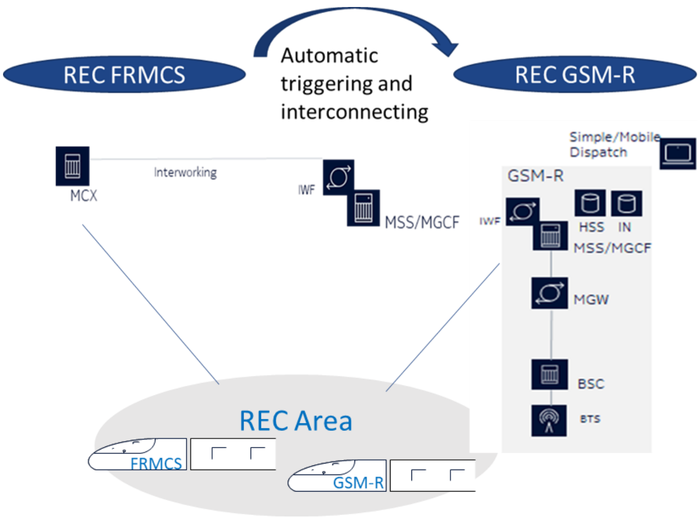


Figure 10: Setup for GSM-R Interworking

The implementation in the Nokia MSS therefore interprets incoming MCX messages defined in 3GPP for Interworking, and maps them to GSM-R messages inside the MSS , normally use by a dispatcher originated REC call.

Important aspect is that no floor control between the networks which lead to some specific behaviour on the terminal (CAB Radio/ Dispatcher) described in the test case descriptions chapter 4.2.10 and 4.2.12.

This configuration also serves the test case for border crossing for voice with transition from GSM-R to FRMCS. In this case a CAB radio connected to GSM-R receives the technology spanning REC call, and is starting a network transition from GSM-R to FRMCS. By manual switching in the CAB radio the CAB radio will leave the GSM-R REC call and joins the ongoing REC call on the FRMCS side. We use the Pre-configuration / Pre-affiliation of the MCX group call on the FRMCS side to allow the CAB radio to do standard Late Join functionality. See below:

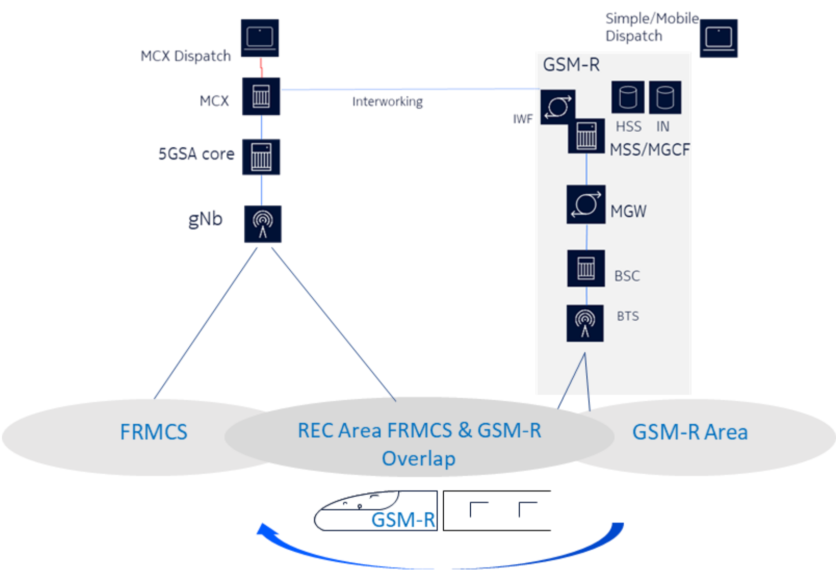


Figure 11: GSM-R IWF for Border Crossing

2.5 QoS handling

As already described in D3-2 the QoS mechanisms used in the 5G core and radio access is configured for the different QoS classes with the help of filtering functionalities in the core network. This is required as for the time of 5GRail test activities a PCF - which is normally used to achieve Application specific end to end QoS setting in core and radio - was not available.

The following picture shows the e2e 5G QoS concept:

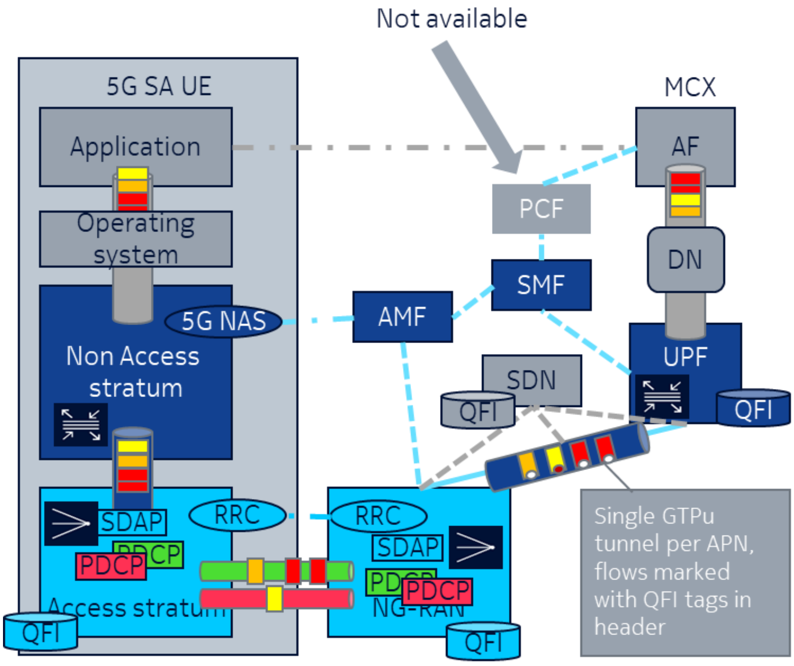


Figure 12: QoS Architecture

In line with 3GPP standardization however local policy filtering capabilities of Nokia 5G core was used as follows:

- 3GPP 23.501 states: The SMF may change the subscribed values for the default 5QI and the ARP and if received, the 5QI Priority Level, based on interaction with the PCF as described in TS 23.503 [45] or, if dynamic PCC is not deployed, based on local configuration, to set QoS parameters for the QoS Flow associated with the default QoS rule.
- This local configuration is realized using 3GPP ADC (application detection and control) functionality in Nokia Core / SMF Traffic Steering function. This allows various options for detecting and assigning QoS flows based on filtering.
- Some configuration option for differentiation can trigger based on may be included in the policy-rule-unit including direction (uplink, downlink or both) and match criteria for:
  - IP and local-port (list or range)
  - IP and remote-port (list or range)
  - tos-tc dscp (Type of Service/Traffic Class (ToS/TC) DSCP). Specifies the DSCP code point value.

As agreed in WP1 the filtering for the different QoS classes is done by the DSCP marking received from the application settings. For TCMS, ETCS and Video different 5QI QoS classes were set based on the DSCP setting.

For 5GRail the Guaranteed Bitrate Class (GBR) for voice was set to 5QI-2 (Note. 5QI-1 requires additional signalling between a VoNR capable UE which is not supported by the 5GRail Modem).

Applications	OB_GTW		Infrastructure static configuration	Extract from TS23.501, Table 5.7.4-1		
comm_profile transmitted by the	DSCP value (bit)	DSCP value (decimal)	QoS parameters used for WP3	Packet Delay	Packet error rate	Comments
1- Voice (*)	101.101	43	5QI: 2, **ARP 7**, GBR	150ms	10^{-3}	Used for Conversational Video (Live Streaming) ?
2- Operational Voice	101.010	42	Not used			
3- Emergency voice (*)	101.001	41	5QI: 2, **ARP 1**, GBR	150ms	10^{-3}	Used for Conversational Video (Live Streaming) ?
4- Video	100.001	33	5QI : 7, non-GBR	100ms	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
5- Low latency Video	100.000	32	Not used			
6- Non harmonized Data (TCMS)	1.000	8	5QI:9, non-GBR	300ms	10^{-6}	Video (Buffered Streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.) ?
7- Operational Data	10.011	19	Not used			
8- Emergency Data	10.111	23	Not used			
9- Low latency Data	10.110	22	Not used			
10 - ETCS	10.101	21	5QI 5, non-GBR	100ms	10^{-6}	Used for IMS signalling?

Table 1: QoS settings

However, a different filter had to be configured for the voice tests, as the CAB radio could not set a different DSCP value for the different test cases, but instead filtering for the IP address of the CAB radio was done. This results in the setting of a GBR /Guaranteed Bit Rate setting for the voice bearer, but also for the signalling bearer (which is normally not required, and not impacting the test results).

For the measurement of voice related performance the KPI 1&2 as described in [S21] were used:

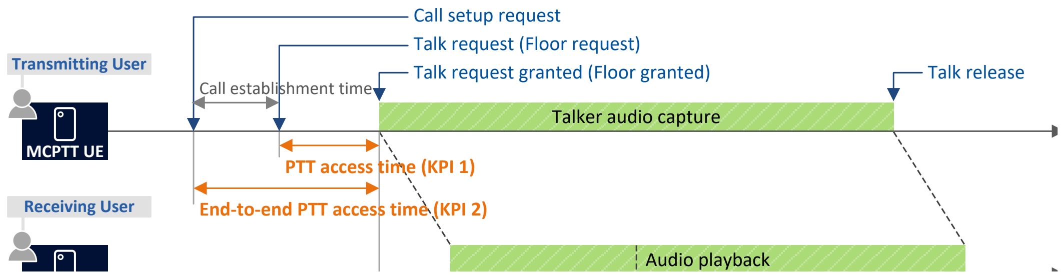


Figure 13 MCX KPI definition for voice

3 Integration update and tests setup

3.1 Introduction

The 5G network (in standalone mode – 5GSA) is the main component of the WP3 lab and most of the test cases will use such infrastructure.

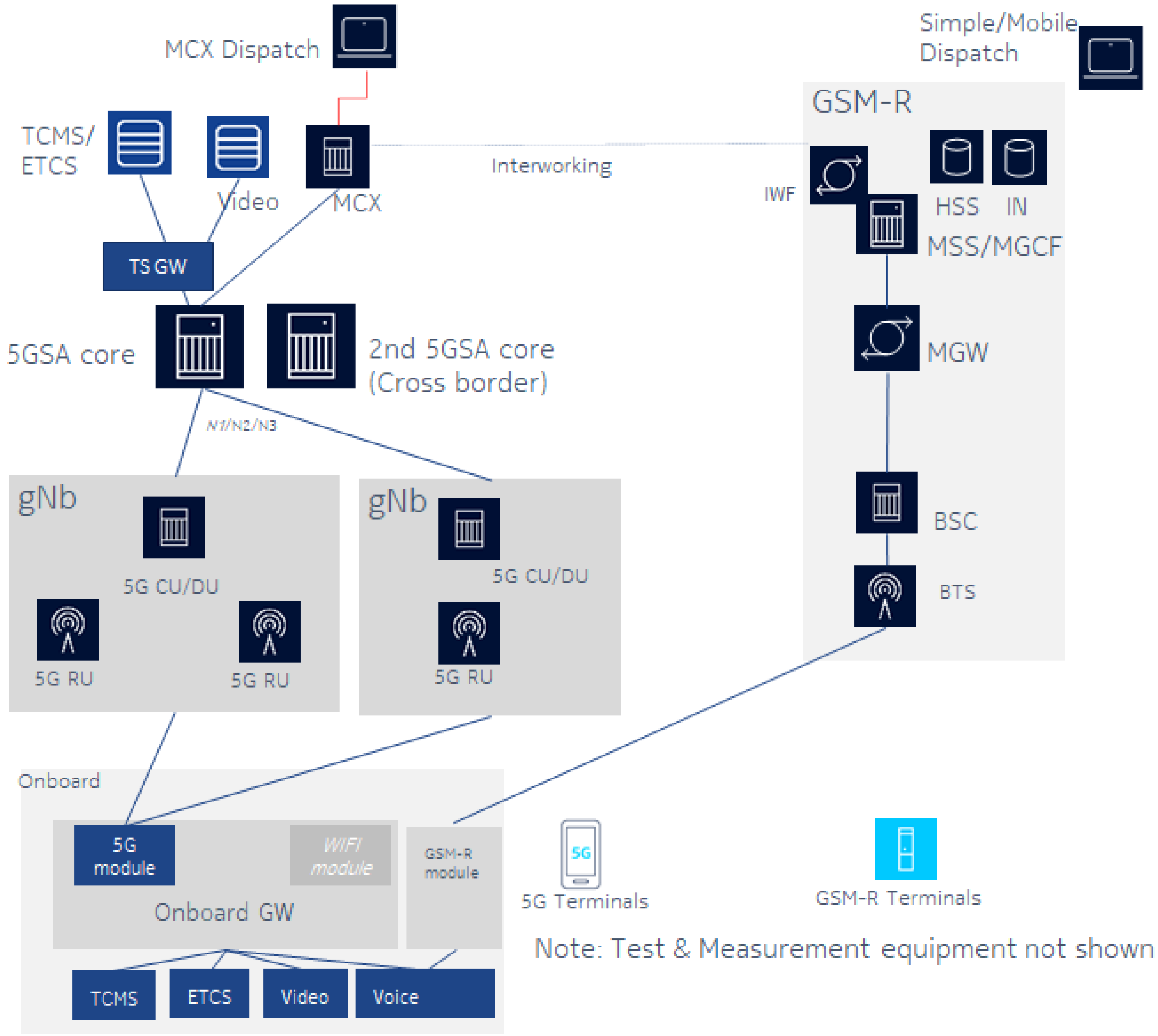


Figure 14: LAB Configuration

The gNB configuration with respect to select RRH (Band N8, Band N78) is flexible to allow the use cases to be tested and to be defined in WP1.

The following picture shows the FRMCS 5G Radio configuration integrated in the lab.

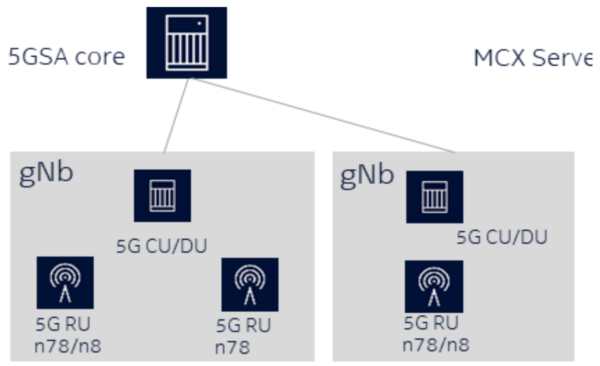


Figure 15: Radio Configuration

The Radio System consist of

- 2 gNB CU/DU: Nokia AirScale ASIK/ABIL
- 5G RU:
  - o 3 Units AZQJ Band n78: 3480 -3800 MHz, 8T8R, 320 W (40W per TRX)
  - o 2 Units AHDB Band n8: UL: 889 – 915 MHz/DL: 934 – 960, 2T4R, 2*80 W

The concrete configuration with RRH supporting band n8 or n78 depend on the use cases defined in WP1. Band n8 is planned to be used for functional e2e tests only.

WP3 decided to focus on two 5G frequencies:

- N8 band, 900 MHz FDD (UL: 880 – 915 MHz, DL: 925 – 960 MHz)
- N78 band, 3300 – 3800 MHz TDD

WP3 started with N78 band.

Integration happened step-by-step starting with 5G SA core, MCX and 5G Radio installation and commissioning.

The following steps were done during the integration with an agreed IP level connectivity:

- 5G SA core install/commission
- 5G Radio (N78) install/commission
- 5G SA core and 5G Radio integration:
  - o smartphones and Thales modems could attach to the network,
  - o could start PDU session and
  - o FTP upload/download were successful
- MCX integration to 5G SA core using N6 interface:
  - o smartphones and dispatcher console could handle private calls, group calls
- CAB radio integration direct connectivity to MCX:
  - o CAB could register to MCX
  - o CAB could handle private and group calls
- Onboard gateway integration (TOBA-K) – CAB is integrated to MCX via TOBA-K
  - o Equipment was preconfigured with the agreed IP
  - o CAB could register to MCX

- CAB could handle private and group calls

Because SIP proxy functionality is missing in TOBA-K, therefore „route through" solution was proposed by Kontron. However, when simple IP forwarding was configured in the OB GW, the floor control did not work towards CAB radio since the RTCP packets did not reach the CAB radio. Further suggestion from Kontron: create GRE tunnel between Thales modem in TOBA-K and MCX server

Generic Routing Encapsulation (GRE) is a protocol for encapsulating data packets that use one routing protocol inside the packets of another protocol.

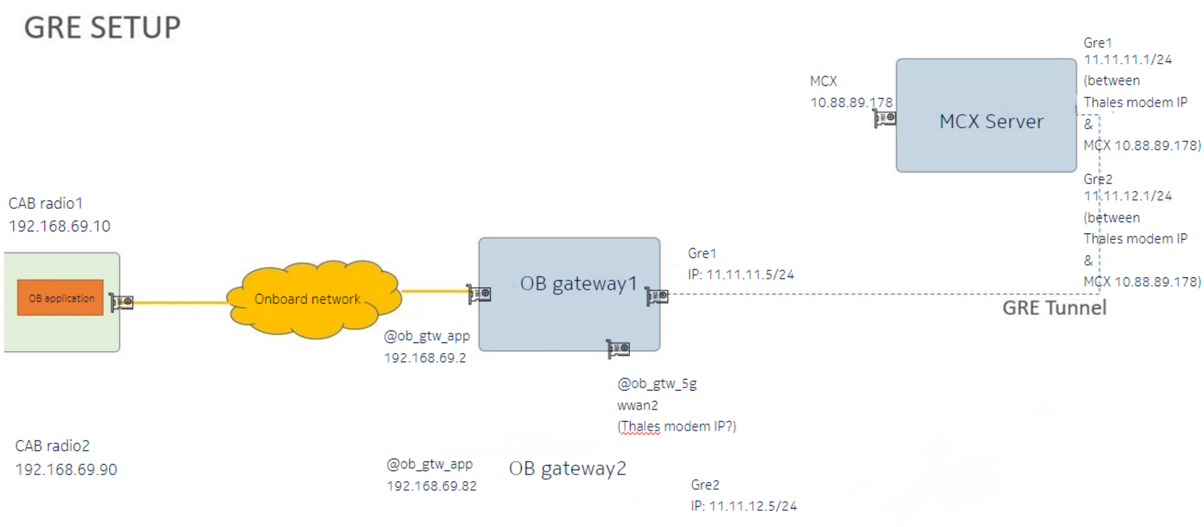


Figure 16: GRE tunnel setup

Issues found during GRE tunnel setup:

- IP address of Thales modem in OB GW is dynamically allocated from 5G user IP pool during PDU session establishment, and the GRE tunnel is set to a fix IP
- when the IP of Thales modem is changing, a new GRE tunnel needs to be specified or the original one needs to be modified on both sides, Nokia & Kontron, according to the new IP of the Thales modem

As a solution WP3 decided to use static IP address allocation instead of dynamic one

- Trackside gateway (Kontron) installation and configuration
  - host OS and IP level configuration were on the PC
  - Remote accessibility was allowed for Kontron
  - Track side gateway VM install and IP level configuration were done by Kontron

- Trackside gateway (Kontron) integration to 5G SA core using N6 interface:
  - Ping between onboard and trackside gateway was ok

- CAF onboard and trackside equipment integration

  - CAF was on site for setup and configure their equipment
  - Remote accessibility was allowed for CAF
  - CAF configured their equipment locally to reach successful IP level connectivity

- Teleste onboard and trackside equipment integration
  - Equipment was sent in IP-level preconfigured state
  - WP3 installed the equipment according to installation guide
  - Remote accessibility was allowed for Teleste
  - Teleste configured their equipment remotely till successful IP level connectivity

- IPCON checking on MCData
  - WP3 installed a SW on MCX with IPCON possibility
  - CAF, Teleste and Kontron did successful IPCON

Logs from integration steps are in 5Grail collaboration SharePoint folder in the following folder structure:

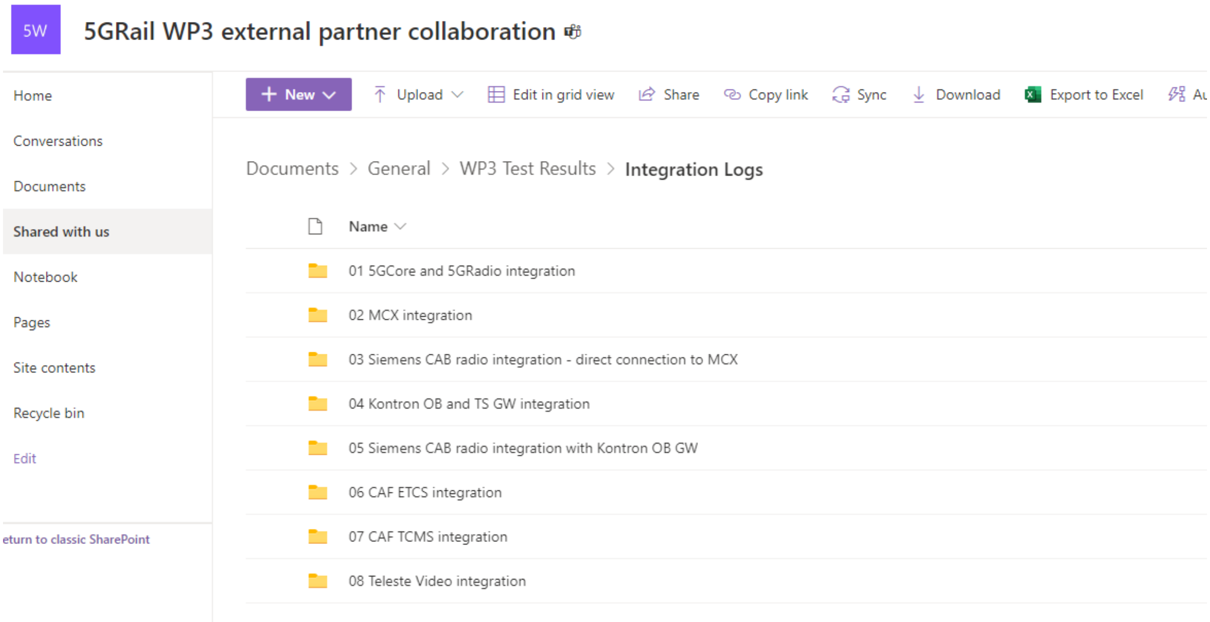


Figure 17: WP3 integration logs folder structure

3.2 Handover configuration and test setup

Different Handover have been realized and tested from the overview figure and described in subsequent chapters. The below figure depicts the different handovers available in 5G:

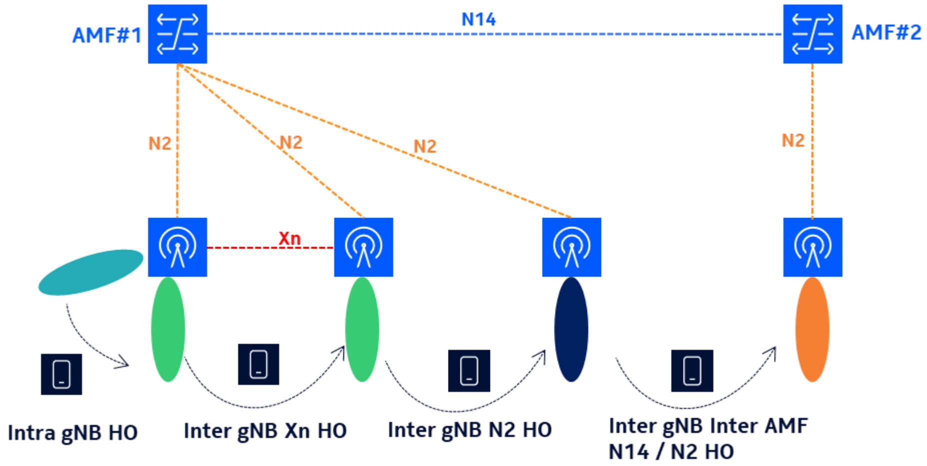


Figure 18: Handover scenarios

3.2.1 Intra-frequenc Xn based handover

XnAP is the control protocol used between gNBs to support a variety of RAN related procedures, coordination of Xn based handovers, data forwarding and RAN Paging. During the handover process, the source gNB will provide the target gNB with all the necessary information it needs to handle the subscriber, including security and User Plane connectivity information.

This type of Handover is only applicable for intra-AMF mobility.

Xn Handover is Faster compared to N2/NGAP Handover due to short signaling path and 5G Core involved in only for switch the PDU session path.

Intra-frequency handover happens from Cell-1 to Cell-3 and backwards (see Figure 19). Both cells have the same frequency, 3570 Mhz.

Our configuration is based on A3 measurement event reporting. A3 is triggered when a neighbor cell becomes better than a special cell (SpCell) by an offset.

3.2.2 Inter-frequency Xn based handover

Inter-frequency handover happens from Cell-2 to Cell-3 and backwards (see Figure 19) within N78 band but between sub-bands of N78. Cell-2 has 3660 Mhz frequency.

Our configuration is based on A1, A2 & A5 measurement event reporting.

A1 is triggered when serving cell becomes better than threshold.

A2 event occurs when the measurement of the signal received from the serving cell falls below that of a threshold.

A5 is triggered when SpCell becomes worse than threshold1 and neighbor becomes better than threshold2

Notes on test execution:

- In these tests the user equipment is connected to the source cell and aim is to simulate the train moving from one cell to another cell. The attenuation level in cells is adjusted with a Hytem attenuator matrix and a Vertex Channel emulator which is described in chapter 3.4.

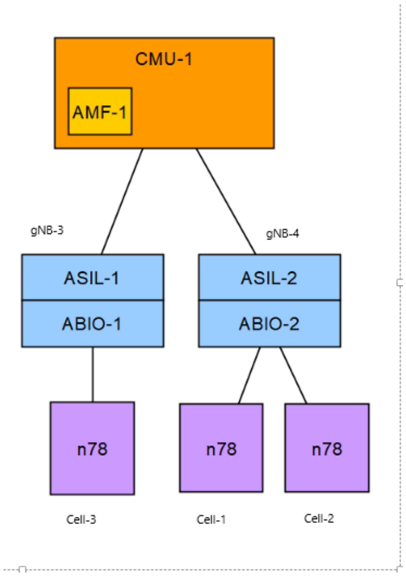


Figure 19: Handover test setup

Comments:

It is important to have a weak signal in source cell when doing the handover from source cell to target cell as it reflects what may happen on field (as such handover will occur at cell edge).

Conclusion:

Tests have been performed successfully.

3.2.3 Inter-gNB Intra-CMU/AMF N2/NG handover

When the source and Target gNB does not have active Xn interface or handover over Xn interface is not allowed, then gNB can decide to perform handover over N2 interface. In this type of handover AMF plays the anchor role for coordinating between Source and Target gNB to make handover as a success (see Figure 20 with strike through XN interface).

From radio RF configuration point of view all configurations are the same as it is based on Xn handover related settings.

Inter gNB Intra-AMF NG handover can be intra-freq and inter-freq handover as well.

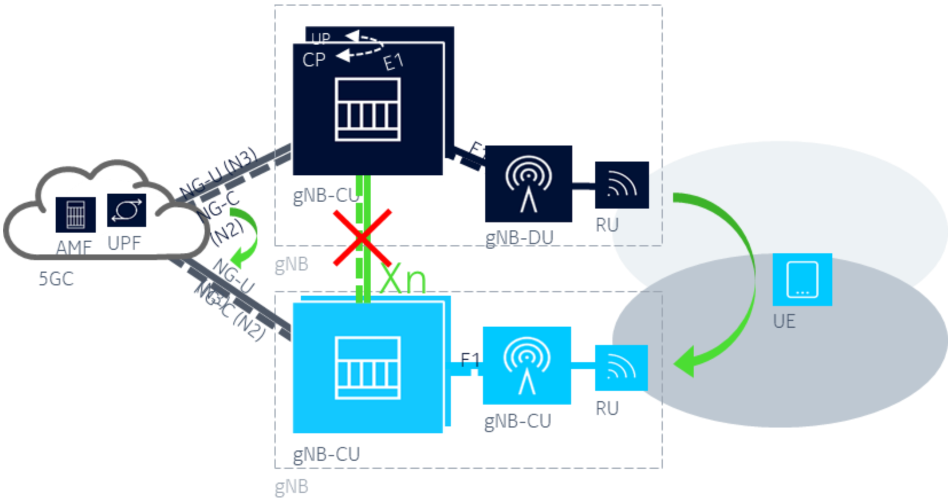


Figure 20: HO test setup

The call flow below is described in 3GPP [S32]:

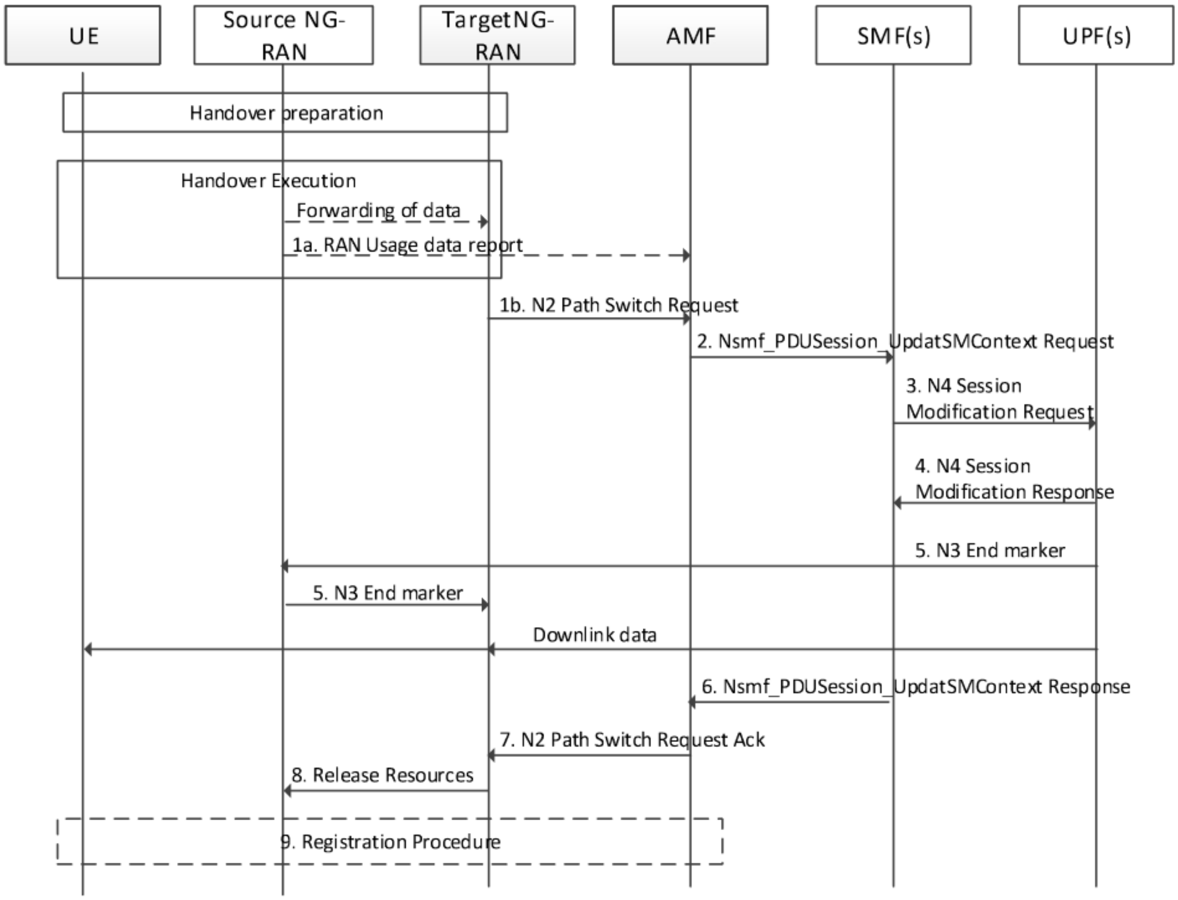


Figure 21 N2/Ng based Handover

Comments:

Same is valid here as in Xn handover chapter 3.2.1.

Conclusion :

Tests have been performed successfully.

3.2.4 Inter-gNB Inter-CMU/AMF N2/NG handover

With integration of a secondary CMU (5GC), there is the opportunity to conduct testing of inter-gNb Ng handover procedures, whereby the transition occurs from the source 5GC, AMF-1, to the target CMU, AMF-2. Notably, throughout this operation, session management remains within the source 5GC, SMF-1 and UPF-1.

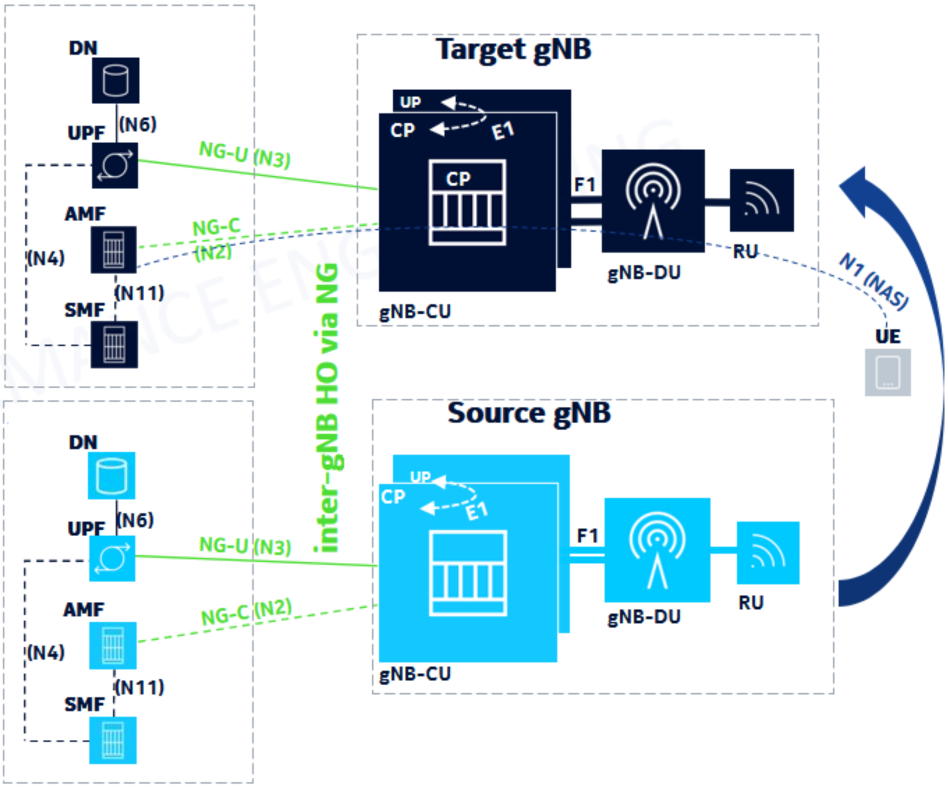


Figure 22: Inter-AMF HO Setup

Connection establishment between source and target AMF can be provisioned of a communication link via the N14 interface, defined as Namf_Communication service.

Inter gNB Inter-AMF NG handover can be intra-frequency and inter-frequency as well.

Test with Iperf (to emulate constant video bitrate):

Call Flows taken from Wireshark on both 5G SA core

5GSA Core / CMU-1

9	10:51:45.101183	10.88.89.211	10.104.6.93	NGAP	514	HandoverRequest
10	10:51:45.111391	10.104.6.93	10.88.89.211	NGAP	854	HandoverRequestAcknowledge
11	10:51:45.143143	10.88.89.211	10.104.6.93	NGAP	150	SACK (Ack=5, Arwnd=131072) , DownlinkRANStatusTransfer
12	10:51:45.229851	10.104.6.93	10.88.89.211	NGAP	106	HandoverNotify
13	10:51:45.274881	10.104.6.93	10.88.89.211	NGAP/NAS-5GS	170	UplinkNASTransport
14	10:51:45.331202	10.88.89.211	10.104.6.93	NGAP/NAS-5GS	170	DownlinkNASTransport
15	10:51:45.347128	10.104.6.93	10.88.89.211	NGAP/NAS-5GS	138	SACK (Ack=5, Arwnd=2097152) , UplinkNASTransport
16	10:51:45.348464	10.88.89.211	10.104.6.93	NGAP/NAS-5GS	150	SACK (Ack=8, Arwnd=131072) , DownlinkNASTransport
17	10:51:47.310857	10.88.89.211	10.104.6.93	NGAP	190	PDUSessionResourceSetupRequest
18	10:51:47.312113	10.104.6.93	10.88.89.211	NGAP	114	SACK (Ack=7, Arwnd=2097152) , PDUSessionResourceSetupResponse
19	10:51:47.340170	10.88.89.211	10.104.6.93	NGAP	114	SACK (Ack=9, Arwnd=131072) , PDUSessionResourceReleaseCommand
20	10:51:47.355930	10.104.6.93	10.88.89.211	NGAP	114	SACK (Ack=8, Arwnd=2097152) , PDUSessionResourceReleaseResponse
21	10:51:47.381229	10.88.89.211	10.104.6.93	NGAP	206	SACK (Ack=10, Arwnd=131072) , PDUSessionResourceSetupRequest
22	10:51:47.410131	10.104.6.93	10.88.89.211	NGAP	130	SACK (Ack=9, Arwnd=2097152) , PDUSessionResourceSetupResponse
23	10:52:33.950407	10.104.6.93	10.88.89.211	SCTP	1406	DATA (TSN=12) (Message Fragment)
24	10:52:33.950407	10.104.6.93	10.88.89.211	NGAP	474	HandoverRequired
25	10:52:34.002981	10.88.89.211	10.104.6.93	NGAP	782	HandoverCommand
26	10:52:34.006333	10.104.6.93	10.88.89.211	NGAP	150	SACK (Ack=10, Arwnd=2097152) , UplinkRANStatusTransfer
27	10:52:36.004201	10.104.6.93	10.88.89.211	NGAP	102	UEContextReleaseRequest
28	10:52:36.021176	10.88.89.211	10.104.6.93	NGAP	106	SACK (Ack=15, Arwnd=131072) , UEContextReleaseCommand
29	10:52:36.044669	10.104.6.93	10.88.89.211	NGAP	110	SACK (Ack=11, Arwnd=2097152) , UEContextReleaseComplete
30	10:54:03.731648	10.88.89.211	10.104.6.93	SCTP	1514	DATA (TSN=12) (Message Fragment)
31	10:54:03.731648	10.88.89.211	10.104.6.93	NGAP	538	HandoverRequest
32	10:54:03.741845	10.104.6.93	10.88.89.211	NGAP	854	HandoverRequestAcknowledge
33	10:54:03.771842	10.88.89.211	10.104.6.93	NGAP	150	SACK (Ack=17, Arwnd=131072) , DownlinkRANStatusTransfer
34	10:54:03.865674	10.104.6.93	10.88.89.211	NGAP	106	HandoverNotify
35	10:54:03.955414	10.104.6.93	10.88.89.211	NGAP/NAS-5GS	170	UplinkNASTransport
36	10:54:04.011834	10.88.89.211	10.104.6.93	NGAP/NAS-5GS	170	DownlinkNASTransport
37	10:54:04.025047	10.104.6.93	10.88.89.211	NGAP/NAS-5GS	138	SACK (Ack=15, Arwnd=2097152) , UplinkNASTransport
38	10:54:04.026540	10.88.89.211	10.104.6.93	NGAP/NAS-5GS	150	SACK (Ack=20, Arwnd=131072) , DownlinkNASTransport
39	10:54:05.821087	10.88.89.211	10.104.6.93	NGAP	190	PDUSessionResourceSetupRequest
40	10:54:05.822276	10.104.6.93	10.88.89.211	NGAP	114	SACK (Ack=17, Arwnd=2097152) , PDUSessionResourceSetupResponse
41	10:54:05.850911	10.88.89.211	10.104.6.93	NGAP	114	SACK (Ack=21, Arwnd=131072) , PDUSessionResourceReleaseCommand
42	10:54:05.868198	10.104.6.93	10.88.89.211	NGAP	114	SACK (Ack=18, Arwnd=2097152) , PDUSessionResourceReleaseResponse
43	10:54:05.882403	10.88.89.211	10.104.6.93	NGAP	206	SACK (Ack=22, Arwnd=131072) , PDUSessionResourceSetupRequest
44	10:54:05.900110	10.104.6.93	10.88.89.211	NGAP	130	SACK (Ack=19, Arwnd=2097152) , PDUSessionResourceSetupResponse
45	10:55:49.135038	10.104.6.93	10.88.89.211	NGAP	102	UEContextReleaseRequest
46	10:55:49.141321	10.88.89.211	10.104.6.93	NGAP	106	SACK (Ack=24, Arwnd=131072) , UEContextReleaseCommand
47	10:55:49.171333	10.104.6.93	10.88.89.211	NGAP	110	SACK (Ack=20, Arwnd=2097152) , UEContextReleaseComplete
48	10:55:49.454773	10.104.6.93	10.88.89.211	NGAP/NAS-5GS/NAS-5GS	162	InitialUEMessage, Service request, Service request
49	10:55:49.471948	10.88.89.211	10.104.6.93	NGAP/NAS-5GS	1266	SACK (Ack=26, Arwnd=131072) , InitialContextSetupRequest
50	10:55:49.500426	10.104.6.93	10.88.89.211	NGAP	130	SACK (Ack=21, Arwnd=2097152) , InitialContextSetupResponse
51	10:55:54.991307	10.104.6.93	10.88.89.211	SCTP	1406	DATA (TSN=28) (Message Fragment)

Figure 23: Wireshark capture about HO CMU-1

5GSA Core / CMU-2:

20	10:51:45.075709	10.104.6.92	10.88.91.19	NGAP	462	HandoverRequired
21	10:51:45.133496	10.88.91.19	10.104.6.92	NGAP	786	HandoverCommand
22	10:51:45.137232	10.104.6.92	10.88.91.19	NGAP	150	SACK (Ack=9, Arwnd=2097152) , UplinkRANStatusTransfer
23	10:51:47.135311	10.104.6.92	10.88.91.19	NGAP	102	UEContextReleaseRequest
24	10:51:47.160488	10.88.91.19	10.104.6.92	NGAP	106	SACK (Ack=12, Arwnd=131072) , UEContextReleaseCommand
25	10:51:47.184435	10.104.6.92	10.88.91.19	NGAP	110	SACK (Ack=10, Arwnd=2097152) , UEContextReleaseComplete
26	10:52:33.971878	10.88.91.19	10.104.6.92	SCTP	1514	DATA (TSN=11) (Message Fragment)
27	10:52:33.971878	10.88.91.19	10.104.6.92	NGAP	526	HandoverRequest
28	10:52:33.982568	10.104.6.92	10.88.91.19	NGAP	854	HandoverRequestAcknowledge
29	10:52:34.011378	10.88.91.19	10.104.6.92	NGAP	150	SACK (Ack=14, Arwnd=131072) , DownlinkRANStatusTransfer
30	10:52:34.105242	10.104.6.92	10.88.91.19	NGAP	106	HandoverNotify
31	10:52:34.194370	10.104.6.92	10.88.91.19	NGAP/NAS-5GS	170	UplinkNASTransport
32	10:52:34.251408	10.88.91.19	10.104.6.92	NGAP/NAS-5GS	170	DownlinkNASTransport
33	10:52:34.259112	10.104.6.92	10.88.91.19	NGAP/NAS-5GS	138	SACK (Ack=14, Arwnd=2097152) , UplinkNASTransport
34	10:52:34.262063	10.88.91.19	10.104.6.92	NGAP/NAS-5GS	150	SACK (Ack=17, Arwnd=131072) , DownlinkNASTransport
35	10:52:36.071610	10.88.91.19	10.104.6.92	NGAP	190	PDUSessionResourceSetupRequest
36	10:52:36.073011	10.104.6.92	10.88.91.19	NGAP	114	SACK (Ack=16, Arwnd=2097152) , PDUSessionResourceSetupResponse
37	10:52:36.100881	10.88.91.19	10.104.6.92	NGAP	114	SACK (Ack=18, Arwnd=131072) , PDUSessionResourceReleaseCommand
38	10:52:36.117263	10.104.6.92	10.88.91.19	NGAP/NAS-5GS	154	SACK (Ack=17, Arwnd=2097152) , UplinkNASTransport
39	10:52:36.118367	10.104.6.92	10.88.91.19	NGAP	98	PDUSessionResourceReleaseResponse
40	10:52:36.151416	10.88.91.19	10.104.6.92	NGAP/NAS-5GS	214	PDUSessionResourceSetupRequest
41	10:52:36.170053	10.104.6.92	10.88.91.19	NGAP	130	SACK (Ack=18, Arwnd=2097152) , PDUSessionResourceSetupResponse
42	10:52:36.211512	10.88.91.19	10.104.6.92	NGAP	206	SACK (Ack=21, Arwnd=131072) , PDUSessionResourceSetupRequest
43	10:52:36.212708	10.104.6.92	10.88.91.19	NGAP	114	SACK (Ack=19, Arwnd=2097152) , PDUSessionResourceSetupResponse
44	10:54:03.710697	10.104.6.92	10.88.91.19	SCTP	1406	DATA (TSN=23) (Message Fragment)
45	10:54:03.710697	10.104.6.92	10.88.91.19	NGAP	486	HandoverRequired
46	10:54:03.762897	10.88.91.19	10.104.6.92	NGAP	786	HandoverCommand
47	10:54:03.766494	10.104.6.92	10.88.91.19	NGAP	150	SACK (Ack=20, Arwnd=2097152) , UplinkRANStatusTransfer
48	10:54:05.764186	10.104.6.92	10.88.91.19	NGAP	102	UEContextReleaseRequest
49	10:54:05.772995	10.88.91.19	10.104.6.92	NGAP	106	SACK (Ack=26, Arwnd=131072) , UEContextReleaseCommand
50	10:54:05.796249	10.104.6.92	10.88.91.19	NGAP	110	SACK (Ack=21, Arwnd=2097152) , UEContextReleaseComplete
51	10:55:55.003602	10.88.91.19	10.104.6.92	SCTP	1514	DATA (TSN=22) (Message Fragment)
52	10:55:55.003602	10.88.91.19	10.104.6.92	NGAP	554	HandoverRequest
53	10:55:55.013940	10.104.6.92	10.88.91.19	NGAP	854	HandoverRequestAcknowledge
54	10:55:55.042427	10.88.91.19	10.104.6.92	NGAP	150	SACK (Ack=28, Arwnd=131072) , DownlinkRANStatusTransfer
55	10:55:55.125903	10.104.6.92	10.88.91.19	NGAP	106	HandoverNotify
56	10:55:55.155034	10.104.6.92	10.88.91.19	NGAP/NAS-5GS	170	UplinkNASTransport
57	10:55:55.252412	10.88.91.19	10.104.6.92	NGAP/NAS-5GS	170	DownlinkNASTransport
58	10:55:55.262553	10.104.6.92	10.88.91.19	NGAP/NAS-5GS	138	SACK (Ack=25, Arwnd=2097152) , UplinkNASTransport
59	10:55:55.265992	10.88.91.19	10.104.6.92	NGAP/NAS-5GS	150	SACK (Ack=31, Arwnd=131072) , DownlinkNASTransport
60	10:55:57.211652	10.88.91.19	10.104.6.92	NGAP	190	PDUSessionResourceSetupRequest

Figure 24: Whireshark capture about HO CMU-2

Comments:

No additional comments.

Conclusion:

The test has been performed successfully.

<u>Test with Voice:</u>

Inter-AMF handover has been tested with voice. Data flow was performed between Cabradio and Train controller (CAB→DISP).

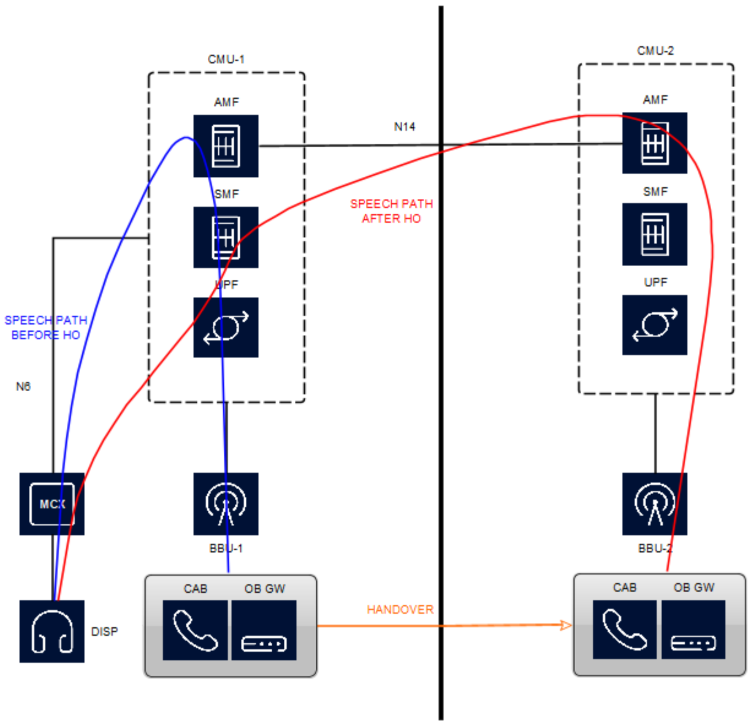


Figure 25: Call flow during Inter-AMF HO

The following screenshots depict the various 5G SA functional entities with their respective status:

Status in AMF/SMF before handover:

AMF-1

```
[cmm@cmu38-necc0 ~]$ cmm subscriber show --imsi 999400000000003 | grep -i amfCmState
|                         |    amfCmState: CONNECTED
```

Figure 26: Subscriber state in AMF-1 before HO

CONNECTED: subscriber is registered and connected to the network

AMF-2

```
[cmm@cmu39-necc0 ~]$ cmm subscriber show --imsi 999400000000003 | grep -i amfCmState
[cmm@cmu39-necc0 ~]$
```

Figure 27: Subscriber state in AMF-2 before HO

Missing status means that subscriber is not registered yet.

SMF-1

```
A:VSR2# show mobile-gateway pdn pdu-session
===============================================================================
SUPI/PEI(#)          DNN        Type     QFIs    PDU Address (IPv4/IPv6) Ref-pt/Si*
  /GPSI(^)/MAC(`)
  /SubId/SEID(~)
  /RAN-UE-NGAP-ID(@)
===============================================================================
999400000000001      internet   IPv4     5       10.88.89.144/-          N11/http2
999400000000003      internet   IPv4     5       10.88.89.147/-          N11/http2
999400000000004      internet   IPv4     5       10.88.89.146/-          N11/http2
-------------------------------------------------------------------------------
Number of PDU sessions : 3
```

Figure 28: Subscriber state in SMF-1 before HO

SMF-2

```
A:VSR2# show mobile-gateway pdn pdu-session
===============================================================================
SUPI/PEI(#)          DNN        Type     QFIs    PDU Address (IPv4/IPv6) Ref-pt/Si*
  /GPSI(^)/MAC(`)
  /SubId/SEID(~)
  /RAN-UE-NGAP-ID(@)
===============================================================================
No Matching Entries
-------------------------------------------------------------------------------
```

Figure 29: Subscriber state in SMF-2 before HO

Status in AMF/SMF after handover:

AMF-1

```
[cmm@cmu38-necc0 ~]$ cmm subscriber show --imsi 999400000000003 | grep -i amfCmState
|                        |    amfCmState: IDLE
```

Figure 30: Subscriber state in AMF-1 after HO

IDLE: subscriber is registered but not connected to the network

AMF-2

```
[cmm@cmu39-necc0 ~]$ cmm subscriber show --imsi 999400000000003 | grep -i amfCmState
|                        |    amfCmState: CONNECTED
```

Figure 31: Subscriber state in AMF-2 after HO

SMF-1

```
A:VSR2# show mobile-gateway pdn pdu-session
===============================================================================
SUPI/PEI(#)          DNN        Type     QFIs    PDU Address (IPv4/IPv6) Ref-pt/Si*
  /GPSI(^)/MAC(`)
  /SubId/SEID(~)
  /RAN-UE-NGAP-ID(@)
===============================================================================
999400000000001      internet   IPv4     5       10.88.89.144/-          N11/http2
999400000000003      internet   IPv4     5       10.88.89.147/-          N11/http2
999400000000004      internet   IPv4     5       10.88.89.146/-          N11/http2
-------------------------------------------------------------------------------
Number of PDU sessions : 3
```

Figure 32: Subscriber state in SMF-1 after HO

SMF-2

```
A:VSR2# show mobile-gateway pdn pdu-session
===============================================================================
SUPI/PEI(#)          DNN        Type     QFIs    PDU Address (IPv4/IPv6) Ref-pt/Si*
  /GPSI(^)/MAC(`)
  /SubId/SEID(~)
  /RAN-UE-NGAP-ID(@)
===============================================================================
No Matching Entries
```

Figure 33: Subscriber state in SMF-2 after HO

After the handover call flow is moved to the target AMF, but session management remains in the source CMU (SMF, UPF, UDM) unit.

Comments:

1. Cabradio towards Train controller speech path is continuous during handover, short crackling was hearable without any loss.
2. Train controller towards Cabradio speech path is not continuous during handover, ~1 sec voice gap is hearable.

Conclusion:

The test has been performed successfully.

3.3 Modem integration test setup

Thales modems were built into plastic assembly boxes with their power supplies to avoid damage.

Figure 34: Picture from Thales modem

Thales modem is connected to the 5G radio network with direct RF cabling to avoid from interferences with the public operators

3.3.1 Integration test with Thales modems…

After the successful 5G SA core and 5G radio integration several tests were done with Thales modems to check the behaviour of it:

- Thales modem attach/detach
- FTP upload/download with Thales modem
- Cell selection with Thales modem
- QoS settings/Static DSCP with Thales modem
- Throughput measuring with Thales modem (IPERF)
- Intra frequency Xn handover with Thales modem
- Inter Frequency Xn handover with Thales modem
- Intra CMU Ng handover with Thales modem

3.4 Speed (fading) test setup

Tests under degraded radio conditions were conducted utilizing the Vertex Channel Emulator. This emulator is an advanced test and measurement system that accurately simulates the complex effects of signal fading on wireless transmissions.

Setup for Vertex Channel Emulator during degraded radio tests

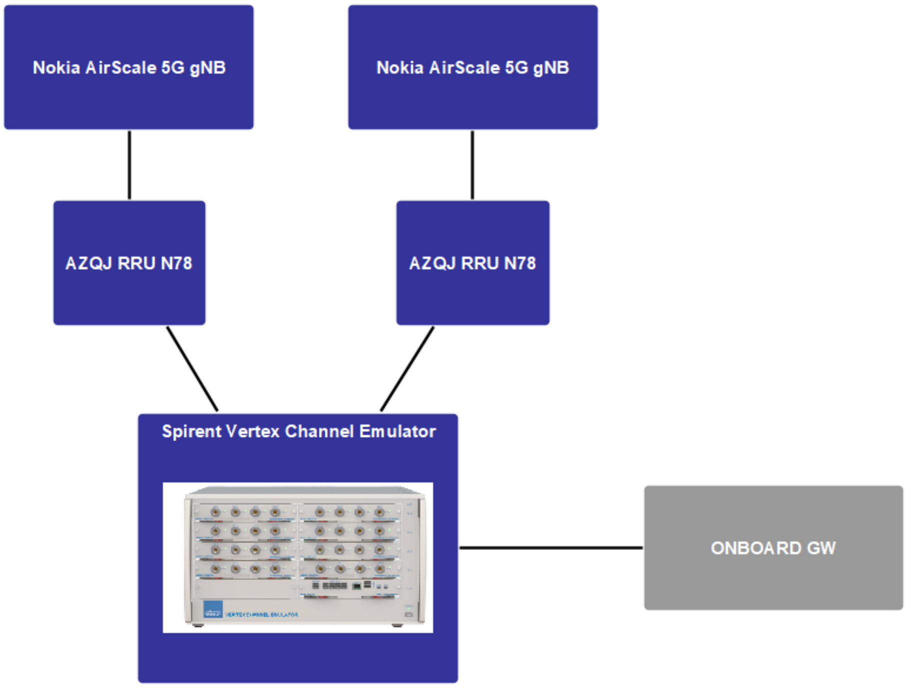


Figure 35: Fading test setup

The connectivity setup looks as follows

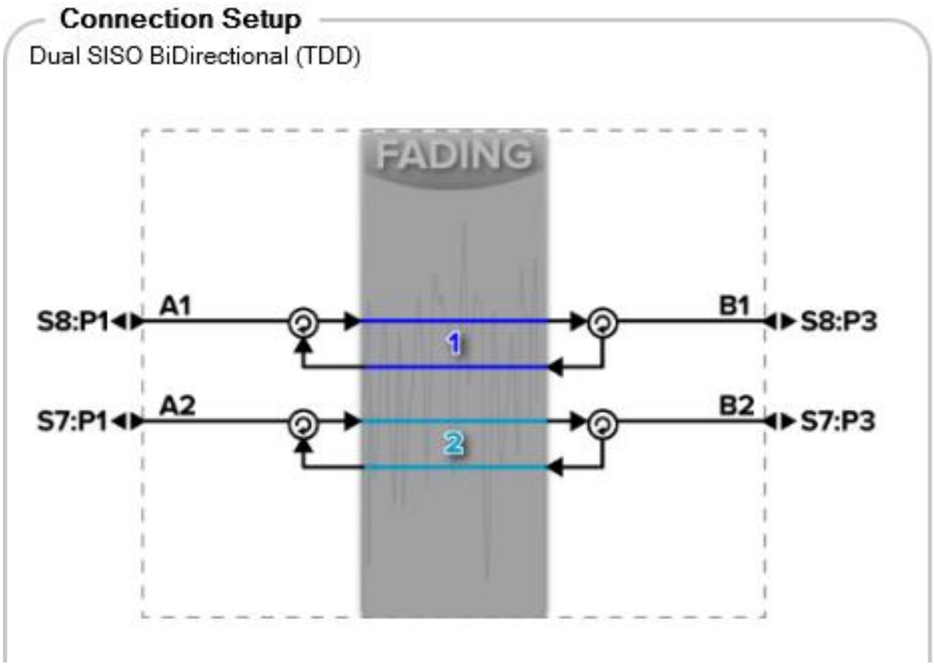


Figure 36: DUAL SISO BiDirectional TDD

3.4.1 Radio Speed Emulation

Emulations were designed to closely replicate the prevailing conditions observed at the WP5 test field site in Erzgebirge, Germany. The emulation was designed to operate in a continuous manner, emulating the movement of the train through multiple cells, as mandated by the test requirements.

3.4.1.1 Parameters of the emulation

- Two antennas with 2km distance between them
- Antenna patterns: it doesn't influence the results in this case, as the train does not change its angle relative to the base station, it only moves away and then back towards the base station.
    - BS antenna was pointing towards the train.
    - Were these included in the result: yes.
- Three distinct scenarios were examined: one involving a velocity of 50 km/h, which aligns with the speed employed at the test site, the other two featuring a higher velocity of 120 km/h and 175 km/h, specifically employed to check the functionality under high-speed conditions.
- The process of handovers was executed by adjusting the signal strength of both the source and target cells.
- Iperf was used before the execution of test cases to verify connectivity. During the test case execution real traffic was used, except where noted in Section 3.3.1.

3.4.2 Propagation

When selecting the propagation model to simulate degraded conditions, consideration was given to the specific rural environment of the WP5 test field site.

3.4.2.1 Used propagation models

- The model was chosen from 3GPP TR 38.901 which are the applicable 5G NR channel models. This is combined with TDL-C 300 delay profile taken from 3GPP TS 38.101-4 which has the longest delay spread, thereby simulating a difficult environment, with the Doppler values changing for different speeds.
- Doubled doppler effect - Notably, in the uplink scenario, a second doppler effect was considered, affecting the previously offset downlink signal. These settings were adjusted to ensure the simulation accurately represent the most challenging conditions possible.

Model for 50 km/h

Path	Fading Type	Fading Doppler (Hz)	Fading Doppler Vel. (km/h)	Cluster Modeling	Relative Path Loss (dB)	Delay Mode	Delay Value (µs)
☑ 1	Rayleigh	330	99.763	☐	6.9	Fixed	0
☑ 2	Rayleigh	330	99.763	☐	0	Fixed	0.065
☑ 3	Rayleigh	330	99.763	☐	7.7	Fixed	0.07
☑ 4	Rayleigh	330	99.763	☐	2.5	Fixed	0.19
☑ 5	Rayleigh	330	99.763	☐	2.4	Fixed	0.195
☑ 6	Rayleigh	330	99.763	☐	9.9	Fixed	0.2
☑ 7	Rayleigh	330	99.763	☐	8	Fixed	0.24
☑ 8	Rayleigh	330	99.763	☐	6.6	Fixed	0.325
☑ 9	Rayleigh	330	99.763	☐	7.1	Fixed	0.52
☑ 10	Rayleigh	330	99.763	☐	13	Fixed	1.045
☑ 11	Rayleigh	330	99.763	☐	14.2	Fixed	1.51
☑ 12	Rayleigh	330	99.763	☐	16	Fixed	2.595

Model for 120 km/h

Path	Fading Type	Fading Doppler (Hz)	Fading Doppler Vel. (km/h)	Cluster Modeling	Relative Path Loss (dB)	Delay Mode	Delay Value (µs)
☑ 1	Rayleigh	800	241.849	☐	6.9	Fixed	0
☑ 2	Rayleigh	800	241.849	☐	0	Fixed	0.065
☑ 3	Rayleigh	800	241.849	☐	7.7	Fixed	0.07
☑ 4	Rayleigh	800	241.849	☐	2.5	Fixed	0.19
☑ 5	Rayleigh	800	241.849	☐	2.4	Fixed	0.195
☑ 6	Rayleigh	800	241.849	☐	9.9	Fixed	0.2
☑ 7	Rayleigh	800	241.849	☐	8	Fixed	0.24
☑ 8	Rayleigh	800	241.849	☐	6.6	Fixed	0.325
☑ 9	Rayleigh	800	241.849	☐	7.1	Fixed	0.52
☑ 10	Rayleigh	800	241.849	☐	13	Fixed	1.045
☑ 11	Rayleigh	800	241.849	☐	14.2	Fixed	1.51
☑ 12	Rayleigh	800	241.849	☐	16	Fixed	2.595

Model for 175 km/h

Path	Fading Type	Fading Doppler (Hz)	Fading Doppler Vel. (km/h)	Cluster Modeling	Relative Path Loss (dB)	Delay Mode	Delay Value (µs)
☑ 1	Rayleigh	1160	350.682	☐	6.9	Fixed	0
☑ 2	Rayleigh	1160	350.682	☐	0	Fixed	0.065
☑ 3	Rayleigh	1160	350.682	☐	7.7	Fixed	0.07
☑ 4	Rayleigh	1160	350.682	☐	2.5	Fixed	0.19
☑ 5	Rayleigh	1160	350.682	☐	2.4	Fixed	0.195
☑ 6	Rayleigh	1160	350.682	☐	9.9	Fixed	0.2
☑ 7	Rayleigh	1160	350.682	☐	8	Fixed	0.24
☑ 8	Rayleigh	1160	350.682	☐	6.6	Fixed	0.325
☑ 9	Rayleigh	1160	350.682	☐	7.1	Fixed	0.52
☑ 10	Rayleigh	1160	350.682	☐	13	Fixed	1.045
☑ 11	Rayleigh	1160	350.682	☐	14.2	Fixed	1.51
☑ 12	Rayleigh	1160	350.682	☐	16	Fixed	2.595

3.5 IWF test setup

To fulfil the requirements for FRMCS – GSM-R interworking WP3 developed a prototype SW in the GSM-R rel4 MSS. It has to be noted that standardisation of this FRMCS – GSM-R interface is ongoing.

Requirements were the following:

- communication between the systems is SIP based
- limited only for group calls
- group call establishment way is limited, only FRMCS to GSM-R is supported
- there is no floor handling between the systems

WP3 decided that MCX originated group call behaves as dispatcher originated group call in GSM-R system.

Problem and solutions:

One issue had to be solved due to missing compatibility of media plane / RTP handling between GSM-R and FRMCS. It is on SDP coding of the data in the initial SIP invite send from the MCX Server towards the GSM-R MSS: The m-tag audio is supported by Nokia MSS, but the m-tag mcptt is not supported which is needed for floor handling and needs to be adjusted using external mapping solution (adding a PC as some kind of Proxy in the signalling exchange) to allow for media plane setup. Additionally – even if floor control between the systems were excluded for 5GRail, a floor control message was required on the MCX system for standard compliant IWF interface handling.

With the above solutions we reached that there is successful group call establishment both in FRMCS and GSM-R systems with user plane connectivity as well.

3.6 WP3 radio settings regarding WP5 expected conditions

During WP3 laboratory network setup integration, WP5 test site characteristics were considered and incorporated.

The following elements have been implemented to achieve the highest possible level of network similarity:

- Nokia BBU AirScale 5G gNB
- Nokia RRU N78

In relation to radio settings, a comparison and modification of WP3 configuration files were conducted in accordance with the WP5 configuration. The focus was placed on essential elements, including TDD connectivit¼1/4 TDD frame structure, band allocation, and power settings.

In order to facilitate end-to-end test scenarios that fulfil the specified requirements, handover-, bearer flex- and QoS configuration were agreed with WP5 test site.

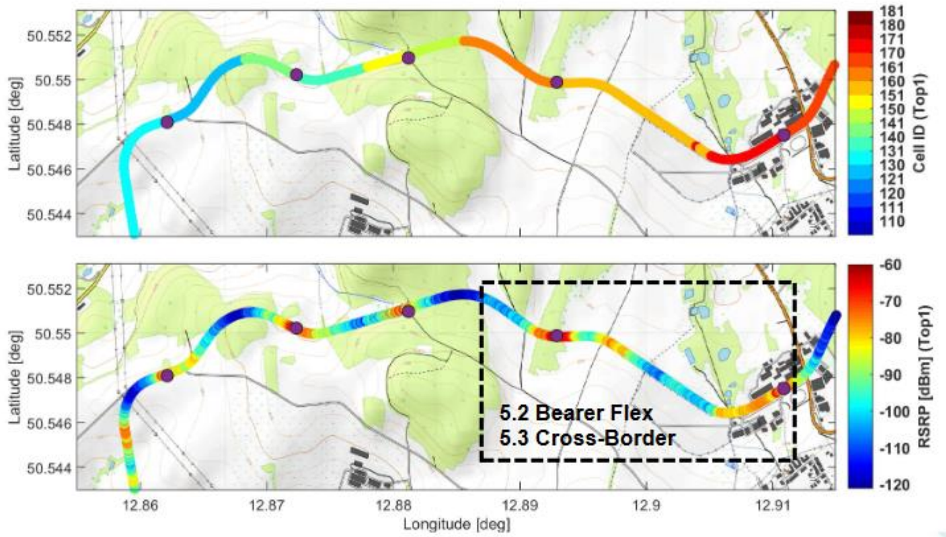


Figure 37 WP5 field configuration

The utilization of Hytem Attenuator Matrix and Vertex Channel Emulator enabled precise RF signal modification possibility during end-to-end testing processes to be able to replicate the expected conditions, such as intra- and inter frequency handover, bearer Flex and border crossing, given at WP5 test site.

3.7 Bearer Flexibility test setup

As described in chapter 2.1, 5GRail Bearer Flexibility solution based on two subbands on the N78 bands was selected to demonstrate the behaviour of relying on a (high performance) second Uplink for the test case CCTV_TC_002 “CCTV offload from train to trackside with bearer-flex”.

The test setup is shown in Figure 38.

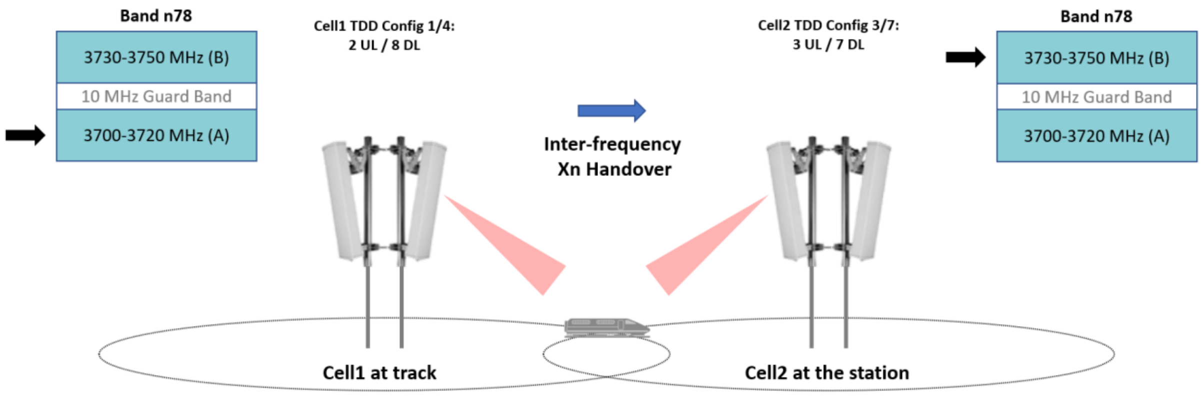


Figure 38 Bearer Flexibility test setup

Cell1 represents 5G coverage at track, and Cell2 represents 5G coverage at the train station.

Cell1 uses 3700-3720 Mhz subband in N78 radio band, whilst Cell2 uses 3730-3750 Mhz subband in N78 band. The TDD frame structure is also different: Cell1 has 1 / 4 Uplink/Downlink ratio, whilst Cell2 has 3 / 7 Uplink/Downlink ratio configured. The TDD frame structure is just a single configurable parameter in the Nokia gNodeB.

In this test setup there is CCTV offload, that is in principle uploading data from train to trackside, where uplink data slots are used in the TDD frame structure. In Cell1 the 1 / 4 ratio means that there are 2 uplink and 8 downlink data slots out of 10 time slots, however in Cell2 the 3 / 7 ratio means that there are 3 uplink and 8 downlink data slots for the same. So in Cell2 there is 1,5x larger bandwidth available (3 data slot instead of 2 data slot in uplink) for data upload.

Therefore, when moving from Cell1 to Cell2, the CCTV offload will utilize a second “access” frequency with higher bandwidth to demonstrate a video archive upload from a train reaching the station.

3.8 Border crossing test setup (second core)

The following network configuration was established to test the Border Crossing use case , based on Inter AMF / Ng handover (refer to chapter 3.2.4) :

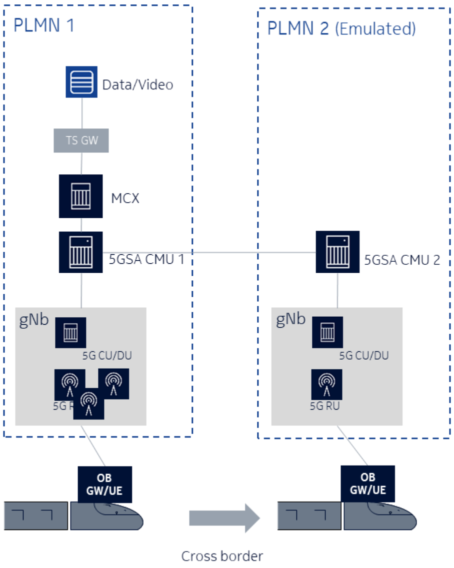


Figure 39: Border Crossing network setup – overview

Note: PLMN2 was emulated, means it is treated as the same network. The Ng handover using Inter AMF function (N14 interface) demonstrated however is one important subfunction of an envisaged Inter PLMN Handover. Refer to detailed setup in chapter 3.2.4

3.9 N8 Band test setup

The following test setup was designed for allowing complex test cases for bearer flexibility, border crossing and handover with mixed N78 (3.7 GHz TDD) and N8 (900 MHz FDD) band RRH:

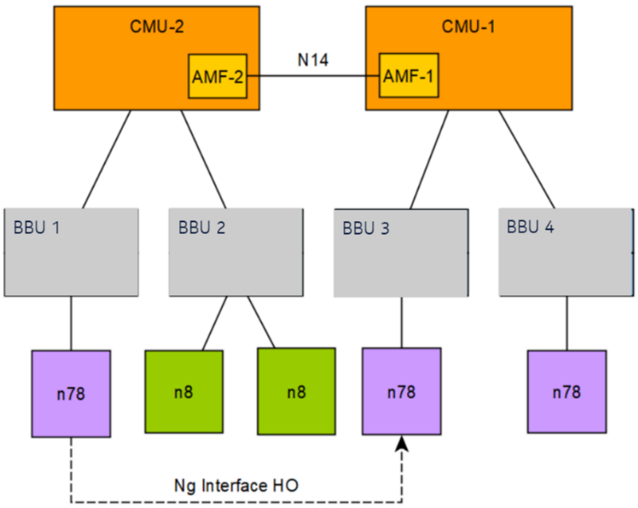


Figure 40: Band n8 setup

3.10 QOS test setup

Referring to Chapter 2.5, which provides a detailed explanation of the QoS concept, here in this section the specific settings will be addressed.

As indicated in the subsequent section, the CMU (Compact Mobility Unit) does not incorporate a PCF (Policy Control Function) unit, therefore instead of dynamic settings, a static policy rule configuration is applied.

In the SMF (Session Management Function), policy rules are established based on the concept of DSCP marked packet flows received from partner applications. These rules are then applied to ensure appropriate handling of the respective packet flows.

```
policy-rule-unit "ETCS"
    pdr-id 400
    flow-description 1
        match
            tos-tc 21
        exit
    exit
exit
policy-rule-unit "TCMS"
    pdr-id 300
    flow-description 1
        match
            tos-tc 8
        exit
    exit
exit
```

```
policy-rule-unit "VIDEO"
    pdr-id 500
    flow-description 1
        match
            tos-tc 33
        exit
    exit
exit
policy-rule-unit "MCXMEDIA"
    pdr-id 100
    qos
        down-link gbr 5000 mbr 5000
        up-link gbr 5000 mbr 5000
    exit
    flow-description 1
        match
            remote-ip 10.88.89.176/29
        exit
    exit
exit
```

```
policy-rule "PR-ALL" policy-rule-unit "ALL" charging-rule-unit "CRU-1" qci 6 arp 11 precedence 5000
policy-rule "PR-ETCS" policy-rule-unit "ETCS" charging-rule-unit "CRU-1" qci 5 arp 11 precedence 3000
policy-rule "PR-TCMS" policy-rule-unit "TCMS" charging-rule-unit "CRU-1" qci 9 arp 11 precedence 3000
policy-rule "PR-VIDEO" policy-rule-unit "VIDEO" charging-rule-unit "CRU-1" qci 7 arp 11 precedence 3000
policy-rule "PR-MCXMEDIA" policy-rule-unit "MCXMEDIA" charging-rule-unit "CRU-1" qci 2 arp 10 precedence 10
```

4 Voice tests

4.1 Introduction to Voice tests

During Voice tests the following network configuration was in use:

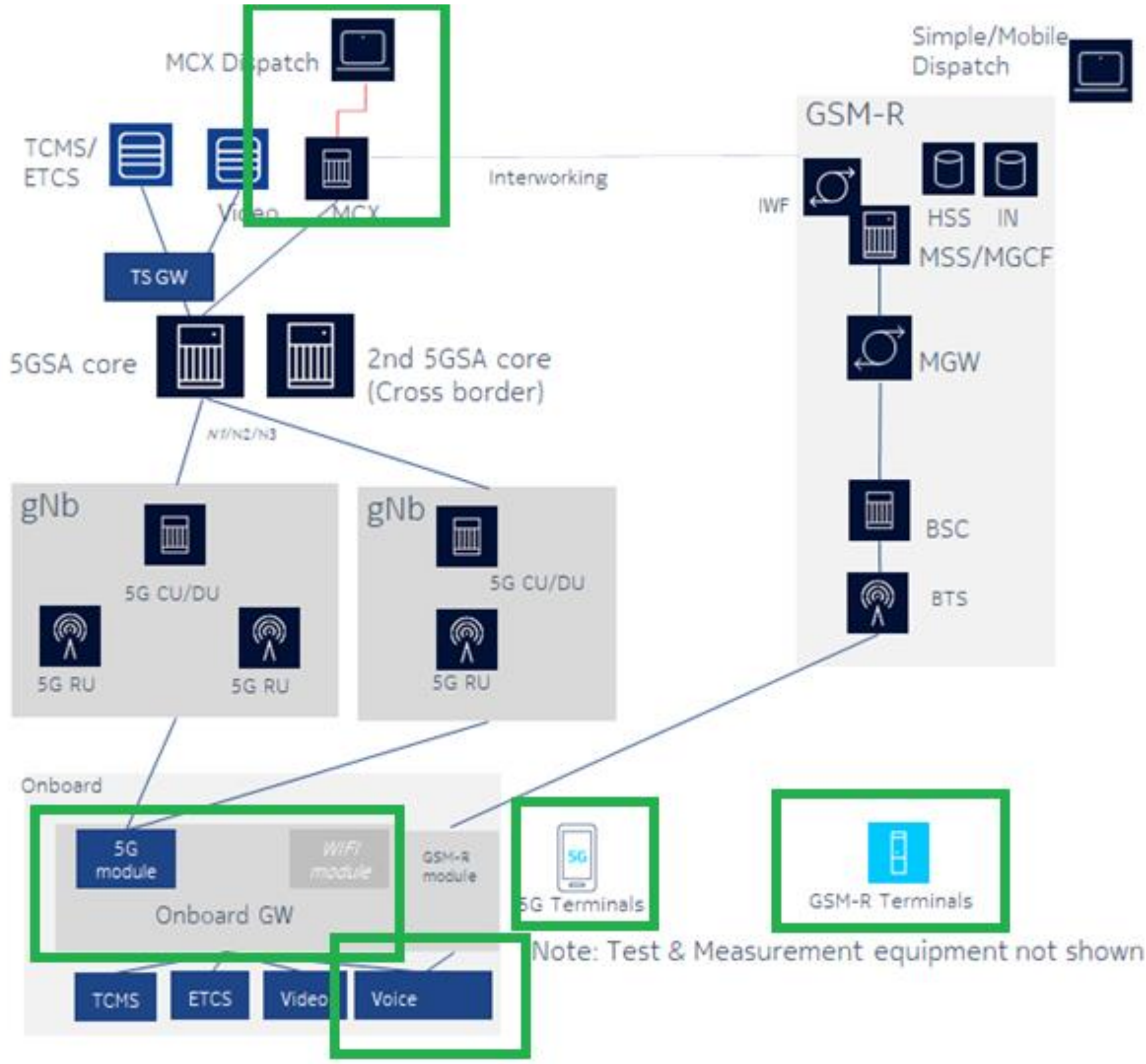


Figure 41: Voice testing lab configurati–n - system overview

The following components were under test:

- Onboard voice application: CAB Radio, provided by Siemens
- Onboard gateway: provided by Kontron
- 5G network (radio and core): provide by Nokia
- GSM-R network (radio and core): provide by Nokia
- MCX: provided by Nokia
- Dispatcher Console: an application running on a WIN10 PC, provide by Nokia
- 5G terminals: a group communication application is running on an Android smartphone (Nokia X20 and Nokia 8.3)
- GSM-R terminals: Sagem TiGR155

4.2 Voice tests

The following voice tests have been planned (Note: TOBA-K is the OB-GW provided by Kontron and solely used in WP3)

TC number	Test Title	Band	OB-GW	Date
Voice_001	Registration of a functional identity related to the user.	N78	TOBA-K	08.06.2023
Voice_002	Deregistration of a functional identity	N78	TOBA-K	08.06.2023
Voice_003	OPTIONAL: Authorisation of communication	N78	TOBA-K	07.06.2023
Voice_004	Authorisation of application	N78	TOBA-K	06.06.2023
Voice_005	Mul–i - user talker control	N78	TOBA-K	08.06.2023
Voice_006	Arbitration	N78	TOBA-K	08.06.2023
Voice_007	QoS negotiation	N78	TOBA-K	there was predefined setting, used in every test executi–n - no independent test case
Voice_008	Initiation of a voice communication from a train driver towards a train controller responsible for the train movement area	N78	TOBA-K	06.06.2023
Voice_009	Initiation of a voice communication from a train controller towards a train driver	N78	TOBA-K	06.06.2023
Voice_010	Initiation of a multi-user voice communication from a train driver towards train drivers and ground users (FRMCS Users only)	N78	TOBA-K	06.06.2023
Voice_021	Initiation of a multi-user voice communication from a train driver towards train drivers and ground users. (FRMCS and GSM-R Users)	N78	TOBA-K	07.06.2023
Voice_011	Railway Emergency Call initiated by a train controller.	N78	TOBA-K	07.06.2023
Voice_022	Railway Emergency Call initiated by a train driver without interworking.	N78	TOBA-K	07.06.2023
Voice_012	Railway Emergency Call initiated by a train driver including interworking.	N78	TOBA-K	07.06.2023
Voice_013	OPTIONAL: Joining an ongoing Railway Emergency Call	N78	TOBA-K	Tested with GSM-R-FRMCS transition
Voice_014	OPTIONAL: Leaving an ongoing Railway Emergency Call	N78	TOBA-K	Test was not executed finally, aligned with WP1 were it was declared as optional.
Voice_015	GSM-R to FRMCS system transition with service continuation	N78	TOBA-K	August 2023
Voice_016	5G to 5G voice cross-border	N78	TOBA-K	September/October 2023
Voice_017	Combined MCPTT private point-to-point voice call (driver to controller) in parallel with MCData application in nominal scenario	N78	TOBA-K	12.05.2023
Voice_018	Combined MCPTT private point-to-point voice call (driver to controller) in parallel with MCData application in degraded conditions	N78, N8	TOBA-K	September/October 2023
Voice_019	MCPTT private point-to-point voice call (driver to controller) with HO (inter or intra) gNodeB.	N78, N8	TOBA-K	September/October 2023
Voice_020	MCPTT private point-to-point voice call (driver to controller) with HO (inter or intra) gNodeB in degraded radio conditions.	N78, N8	TOBA-K	September/October 2023

Table 2: Planned Voice test cases

4.2.1 Voice_001 Registration of a functional identity related to the user

- <u>Objective of the test:</u>

The purpose of this test is to demonstrate that an FRMCS User can register a functional identity on the FRMCS system. Once the registration is completed the FRMCS User can be reached by its FRMCS functional identity/alias.

- Test description:

This test is described in D1.1 v4 - WP1 test plan, chapter 7.2.1.

- Test results and comments:

Test is passed.

Comments by Nokia

Test is passed.

Comments by Siemens

Test case Voice_001, as defined in D1.1, specifies that the functional alias registration should occur prior to manual subscription. However, in the future, the subscription process will be automated during registration, eliminating the need for user interaction.

Currently, the functional alias registration is implemented using a predetermined list of functional aliases stored in the cab radio configuration file. However, in the future, users will register a functional alias by either manually entering their user ID and password, utilising a PKI card, or retrieving the list of functional aliases from the MCX Server.

At present, the MCX Server limitations allow the cab radio to register only a single functional alias. However, in the future, there will be an enhanced capability to register multiple functional aliases on a single cab radio, expanding its functionality.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Voice_001 Registration of a functional identity related to the user

4.2.2 Voice_002 Deregistration of a functional identity

- Objective of the test:

The purpose of this test is to demonstrate that an FRMCS User can successfully deregister a functional identity.

- Test description:

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.2.2.

- Test results and comments:

Test is passed.

Comments by Nokia

Test is passed.

Comments by Siemens

Test case Voice_002, as defined in D1.1, suggests in step 1 to navigate to Menu - Reg / Dereg - Deregistration in order to deregister the user completely (MC ID and functional alias), instead of deregistering the functional alias only. To address this, step 1 should guide the user to navigate to soft key 8 and select their functional alias for deregistration.

Additionally, in step 3, the result mentioned as "train running number removed from the display" should be updated to "functional alias removed from the display" to accurately reflect the action taken.

Furthermore, an additional step, 3a, has been added to the script for Test case Voice_002, which includes steps 1 to 3 from Voice_001. This addition ensures that the test case covers the functional alias deregistration only, with the MC ID registration remaining intact.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Voice_002 Deregistration of a functional identity

4.2.3 Voice_003 OPTIONAL Authorisation of communication

- Objective of the test:
  The purpose of this test is to demonstrate that the FRMCS System can be configured by the network operator to prevent unauthorised voice communication between FRMCS Users. The MC Service ID and authorisation of communication list shall be used to control and regulate voice communications.

- Test description:
  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.2.3.

- Test results and comments:
  Test is passed with limitations.

Comments by Nokia

There is a limitation on Dispatcher related to this functionality. The current implementation allows/denies calling Dispatcher on MCX level.

It is not possible to configure that dedicated participants can call or cannot call it.

Comments by Siemens

Test case Voice_003, as defined in D1.1, aims to demonstrate that the FRMCS System can be configured by the network operator to prevent unauthorised voice communication between any FRMCS Users. However, the current MCX Server implementation only offers prevention from calling the Controller but does not provide complete prevention of unauthorised voice communication between other FRMCS Users.

- Traces and logs recorded during the test:
  The results of the tests were stored in WP3 Teams collaboration space (folder/file)
  Voice_003 OPTIONAL Authorisation of communication

4.2.4 Voice_004 Authorisation of application

- Objective of the test:
  The purpose of this test is to demonstrate that the FRMCS System can be configured by the network operator, so that access to the voice application can be controlled through the use of MC ID.

- Test description:
  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.2.4.

- Test results and comments:
  Test is passed.

Comments by Nokia

MC database was checked to ensure the correct assignment of the functional identity.

Comments by Siemens

Test case Voice_004, as defined in D1.1, specifies in step 1 that the cab radio self-test will be displayed on the screen. However, the current implementation does not include the cab radio self-test.

Additionally, the audible indication for authorisation rejected in step 2 has not been implemented.

Moreover, the authorisation of the application currently requires manual user interaction. However, in the future, the authorisation of the application will be done via a web browser or a PKI card.

Furthermore, the MC Service ID credentials are currently stored in the cab radio configuration file in plain text format, which is not secure. In the future, the stored passwords will need to be encrypted to improve system security.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Link of Voice_004

4.2.5 Voice_005 Multi - user talker control

- Objective of the test:
  The purpose of this test is to demonstrate that multiple FRMCS Users can speak simultaneously in a multi – user voice conversation if the number of users that are granted the right to talk does not exceed the maximum number set in the FRMCS system.

- Test description:

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.2.5.

- Test results and comments:
  Test is passed.

  Comments by Nokia
  User–A - CAB
  Controller
  User–B - handheld
  When A and controller pressing PPT button simultaneously the user B is not able to speak as 2 users are allowed to simultaneous speak. There is no visual indication for rejection in GCapp, only a longer beep sound can be heard in GCapp as a rejection indication, when PTT button is pushed.

  Comments by Siemens

  Test case Voice_005, as defined in D1.1, specifies in step 1 to navigate to Menu – Calls… – Other Calls… – Group Call. However, insertion of the group id for the FRMCS system has not yet been implemented. Therefore, the group calls need to be selected from the cab radio phonebook. The user shall navigate to the phonebook (soft key 1) and select the group that wishes to call. The results will be as per the results of step 2.

  The test case was conducted twice using a cab radio and a handheld device as the second cab radio provided by Siemens was already shipped to Germany in order to conduct field testing as part of WP5.

  Test run 1 – the handheld was the device that did not have the permission to talk. When the PTT button was pressed on the HHD device with the cab radio and the controller holding their PTT buttons, there was no visual indication on the HHD screen that the request was sent to the MCX Server or that the request was denied. There was only a single denied sound plaid.

  Test run 2 – the same scenario was conducted but this time the cab radio was the user that had no permissions to talk. When the PPT button was pressed on the cab radio, "Wait" was displayed on the cab radio graphical display, followed by "Denied". The "Wait" message indicated that a successful message was sent to the MCX Server. The "Denied" message was sent back to the cab radio from the MCX Server.

The SSRC value is incorrect, resulting in no voice being heard on the cab radio. However, the voice from the cab radio is successfully transmitted to the controller, and the controller can hear the cab radio operator without any issues.

Comments by Nokia: Test was repeated with corrected SSRC value and worked fine.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

test20230905_Voice_005_02.pcap

Voice_005 Multi - user talker control

4.2.6 Voice_006 Arbitration: ongoing P2P call, incoming normal (preconfigured) emergency call

- Objective of the test:

The purpose of this test is to demonstrate that a lower priority call is terminated by the FRMCS system when the higher priority call comes in.

- Test description:

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.2.6.

- Test results and comments:
Test is passed.

Comments by Nokia

MC database was checked to ensure the correct assignment of the functional identity.

Comments by Siemens

The FRMCS arbitration currently relies on the GRM-R arbitration tables, as no specific FRMCS standards for arbitration have been established yet.

Test case Voice_006, as defined in D1.1, requires a clear specification in the description of the initial state/configuration that all users must be subscribed to the same Railway Emergency MCPTT GroupID.

During the test case, three users were involved: User A, represented by a cab radio; User B, using a handheld device; and User C, operating a controller terminal. Neither the Controller (User C) nor User B were signed on to the functional alias due to limitations on the MCX Server.

As a result, in Step 2, the MCID of User B was displayed on the cab radio graphical display instead of the functional alias, and in Step 4, the MCID of the controller (User C) was displayed on the cab radio graphical display instead of the functional alias.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Voice 006 Arbitration

4.2.7 Voice_008 Initiation of a voice communication from a train driver towards a train controller responsible for the train movement area

- Objective of the test:

The purpose of this test is to demonstrate that a train driver can initiate a voice communication with a train controller responsible for the train movement area and that the call initiator can terminate the voice communication.

- Test description:

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.3.1.

Initiation of a voice communication from a train driver (CAB) towards a train controller (dispatcher) responsible for the train movement area - only FRMCS users

- Test results and comments:

Test is passed.

Comments by Nokia

MC database was checked to ensure the correct assignment of the functional identity.

Train controller is not able to handle FA (Functional Alias). In proportion to this the following comments must be taken:

Step 1: FA ID is not visible on the display of the controller (MC ID is visible)

Step 2: There is no FA ID added to controller, therefore it is not visible on the display of the train driver (MC ID is visible)

Comments by Siemens

Test case Voice_008, as defined in D1.1, outlines the requirement that the functional alias of the cab radio should be displayed on the Controller's terminal during the entire voice communication process. Unfortunately, this expectation cannot be met due to limitations on the controller terminal, resulting in the functional alias of the cab radio not being displayed and the MCID of the cab radio displayed instead.

In Step 2 of the test case, it is specified that the functional alias of the Controller should be visible on the graphical display of the cab radio throughout the voice communication. However, since the controller terminal is not signed on to the functional alias, the MCID of the Controller is displayed instead of the functional alias.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Link of Voice_008

4.2.8 Voice_009 Initiation of a voice communication from a train controller towards a train driver

- Objective of the test:

The purpose of this test is to demonstrate that a train controller can initiate a voice communication with a train driver and that the call initiator can terminate the voice communication.

The MCX building blocks validated with this test case are presented in §16.6 Applicability of MCX building blocks to the test cases of WP3 [Voice_009]

- Test description:

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.4.1.

Initiation of a voice communication from a train controller (dispatcher) to the train driver - only FRMCS users.

Mention the limitation D1.1 v4 WP1 test plan, chapter 7.2.1. Used workaround with smart phones.

- Test results and comments:

Test is passed.

Comments by Nokia

MC database was checked to ensure the correct assignment of the functional identity.

Train controller is not able to handle FA (Functional Alias). In proportion to this the following comments must be taken:

Step 1: FA ID is not visible on the display of the controller (MC ID is visible)

Step 2: There is no FA ID added to controller, therefore it is not visible on the display of the train driver (MC ID is visible)

Train controller is not able to initiate point-to-point call with manual answer option, therefore train driver is accepting the call automatically.

Comments by Siemens

Test case Voice_009, as defined in D1.1, outlines the requirement the functional alias of the Controller should be visible on the graphical display of the cab radio throughout the voice communication. However, since the controller terminal is not signed on to the functional alias, the MCID of the Controller is displayed instead of the functional alias.

In Step 2 of the test case, it is specified that the functional alias of the cab radio should be displayed on the Controller's terminal during the entire voice communication process. Unfortunately, this expectation cannot be met due to limitations on the controller terminal, resulting in the functional alias of the cab radio not being displayed and the MCID of the cab radio displayed instead.

During Step 3, the call was automatically accepted by the cab radio as the controller terminal lacks the capability to initiate a call with a manual answer option.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Link of Voice_009

4.2.9 Voice_010: Initiation of a multi-user voice communication from a train driver towards train drivers and ground users (FRMCS Users only)

- Objective of the test:

The purpose of this test is to demonstrate that a train driver can initiate a multi-user voice communication towards train drivers registered to the FRMCS System and a train controller subscribed to the same valid MCPTT Group ID. The multi-user voice communication can be terminated by the call initiator.

- Test description:

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.5.1.

- Test results and comments:

Test is passed.

Comments by Nokia

During multi-user voice communication (group call) only group ID is visible on the terminals of the participants. Therefore in Step 6, there is no visual indication of the fact, that User B has left the call.

Comments by Siemens

Test case Voice_010, as defined in D1.1, specifies in step 1 to navigate to Menu – Calls… – Other Calls… – Group Call. However, insertion of the group id for the FRMCS system has not yet been implemented. Therefore, the group calls need to be selected from the cab radio phonebook. The user shall navigate to the phonebook (soft key 1) and select the group that wishes to call. The results will be as per the results of step 2.

Step 6 of the test results specifies that there should be a clear indication on the remaining devices when a user leaves the call. Unfortunately, during the test, there was no indication on either the cab radio or the controller terminal when FRMCS user B left the call. This lack of indication highlights a potential issue that needs to be addressed to ensure proper communication feedback in such scenarios.

In the current system, the multi-user call is initiated through the phonebook. To establish dynamic group calls in the future, it is necessary to refer to the relevant standards and determine the procedures for affiliation and utilisation of location information.

Furthermore, we need to explore how subscriptions to groups will be handled, as the current method involves subscribing to a list of preconfigured groups stored on the cab radio.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Link of Voice_010

4.2.10 Voice_021: Initiation of a multi-user voice communication from a train driver towards train drivers and ground users. (FRMCS and GSM-R Users)

- Objective of the test:
  The purpose of this test is to demonstrate that a train driver registered to the FRMCS system can initiate a multi-user voice communication towards train drivers registered to the FRMCS and GSM-R Systems and a train controller subscribed to the same valid MCPTT Group ID. The multi-user voice communication can be terminated by the call initiator.

- Test description:
  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.5.2.

- Test results and comments:
  Test is passed.

  Comments by Nokia

  GSM-R train drivers are simulated with GSM-R handhelds, functional numbering is not used
  Other FRMCS driver is simulated with GCapp
  Train controller is a FRMCS Dispatcher Client, not supporting FA

FA registration of FRMCS CAB A is a precondition, not included in the logs

G711(PCMA) codec is used

Because there is no floor handling between FRMCS and GSM-R systems, CAB doesn't know the floor is taken by GSM-R subscriber so audio receive of CAB is OFF -> Siemens did a patch to set it by default ON

STEP1 - OK
STEP2 - OK
STEP3 - OK, note: nobody is speaking at this point but expected result contains: "The voice quality is clear and loud" -> sentence should be removed from WP1 test case description
STEP4

- C–B - Controller voice OK,
- C–B - GSM-R subscribers voice OK,
- C–B - GCapp voice "robotic/corrupt" because there is no floor handling between the two systems. Application receives 2 RTP streams parallelly one from CAB one from GSM-R system

STEP5 - OK
STEP6

- GSM–R - CAB voice OK,
- GSM–R - GSM-R voice OK,
- GSM–R - GCapp voice OK,
- GSM–R - Controller voice NOK because there is no floor handling between FRMCS and GSM-R systems, controller doesn't know the floor is taken by GSM-R subscriber "loudspeaker" of controller is OFF

STEP7 - OK
STEP8 - OK
STEP9 – OK

Comments by Siemens

Test case Voice_021, as defined in D1.1, specifies in step 1 to navigate to Menu – Calls… – Other Calls… – Group Call. However, insertion of the group id for the FRMCS system has not yet been implemented. Therefore, the group calls need to be selected from the cab radio phonebook. The user shall navigate to the phonebook (soft key 1) and select the group that wishes to call. The results will be as per the results of step 2.

The test case was conducted using a FRMCS cab radio and a GSM-R handheld device. The cab radio was unable to be operated in GSM-R mode due to the non-delivery of the FRMCS to GSM-R transition.

In the current system, the multi-user call is initiated through the phonebook. To establish dynamic group calls in the future, it is necessary to refer to the relevant standards and determine the procedures for affiliation and utilisation of location information.

Furthermore, we need to explore how subscriptions to groups will be handled, as the current method involves subscribing to a list of preconfigured groups stored on the cab radio.

- Traces and logs recorded during the test:
The results of the tests were stored in WP3 Teams collaboration space (folder/file):

Voice_021 Initiation of a multi-user voice communication from a train driver towards train drivers and ground users (FRMCS and GSM-R Users)

4.2.11 Voice_011: Railway Emergency Call initiated by a train controller

- Objective of the test:
The purpose of this test is to demonstrate that a train controller can initiate a Railway Emergency Call. The Railway Emergency Call can be terminated by the call initiator. The definition of the REC area and the procedure of affiliation is described in the appendices §16.9 of D1.1 v4 [S22] WP1 test plan.

- Test description:
This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.6.1.

- Test results and comments:
Test is passed.

Comments by Nokia

Other FRMCS drivers are simulated with GCapps

Train controller is a FRMCS Dispatcher Client, not supporting FA

FA registration of FRMCS CAB A is a precondition, not included in the logs
FA registration of one of the FRMCS user is a precondition, not included in the logs

Mock journey start (simulation of the CAB's position, same inside REC area positions are sending by CAB continuously) and group affiliation is part of the logs

All STEPs are OK

Comments by Siemens

Test case Voice_011, as defined in D1.1, specifies in step 2 that all FRMCS devices/users within a targeted area will receive the railway emergency call. The targeted area is currently simulated on the cab radio by running a MOC Journey that simulates a train movement along a track. In the future, the cab radio will send real GPS coordinates to the MCX Server, allowing the server to determine if the cab radio is within the targeted area.

- Traces and logs recorded during the test:
  The results of the tests were stored in WP3 Teams collaboration space (folder/file):
  Voice_011 Railway Emergency Call initiated by a train controller

4.2.12 Voice_022: Railway Emergency Call initiated by a train driver without interworking

- Objective of the test:
  The purpose of this test is to demonstrate that a train driver can initiate a Railway Emergency Call. The FRMCS system will automatically routes the Railway Emergency voice communication to all FRMCS users in the targeted area. The Railway Emergency Call can be terminated by the call initiator. The definition of the REC area and the procedure of affiliation is described in the appendices §16.10 of D1.1 v4 [S22] WP1 test plan.

- Test description:
  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.6.2.

- Test results and comments:
  Test is passed.

  Comments by Nokia

  Other FRMCS drivers are simulated with GCapps
  Train controller is a FRMCS Dispatcher Client, not supporting FA

  FA registration of FRMCS CAB A is a precondition, not included in the logs
  FA registration of one of the FRMCS user is a precondition, not included in the logs

  Mock journey start (simulation of the CAB's position, same inside REC area positions are sending by CAB continuously) and group affiliation is part of the logs

  All STEPs are except STEP7:
  On GDCP of the CAB radio there is EMERGENCY indication after the call release

  Comments by Siemens

  Test case Voice_022, as defined in D1.1, specifies in step 1 to press the REC button in order to initiate the Railway Emergency Call. However, the current implementation requires the cab radio operator to select the appropriate group from the cab radio phonebook to initiate the call. The user should navigate to the phonebook (soft key 1) and select the desired group for the call. The results will not be affected.

  The railway emergency area is currently simulated on the cab radio by running a MOC Journey that simulates a train movement along a track. In the future, the cab radio will send real GPS coordinates to the MCX Server, allowing the server to determine if the cab radio is within the targeted area.

- Traces and logs recorded during the test:
  The results of the tests were stored in WP3 Teams collaboration space (folder/file):
  Voice_022 Railway Emergency Call initiated by a train driver without interworking (FRMCS Users only)

4.2.13 Voice_012: Railway Emergency Call initiated by a train driver including interworking.

- Objective of the test:
  The purpose of this test is to demonstrate that a train driver can initiate a Railway Emergency Call. The FRMCS system will automatically routes the Railway Emergency voice communication to all users in the targeted area including GSM-R users. The Railway Emergency Call can be terminated by the call initiator. The definition of the REC area and the procedure of affiliation is described in the appendices 16.10 of D1.1 v4 [S22] WP1 test plan.

- Test description:

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.2.7.

- Test results and comments:
  Test is passed.

  Comments by Nokia

  GSM-R train drivers are simulated with GSM-R handhelds, functional numbering is not used
  Other FRMCS driver is simulated with GCapp
  Train controller is a FRMCS Dispatcher Client, not supporting FA

  FA registration of FRMCS CAB A is a precondition, not included in the logs

  Mock journey start (simulation of the CAB's position, same inside REC area positions are sending by CAB continuously) and group affiliation is part of the logs

  G711(PCMA) codec is the only codec used for this test case

  Because there is no floor handling between FRMCS and GSM-R systems, CAB doesn't know the floor is taken by GSM-R subscriber so audio receive of CAB is OFF -> Siemens did a patch to set it by default ON

  STE–1 - OK
  STE–2 - OK
  STEP3

C–B - Controller voice OK,

C–B - GSM-R subscribers voice OK,

C–B - GCapp voice "robotic/corrupt" because there is no floor handling between the two systems application receives 2 RTP streams parallelly one from CAB one from GSM-R system

STE–4 - OK

STEP5

GSM–R - CAB voice OK,

GSM–R - GSM-R voice OK,

GSM–R - GCapp voice OK,

GSM–R - Controller voice NOK because there is no floor handling between FRMCS and GSM-R systems, controller doesn't know the floor is taken by GSM-R subscriber "loudspeaker" of controller is OFF

STE–6 - OK

STE–7 - OK, but on GDCP there is EMERGENCY indication after the call release

Comments by Siemens

Test case Voice_012, as defined in D1.1, specifies in step 1 to press the REC button in order to initiate the Railway Emergency Call. However, the current implementation requires the cab radio operator to select the appropriate group from the cab radio phonebook to initiate the call. The user should navigate to the phonebook (soft key 1) and select the desired group for the call. The results will not be affected.

In step 5 in order for the FRMCS User A to hear the voice of the GSM-R User B, all codecs except G711 must be disabled on the FRMCS User A device. The voice is then transmitted without any interruptions.

The railway emergency area is currently simulated on the cab radio by running a MOC Journey that simulates a train movement along a track. In the future, the cab radio will send real GPS coordinates to the MCX Server, allowing the server to determine if the cab radio is within the targeted area.

- Traces and logs recorded during the test:
  The results of the tests were stored in WP3 Teams collaboration space (folder/file):
  Voice_012 Railway Emergency Call initiated by a train driver including interworking (FRMCS and GSM-R Users)

4.2.14 Voice_013 OPTIONAL: Joining an ongoing Railway Emergency Call

- Objective of the test:
  The purpose of this test is to demonstrate that a train driver that moves into an area where a Railway Emergency voice communication is active, automatically joins the ongoing voice communication.

- Test description:
  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.6.4.

- Test results and comments:
  Test is executed as part of the GSM-R - FRMCS Transition, refer to chapter 4.2.16

  Comments by Nokia

  There is no such kind of functionality implemented in MCX

  Comments by Siemens

  The test case was not conducted; therefore, there are no comments.

- Traces and logs recorded during the test:
  There is no execution result

4.2.15 Voice_014 OPTIONAL: Leaving an ongoing Railway Emergency Call

- Objective of the test:
  The purpose of this test is to demonstrate that a train driver that moves out of an area where a Railway Emergency voice communication is active, automatically leaves the ongoing voice communication.

- Test description:

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.6.5.

- Test results and comments:
  Test was not executed finally, aligned with WP1 were it was declared as optional.

  Comments by Nokia

  Functionality is not implemented in MCX

  Comments by Siemens

  The test case was not conducted; therefore, there are no comments.

- Traces and logs recorded during the test:
  There is no execution result

4.2.16 Voice_015: GSM-R to FRMCS system transition with service continuation

- Objective of the test:

The purpose of this test is to demonstrate that a train driver can manually switch the network in case the current network becomes unavailable.

- Test description:
  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.2.7.

- Test results and comments:
  Test is passed.

  Comments by Nokia

  Test in Lab done but open topics on the voice codecs occurred as described below

  Comments by Siemens

  Test case Voice_015, as defined in D1.1, specifies in the description of the initial state/configuration that GSM-R User B must be registered on the network. However, this prerequisite is not necessary, and the user was not registered during the test case.

  In step 5, in order to ensure voice is transmitted and received between FRMCS and GSM-R users, all codecs except G711 must be disabled on the FRMCS User A device. The voice is then transmitted without any interruptions.

  Steps 9 and 10 were not required for User B to receive the Railway Emergency Call. The call connected as soon as the transition from GSM-R to FRMCS was completed.

  In step 14, the voice transmission from User B, previously a GSM-R user and now an FRMCS user, sounded robotic. This was due to only the G711 codec being enabled on the FRMCS User A device.

- Traces and logs recorded during the test:

  The results of the tests were stored in WP3 Teams collaboration space (folder/file):

  Voice_015 GSM-R to FRMCS system transition with service continuation

4.2.17 Voice_017: Combined MCPTT private point-to-point voice call (driver to controller) in parallel with MCData application in nominal scenario

- Objective of the test:

  The purpose of this test is to demonstrate system behavior using simultaneously two applications requesting different MCX services, such as MCPTT service for voice application and MCData service for the data application. The expected outcome of this test case is that in nominal radio conditions, each application keeps the standalone performances.

  The combined scenario encompasses a driver to controller MCPTT point-to-point call and an On-board to trackside MCData communication, using MCData IPCon.

The above combined scenario will be performed in WP3 lab, using an MCData application Video and TOBA-K, as FRMCS On-board gateway, on n78 band.

Initial state/configuration of both applications shall be applied before launching the combined scenario. The QoS (DSCP) configuration of each application is impacting the results of the combined scenarios, mainly in the degraded conditions. 5G QoS value for Video was set to 5QI=7, non-GBR and for voice 5QI=2, GBR, according to Table 1: QoS settings Chapter 2.5. Note: As the cab radio does not support DSCP marking, the voice QoS (5QI) was set with a workaround using IP filtering rules instead of DSCP filtering.

- Test description:

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.8.1.

- Test results and comments:

Test is passed.

Comments by Nokia

The video view and object move within the view was smooth, no major jerks or picture blinking, trackside VMS indicated around 20-25 fps on the display overlay. This means the quality of the video was nearly perfect.

The voice quality was clear and loud.

Comments by Siemens

No comments.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file):

Voice_017 Combined MCPTT private point-to-point voice call (driver to controller) in parallel with MCData application in nominal scenario

4.2.18 Voice_018: Combined MCPTT private point-to-point voice call (driver to controller) in parallel with MCData application in degraded conditions

- Objective of the test:

It is particularly interesting to repeat the combined scenario, MCPTT voice (configured as GBR) and MCData application (configured as non-GBR), in degraded conditions, using Vertex emulator. In such conditions the QoS, prioritization and radio resource management of voice application, as the most critical one, will be revealed, thanks to the QoS (DSCP) configuration of both applications.

5G QoS value for Video was set to 5QI=7, non-GBR and for voice 5QI=2, GBR, according to Table 1: QoS settings Chapter 2.5. Note: As the cab radio does not support DSCP marking, the voice QoS (5QI) was set with a workaround using IP filtering rules instead of DSCP filtering.

Simulation was done with two different train speeds: 50 km/h and 175 km/h. In both scenarios a propagation model with the most challenging condition, namely with double doppler effect was applied.

Couple of inter-gNodeB handovers were executed during the simulation, where also the so-called intra-frequency Xn handover was triggered (see chapter 3.2.1).

- Test description:

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.2.7.

- Test results and comments:

Test is passed.

Comments by Nokia

At simulated train speed of 50 km/h, the perceived video quality was acceptable. During handovers no degradation in video quality was observed. Sometimes the framerate was dropped, assumably due to temporary bandwidth degradations. The voice quality was clear and loud.

At simulated train speed of 175 km/h there was slight degradation of the perceived quality, but still acceptable. Framerate of the video stream was dropping frequently from 25 fps to 15 fps and above (see Figure 96). Also the bitrate was dropping from 1000 kbps to 600 kbps and above. During handovers buffering occurred, as framerate and as well as bitrate exceeded above 25 fps and 1000 kbps after the handover in order to send buffered data.

The voice was not affected much, however. The voice quality was clear and loud.

Comments by Siemens

No comments.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Voice_018 Combined MCPTT private point-to-point voice call (driver to controller) in parallel with MCData application in degraded conditions

And in subfolders:

train speed 50 kmph

train speed 175 kmph

4.2.19 Voice_019: MCPTT private point-to-point voice call (driver to controller) with HO (inter or intra) gNodeB.

- Objective of the test:

The purpose of this test is to demonstrate that a train driver can initiate a voice communication with a train controller responsible for the train movement area and can maintain it without drops and with a good quality even in mobility conditions (inter/intra gNodeB HO). The call initiator can terminate the voice communication, as in nominal conditions.

The test was done with N78 band, but also repeated in N8.

- Test description:

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.10.

- Test results and comments:

Test is passed.

Comments by Nokia

MC database was checked to ensure the correct assignment of the functional identity.

Instead of using Hytem Attenuator Matrix for initiating handover manually, Vertex Fading Simulator has been used.

During the test Vertex Fading Simulator simulated handovers by modifying signal strength of the source and target cells. The test was performed in nominal conditions.

Tests have been performed on n78 and n8 band as well.

Comments by Siemens

No comments.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Link of Voice_019

4.2.20 Voice_020: MCPTT private point-to-point voice call (driver to controller) with HO (inter or intra) gNodeB in degraded radio conditions.

- Objective of the test:

  The purpose of this test is to demonstrate that a train driver can initiate a voice communication with a train controller responsible for the train movement area and can maintain it without drops even during degraded conditions simulated using Vertex tool.

  This test can be repeated in n8 and n78 to compare the impact of frequency band in the results.

- Test description:

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.11.

- Test results and comments:

  Test is passed

  Comments by Nokia

  Scenario 1: simulated movement with 50 km/h in degraded conditions

  Scenario 2: simulated movement with 175 km/h in degraded conditions

  Tests have been performed on n78 and n8 band as well.

  Comments by Siemens

  No comments.

  - Traces and logs recorded during the test:

  The results of the tests were stored in WP3 Teams collaboration space (folder/file)

  Link of Voice_020

4.3 Conclusion on Voice tests

It can be concluded that all possible test cases were executed successfully. The test cases have demonstrated that the performance of the overall system have fulfilled the objectives:

- there is speech between the participants,
- speech is clear and loud,
- findings are mentioned at the test cases,
- KPI 2 requirements from 3GPP TS 22.179 were fulfilled, even if not full statistical evidence was reached due to limited number of test runs. More detailed performance KPI are described in chapter 9.1

5 ETCS Tests

5.1 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 located in the RBC. A new application has been developed, as part of the EVC, to be able to be interfaced with the FRMCS on-board system (OBapp) in order to communication with the ground system via the FRMCS infrastructure.

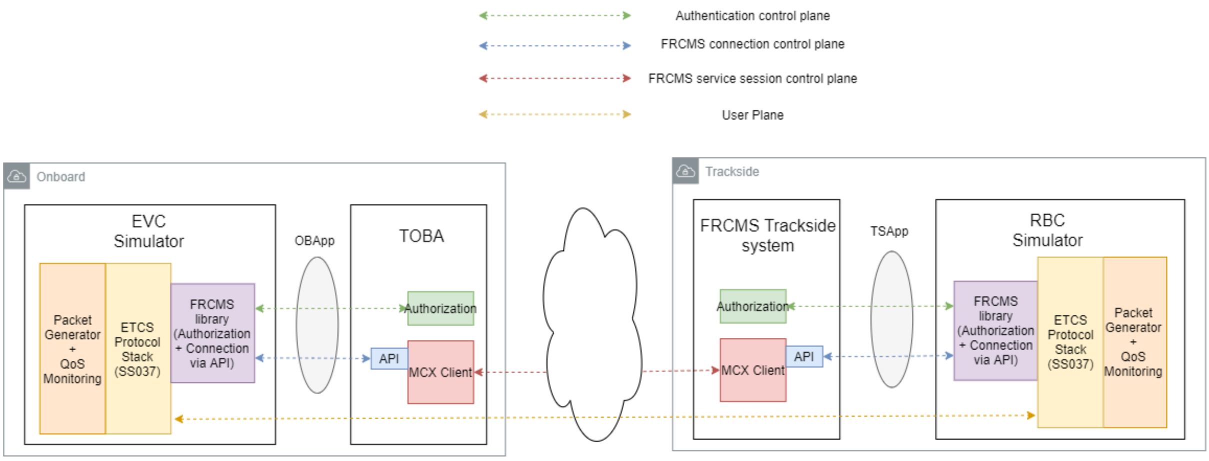


Figure 42: ETCS system overview

5.2 ETCS tests

The following table gives information about ETCS tests executed:

TC_ID	Test case	optional	Frequency	Date of execution
ETCS_WP3-WP5_TC_001	Nominal communication between ETCS on board application and RBC	no	n78	28.03.2023
ETCS_WP3-WP5_TC_005	Nominal communication between ETCS on board application and RBC, including BTS handover (same 5G network)	no	n78	28.03.2023
ETCS_WP3-WP5_TC_002	Communication between ETCS on board application and RBC (same 5G network) in degraded radio conditions	no	n78	28.03.2023 03.05.2023
ETCS_WP3-WP5_TC_003	Increase data transferred in the ETCS communication	no	n78	28.03.2023
ETCS_WP3-WP5_TC_004	ETCS onboard combined with other data application	no	n78	19.04.2023

Table 3: List of ETCS test cases planned in the WP3 lab

5.2.1 ETCS-CAF_TC_001: Nominal communication between ETCS on board application and RBC

- **Objective of the test:**
  The purpose of this test is to check a nominal data transfer between ETCS on board application and RBC on the same 5G network.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 8.1.1.3

  The MCX building blocks validated with this test case are presented in §16.6 "Applicability of MCX building blocks to the test cases of WP3 [ETCS_WP3-WP5_TC_001]" of document D1.1 v4 [S22] WP1 test plan.

- **Specific Test configuration:**
  ETCS data was transferred by nominal data rate of 200 Bytes/sec (2 packets/sec, packet size: 100 bytes). Test duration was about 10 minutes to get enough packets (~ 1200 pcs) for statistical analysis.
  Radio condition was ideal, no fading effect, no simulation of movement. 5G frequency band was N78.
  5G QoS value for ETCS was set to 5QI=5, non-GBR, according to Table 1: QoS settings Chapter 2.5.

- **Test results and comments:**

  Test is passed.

  Comments by CAF

  From integration perspective, a delay between the OBapp registration response and the session start command have been implemented in the application side to avoid the FRMCS GW to get stuck in trying state.

  From performance perspective, it can be observed that the communication is very stable. The round-trip-time stays always below 120ms.

  Comments by Nokia

  IPCon setup messaging and ETCS data transfer was stable, no interruption was observed during the tests.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under
  ETCS tests and in subfolder 8.1.1–3 - ETCS_WP3-WP5_TC_001 (Nominal communication)

<u>Detailed analyses by CAF about the traces that have been recorded</u>:

TC1_EVC.pcapng: Traces captured in the On-Board application

- Number Packets sent: 1179
- Number Packets received: 1179
- Number of retransmitted packets: 0
- Average sent data rate: 2694 bits/s
- Average received data rate: 2694 bits/s
- Roundtrip average time*: 81,3 ms

Note: The roundtrip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

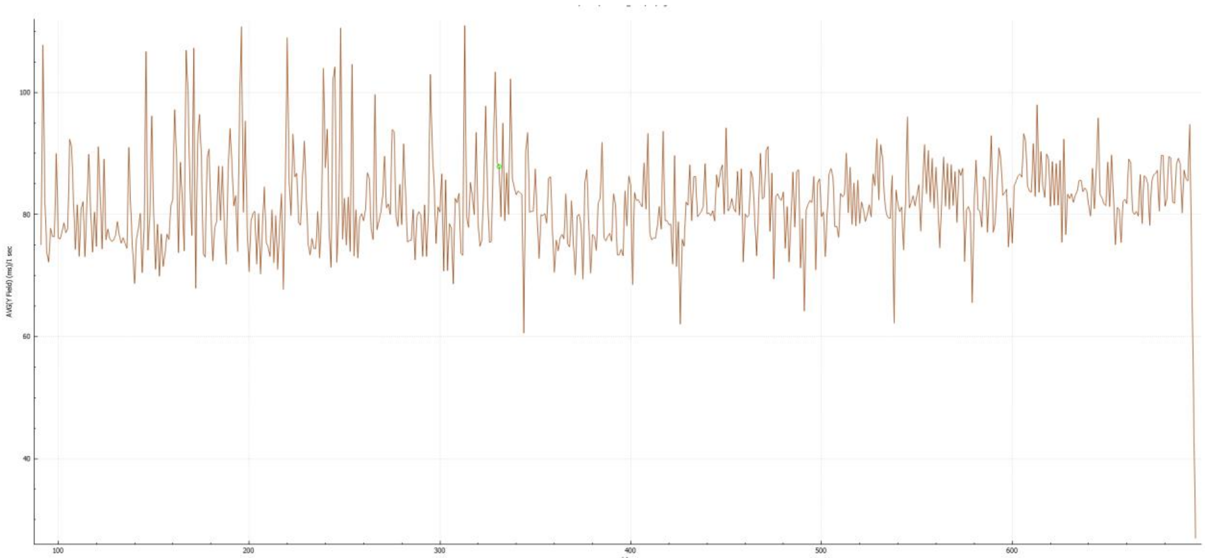


Figure 43: RTT of ETCS TCP data flow in nominal conditions (EVC side)

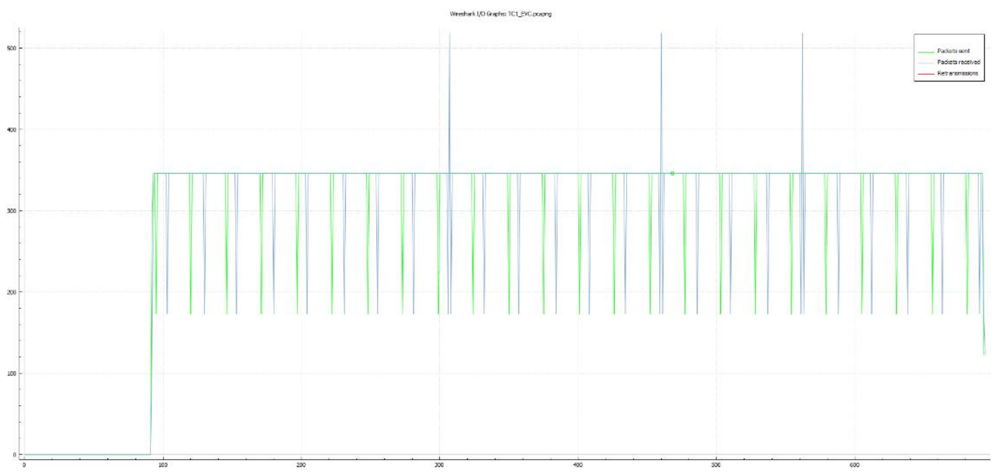


Figure 44: Packets sent/received/retransmitted of ETCS TCP data flow in nominal conditions (EVC side)

- TC1_RBC.pcapng: Traces captured in the Trackside application
  - Number Packets sent: 1179
  - Number Packets received: 1179
  - Number of retransmitted packets: 0
  - Average sent data rate: 2695 bits/s
  - Average received data rate: 2695 bits/s
  - Roundtrip average time*: 88,5 ms

Note: The roundtrip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

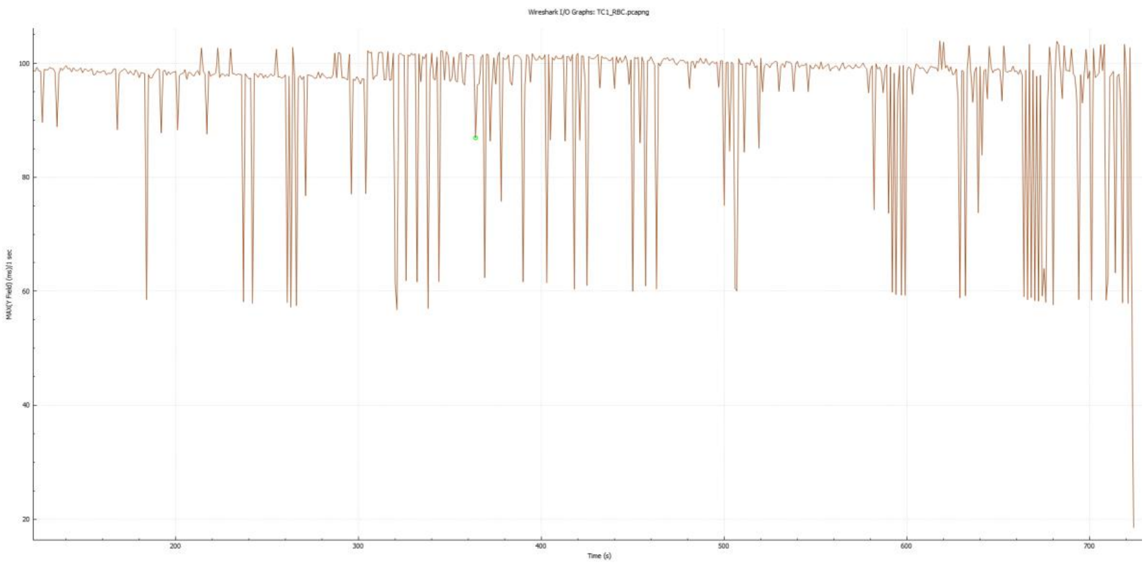


Figure 45: RTT of ETCS TCP data flow in nominal conditions (RBC side)

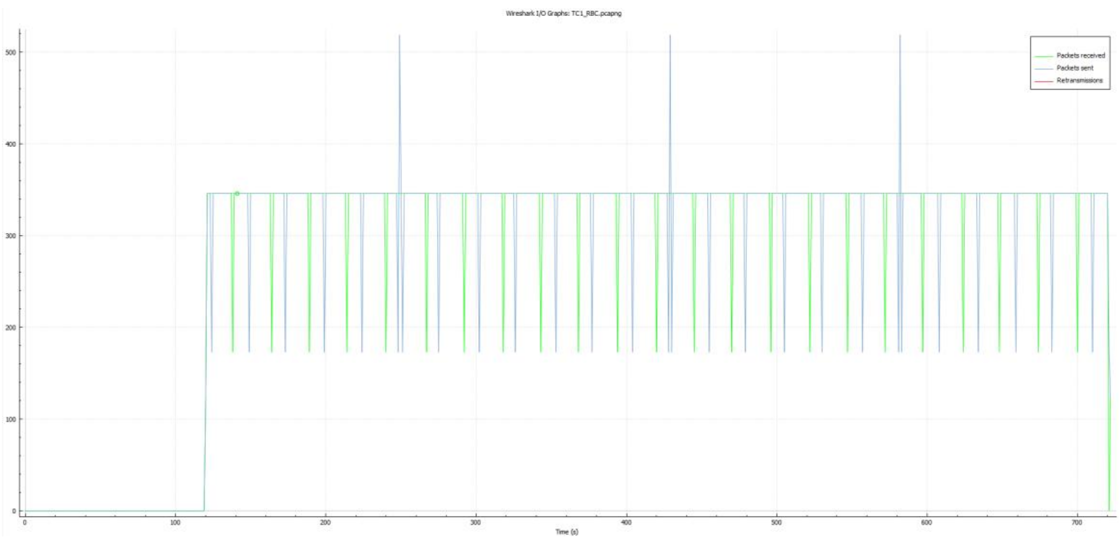


Figure 46: Packets sent/received/retransmitted of ETCS TCP data flow in nominal conditions (RBC side)

5.2.2 ETCS-CAF_TC_005: Nominal communication between ETCS on board application and RBC, including BTS handover (same 5G network)

- **Objective of the test:**
  The purpose of this test is to check a nominal data transfer between ETCS on board application and RBC on the same 5G network, while there are handovers in the 5G radio network.

- **Test description:**
  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 8.1.1.4
  The MCX building blocks validated with this test case are presented in §16.6 "Applicability of MCX building blocks to the test cases of WP3 [ETCS_WP3-WP5_TC_005]" of document D1.1 v4 [S22] WP1 test plan.

- **Specific Test configuration:**
  ETCS data was transferred by nominal data rate of 200 Bytes/sec (2 packets/sec, packet size: 100 bytes). Test duration was about 10 minutes to get enough packets (~ 1200 pcs) for statistical analysis.
  5G QoS value for ETCS was set to 5QI=5, non-GBR, according to Table 1: QoS settings Chapter 2.5.

  Radio condition was ideal, no fading effect. 5G frequency band was N78.

  During the test at about every 2 minutes intra-gNodeB and inter-gNodeB handovers were executed with the help of the HYTEM attenuator in order to simulate the movement between two 5G cells.
  In case of inter-gNodeB handover also the so-called intra-frequency Xn handover was triggered (see chapter 3.2.1).

  For 5G handover testing HYTEM 6x6 FULL FAN OUT Attenuation Matrix (6–6 - 93/110 –B - 3 to 6 GHz) on n78 band. Configuration can be seen in the figure Figure 47 below where RRUs represent separate 5G cells.

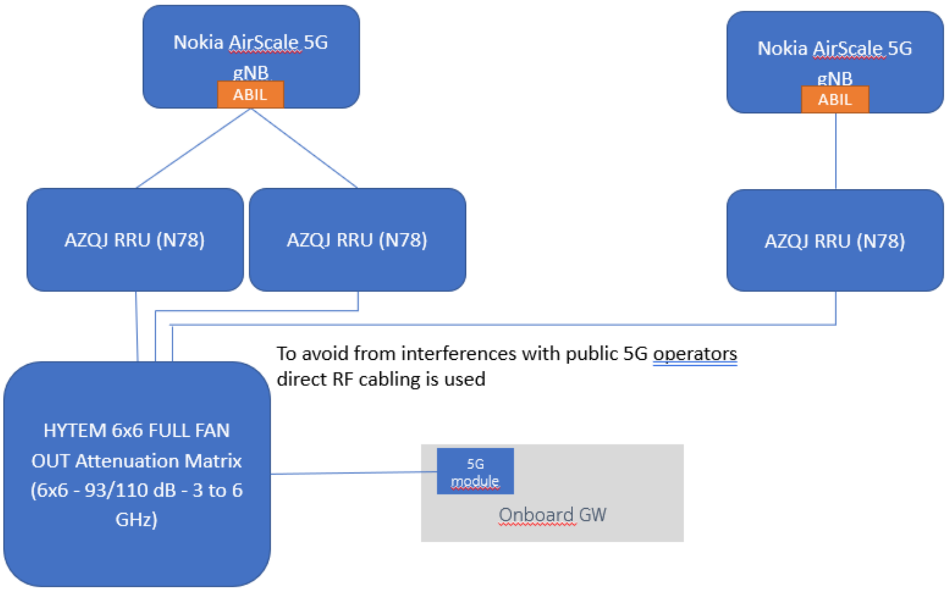


Figure 47 5G Handover RF configuration

- **Test results and comments:**

  Test is passed.

  Comments by CAF

  From integration perspective, a delay between the OBapp registration response and the session start command have been implemented in the application side to avoid the FRMCS GW to get stuck in trying state.

  From performance perspective, a slight increase (5ms) in the EVC measured round-trip-time can be observed compared with the TC01. This increase is negligible, specially taking into account that there were BTS handovers during the test.

  Comments by Nokia

  IPCon setup messaging and ETCS data transfer was stable, no interruption was observed during the tests.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under ETCS tests and in subfolder 8.1.1–4 - ETCS_WP3-WP5_TC_005 (Nominal communication with handovers)

  Detailed analyses by CAF about the traces that have been recorded:

  TC05_EVC.pcapng: Traces captured in the On-Board application

- Number Packets sent: 1179
- Number Packets received: 1179
- Number of retransmitted packets: 1
- Average sent data rate: 2694 bits/s
- Average received data rate: 2696 bits/s
- Roundtrip avg time*: 86,3 ms

Note: The roundtrip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

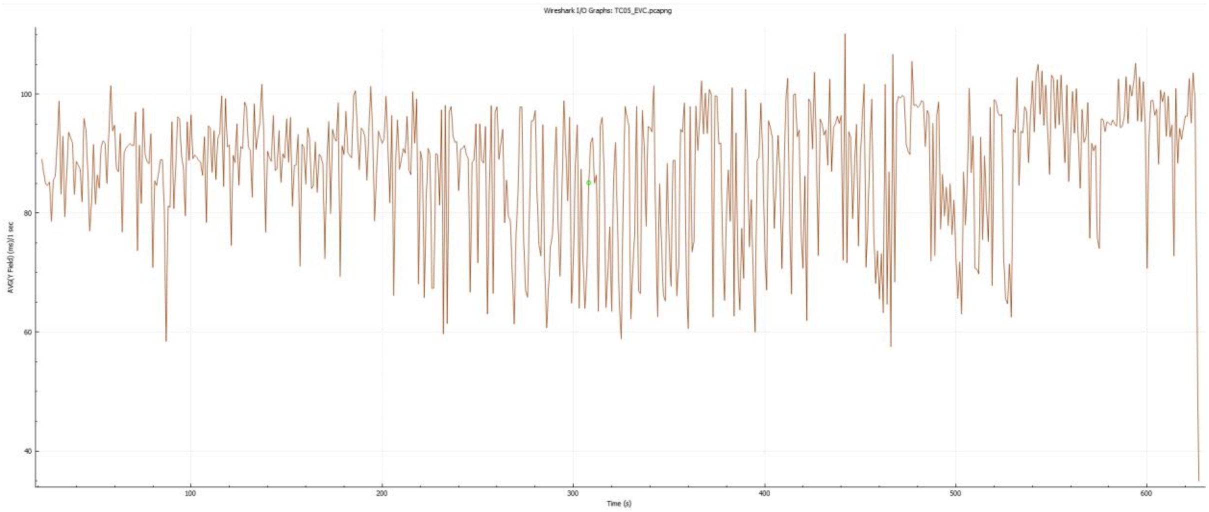


Figure 48: RTT of ETCS TCP data flow with handovers (EVC side)

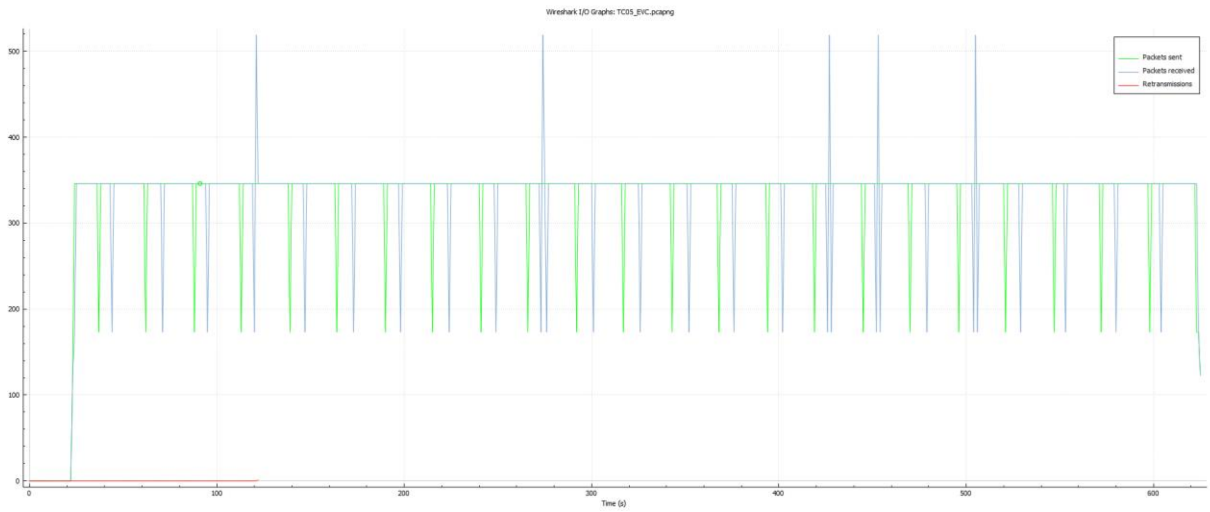


Figure 49: Packets sent/received/retransmitted of ETCS TCP data flow with handovers (EVC side)

- TC05_RBC.pcapng: Traces captured in the Trackside application

- Number Packets sent: 1179
- Number Packets received: 1179
- Number of retransmitted packets: 0
- Average sent data rate: 2694 bits/s
- Average recv data rate: 2694 bits/s
- Roundtrip average time*: 87,4 ms

Note: The roundtrip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

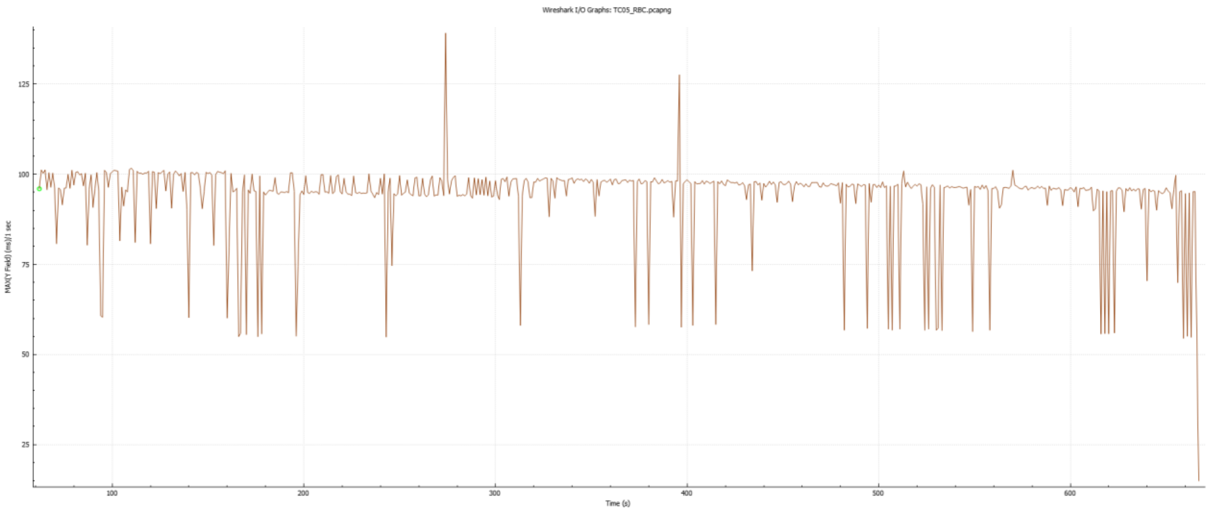


Figure 50: RTT of ETCS TCP data flow in nominal handovers (RBC side)

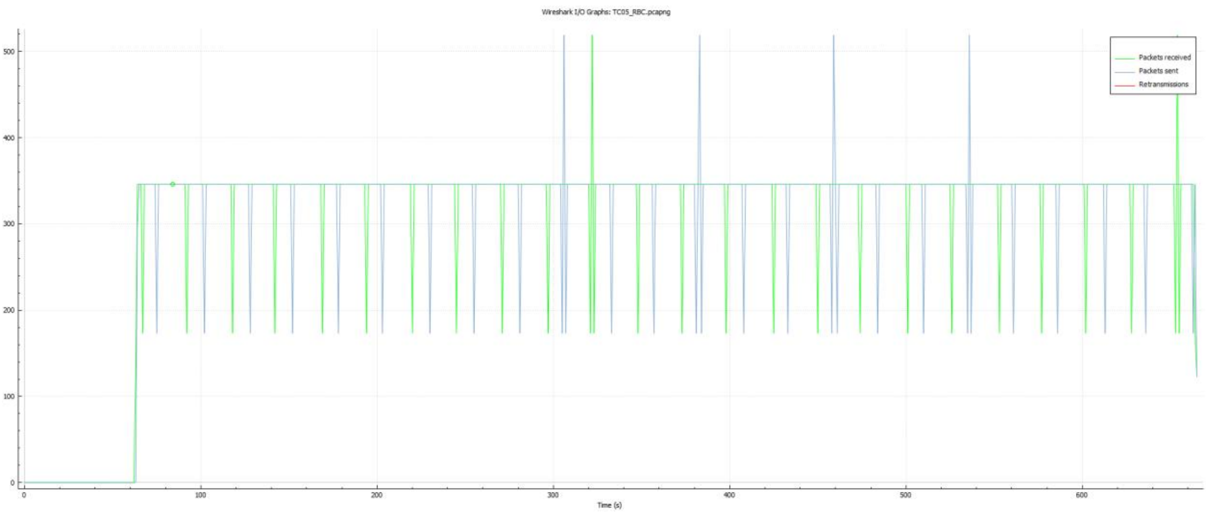


Figure 51: Packets sent/received/retransmitted of ETCS TCP data flow with handovers (RBC side)

5.2.3 ETCS-CAF_TC_002: Communication between ETCS on board application and RBC (same 5G network) in degraded radio mode

- **Objective of the test:**

  The purpose of this test is to evaluate ETCS application performance in various radio conditions and check against the nominal ETCS performance measured in ETCS-CAF_TC_001.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 8.1.2.

  The MCX building blocks validated with this test case are presented in §16.6 “Applicability of MCX building blocks to the test cases of WP3 [ETCS_WP3-WP5_TC_002]” of document D1.1 v4 [S22] WP1 test plan.

- **Specific Test configuration:**

  ETCS data was transferred by nominal data rate of 200 Bytes/sec (2 packets/sec, packet size: 100 bytes). Test duration was about 10 minutes to get enough packets (~ 1200 pcs) for statistical analysis.
  5G QoS value for ETCS was set to 5QI=5, non-GBR, according to Table 1: QoS settings Chapter 2.5.
  Radio condition was degraded with variable radio signal strength incl. fading effect. Also high speed train environment was simulated. 5G frequency band was N78.

  To test high speed handovers and degraded radio condition situations RF emulator tool is used, namely Spirent Vertex Channel Emulator. More info on this configuration can be found in chapter 3.4

  Simulation was done with two different train speeds: 50 km/h and 120km/h. In all two scenarios a propagation model with the most challenging condition, namely with double doppler effect was applied.

  Couple of inter-gNodeB handovers were executed during the simulation, where also the so-called intra-frequency Xn handover was triggered (see chapter 3.2.1).

- **Test results and comments:**

  Test is passed with limitations.

  Comments by CAF

  From integration perspective, a delay between the OBapp registration response and the session start command have been implemented in the application side to avoid the FRMCS GW to get stuck in trying state.

  From performance perspective, the main difference is in the delays observed in the round-trip-time. In the nominal testcase the RTT is always below 120ms, in this testcase that limit is overpassed several times. Due to the delays and the radio degradation, some packet retransmissions at TCP level were required, but no connection disruption was observed.

Comments by Nokia

At simulated train speed of 50 km/h: IPCon setup messaging and ETCS data transfer was stable, no interruption was observed during the tests.

At simulated train speed of 120 km/h: IPCon setup messaging was fine, but ETCS data transfer stopped incorrectly after 5-6 minutes, before the data session could have ended normally after 10 minutes. This instable behaviour was reproducible.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under
  ETCS tests and in subfolders:
  degraded radio with 50kmph
  degraded radio with 120kmph

  Detailed analyses by CAF about the traces that have been recorded **at simulated train speed of 50 km/h:**
  - TC02_EVC.pcapng: Traces captured in the On-Board application
    - Number Packets sent: 1179
    - Number Packets received: 1179
    - Number of retransmitted packets: 3
    - Average sent data rate: 2698 bits/s
    - Average received data rate: 2695 bits/s
    - Roundtrip average time*: 111,6 ms

  Note: The roundtrip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

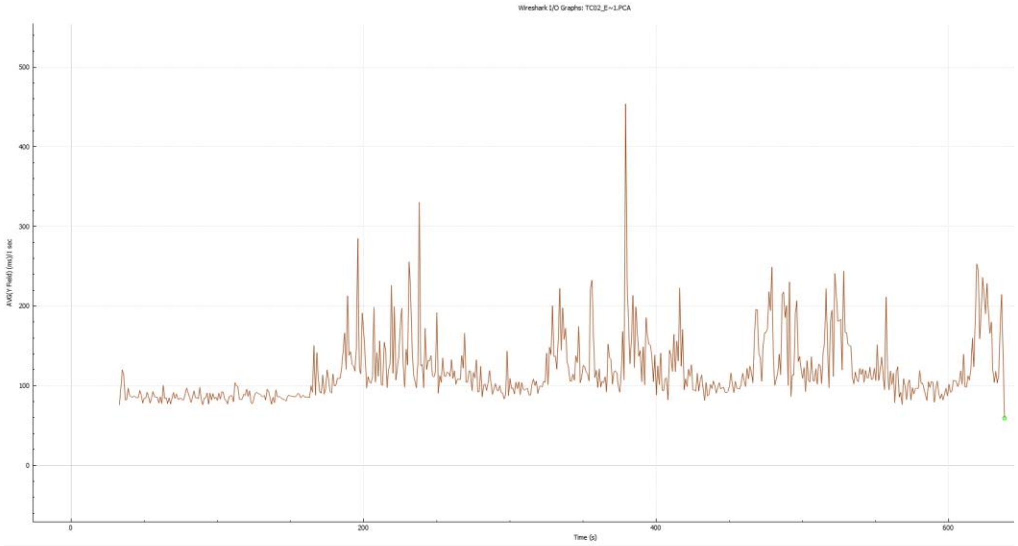


Figure 52: RTT of ETCS TCP data flow in degraded conditions (EVC side)

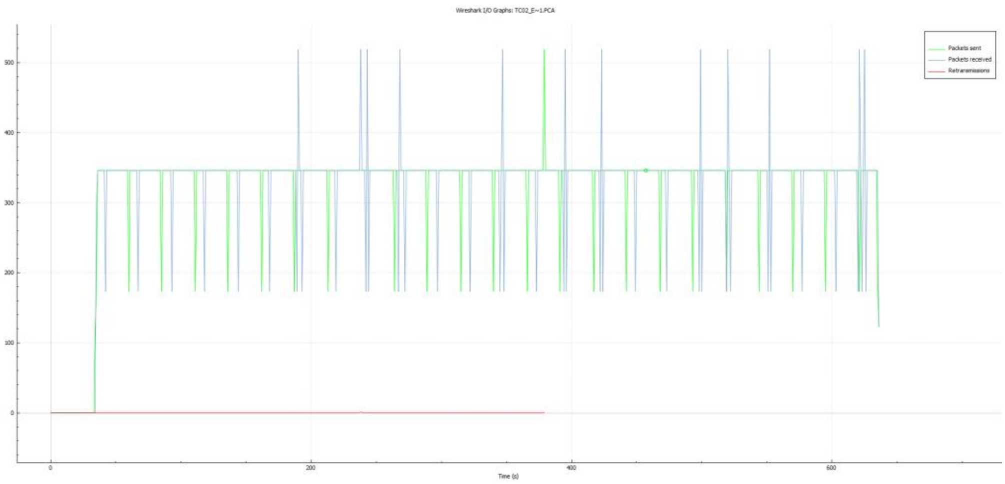


Figure 53: Packets sent/received/retransmitted of ETCS TCP data flow in degraded conditions (EVC side)

- TC02_RBC.pcapng: Traces captured in the Trackside application
  - Number Packets sent: 1179
  - Number Packets received: 1179
  - Number of retransmitted packets: 3
  - Average sent data rate: 2698 bits/s
  - Average received data rate: 2696 bits/s
  - Roundtrip average time*: 101,6 ms

Note: The roundtrip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

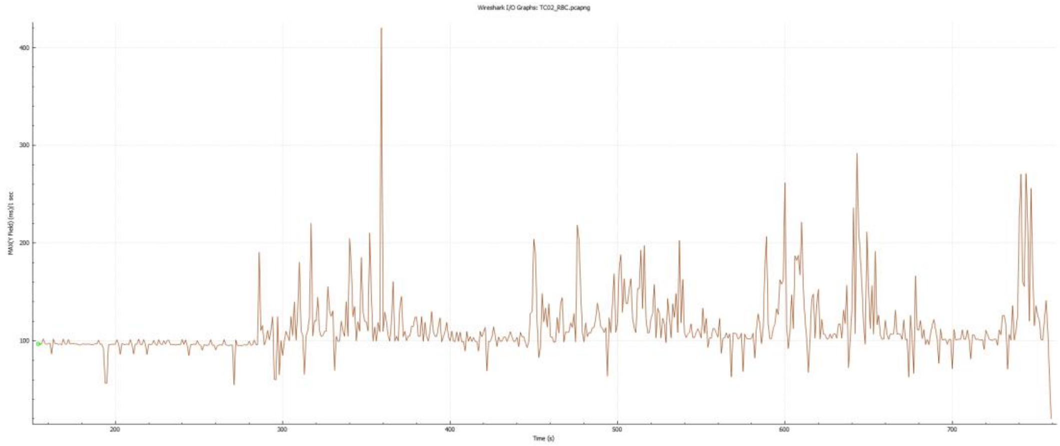


Figure 54: RTT of ETCS TCP data flow in degraded conditions (RBC side)

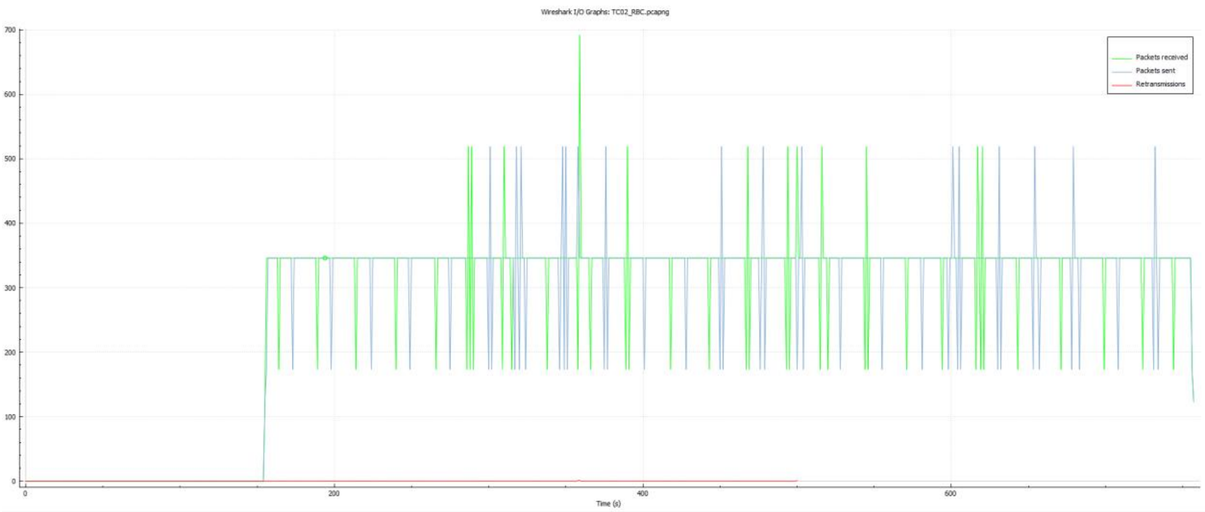


Figure 55: Packets sent/received/retransmitted of ETCS TCP data flow in degraded conditions (RBC side)

5.2.4 ETCS-CAF_TC_003: Increase data transferred in the ETCS communication

- **Objective of the test:**

  The purpose of this test is to check that even if the load of data sent by the ETCS application increases, the FRMCS system is still able to handle it. Average ETCS data transfer is around 200 Bytes/s in actual ETCS deployments. The objective of this test is to validate that there is room for more data transfer in the future ETCS application versions. In order to do so, the data transfer will increase up to 4 kbps only for ETCS application.

- **Test description:**
  The MCX building blocks validated with this test case are presented in §16.6 Applicability of MCX building blocks to the test cases of WP3 [ETCS_WP3-WP5_TC_003] of document D1.1 v4 [S22] WP1 test plan.

This test is described in D1.1 v4 [S22] WP1 test plan, chapter 8.1.3

- **Specific Test configuration:**
  ETCS data was transferred by increased data rate of 500 Bytes/sec (2 packets/sec, packet size: 250 bytes). Test duration was about 10 minutes to get enough packets (~ 1200 pcs) for statistical analysis.
  Radio condition was ideal, no fading effect, no simulation of movement. 5G frequency band was N78.
  5G QoS value for ETCS was set to 5QI=5, non-GBR, according to Table 1: QoS settings Chapter 2.5.

- **Test results and comments:**

  Test is passed.

  Comments by CAF

  From integration perspective, a delay between the OBapp registration response and the session start command have been implemented in the application side to avoid the FRMCS GW to get stuck in trying state.

  From performance perspective, it can be observed that the communication is as stable as the nominal testcase, demonstrating that the FRMCS GW can handle bigger data rates with almost no impact. A small increase of 5ms was observed in the average round-trip-time.

  Comments by Nokia

  IPCon setup messaging and ETCS data transfer was stable, no interruption was observed during the tests.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under ETCS tests and in subfolder 8.1–3 - ETCS_WP3-WP5_TC_003 (Increased data transfer)

  Detailed analyses by CAF about the traces that have been recorded:

  - TC03_EVC.pcapng: Traces captured in the On-Board application
    - Number Packets sent: 1179
    - Number Packets received: 1179
    - Number of retransmitted packets: 0
    - Average sent data rate: 5028 bits/s
    - Average received data rate: 5028 bits/s
    - Roundtrip average time*: 86,7 ms

  Note: The roundtrip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

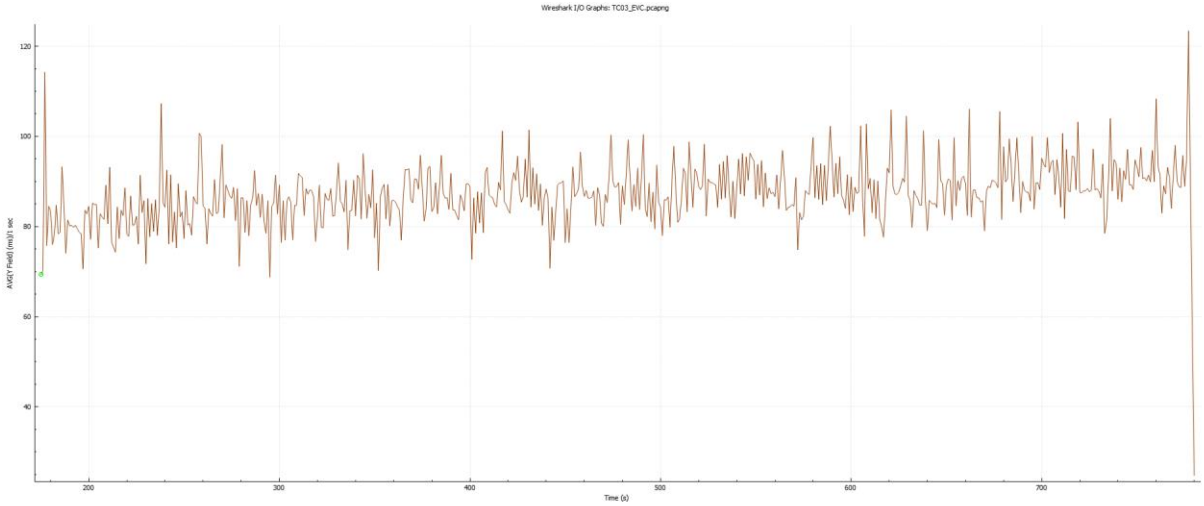


Figure 56: RTT of ETCS TCP data flow with increased data rate (EVC side)

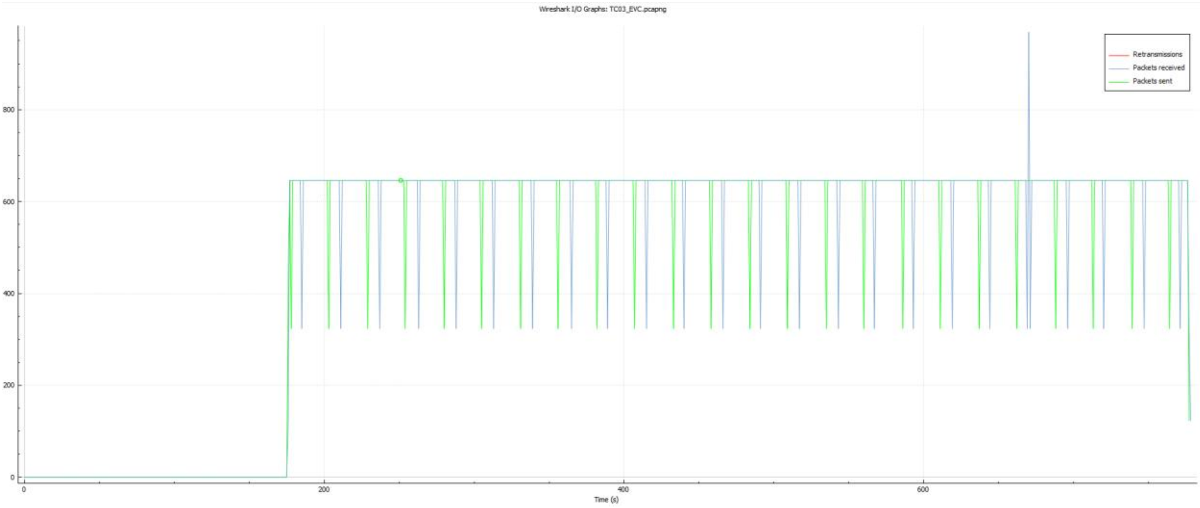


Figure 57: Packets sent/received/retransmitted of ETCS TCP data flow with increased data rate (EVC side)

- TC03_RBC.pcapng: Traces captured in the Trackside application
  - Number Packets sent: 1179
  - Number Packets received: 1179
  - Number of retransmitted packets: 0
  - Average sent data rate: 5028 bits/s
  - Average received data rate: 5028 bits/s
  - Roundtrip average time*: 89,6 ms

Note: The round trip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

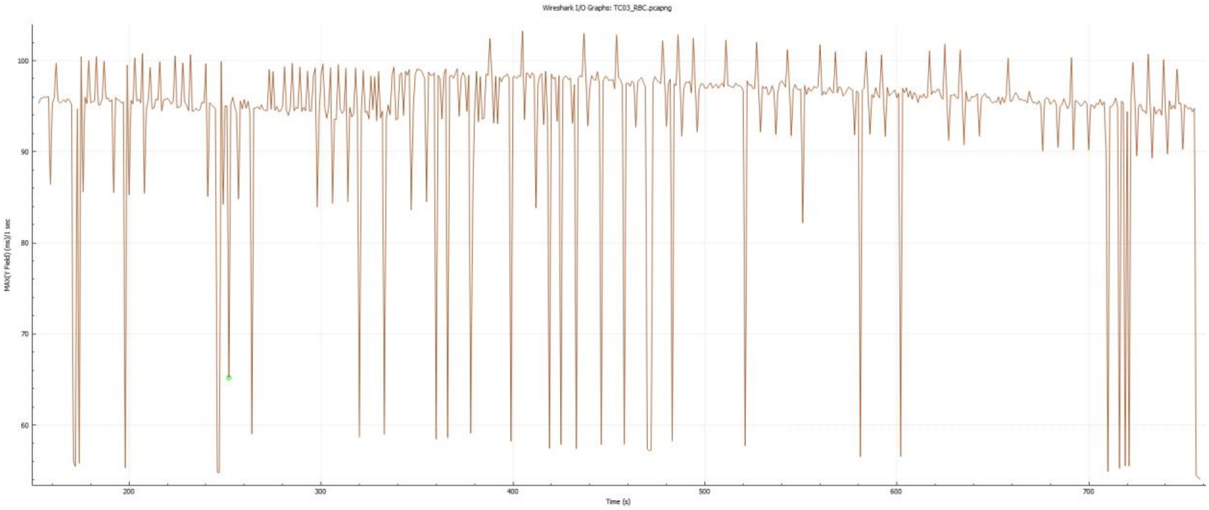


Figure 58: RTT of ETCS TCP data flow with increased data rate (RBC side)

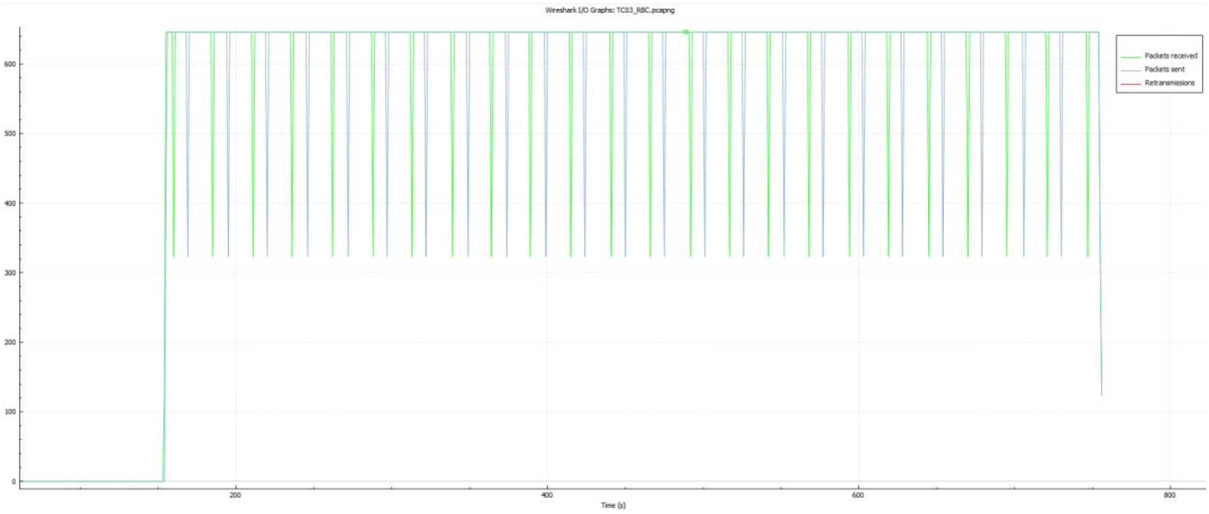


Figure 59: Packets sent/received/retransmitted of ETCS TCP data flow with increased data rate (RBC side)

5.2.5 ETCS-CAF_TC_004: ETCS onboard combined with other application (TCMS)

- **Objective of the test:**

  The purpose of this test is to check a nominal data transfer between ETCS on board application and RBC on the same 5G network when another non-critical data application (e.g., TCMS or Video) is also transmitting data in parallel using the same FRMCS GW.

- **Test description:**
  The MCX building blocks validated with this test case are presented in §16.6 Applicability of MCX building blocks to the test cases of WP3 [ETCS_WP3-WP5_TC_004] of document D1.1 v4 [S22] WP1 test plan.
  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 8.1.4

- **Specific Test configuration:**

  ETCS and TCMS data was transferred in parallel. Both application was transferred by increased data rate (above nominal) to check if they can have impact on each other's performance with such larger data rates.
  ETCS was transferred by increased data rate of 500 Bytes/sec (2 packets/sec, packet size: 250 bytes). TCMS was transferred by increased of 10 packets / sec (packet size < 100 bytes)
  Test duration was about 10 minutes to get enough packets (~ 1200 pcs) for statistical analysis.
  Radio condition was ideal, no fading effect, no simulation of movement. 5G frequency band was N78.
  5G QoS value for ETCS was set to 5QI=5, non-GBR, according to Table 1: QoS settings Chapter 2.5.
  5G QoS value for TCMS was set to 5QI=9, non-GBR, according to Table 1: QoS settings Chapter 2.5.

- **Test results and comments:**

  Test is passed.

  Comments by CAF

  From testcase perspective, the combined application testcase was executed using an increased data rate from the ETCS application.

  From integration perspective, a delay between the OBapp registration response and the session start command have been implemented in the application side to avoid the FRMCS GW to get stuck in trying state.

  From performance perspective, it can be observed that the communication is as stable as the nominal testcase, demonstrating that the FRMCS GW can handle multiple applications running at the same time, keeping the performance of the ETCS almost intact.

  Comments by Nokia

  IPCon setup messaging and ETCS data transfer was stable, no interruption was observed during the tests.

- Traces and logs recorded during the test:

  Traces and recordings have been saved in 5Grail collaboration Sharepoint under ETCS tests and in subfolder TEST2 - ETCS increased data rate - TCMS much increased data rate

  Detailed analyses by CAF about the ETCS traces that have been recorded:

  - TC04_EVC.pcapng: Traces captured in the On-Board application
    - Number Packets sent: 1179
    - Number Packets received: 1179
    - Number of retransmitted packets: 0

- Average sent data rate: 5028 bits/s
- Average received data rate: 5028 bits/s
- Roundtrip average time*: 91,1 ms

Note: The roundtrip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

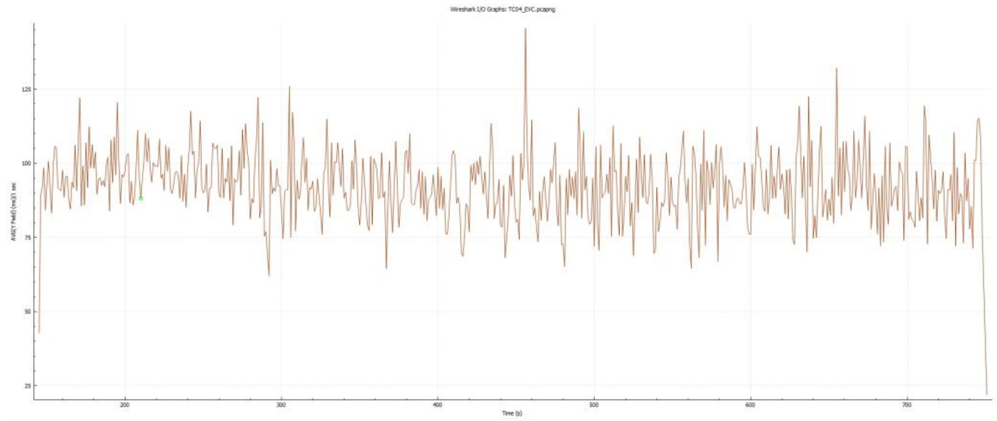


Figure 60: RTT of ETCS TCP data flow combined with TCMS (EVC side)

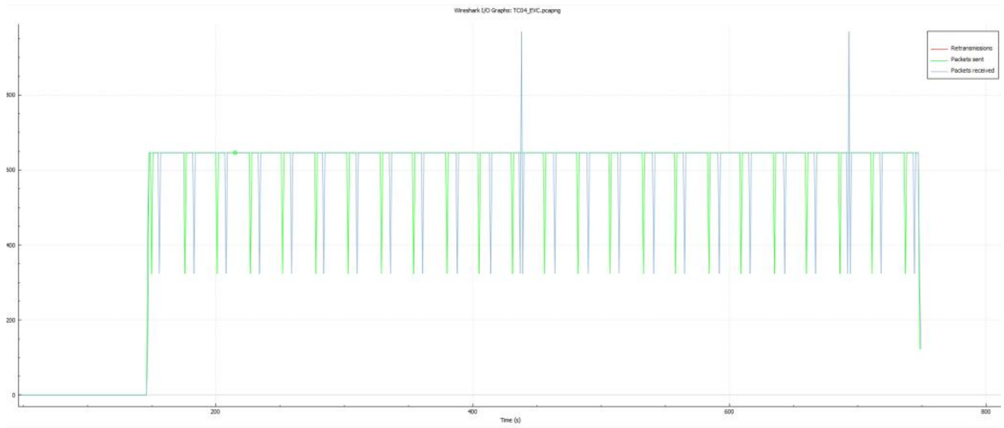


Figure 61: Packets sent/received/retransmitted of ETCS TCP data flow combined with TCMS (EVC side)

- TC04_RBC.pcapng: Traces captured in the Trackside application
  - Number Packets sent: 1179
  - Number Packets received: 1179
  - Number of retransmitted packets: 0
  - Average sent data rate: 5028 bits/s
  - Average received data rate: 5028 bits/s
  - Roundtrip average time*: 85,7 ms

Note: The round trip average time value have been derived from the TCP acknowledgements, to minimize the processing times of the applications (on-board and trackside). However, there is still a processing delay from the applications inherent in this value. Therefore, it can be assumed that the real RTT is lower than the value monitored in the application side. The processing time is normally between 40 to 55ms on the application side.

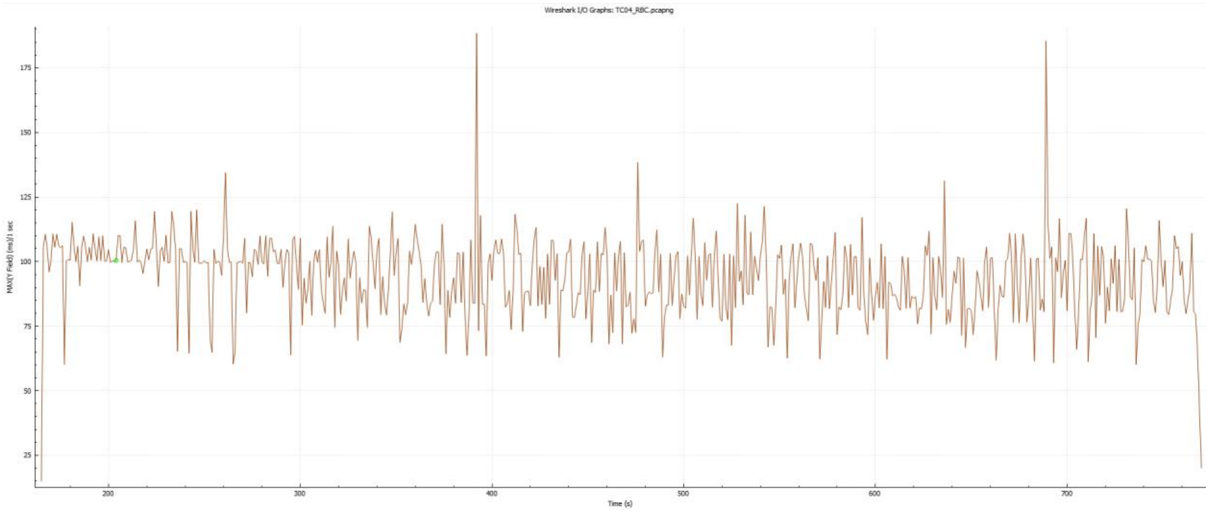


Figure 62: RTT of ETCS TCP data flow combined with TCMS (RBC side)

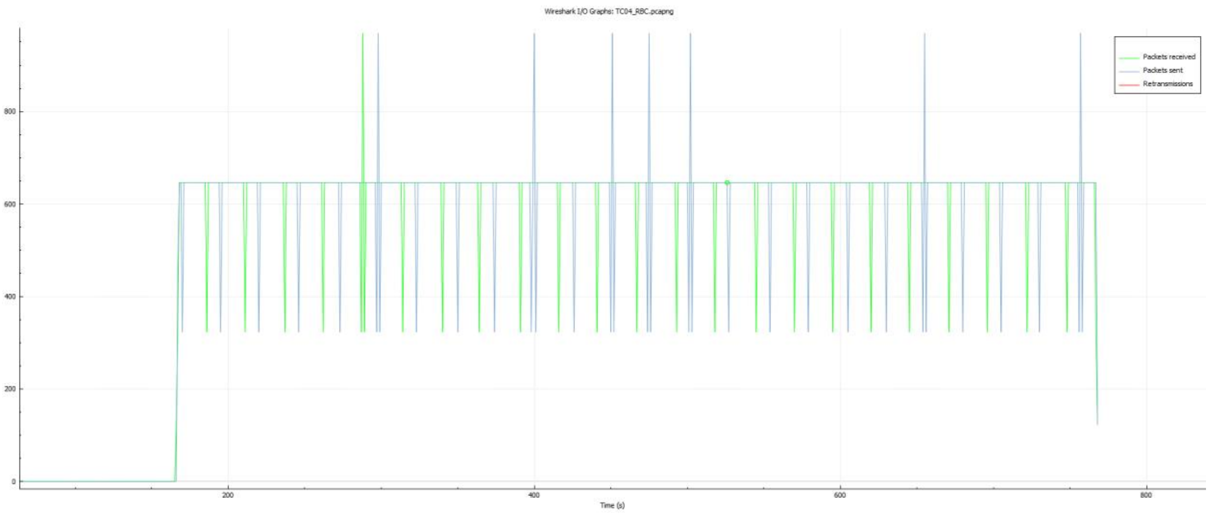


Figure 63: Packets sent/received/retransmitted of ETCS TCP data flow combined with TCMS (RBC side)

Additionally, the following graph the information related to the TCMS is depicted using the same axis and legend. As it can be seen the number of bytes per second received/transmitted is different as in this case the data flow in one way, from the on-board system to the trackside. In the data captures there are some packets detected as TCP Spurious Retransmission, but by analyzing the payload packets are different to the previous sent so this is misleadingly detected by the Wireshark (see Figure 65).

- CAF_KONTRON_COMBINED_ETCS_INCREASED_TCMS_INCREASED_DATA_2023-04-19_TS.pcapng (Figure 64):
  - Number Packets sent: 5276
  - Number Packets received: 5276
  - Number of retransmitted packets: 0

- Average sent data rate: 11928 bits/s
- Average received data rate: 7285 bits/s

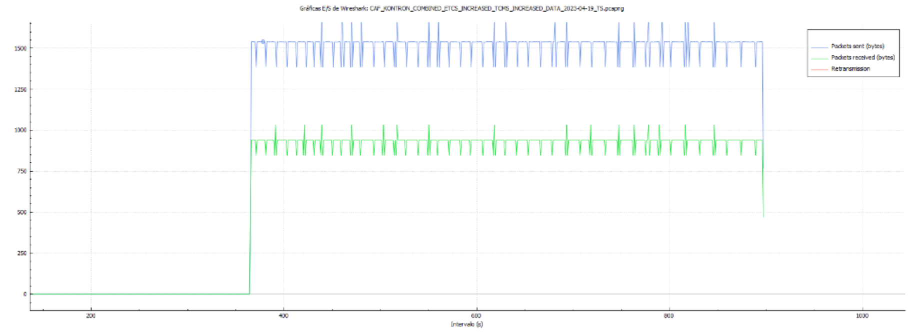


Figure 64: Packets sent/received/retransmitted of TCMS TCP data flow combined test case

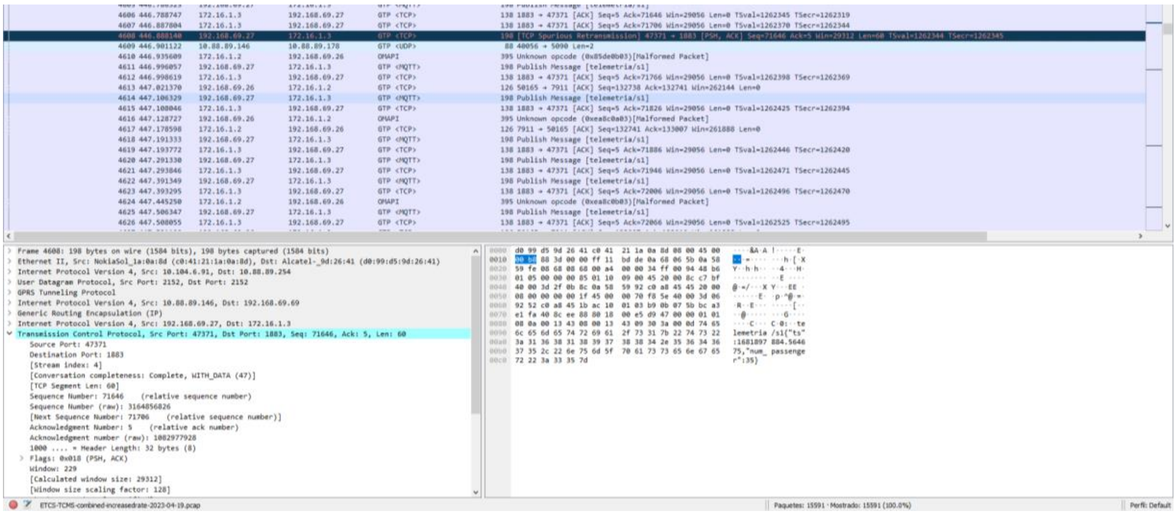


Figure 65 TCP Spurious Retransmission

For the time impact the jitter of the received packets in the application is going to be used. This is because the TCMS information is one-way only and thus the importance is into the effect that has in the trackside. In Figure 66, the upper picture shows the transmitted packet time difference meanwhile the bottom one the time difference of the transmitted packets. The expected behavior in an ideal network is having the same shape. However, packets are suffering different delays over the network.

In this case, the performance indicator that it is going to provided is the standard deviation of the measures over the mean that it should be approximately 100ms (increased data rate test case). In this case the obtained results are around 17,4 ms, which can be acceptable and won't interfere with the application.

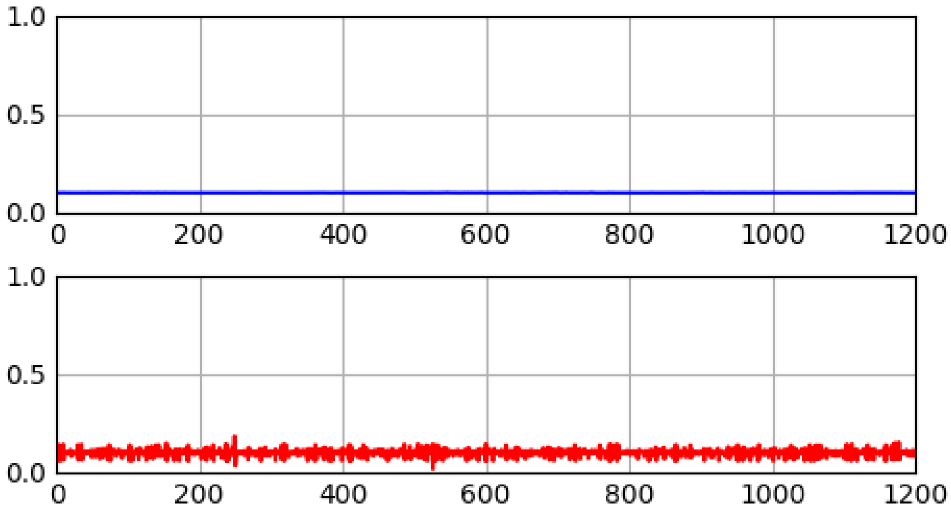


Figure 66 Time difference between consecutive packets

5.3 Conclusion on ETCS tests

It can be concluded that ETCS test cases were executed successfully except for high speed train conditions. At simulated train speed of 120 km/h the ETCS data transfer showed some instability, however at train speed of 50 km/h it was still stable.

Beside the above-mentioned condition the performance of the overall system have fulfilled the objectives:

- The data rate as well as the latency was very stable over the time.
- The increasing of the data rate or sharing the resources with an additional application (TCMS) did not have a relevant impact on KPIs either.

6 TCMS Tests

6.1 Introduction to TCMS tests

For TCMS non-critical application, 2 types of use cases are considered:

a) On-train telemetry communications (initiated by the MCG on onboard)

b) On-train remote equipment control (HTTP request initiated by the GCG on trackside)

The detailed architecture of the TCMS application is described in Figure 67. The TCMS Mobile Communication Gateway (MCG) interacts with the On-board FRMCS Gateway, and the Ground Communication Gateway (GCG) interacts with the FRMCS Trackside System.

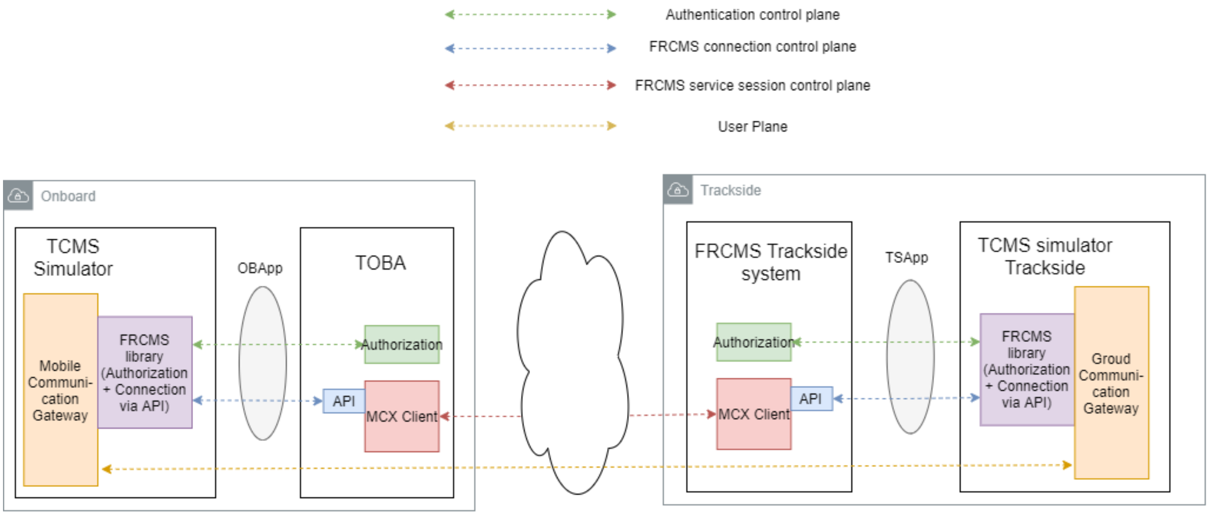


Figure 67: TCMS system overview

6.2 TCMS tests

The following table gives information about TCMS tests executed:

TC_ID	Test case	optional	Frequency	Date of execution
TCMS_TC_001 (Telemetry)	Nominal communication between MCG on board application and GCG	no	n78	27.01.2023
TCMS_TC_004 (Telemetry)	Nominal communication between MCG on board application and GCG, including BTS handover (same 5G network)	no	n78	27.01.2023
TCMS_TC_002 (Telemetry)	Evaluate FRMCS On-Board System and impact on application with degraded radio conditions	no	n78	19.04.2023 03.05.2023
TCMS_TC_003 (Telemetry)	Cross border scenario with TCMS (Telemetry) or other MCData application	optional	n78	Executed with Video application / constant data rate
TCMS_RC_TC_001 (On-train remote equipment control)	Nominal communication between GCG trackside application and onboard MCG (same 5G network)	no	n78	19.04.2023

Table 4: List of TCMS test cases planned in the WP3 lab

6.2.1 TCMS_TC_001 Nominal communication between MCG on board application and GCG (same 5G network)

- **Objective of the test:**

  The purpose of this test is to check IP communication between MCG on board application and GCG trackside application on the same 5G network, started by the MCG.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.2.1.3

- **Specific Test configuration:**

  TCMS data was transferred by nominal data rate of 2 packets / sec (packet size < 100 bytes)
  Test duration was about 10 minutes to get enough packets (~ 1200 pcs) for statistical analysis.
  Radio condition was ideal, no fading effect, no simulation of movement. 5G frequency band was N78.
  5G QoS value for TCMS was set to 5QI=9, non-GBR, according to Table 1: QoS settings Chapter 2.5.

- **Test results and comments:**

  Test is passed.

  Comments by CAF

  From testcase perspective, the combined application testcase was executed using a nominal data rate from the TCMS application.

  From integration perspective, a mismatch between the parsing of the JSON messages was detected and this was corrected by KONTRON. The order of the JSON if the format is correct does not imply a registration error.

  Additionally, some routes are not persistent and have to be checked during the initialization to be able to communicate properly with the GWs.

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

  A TCP dump capture is set up by Nokia and the following steps are made:

  1. Session start
  2. Session status
  3. Data exchanges between TCMS Onboard and TCMS trackside app
  4. Session end

  From performance perspective, this defines the nominal behaviour of the system.

  Comments by Nokia

IPCon setup messaging and TCMS data transfer was stable, no interruption was observed during the tests.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under TCMS tests and in subfolder 9.2.1.3 - TCMS_TC_001 (nominal communication)

Figure 68 as it can be seen the number of bytes per second received/transmitted is different as in this case the data flow in one way, from the on-board system to the trackside. No retransmissions are detected from the application to the GW.

- KONTRON_CAF_TCMS_NOMINAL_TEST_1_OB_27-01-2023.pcap:
  - Number Packets sent: 1087
  - Number Packets received: 1085
  - Number of retransmitted packets: 0
  - Average sent data rate: 3087 bits/s
  - Average received data rate: 2151 bits/s

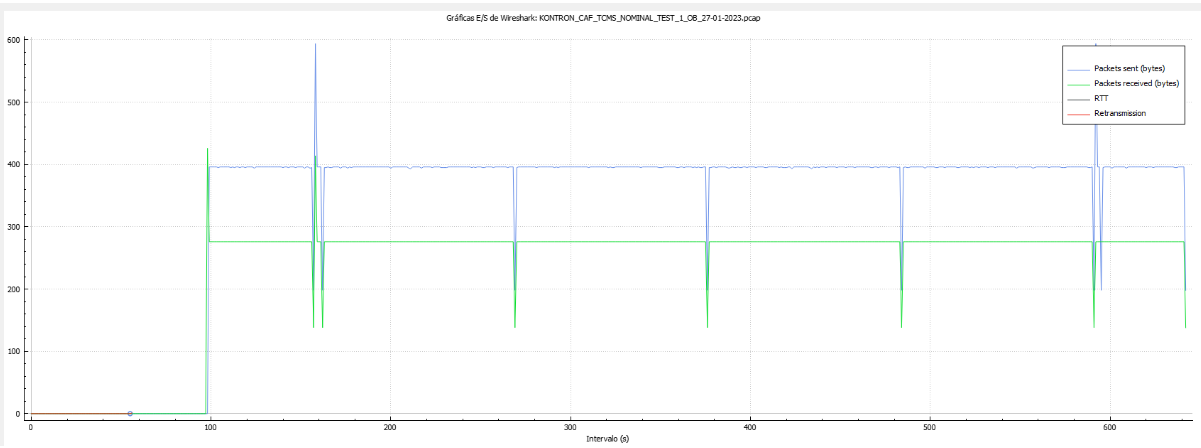


Figure 68: Packets sent/received/retransmitted of TCMS TCP data flow nominal test case

For the time impact the jitter of the received packets in the application is going to be used. This is because the TCMS information is one-way only and thus the importance is into the effect that has in the trackside. In Figure 69,the upper picture shows the transmitted packet time difference meanwhile the bottom one the time difference of the transmitted packets. The expected behavior in an ideal network is having the same shape. However, packets are suffering different delays over the network.

In this case, the performance indicator that it is going to provided is the standard deviation of the measures over the mean that it should be approximately 500ms (increased data rate test case). In this case the obtained results are around 26,4 ms, which can be acceptable and won't interfere with the application.

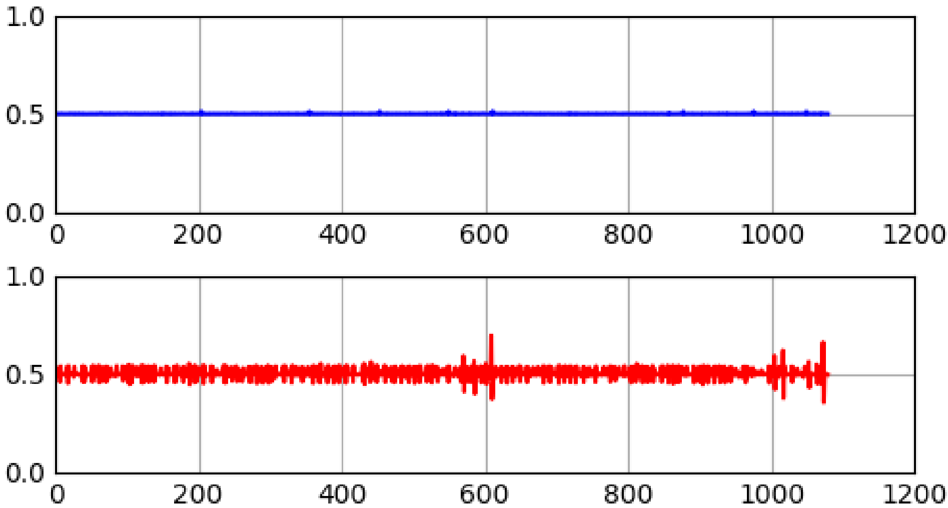


Figure 69 Time difference between consecutive packets

6.2.2 TCMS_TC_004 Nominal communication between MCG on board application and GCG, including BTS handover (same 5G network)

- **Objective of the test:**

  The purpose of this test is to check IP communication between MCG on board application and GCG on the same 5G network, while there are handovers in the 5G radio network.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.2.1.4

- **Specific Test configuration:**

  TCMS data was transferred by nominal data rate of 2 packets / sec (packet size < 100 bytes)
  Test duration was about 10 minutes to get enough packets (~ 1200 pcs) for statistical analysis.
  Radio condition was ideal, no fading effect. 5G frequency band was N78.
  5G QoS value for TCMS was set to 5QI=9, non-GBR, according to Table 1: QoS settings Chapter 2.5.

  During the test at about every 2 minutes intra-gNodeB and inter-gNodeB handovers were executed with the help of the HYTEM attenuator in order to simulate the movement between two 5G cells. The 5G Handover RF test setup with the attenuator can be found in **Figure** 47 in Chapter 5.2.2**.**

  In case of inter-gNodeB handover also the so-called intra-frequency Xn handover was triggered (see chapter 3.2.1).

- **Test results and comments:**

Test is passed.

Comments by CAF

From testcase perspective, the combined application testcase was executed using a nominal data rate from the TCMS application and having BTS handovers.

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

A TCP dump capture is set up by Nokia and the following steps are made:

1. Session start
2. Session status
3. Data exchanges between TCMS Onboard and TCMS trackside app

Session end

Comments by Nokia

IPCon setup messaging and TCMS data transfer was stable, no interruption was observed during the tests.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under

  TCMS tests and in subfolder 9.2.1.4 - TCMS_TC_004 (nominal com with BTS handover)

  Figure 70 as it can be seen the number of bytes per second received/transmitted is different as in this case the data flow in one way, from the on-board system to the trackside. In the data captures there are some packets detected as TCP Retransmission (see Figure 71). Both GNBs data captures are analyzed.

  - KONTRON_CAF_TCMS_NOMINAL_TEST_2_WITH_INTRA_INTER_HO_OB_GNB1_27-01-2023.pcap:
    - Number Packets sent: 641
    - Number Packets received: 637
    - Number of retransmitted packets: 8
    - Average sent data rate: 3068 bits/s
    - Average received data rate: 2111 bits/s

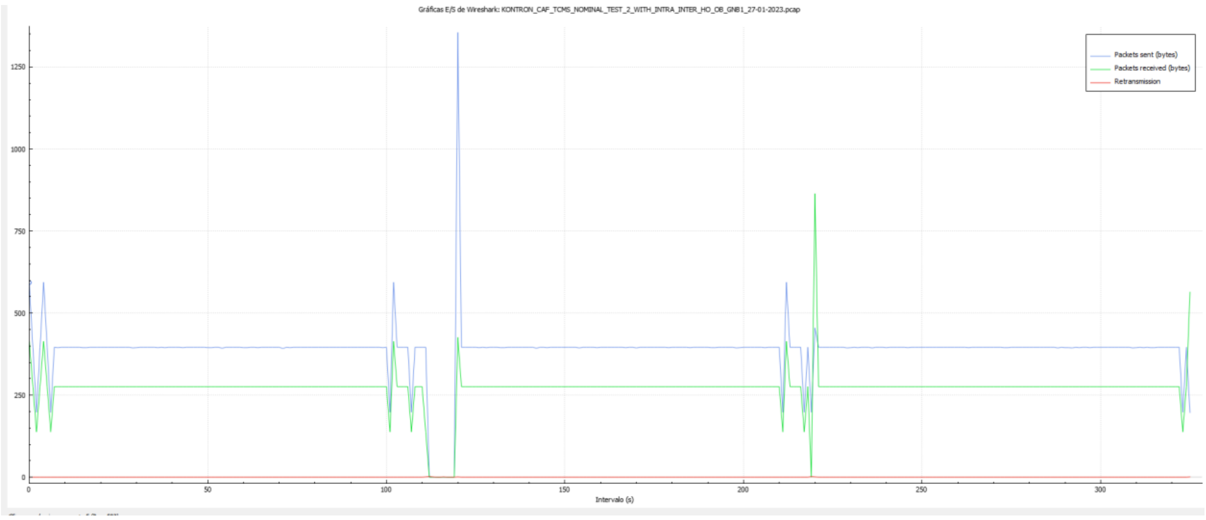


Figure 70: Packets sent/received/retransmitted of TCMS TCP data flow BTS handover GNB1 test case

463	111.775509	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Retransmission] 42861 → 1883 [PSH, ACK] Seq=13295 Ack=1 Win=229 Len=60 TSval=153184416 TSecr=4024041526
464	112.055425	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Retransmission] 42861 → 1883 [PSH, ACK] Seq=13295 Ack=1 Win=229 Len=60 TSval=153184488 TSecr=4024041526
465	112.615741	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Retransmission] 42861 → 1883 [PSH, ACK] Seq=13295 Ack=1 Win=229 Len=60 TSval=153184624 TSecr=4024041526
466	113.695442	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Retransmission] 42861 → 1883 [PSH, ACK] Seq=13295 Ack=1 Win=229 Len=60 TSval=153184896 TSecr=4024041526
467	116.048264	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Retransmission] 42861 → 1883 [PSH, ACK] Seq=13295 Ack=1 Win=229 Len=60 TSval=153185472 TSecr=4024041526
476	120.368119	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Retransmission] 42861 → 1883 [PSH, ACK] Seq=13295 Ack=1 Win=229 Len=60 TSval=153186560 TSecr=4024041526
888	219.966135	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Retransmission] 42861 → 1883 [PSH, ACK] Seq=26112 Ack=1 Win=229 Len=60 TSval=153211284 TSecr=4024068404
889	219.966135	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Retransmission] 42861 → 1883 [PSH, ACK] Seq=26112 Ack=1 Win=229 Len=60 TSval=153211348 TSecr=4024068404
893	220.031102	192.168.69.27	172.16.1.2	GTP <TCP>	198	[TCP Spurious Retransmission] 42861 → 1883 [PSH, ACK] Seq=26112 Ack=1 Win=229 Len=60 TSval=153211480 TSecr=4024068404
1323	325.221514	192.168.69.27	172.16.1.2	GTP <TCP>	197	[TCP Spurious Retransmission] 42861 → 1883 [PSH, ACK] Seq=38746 Ack=1 Win=229 Len=59 TSval=153237776 TSecr=4024094890

Figure 71 TCP Retransmission

- KONTRON_CAF_TCMS_NOMINAL_TEST_2_WITH_INTRA_INTER_HO_OB_GNB2_27-01-2023.pcap:
  - Number Packets sent: 492
  - Number Packets received: 490
  - Number of retransmitted packets: 0
  - Average sent data rate: 1243 bits/s
  - Average received data rate: 887 bits/s

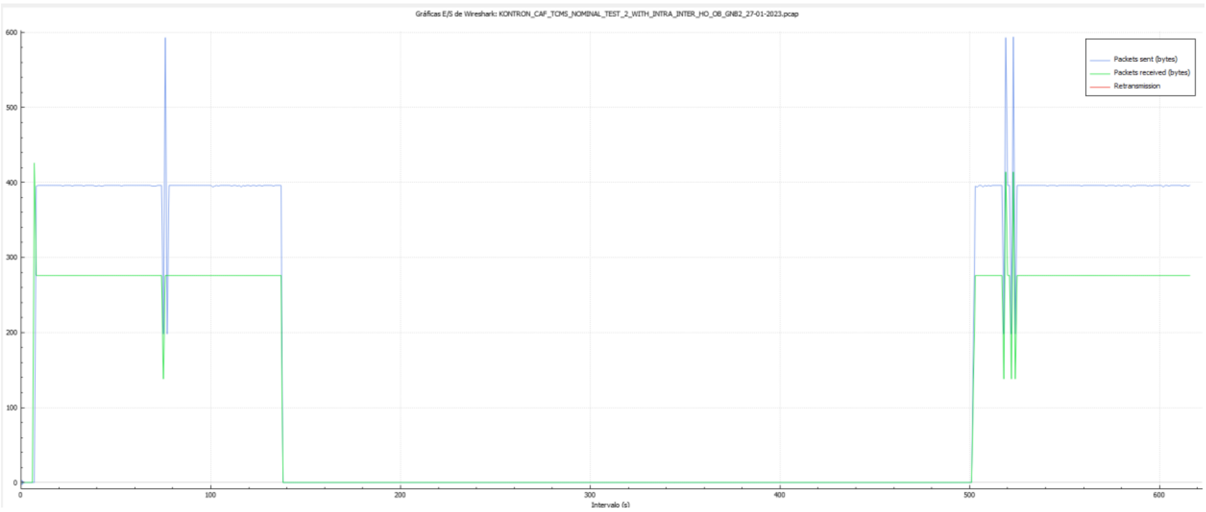


Figure 72: Packets sent/received/retransmitted of TCMS TCP data flow BTS handover GNB2 test case

For the time impact the jitter of the received packets in the application is going to be used. This is because the TCMS information is one-way only and thus the importance is into the effect that has in the trackside. In Figure 73,the upper picture shows the transmitted packet time difference meanwhile the bottom one the time difference of the transmitted packets. The expected behavior in an ideal network is having the same shape. However, packets are suffering different delays over the network.

In this case, the performance indicator that it is going to provided is the standard deviation of the measures over the mean that it should be approximately 500ms (increased data rate test case). In this case the obtained results are around 25,2 ms, which can be acceptable and won't interfere with the application.

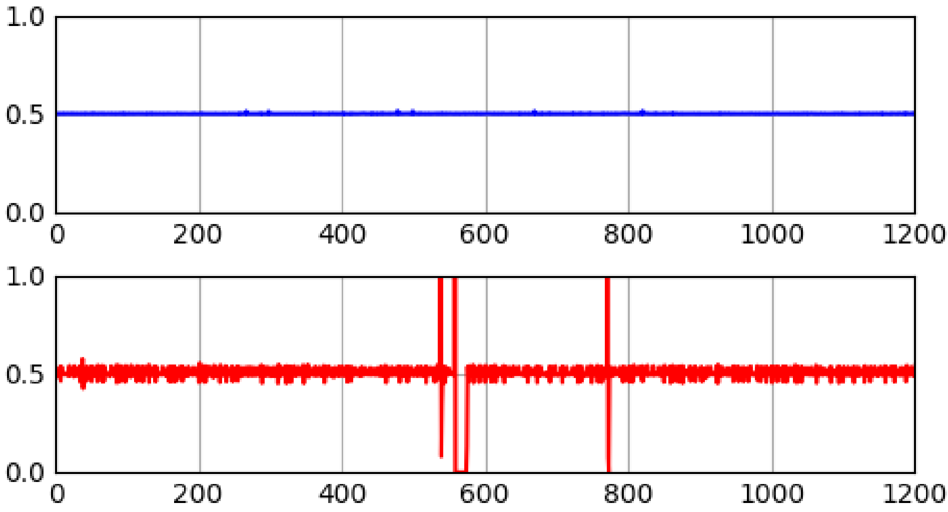


Figure 73 Time difference between consecutive packets

6.2.3 TCMS_TC_002 Evaluate FRMCS On-Board System and impact on application with degrading radio conditions

- **Objective of the test:**
  The purpose of this test is to evaluate TCMS application performance in various radio conditions and check against the nominal TCMS performance measured in TCMS_TC_001.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.2.2

- **Specific Test configuration:**
  TCMS data was transferred by nominal data rate of 2 packets / sec (packet size < 100 bytes).
  Test duration was about 10 minutes to get enough packets (~ 1200 pcs) for statistical analysis.
  5G QoS value for TCMS was set to 5QI=9, non-GBR, according to Table 1: QoS settings Chapter 2.5.
  Radio condition was degraded with variable radio signal strength incl. fading effect. Also high speed train environment was simulated. 5G frequency band was N78.

To test high speed handovers and degraded radio condition situations RF emulator tool is used, namely Spirent Vertex Channel Emulator. More info on this configuration can be found in chapter 3.4

Simulation was done with two different train speeds: 50 km/h and 120km/h. In all two scenarios a propagation model with the most challenging condition, namely with double doppler effect was applied.

Couple of inter-gNodeB handovers were executed during the simulation, where also the so-called intra-frequency Xn handover was triggered (see chapter 3.2.1).

- **Test results and comments:**

Test is passed.

Comments by CAF

From testcase perspective, the combined application testcase was executed using nominal data rate from the TCMS application.

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

A TCP dump capture is set up by Nokia and the following steps are made:

1. Session start
2. Session status
3. Data exchanges between TCMS Onboard and TCMS trackside app
4. Session end

Comments by Nokia

At simulated train speed of 50 km/h and at simulated train speed of 120 km/h: in both cases IPCon setup messaging and TCMS data transfer was stable, no interruption was observed during the tests.

- Traces and logs recorded during the test:

Traces and recordings have been saved in 5Grail collaboration Sharepoint under

TCMS tests and in subfolders:

Train speed 50 kmph

Figure 74 as it can be seen the number of bytes per second received/transmitted is different as in this case the data flow in one way, from the on-board system to the trackside. In the data captures there are some packets detected as TCP Retransmission (see Figure 76). Both GNBs data captures are analyzed.

- TCMSradiodegradationGNB1-2023-04-29.pcap:
  - Number Packets sent: 536
  - Number Packets received: 535
  - Number of retransmitted packets: 4
  - Average sent data rate: 1512 bits/s
  - Average received data rate: 1051 bits/s

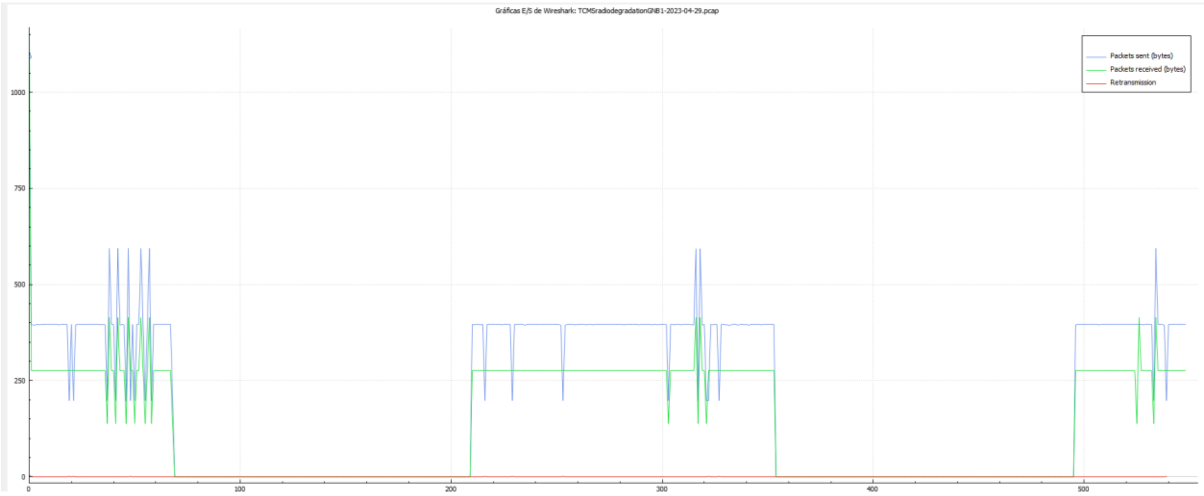


Figure 74: Packets sent/received/retransmitted of TCMS TCP data flow train speed 50km/h for GNB1

2	0.009744	192.168.69.27	172.16.1.2	GTP <TCP>	198 [TCP Retransmission] 50315 → 1883 [PSH, ACK] Seq=1 Ack=1 Win=229 Len=60 TSval=3108257 TSecr=3108089
4	0.009744	192.168.69.27	172.16.1.2	GTP <TCP>	198 [TCP Retransmission] 50315 → 1883 [PSH, ACK] Seq=1 Ack=1 Win=229 Len=60 TSval=3108320 TSecr=3108089
5	0.009744	192.168.69.27	172.16.1.2	GTP <TCP>	198 [TCP Retransmission] 50315 → 1883 [PSH, ACK] Seq=1 Ack=1 Win=229 Len=60 TSval=3108448 TSecr=3108089
6	0.009744	192.168.69.27	172.16.1.2	GTP <TCP>	198 [TCP Retransmission] 50315 → 1883 [PSH, ACK] Seq=1 Ack=1 Win=229 Len=60 TSval=3108704 TSecr=3108089

Figure 75 TCP Retransmissions

- TCMSradiodegradationGNB2-2023-04-29.pcap:
  - Number Packets sent: 794
  - Number Packets received: 795
  - Number of retransmitted packets: 0
  - Average sent data rate: 2001 bits/s
  - Average received data rate: 1399 bits/s

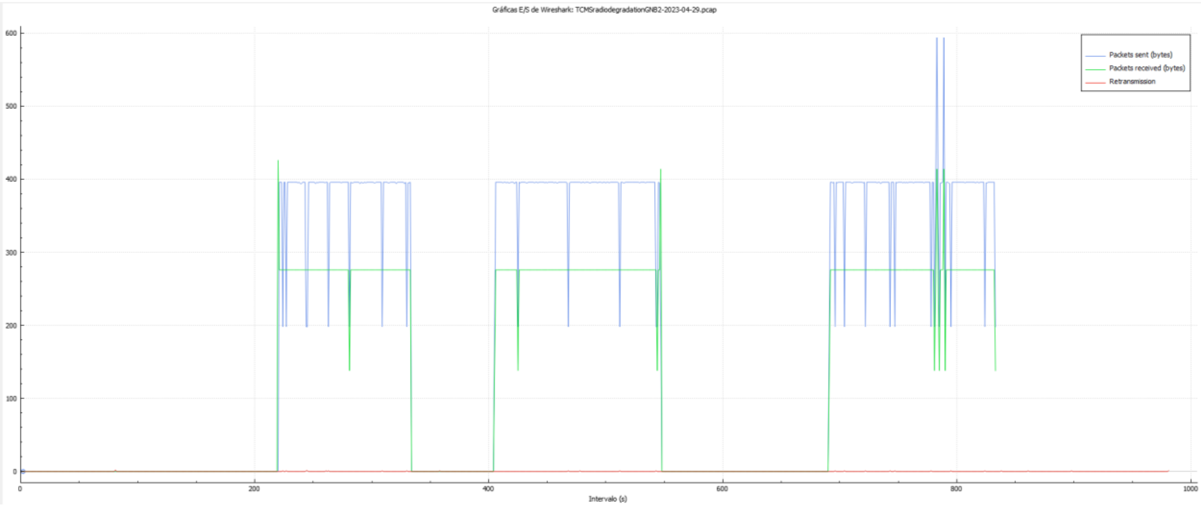


Figure 76: Packets sent/received/retransmitted of TCMS TCP data flow train speed 50km/h for GNB1

For the time impact the jitter of the received packets in the application is going to be used. This is because the TCMS information is one-way only and thus the importance is into the effect that has in the trackside. In Figure 77,the upper picture shows the transmitted packet time difference meanwhile the bottom one the time difference of the transmitted packets. The expected behavior in an ideal network is having the same shape. However, packets are suffering different delays over the network.

In this case, the performance indicator that it is going to provided is the standard deviation of the measures over the mean that it should be approximately 500ms (increased data rate test case). In this case the obtained results are around 10,1 ms, which can be acceptable and won't interfere with the application.

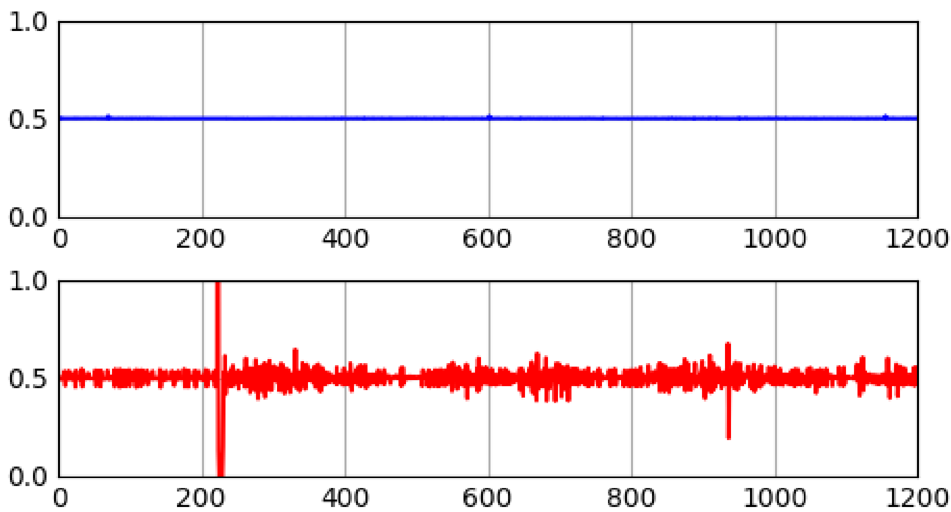


Figure 77 Time difference between consecutive packets

Train speed 120 kmph

Figure 78 as it can be seen the number of bytes per second received/transmitted is different as in this case the data flow in one way, from the on-board system to the trackside. In the data captures there are some packets detected as TCP Retransmission (see Figure 79).

- TCMS-2023-05-03-highspeed-degraded-gnb1.pcap:
  - Number Packets sent: 977
  - Number Packets received: 992
  - Number of retransmitted packets: 4
  - Average sent data rate: 1753 bits/s
  - Average received data rate: 1241 bits/s

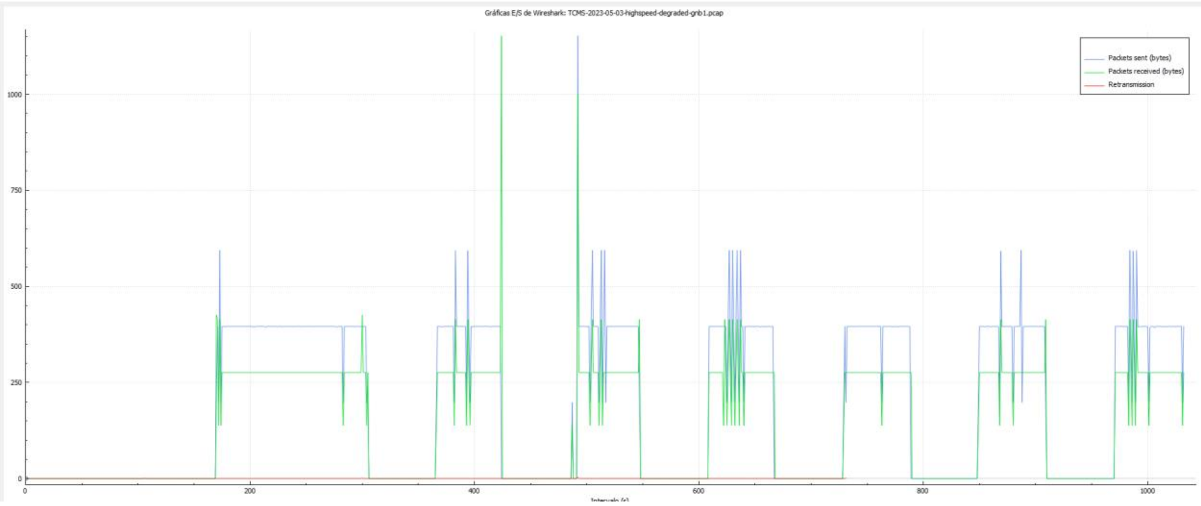
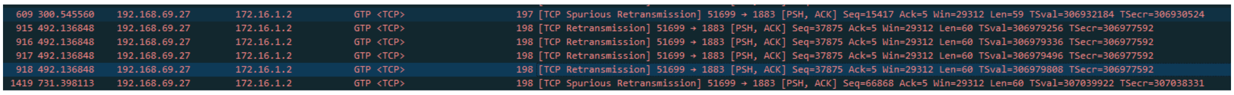


Figure 78: Packets sent/received/retransmitted of TCMS TCP data flow train speed 120km/h for GNB1



```
 609 300.545560  192.168.69.27  172.16.1.2  GTP <TCP>  197 [TCP Spurious Retransmission] 51699 → 1883 [PSH, ACK] Seq=15417 Ack=5 Win=29312 Len=59 TSval=306932184 TSecr=306930524
 915 492.136848  192.168.69.27  172.16.1.2  GTP <TCP>  198 [TCP Retransmission] 51699 → 1883 [PSH, ACK] Seq=37875 Ack=5 Win=29312 Len=60 TSval=306979256 TSecr=306977592
 916 492.136848  192.168.69.27  172.16.1.2  GTP <TCP>  198 [TCP Retransmission] 51699 → 1883 [PSH, ACK] Seq=37875 Ack=5 Win=29312 Len=60 TSval=306979336 TSecr=306977592
 917 492.136848  192.168.69.27  172.16.1.2  GTP <TCP>  198 [TCP Retransmission] 51699 → 1883 [PSH, ACK] Seq=37875 Ack=5 Win=29312 Len=60 TSval=306979496 TSecr=306977592
 918 492.136848  192.168.69.27  172.16.1.2  GTP <TCP>  198 [TCP Retransmission] 51699 → 1883 [PSH, ACK] Seq=37875 Ack=5 Win=29312 Len=60 TSval=306979808 TSecr=306977592
1419 731.398113  192.168.69.27  172.16.1.2  GTP <TCP>  198 [TCP Spurious Retransmission] 51699 → 1883 [PSH, ACK] Seq=66868 Ack=5 Win=29312 Len=60 TSval=307039922 TSecr=307038331
```

Figure 79 TCP Retransmission

- TCMS-2023-05-03-highspeed-degraded-gnb2.pcap:
  - Number Packets sent: 809
  - Number Packets received: 811
  - Number of retransmitted packets: 0
  - Average sent data rate: 1645 bits/s
  - Average received data rate: 1150 bits/s

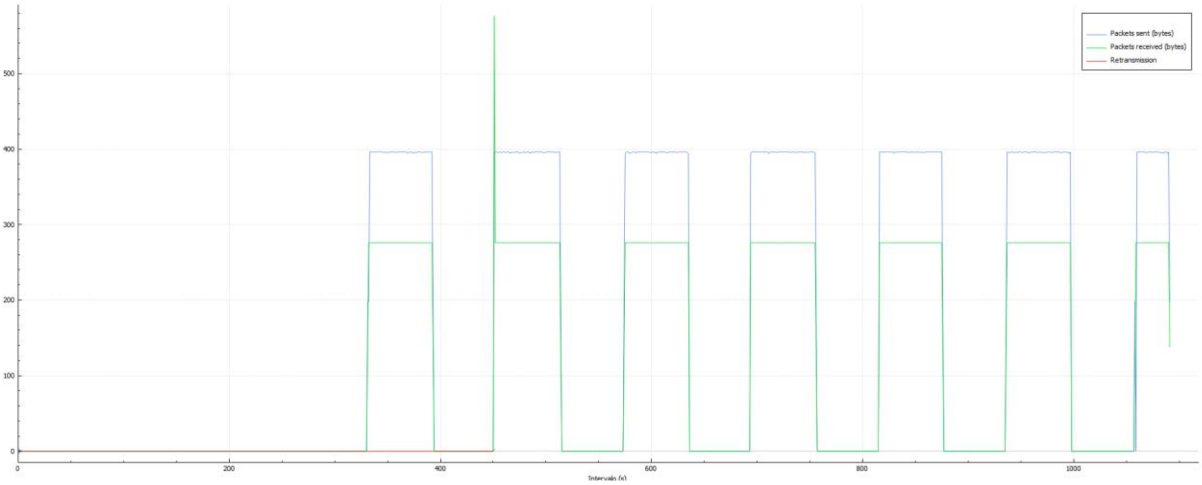


Figure 80: Packets sent/received/retransmitted of TCMS TCP data flow train speed 120km/h for GNB2

For the time impact the jitter of the received packets in the application is going to be used. This is because the TCMS information is one-way only and thus the importance is into the effect that has in the trackside. In Figure 81,the upper picture shows the transmitted packet time difference meanwhile the bottom one the time difference of the transmitted packets. The expected behavior in an ideal network is having the same shape. However, packets are suffering different delays over the network.

In this case, the performance indicator that it is going to provided is the standard deviation of the measures over the mean that it should be approximately 500ms (increased data rate test case). In this case the obtained results are around 10,2 ms, which can be acceptable and won't interfere with the application.

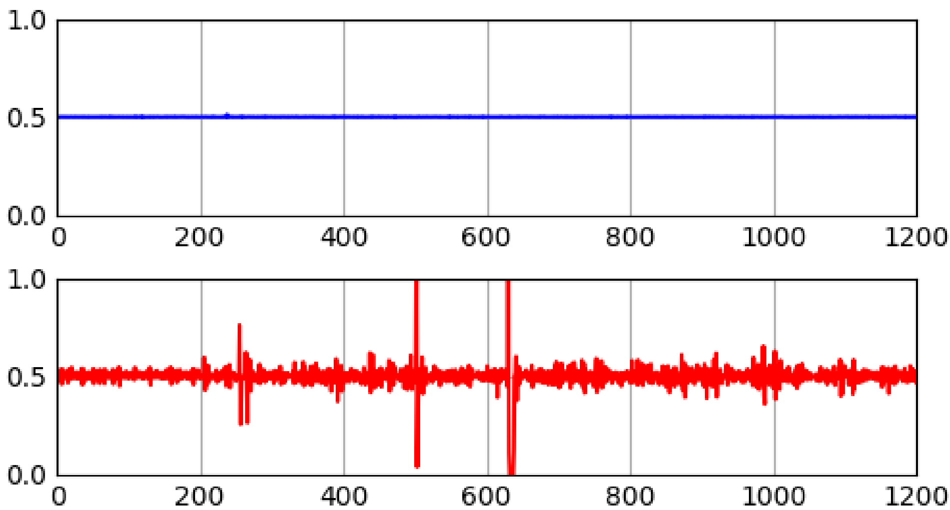


Figure 81 Time difference between consecutive packets

6.2.4 TCMS_TC_003 Cross border scenario with TCMS – Telemetry OPTIONAL

- **Objective of the test:**
  The purpose of this test is to evaluate FRMCS network performance when there is a cross border happening, using TCMS Telemetry Service as an example. Other MCData application (e.g., Video) can also be tested based on the lab feedback.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.2.3

- **Specific Test configuration:**
  N/A

- **Test results and comments:**
  This testcase was not executed, as the same border crossing testcase is defined for video (Video_TC_004). This testcase is anyway optional.

  Comments by CAF

  N/A

  Comments by …

  N/A

- Traces and logs recorded during the test:

  Following traces have been recorded: N/A

6.2.5 TC_001 Nominal communication between GCG trackside application and onboard MCG (same 5G network) (remote control of equipment)

- **Objective of the test:**
  The purpose of this test is to check IP communication between GCG trackside application and onboard MCG on the same 5G network, started by the GCG.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.3.1

- **Specific Test configuration:**
  Radio condition was ideal, no fading effect, no simulation of movement. 5G frequency band was N78.

5G QoS value for TCMS was set to 5QI=9, non-GBR, according to Table 1: QoS settings Chapter 2.5.

- **Test results and comments:**

Test is passed.

Comments by CAF

From testcase perspective, the combined application testcase was executed using a nominal data rate from the TCMS application and having a HTTP message exchange in parallel.

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

A TCP dump capture is set up by Nokia and the following steps are made:

1. Session start
2. Session status
3. Data exchanges between TCMS Onboard and TCMS trackside app
4. HTTP message exchange
5. Session end

Comments by Nokia

An HTML request was sent by the GCG and MCG replied.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under TCMS tests and in subfolder 9.3.1 - TC_001 Nominal communication from GCG to MCG (with HTTP request)

Figure 82 the as it can be seen the number of bytes per second received/transmitted is different as in this case the data flow in one way, from the on-board system to the trackside. The HTTP request is negligible compared to the TCMS data transferred and not visible in the diagram. In the data captures there are some packets detected as TCP Retransmission (see Figure 83). Finally, the HTTP request is shown in Figure 83 as a peculiarity the message is retransmitted, however, at application level did not have any consequence.

- CAF_KONTRON_GCG_MCG_DATA_WITH_HTML_OB_2023-02-01.pcap:
  - Number Packets sent: 112
  - Number Packets received: 110
  - Number of retransmitted packets: 1
  - Average sent data rate: 3149 bits/s
  - Average received data rate: 2186 bits/s

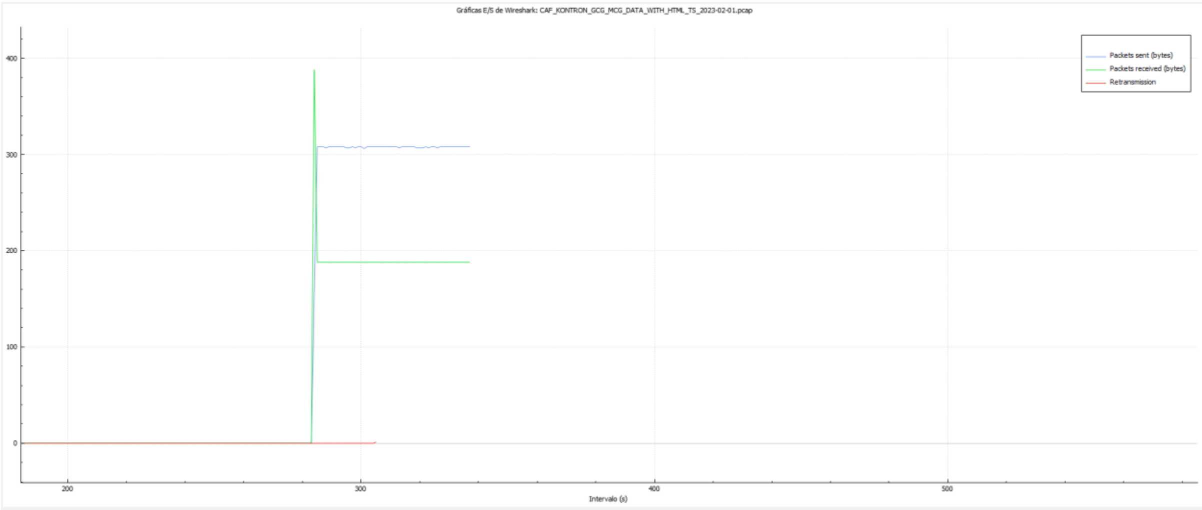


Figure 82: Packets sent/received/retransmitted of TCMS TCP data flow nominal test case

198	444.914356	192.168.69.35	172.16.2.1	GTP <HTTP/JSON>	389	POST / HTTP/1.1 , JavaScript Object Notation (application/json)
199	444.957781	192.168.69.35	172.16.2.1	GTP <TCP>	389	[TCP Retransmission] 57676 → 9000 [PSH, ACK] Seq=201 Ack=1 Win=29312 Len=251 TSval=4132661324 TSecr=261804561
200	444.966500	172.16.2.1	192.168.69.35	GTP <TCP>	138	9000 → 57676 [ACK] Seq=1 Ack=201 Win=30080 Len=0 TSval=261804567 TSecr=4132661313
201	444.966500	172.16.2.1	192.168.69.35	GTP <TCP>	138	9000 → 57676 [ACK] Seq=1 Ack=452 Win=31104 Len=0 TSval=261804567 TSecr=4132661313
202	444.971486	172.16.2.1	192.168.69.35	GTP <TCP>	342	9000 → 57676 [PSH, ACK] Seq=1 Ack=452 Win=31104 Len=204 TSval=261804568 TSecr=4132661313 [TCP segment of a reassembled PDU]
203	444.971486	172.16.2.1	192.168.69.35	GTP <HTTP>	155	HTTP/1.1 200 OK (text/html)
204	444.971486	172.16.2.1	192.168.69.35	GTP <TCP>	150	[TCP Dup ACK 201#1] 9000 → 57676 [ACK] Seq=223 Ack=452 Win=31104 Len=0 TSval=261804576 TSecr=4132661324 SLE=201 SRE=452
205	444.974067	192.168.69.35	172.16.2.1	GTP <TCP>	138	57676 → 9000 [ACK] Seq=452 Ack=205 Win=30336 Len=0 TSval=4132661328 TSecr=261804568
206	444.981751	192.168.69.35	172.16.2.1	GTP <TCP>	138	57676 → 9000 [FIN, ACK] Seq=452 Ack=223 Win=30336 Len=0 TSval=4132661329 TSecr=261804568

Figure 83 HTTP communication

For the time impact the jitter of the received packets in the application is going to be used. This is because the TCMS information is one-way only and thus the importance is into the effect that has in the trackside. In Figure 84,the upper picture shows the transmitted packet time difference meanwhile the bottom one the time difference of the transmitted packets. The expected behavior in an ideal network is having the same shape. However, packets are suffering different delays over the network.

In this case, the performance indicator that it is going to provided is the standard deviation of the measures over the mean that it should be approximately 500ms (increased data rate test case). In this case the obtained results are around *1,3 ms, which can be acceptable and won't interfere with the application.

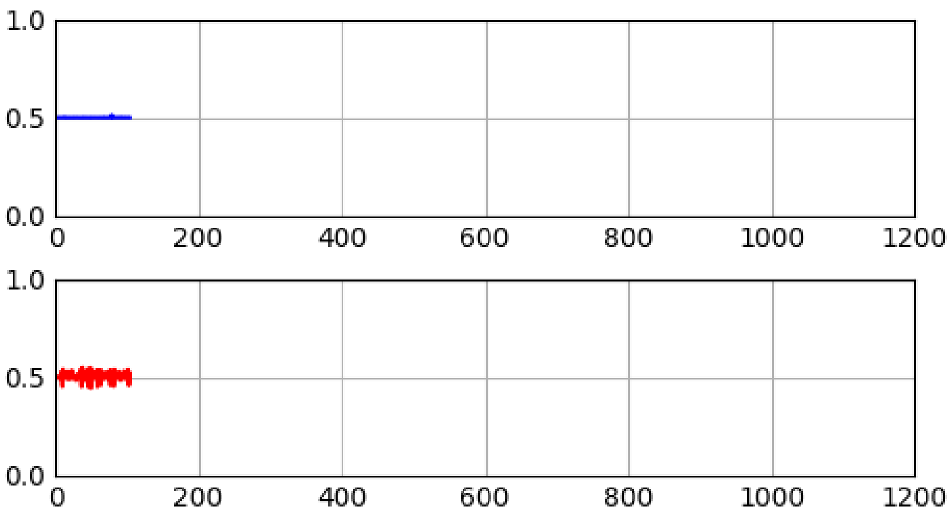


Figure 84 Time difference between consecutive packets

Note : In this case the information is not really relevant as the aims was to validate the parallel communication and the number of samples was reduced.

6.3 Conclusion on TCMS tests

In general, it can be concluded that all the TCMS tests were executed with successful results.

The one optional testcase (TCMS_TC_003) was not executed, instead border crossing with video type application (constant bit rate) was selected.

Regarding the behaviour of the systems, it can be seen that GNB1 is less reliable that the GNB2 due to the faced retransmission but in the overall it does not affect to the nominal behaviour.

The data rate information in the cases where handovers have happened could be misleading as the value is calculated by diving the amount of data over the time (including the gaps, where the other GNB was working).

7 Video Tests

7.1 Introduction to Video tests

There are two types of use cases for Video tests:

Non-critical real time video streaming is live streaming of CCTV video from the onboard video management system into the trackside video management system. This application facilitates data communication for real time transmission of video for non-critical railway operation.

Transfer of CCTV archives that is off-loading of archived video surveillance data from the onboard video recorder into the trackside video management system e.g. whenever the train approaches the stations and/or stops or arrives at the depot.

Non-critical real time video is considered as an effective mitigation measure to optimize the performance and safety of the railway system. The application can be used for example for:

- Passenger Information
- Help Points
- Ticketing
- To transfer video in parallel with voice communication
- Supervision of railway assets and passengers

For the Non-critical real time video streaming use case the Trackside application initiates the connection (session) from the Trackside to the On-board over Trackside FRMCS Gateway.

For the Transfer of CCTV archives use case the onboard application initiates the connection (session) from the On-board to the Trackside over On-board FRMCS Gateway.

Both use cases are independent and applications are designed to work independently, but at the same time allowing for simultaneous operations.

To achieve this a second MCX client was required on the Trackside. So, in total 3 MCX clients (2 in Trackside FRMCS Gateway and 1 in On-board FRMCS Gateway) were required.

The Trackside was registering with IDs "00100100015" and "00100100016". The On-board side was registering with ID "00100100014".

During the tests simultaneous operations were not used. CCTV Offload data session opening was disabled during real time video streaming tests and real time video streaming data session opening was disabled during CCTV offload tests.

From integration perspective, it was observed that the TOBA GW (after start or restart) needs to send ICMP ping request to devices before WebSocket IP can be reachable.

- FRMCS GW gets stuck when session start is initiated before registration process is completed and therefore currently the registration process and the session start are enabled manually on the application side.

7.2 Video tests

The following table gives information about Video tests were planned to be executed:

TC_ID	Test case	optional	Frequency	Date of execution
Video_TC_001	Nominal communication: Streaming of video from train to trackside	no	n78&n8	06.03.2023
Video_TC_003	Streaming of video from train to trackside including BTS handover (same 5G network)	no	n78&n8	06.03.2023
Video_TC_002	Degraded communication: streaming of video from train to trackside	no	n78&n8	28.04.2023 12.05.2023
Video_TC_004	Cross-border with streaming of video from train to trackside, using inter-gNodeB handover over AMF	no	n78	September 2023, Executed using iPerf for constant data rate
CCTV_TC_001	CCTV offload from train to trackside	no	n78&n8	19.06.2023
CCTV_TC_002	CCTV offload from train to trackside with bearer-flex	no	n78&n8	19.06.2023

Table 5: List of Video test cases planned in the WP3 lab

7.2.1 Video_TC_001 Video integration test - nominal comm. Testing Streaming of video from train to trackside

- **Objective of the test:**
  The purpose of this test case is to test live streaming of CCTV video from the onboard video management system into the trackside video management system in nominal communication.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.4.1.3

- **Specific Test configuration:**
  The test was executed with a video stream coded with 1 mbps bitrate. Radio condition was ideal, no fading effect, no simulation of movement. Radio signal strength was 93% according to the OB GW. 5G frequency band was N78.
  5G QoS value for video was set to 5QI=7, non-GBR, according to Table 1: QoS settings Chapter 2.5.

- **Test results and comments:**

  Test is passed.

  Comments by Teleste

  During the test the visual effects of the video was good, framerate was kept within expected rage.

  No significant TCP retransmissions observed in the traces for a video session.

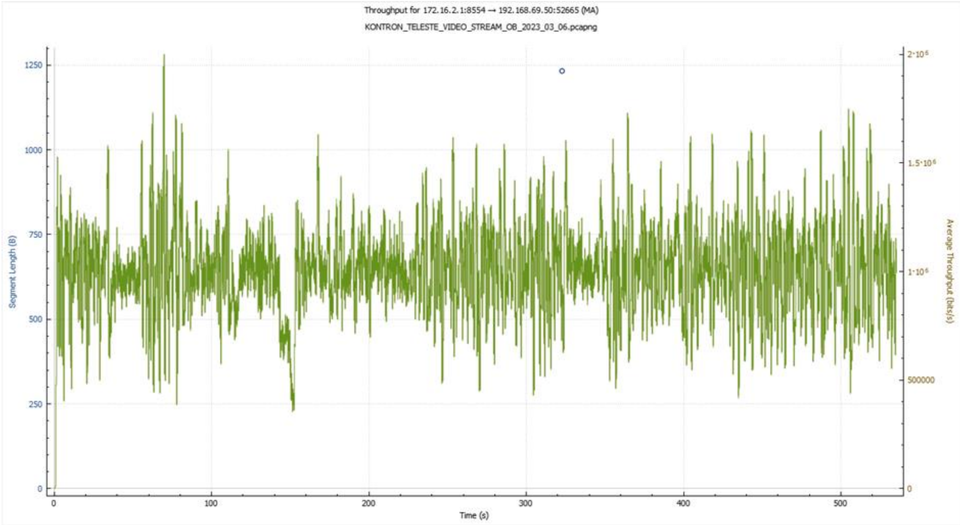


Figure 85 Video streaming nominal conditions – throughput/goodput

Detailed Wireshark dumps analyses of RTP packets shows 6 packets lost and 4 sequence errors.

172.16.2.1:8554 →
192.168.69.50:52665

SSRC	0x29fbdc01
Max Delta	300.032000 ms @ 20366
Max Jitter	0.000000 ms
Mean Jitter	0.000000 ms
Max Skew	0.000000 ms
RTP Packets	55104
Expected	55110
Lost	6 (0.01 %)
Seq Errs	4
Start at	356.010828 s @ 243
Duration	533.95 s
Clock Drift	0 ms
Freq Drift	0 Hz (0.00 %)

Figure 86 Video streaming nominal conditions – RTP Stream Analysis

Comments by Nokia

The video view and object move within the view was smooth, no major jerks or picture blinking, trackside VMS indicated around 20-25 fps on the display overlay. This means the quality of the video was nearly perfect (see Figure 87).

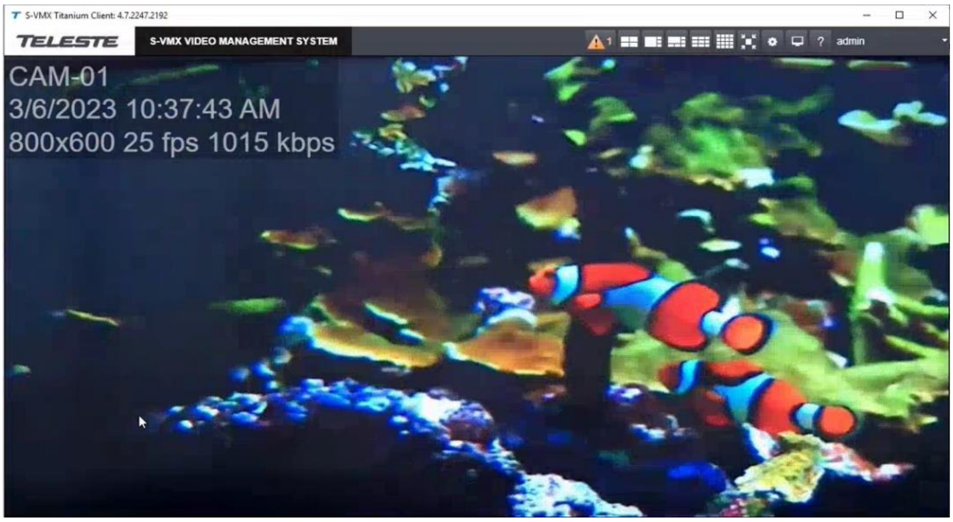


Figure 87 Video streaming with nearly perfect quality in ideal radio conditions

- Traces and logs recorded during the test:

  Traces and recordings have been saved in 5Grail collaboration Sharepoint under

  Video tests and in subfolder 1mbps_06032023.

7.2.2 Video_TC_003 Streaming of video from train to trackside (nominal conditions including BTS handover also)

- **Objective of the test:**
  The purpose of this test case is to test live streaming of CCTV video from the onboard video management system into the trackside video management system in nominal communication including BTS handovers.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.4.1.4

- **Specific Test configuration:**
  The test was executed with a video stream coded with 1 mbps bitrate. Radio condition was ideal, no fading effect. Radio signal strength was 93% according to the OB GW. 5G frequency band was N78.
  5G QoS value for video was set to 5QI=7, non-GBR, according to Table 1: QoS settings Chapter 2.5.
  During the test a couple of intra-gNodeB and inter-gNodeB handovers were executed with the help of the HYTEM attenuator in order to simulate the movement between two 5G cells. The 5G Handover RF test setup with the attenuator can be found in Figure 47 in Chapter 5.2.2

In case of inter-gNodeB handover also the so-called intra-frequency Xn handover was triggered (see Chapter Intra-frequenc Xn based handover3.2.1).

- **Test results and comments:**

Test is passed.

Comments by Teleste

Inter-gNodeB handovers did not impacted the video that could be easily noticeable on the screen. Intra-gNodeB handovers impacted the video presentation for a short time.

No significant TCP retransmissions observed in the traces for the video session. Wireshark dumps analyses of RTP session throughput shown very short transmission brake during handovers, and immediate buffered data transmission (increased throughput) after re-connection.

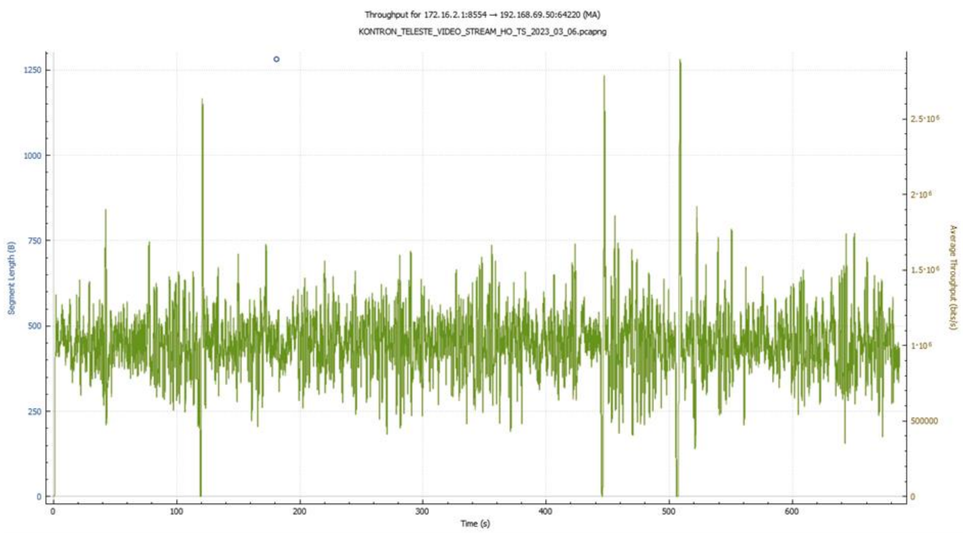


Figure 88 Video streaming nominal conditions with BTS handover – throughput/goodput

Detailed Wireshark dumps analyses of RTP packets shows 10 packets lost and 7 sequence errors.

172.16.2.1:8554 →
192.168.69.50:64220

SSRC	0x32778148
Max Delta	2322.592000 ms @ 127424
Max Jitter	0.000000 ms
Mean Jitter	0.000000 ms
Max Skew	0.000000 ms
RTP Packets	71053
Expected	71063
Lost	10 (0.01 %)
Seq Errs	7
Start at	63.668774 s @ 304
Duration	685.64 s
Clock Drift	0 ms
Freq Drift	0 Hz (0.00 %)

Figure 89 Video streaming nominal conditions including BTS handover – RTP Stream Analysis

Comments by Nokia

During the inter-gNodeB handovers the video quality remained nearly perfect: the video view and object move within the view was smooth, no major jerks or picture blinking, trackside VMS indicated around 20-25 fps on the display overlay. So no noticeable change in video quality was observed.

During the intra-gNodeB handovers there was a noticeable freeze of the video stream for about 2 sec. The framerate dropped a bit indicating that there was buffering during the handover. But there was no frame loss shown on the display.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under Video tests and in subfolder: 9.4.1. - Video_TC_003 (streaming with BTS handover)

7.2.3 Video_TC_002 Degraded communication: streaming of video from train to trackside

- **Objective of the test:**
  The purpose of this test case is to test live streaming of CCTV video from the onboard video management system into the trackside video management system in degraded communication.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.4.2

- **Specific Test configuration:**

The test was executed with a video stream coded with 1 mbps bitrate. Radio condition was degraded with variable radio signal strength incl. fading effect. Also high speed train environment was simulated. 5G frequency band was N78.
5G QoS value for video was set to 5QI=7, non-GBR, according to Table 1: QoS settings Chapter 2.5.
To test high speed handovers and degraded radio condition situations RF emulator tool is used, namely Spirent Vertex Channel Emulator. More info on this configuration can be found in chapter 2.4

Simulation was done with three different train speeds: 50 km/h, 120km/h and 175 km/h. In all three scenarios a propagation model with the most challenging condition, namely with double doppler effect was applied.

Couple of inter-gNodeB handovers were executed during the simulation, where also the so-called intra-frequency Xn handover was triggered (see chapter 3.2.1).

- **Test results and comments:**

Test is passed.

Comments by Teleste

At simulated train speed of 50 km/h

During the test brake in the video session has occurred, the onboard application could not send any data over the network within 10s, that resulted in a view on the screen in the trackside app being stopped for a while.

Wireshark dumps analyses of RTP session throughput shown 10s transmission brake during test for unknown reason. Increased throughput as of TCP retransmissions observed in the traces for the video session (throughput vs goodput).

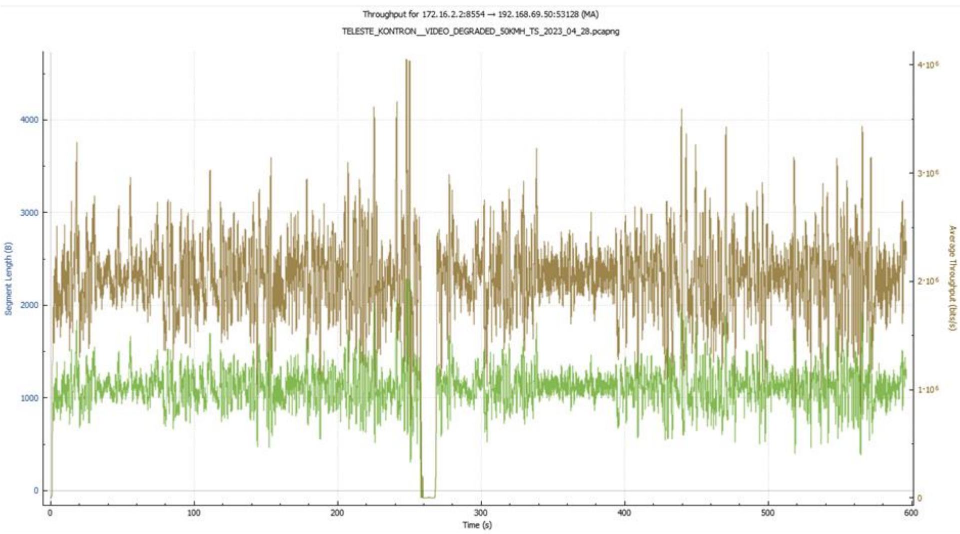


Figure 90 Video streaming at simulated train speed of 50 km/h– – throughput/goodput

Detailed Wireshark dumps analyses of RTP packets shows 1102 packets lost (due to connection lost) and 2 sequence errors.

172.16.2.2:8554 →
192.168.69.50:53128

SSRC	0x82868ab1
Max Delta	9370.482000 ms @ 134663
Max Jitter	0.000000 ms
Mean Jitter	0.000000 ms
Max Skew	0.000000 ms
RTP Packets	60633
Expected	61735
Lost	1102 (1.79 %)
Seq Errs	2
Start at	205.693357 s @ 563
Duration	595.15 s
Clock Drift	0 ms
Freq Drift	0 Hz (0.00 %)

Figure 91 Video streaming at simulated train speed of 50 km/h– RTP Stream Analysis

Except for this short anomaly, no significant visual degradation in video quality was observed.

At simulated train speed of 120km/h

No significant visual degradation in video quality was observed.

Increased throughput as of TCP retransmissions observed in the traces for the video session (throughput vs goodput).

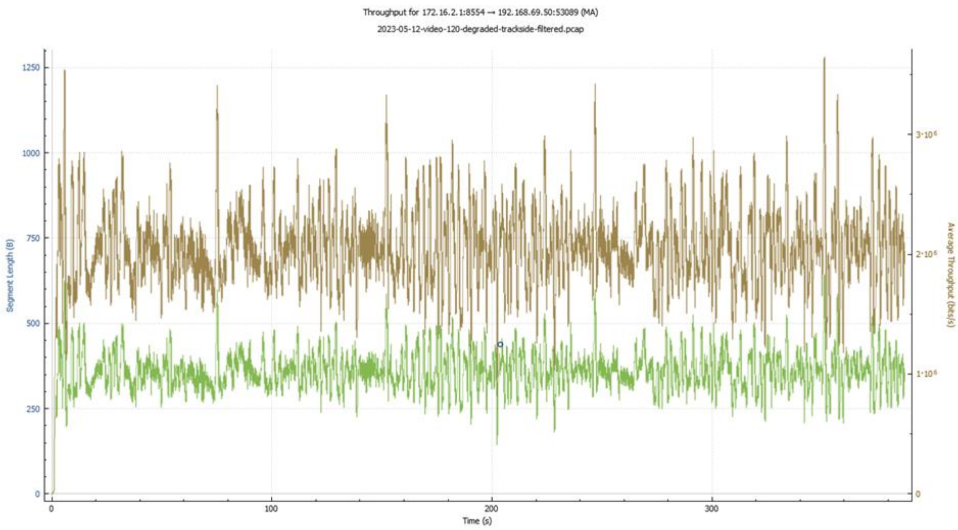


Figure 92 Video streaming at simulated train speed of 120km/h– – throughput/goodput

Detailed Wireshark dumps analyses of RTP packets show 1 packet lost and 1 sequence error.

172.16.2.1:8554 →
192.168.69.50:53089

SSRC	0xb3b68bcb
Max Delta	307.165000 ms @ 174230
Max Jitter	0.000000 ms
Mean Jitter	0.000000 ms
Max Skew	0.000000 ms
RTP Packets	40268
Expected	40269
Lost	1 (0.00 %)
Seq Errs	1
Start at	55.329577 s @ 327
Duration	386.56 s
Clock Drift	0 ms
Freq Drift	0 Hz (0.00 %)

Figure 93 Video streaming at simulated train speed of 120km/h– RTP Stream Analysis

At simulated train speed of 175 km/h

There was a slight degradation of the video form time to time, small picture jerks as well as fps drops and increase due to the video buffering that could not be send immediately.

Increased throughput as of TCP retransmissions observed in the traces for the video session (throughput vs goodput).

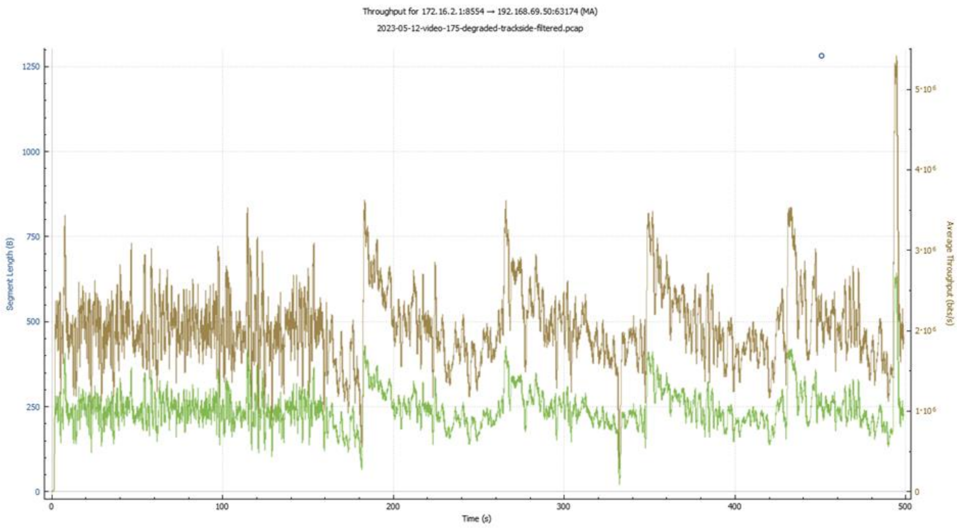


Figure 94 Video streaming at simulated train speed of 175 km/h– – throughput/goodput

Detailed Wireshark dumps analyses of RTP packets show 17 packets lost and 5 sequence errors.

172.16.2.1:8554 →
192.168.69.50:63174

SSRC	0x32f0f632
Max Delta	407.344000 ms @ 175737
Max Jitter	0.000000 ms
Mean Jitter	0.000000 ms
Max Skew	0.000000 ms
RTP Packets	51577
Expected	51594
Lost	17 (0.03 %)
Seq Errs	5
Start at	229.405198 s @ 359
Duration	497.56 s
Clock Drift	0 ms
Freq Drift	0 Hz (0.00 %)

Figure 95 Video streaming at simulated train speed of 175 km/h– RTP Stream Analysis

Comments by Nokia

At simulated train speed of 50 km/h, and also at simulated train speed of 120km/h the perceived video quality was acceptable. During handovers no degradation in video quality was observed. Sometimes the framerate was dropped, assumably due to temporary bandwidth degradations.

At simulated train speed of 175 km/h there was slight degradation of the perceived quality, but still acceptable. Framerate of the video stream was dropping frequently from 25 fps to 15 fps and above (see Figure 96). Also the bitrate was dropping from 1000 kbps to 600 kbps and above. During handovers buffering occurred, as framerate and as well as bitrate exceeded above 25 fps and 1000 kbps after the handover in order to send buffered data.

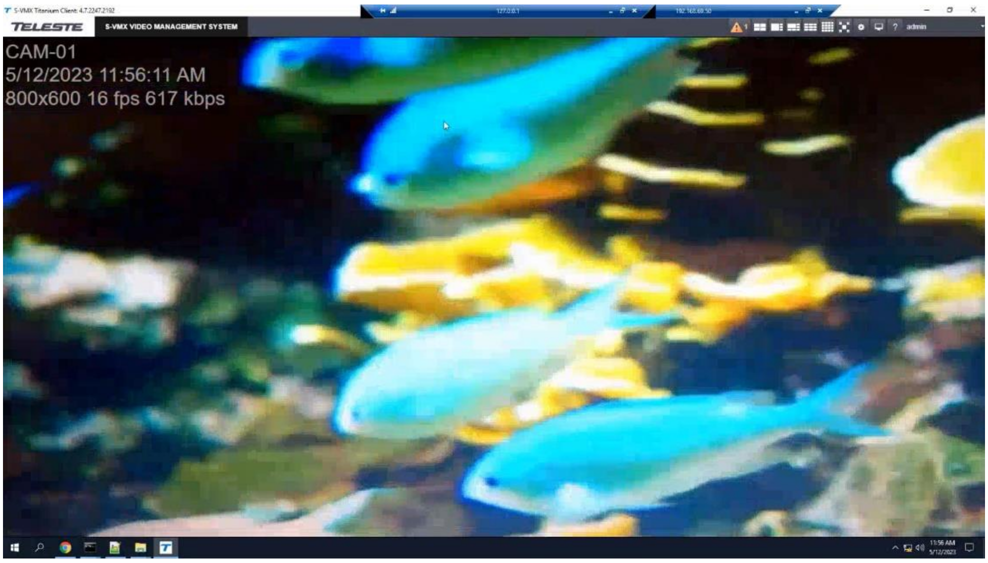


Figure 96 Video streaming quality at simulated trains speed of 175 km/h

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under
  Video tests and in the following subfolders:
  train speed 50 kmph

  train speed 120kmph

  train speed 175kmph

7.2.4 Video_TC_004 Border crossing from train to trackside - inter AMF handover

- **Objective of the test:**
  The purpose of this test is to demonstrate that the performance of Video application is not impacted in border-crossing conditions.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.4.3

- **Specific Test configuration:**
  In the WP3 framework the border-crossing is implemented as an inter-gNodeB handover between AMFs (using NG interface). In that case only one IP address is used, as if it was one PLMN, although there are two 5G cores implemented.
  More info on border crossing test setup can found in chapter 3.8 (and about border crossing concept in general in chapter 2.2)

5G QoS value for video was set to 5QI=7, non-GBR, according to Table 1: QoS settings Chapter 3.10.

- **Test results and comments:**

  The test was executed using iPerf continuous data stream

  Comments by Teleste

  N/A

  Comments by Nokia

  N/A.

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under Video tests

7.2.5 CCTV_TC_001 CCTV offload from train to trackside

- **Objective of the test:**
  In a CCTV offload system, FRMCS provides means for transferring video surveillance data between a mobile communication unit in the train and ground communication units located at the depot and at the stations and/or stops alongside the predetermined route of the train. Whenever the train approaches the stations and/or stops or arrives at the depot, FRMCS facilitates the communication between the mobile and ground communication unit. The mobile communication unit in the train forwards the video surveillance data from the onboard video recorder to Trackside VMS.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.5.1

- **Specific Test configuration:**
  Radio condition was ideal, no fading effect. 5G frequency band was N78.
  5G QoS value for video was set to 5QI=7, non-GBR, according to Table 1: QoS settings Chapter 2.5.
  In the tests it was also simulated as if the train was leaving the station e.g. moving out of radio coverage of the radio cell during the CCTV offload in order to see if this has any impact on the performance of the CCTV offload.

- **Test results and comments:**

Test is passed.

Comments by Teleste

No additional comments.

Comments by Nokia

From the integration point of view, it shall be mentioned that on the trackside two MCX clients were needed to handle CCTV offload. So in total 3 MCX clients (2 in TS GW and 1 in OB GW) were required.

As for the CCTV offload (that is the upload of the CCTV video surveillance data), it was transferred at about 11 Mbps, almost constantly, without any issue. Then the radio cell was locked (radio coverage was completely removed) and therefore CCTV offload stopped. Then radio cell was unlocked (radio coverage was back again) and the CCTV offload continued in about 1,5 minutes, without any issue. (see Figure 97)

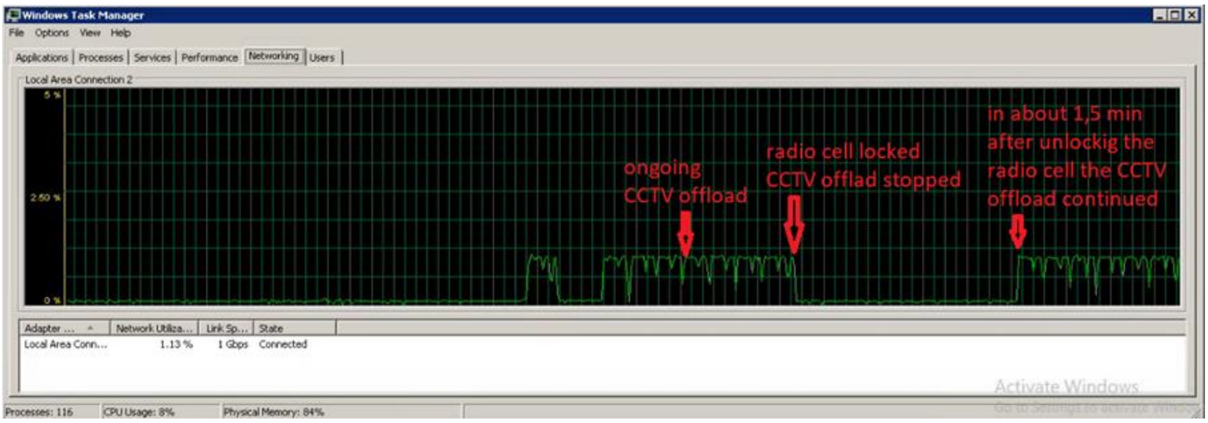


Figure 97 Interface bandwidth monitoring during CCTV offload test

- Traces and logs recorded during the test:

Traces and recordings have been saved in 5Grail collaboration Sharepoint under

Video tests and in subfolder radio signal loss by radio cell lock

7.2.6 CCTV_TC_002 CCTV offload from train to trackside with bearer-flex

- **Objective of the test:**
  In a CCTV offload system, FRMCS provides means for transferring video surveillance data between a mobile communication unit in the train and ground communication units located at the depot and at the stations and/or stops alongside the predetermined route of the train. Whenever the train approaches the stations and/or stops or arrives at the depot, FRMCS facilitates the communication between the mobile and ground communication unit with the frequency available at stations and depots.
  FRMCS facilitates the communication between the mobile and ground communication unit outside of the depots or stops as well using other links / sub-bands with the frequency available along track. With this use case the bearer flexibility is demonstrated as multi access use case using two sub bands for track and station coverage.

- **Test description:**

  This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.5.2

- **Specific Test configuration:**
  The generic Bearer flexibility test setup is described in chapter 2.1.
  During the test an inter-frequency Xn handover was executed with the help of the HYTEM attenuator in order to simulate the movement from Cell1 (track) to Cell2 (station). These cells were on different frequency subbands of N78. See more details about this handover setup in Chapter 3.2.2.
  During the test the radio condition was ideal, no fading effect. Cell1 and Cell2 were configured also with different frame structures in order to achieve higher bandwidth in Cell2, as described in chapter 3.7.
  In Cell1 there was also background traffic generated to lower the available bandwidth for CCTV offload in Cell1.
  5G QoS value for video was set to 5QI=7, non-GBR, according to Table 1: QoS settings Chapter 2.5.

- **Test results and comments:**

  Test is passed.

  Comments by Teleste

  No additional comments.

  Comments by Nokia

  From the integration point of view, it shall be mentioned that on the trackside two MCX clients were needed to handle CCTV offload. So in total 3 MCX clients (2 in TS GW and 1 in OB GW) were required.

  At the beginning of the test, the CCTV offload, actually the upload of CCTV video surveillance data was transferred in Cell1 at about 11 Mbps, almost constantly, without any issue. Then background traffic was generated in Cell1, which lowered the bandwidth of CCTV offload to about 6 Mbps. After 2 minutes, the CCTV offload moved from Cell1 to Cell2, when suddenly the bandwidth of the CCTV offload increased to about 17 Mbps in Cell2. (see Figure 98). The test behaved successfully, as expected.

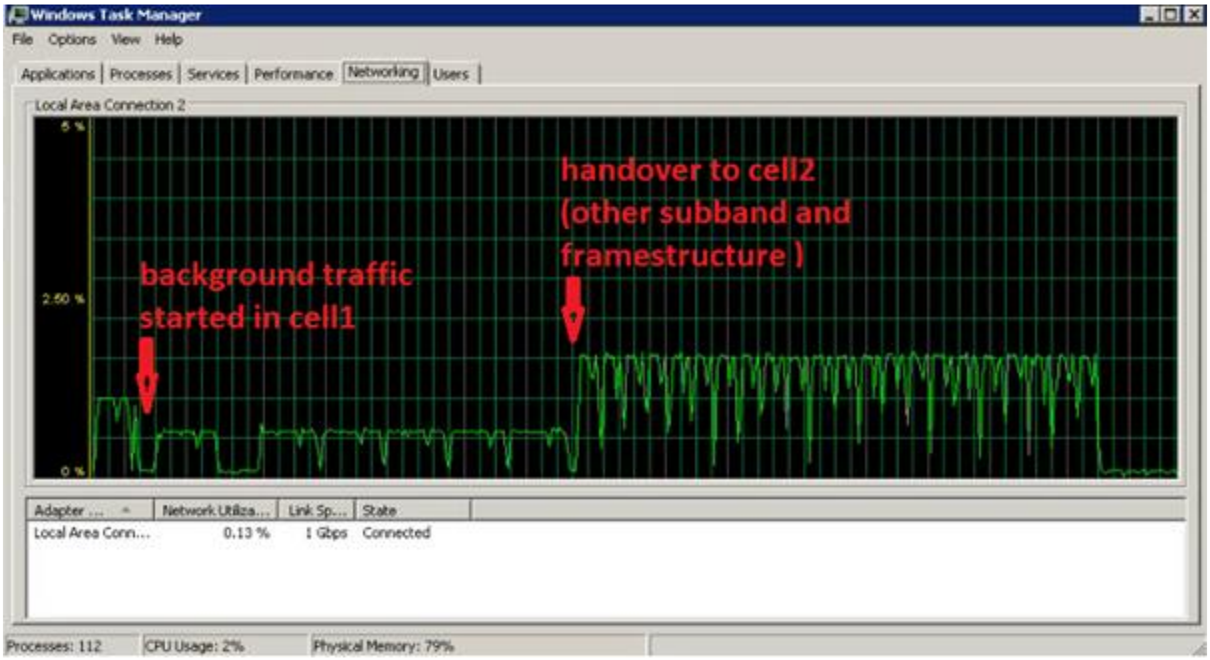
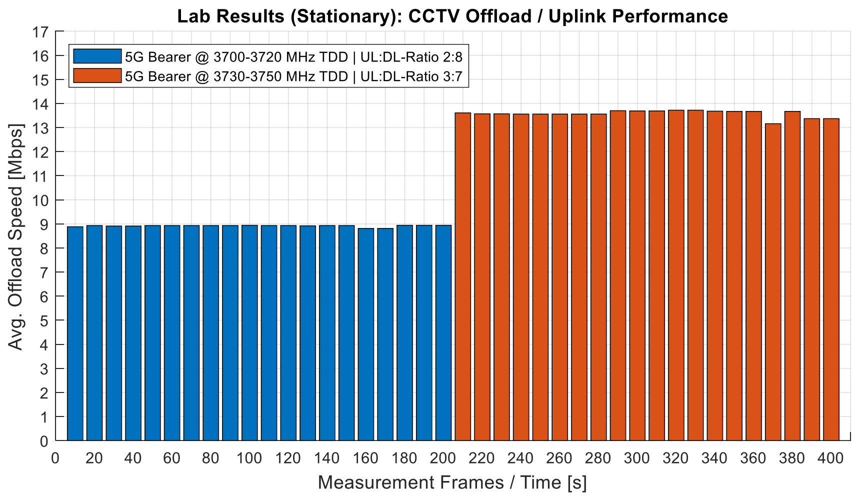


Figure 98: Interface bandwidth monitoring during Bearer Flexibility testing

Further performance test have been captured and are shown below for peak and average values:



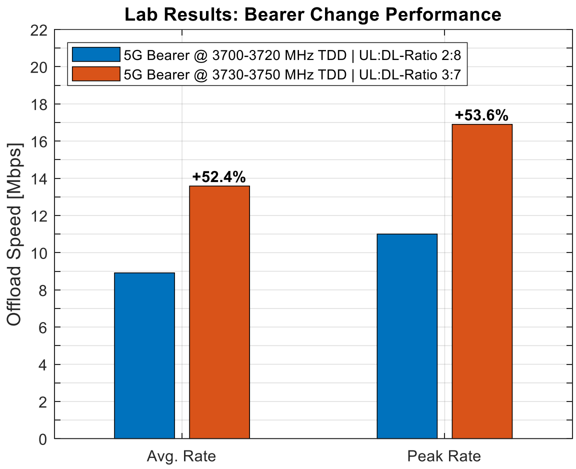


Figure 99 Interface bandwidth monitoring during Bearer Flexibility testing

- Traces and logs recorded during the test:
  Traces and recordings have been saved in 5Grail collaboration Sharepoint under Video tests and in subfolder: 9.5–2 - CCTV_TC_002 (CCTV offload with bearer flex)

7.3 Conclusion on Video tests

In general it can be concluded that the Video tests were executed with successful results, including the bearer flex test cases..

However, there are a few testcases that required some changes in test setup:

- the Cross-border case (Video_TC_004) was verified using iPerf constant data stream (as well as Voice).
- most of the video tests (except for Video_TC_004) are planned to be executed on two different 5G frequencies: on N78 and on N8. However, for N8 test also iPerf constant data stream was used.

8 WP3 activities linked with WP5 preparation

8.1 Introduction

WP3 team had to consider that their equipment will be reused by WP5 after their test period. Indeed, the complete trackside installation remains in the WP3 lab in Budapest, including radio. Separate radio system in WP5 field was used for 5GRail, with leased line connection between the field and the trackside at Budapest. Consequently, WP5 preparation was also a concern for WP3 members and, as this report is the final one on WP3 activities, it is worth mentioning related work around that. Besides, several tests, among them some not in the initial plan of WP3, were carried out in a WP5 derisking perspective, for example device pre-testing, pre-configuration, monitoring and test-support.

This requires for Onboard Equipment to be shipped between Lab and Field to allow overlapping test activities (mainly for video and ETCS/TCMS test cases).

8.2 Remote configuration – leased lines, measurements setup

As WP5 test-setup is using same devices and trackside infrastructure of WP3 laboratories in Budapest, a dedicated leased line between field network radio sites and Budapest laboratory was integrated.

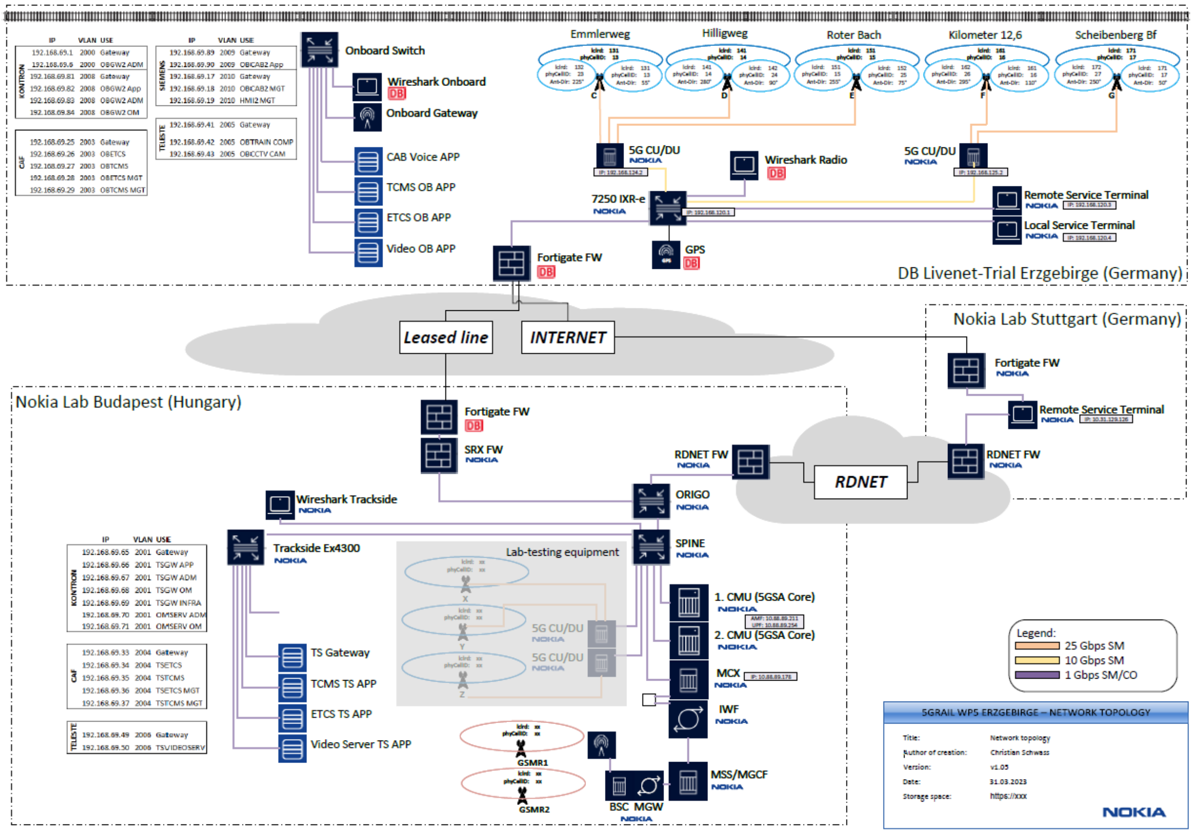


Figure 100 WP3-WP5 Test Configuration

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

There are three mirroring points integrated to monitor all interfaces. Onboard mirroring on the onboard switch, Radio mirroring on the Radio switch and Trackside mirroring on the trackside switch. To ensure best combining and analysis of end to end data flow, all mirroring devices were connected to same NTP-Server (Nokia 7250 IXR in Erzgebirge).

For the evaluation of log files additional measures to synchronize the wireshark systems on field and lab using a NTP server deployed in Budapest.

8.3 WP3 related activities to address the WP5 needs

In order to optimize investment, it was agreed at the beginning of the project that part of WP3 lab will be reused in WP5 Germany.

As RAN is mostly located on site in Erzgebirge, there are still RAN (5G & GSM-R) in use at WP3 test laboratories in Budapest. These RAN sites will be used as counterpart for dispatcher or other specific calls (5G & GSM-R) with support of Budapest engineers.

Core is completely reused from WP3, as described in chapter 9.2. WP5 has just setup RAN on site and uses Core from WP3.

This setup eases the overall project as it could allow (to some extend) parallel testing in lab and field. However, additional effort had to be spent on field site on proper (re-)configuration of the radio for 5GRail purpose (change in configuration was needed as other non 5GRail tests were done as well). The experience with remote access using fixed leased lines shows that stable connection with sufficient bandwidth and continuous low latency is needed to avoid performance impacts.
For analysing performance issues in the field additional configurations in the lab had been setup to emulate and evaluate the impact of increased end to end latency on the performance of especially video applications which occurred during WP5 tests on Bearer Flexibility

9 Performance Measurements Summary

Several measurements have been executed , on application level (refer to chapter 4,5, 6 and 7), and for specific 5G scenarios as handover.

In the following chapter we summarize especially the measurements on Voice KPI and quality, measurements comparing some KPI to GSM-R requirements, cross border and radio related handover including measurements related to Band n8 .

9.1 Voice QoS test results

During voice testing also KPI 1 and KPI 2 measurements were taken (refer to chapter 2.5) in lab, but also in field as not all measurement could be done in time during the lab tests.

According 3GPP TS 22.179 the following requirements are defined:

MCPTT Access time (KPI 1)

- The time between when an MCPTT User request to speak (normally by pressing the PTT butt on) and when this user gets a signal to start speaking. This time does not include confirmatio ns from receiving users.
- MCPTT Access time (KPI 1) is less than 300ms for 95% of all MCPTT requests, for MCPTT Eme rgency Group Calls and Imminent Peril Calls, the KPI 1 is less than 300ms for 99% of all MCPTT requests.

  Note: As no KPI1 measurements could be done in time during test we have shifted the testing directly to the WP5 field activities. Please refer to D5.1 document

End-to-end MCPTT Access time (KPI 2)

- The time between when an MCPTT User requests to speak and when this user gets a signal to start speaking, including MCPTT call establishment (if applicable) and acknowledgement (i f used) from first receiving user before voice can be transmitted. A typical case for the End-t o-end MCPTT Access time including acknowledgement is an MCPTT Private Call (with Floor c ontrol) request where the receiving user’s client accepts the call automatically.
- The MCPTT Service shall provide an End-to-end MCPTT Access time (KPI 2) less than 1000 ms for users under coverage of the same network when the MCPTT Group call has not been est ablished prior to the initiation of the MCPTT Request.

It is noted that 3GPP defines the following load condition:

The KPIs defined in this subclause shall apply in an 3GPP network under traffic load not exceeding 70% of each network nodes capacity.

9.1.1 Results of KPI 1 measurements

As no KPI1 measurements could be done in time during test we have shifted the testing directly to the WP5 field activities. Please refer to D5.1 document

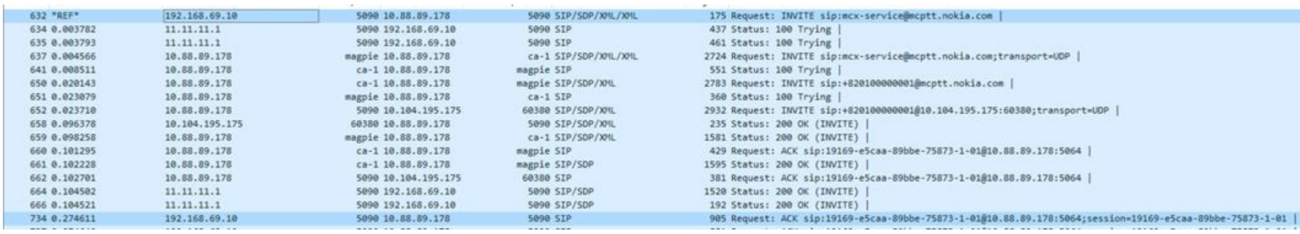
9.1.2 Results of KPI 2 measurements

1. Private / PTP call: CAB Radio to Dispatcher

- Test results and comments:
  Test is passed, fulfilling 3GPP requirements.
  Only few examples are captured, no statistical evidence

Comments by Nokia

Message Trace:



632	*REF*	192.168.69.10	5090	10.88.89.178	5090	SIP/SDP/XML/XML	175	Request: INVITE sip:mcx-service@mcptt.nokia.com |
634	0.003782	11.11.11.1	5090	192.168.69.10	5090	SIP	437	Status: 100 Trying |
635	0.003793	11.11.11.1	5090	192.168.69.10	5090	SIP	461	Status: 100 Trying |
637	0.004566	10.88.89.178	magpie	10.88.89.178	ca-1	SIP/SDP/XML/XML	2724	Request: INVITE sip:mcx-service@mcptt.nokia.com;transport=UDP |
641	0.008511	10.88.89.178	ca-1	10.88.89.178	magpie	SIP	551	Status: 100 Trying |
650	0.020143	10.88.89.178	ca-1	10.88.89.178	magpie	SIP/SDP/XML	2783	Request: INVITE sip:+820100000001@mcptt.nokia.com |
651	0.023079	10.88.89.178	magpie	10.88.89.178	ca-1	SIP	360	Status: 100 Trying |
652	0.023710	10.88.89.178	5090	10.104.195.175	60380	SIP/SDP/XML	2932	Request: INVITE sip:+820100000001@10.104.195.175:60380;transport=UDP |
658	0.096378	10.104.195.175	60380	10.88.89.178	5090	SIP/SDP/XML	235	Status: 200 OK (INVITE) |
659	0.098258	10.88.89.178	magpie	10.88.89.178	ca-1	SIP/SDP/XML	1581	Status: 200 OK (INVITE) |
660	0.101295	10.88.89.178	ca-1	10.88.89.178	magpie	SIP	429	Request: ACK sip:19169-e5caa-89bbe-75873-1-01@10.88.89.178:5064 |
661	0.102228	10.88.89.178	ca-1	10.88.89.178	magpie	SIP/SDP	1595	Status: 200 OK (INVITE) |
662	0.102701	10.88.89.178	5090	10.104.195.175	60380	SIP	381	Request: ACK sip:19169-e5caa-89bbe-75873-1-01@10.88.89.178:5064 |
664	0.104502	11.11.11.1	5090	192.168.69.10	5090	SIP/SDP	1520	Status: 200 OK (INVITE) |
666	0.104521	11.11.11.1	5090	192.168.69.10	5090	SIP/SDP	192	Status: 200 OK (INVITE) |
734	0.274611	192.168.69.10	5090	10.88.89.178	5090	SIP	905	Request: ACK sip:19169-e5caa-89bbe-75873-1-01@10.88.89.178:5064;session=19169-e5caa-89bbe-75873-1-01 |

Measured KPI2 :

KPI 2 [ms]						
Private call: CAB Radio to Dispatcher	275	235	260	240	280	240

Comments by Siemens

N/A

- Traces and logs recorded during the test:

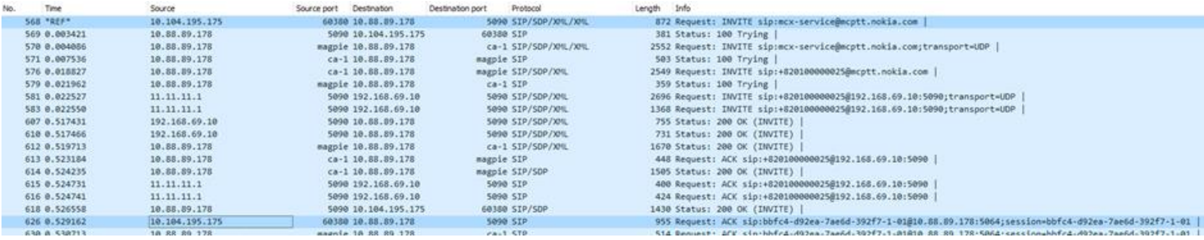
The results of the tests were stored in WP3 Teams collaboration space (folder/file)
Logfile test20230724_02_CAB_DISP.pcap (6 attempts)

2. Private / PTP call: Dispatcher to CAB Radio

- Test results and comments:
  Test is passed, fulfilling 3GPP requirements.
  Only few examples are captured, no statistical evidence

Comments by Nokia

Message Trace:



Measured KPI2:

KPI 2 [ms]								
Private call: Dispatcher to CAB Radio	529	531	555	535	584	507	542	517

Observation: The higher values for this test cases is due to later message response from CAB Radio

Comments by Siemens

N/A

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Logfile test20230724_02_CAB_DISP.pcap (6 attempts)

3. Group/REC Calls : CAB Initiated

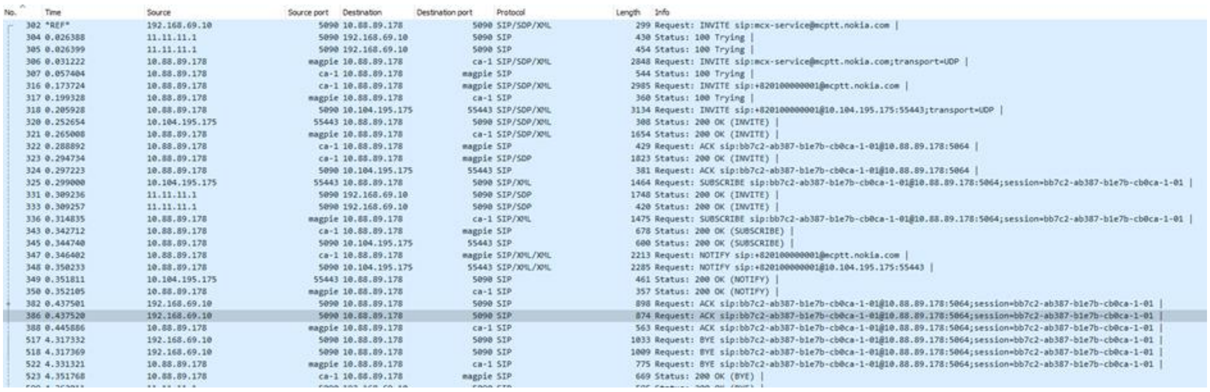
   - Test results and comments:

Test is passed, fulfilling 3GPP requirements.

Only few examples are captured, no statistical evidence

Comments by Nokia

Message Trace:



Measured KPI2

KPI 2 [ms]										
Group/REC Calls : CAB Initiated	438	438	438	408	438	438	437	408	438	478

<u>Comments by Siemens</u>

N/A

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

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Logfile test test20230814-CAB-init-REC

4. Group/REC Calls : Dispatcher Initiated

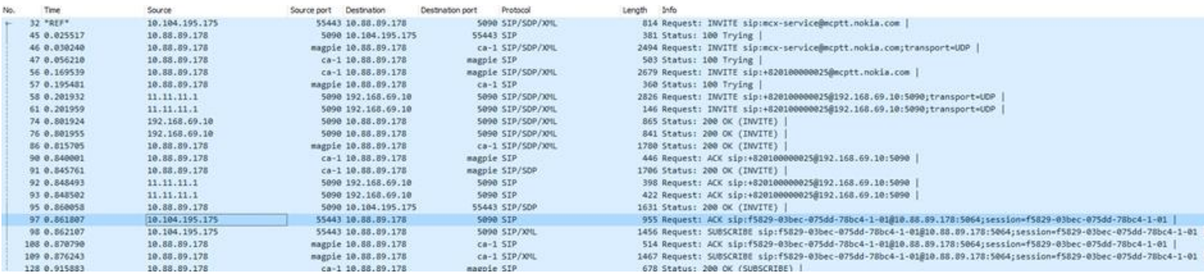
- <u>Test results and comments:</u>

Test is passed, fulfilling 3GPP requirements.

Only few examples are captured, no statistical evidence

<u>Comments by Nokia</u>

Message Trace:



No.	Time	Source	Source port	Destination	Destination port	Protocol	Length	Info
32	*REF*	10.104.195.175	55443	10.88.89.178	5090	SIP/SDP/XML	814	Request: INVITE sip:mcx-service@mcptt.nokia.com |
45	0.025517	10.88.89.178	5090	10.104.195.175	55443	SIP	381	Status: 100 Trying |
46	0.030240	10.88.89.178	magpie	10.88.89.178	ca-1	SIP/SDP/XML	2494	Request: INVITE sip:mcx-service@mcptt.nokia.com;transport=UDP |
47	0.056210	10.88.89.178	ca-1	10.88.89.178	magpie	SIP	503	Status: 100 Trying |
56	0.169539	10.88.89.178	ca-1	10.88.89.178	magpie	SIP/SDP/XML	2679	Request: INVITE sip:+820100000025@mcptt.nokia.com |
57	0.195481	10.88.89.178	magpie	10.88.89.178	ca-1	SIP	360	Status: 100 Trying |
58	0.201932	11.11.11.1	5090	192.168.69.10	5090	SIP/SDP/XML	2826	Request: INVITE sip:+820100000025@192.168.69.10:5090;transport=UDP |
61	0.201959	11.11.11.1	5090	192.168.69.10	5090	SIP/SDP/XML	146	Request: INVITE sip:+820100000025@192.168.69.10:5090;transport=UDP |
74	0.801924	192.168.69.10	5090	10.88.89.178	5090	SIP/SDP/XML	865	Status: 200 OK (INVITE) |
76	0.801955	192.168.69.10	5090	10.88.89.178	5090	SIP/SDP/XML	841	Status: 200 OK (INVITE) |
86	0.815705	10.88.89.178	magpie	10.88.89.178	ca-1	SIP/SDP/XML	1780	Status: 200 OK (INVITE) |
90	0.840001	10.88.89.178	ca-1	10.88.89.178	magpie	SIP	446	Request: ACK sip:+820100000025@192.168.69.10:5090 |
91	0.845761	10.88.89.178	ca-1	10.88.89.178	magpie	SIP/SDP	1706	Status: 200 OK (INVITE) |
92	0.848493	11.11.11.1	5090	192.168.69.10	5090	SIP	398	Request: ACK sip:+820100000025@192.168.69.10:5090 |
93	0.848502	11.11.11.1	5090	192.168.69.10	5090	SIP	422	Request: ACK sip:+820100000025@192.168.69.10:5090 |
95	0.860058	10.88.89.178	5090	10.104.195.175	55443	SIP/SDP	1631	Status: 200 OK (INVITE) |
97	0.861807	10.104.195.175	55443	10.88.89.178	5090	SIP	955	Request: ACK sip:f5829-03bec-075dd-78bc4-1-01@10.88.89.178:5064;session=f5829-03bec-075dd-78bc4-1-01 |
98	0.862107	10.104.195.175	55443	10.88.89.178	5090	SIP/XML	1456	Request: SUBSCRIBE sip:f5829-03bec-075dd-78bc4-1-01@10.88.89.178:5064;session=f5829-03bec-075dd-78bc4-1-01 |
108	0.870790	10.88.89.178	magpie	10.88.89.178	ca-1	SIP	514	Request: ACK sip:f5829-03bec-075dd-78bc4-1-01@10.88.89.178:5064;session=f5829-03bec-075dd-78bc4-1-01 |
109	0.876243	10.88.89.178	magpie	10.88.89.178	ca-1	SIP/XML	1467	Request: SUBSCRIBE sip:f5829-03bec-075dd-78bc4-1-01@10.88.89.178:5064;session=f5829-03bec-075dd-78bc4-1-01 |
128	0.915883	10.88.89.178	ca-1	10.88.89.178	magpie	SIP	678	Status: 200 OK (SUBSCRIBE) |

Measured KPI2

KPI 2 [ms]										
Group/REC Calls : Dispatcher Initiated	862	801	826	809	785	804	809	826	834	818

Observation: The higher values for this test cases is due to later message response from CAb Radio

<u>Comments by Siemens</u>

N/A

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

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

Logfile test test20230814-DISP-init-REC

5. Results:

The following graphic summarizes the results for Point to Point and REC calls

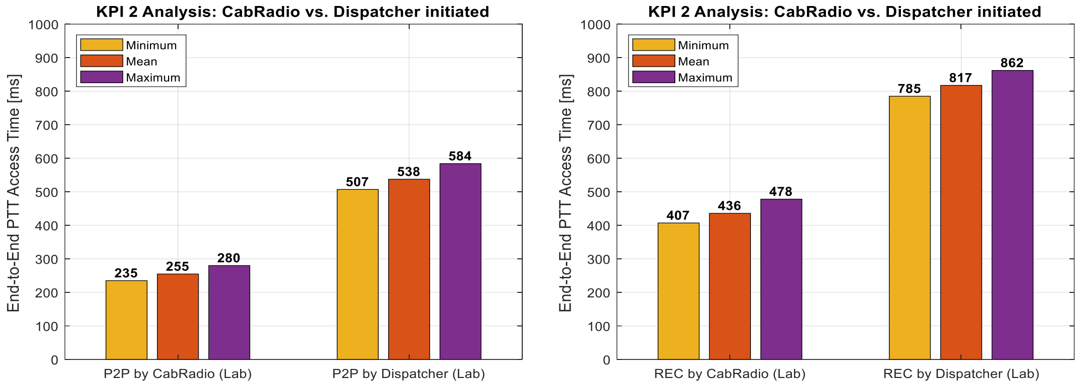


Figure 101: Voice KPI 2 results

9.1.3 Voice Quality

- Objective of the test:

The purpose of this test is to compare the quality of speech path during voice communication. This comparison was performed by the experience and Wireshark RTP Stream tool during ongoing voice call.

- Test description:

As Wireshark RTP Stream Player is only able to work with voice streams initiated on G.711 codec type the following testcases were used for the comparison.

For N78 band the used testcase is Voice_021. This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.5.2.

For N8 band the used testcase is based on Voice_019. To ensure the used codec type is G.711 in this scenario Train Controller initiates the call instead of Train Driver. Voice_019 is described in D1.1 v4 [S22] WP1 test plan, chapter 7.10.

- Test results and comments:

Test is passed.

- Comments by Nokia

During voice communication no difference was experienced related to speech path. Voice was clear and continuous on both n78 and n8 band.

RTP stream on n78 band:

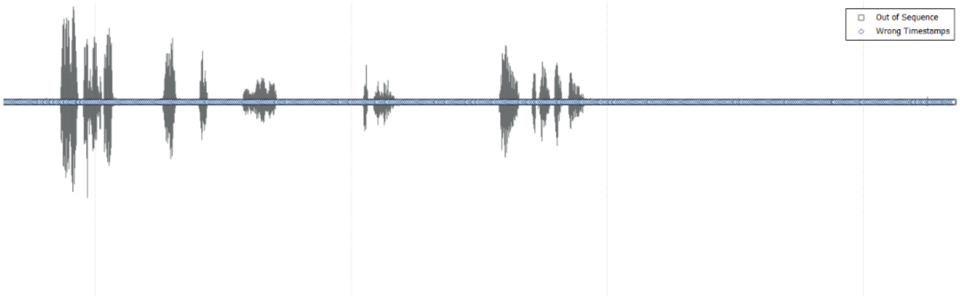


Figure 102: RTP stream on n78

RTP stream on n8 band:

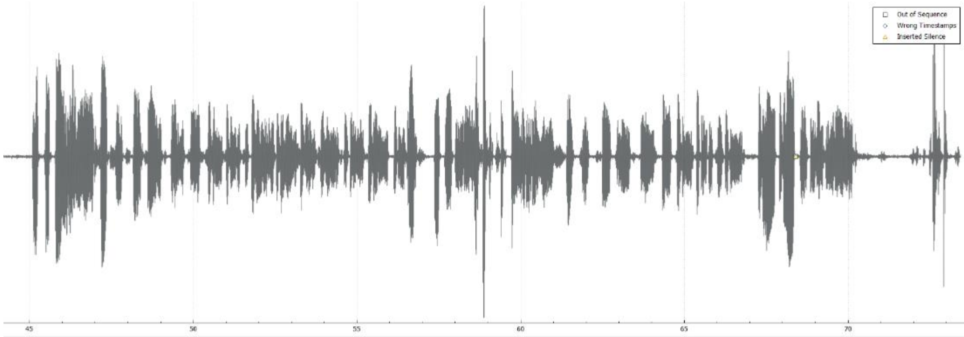


Figure 103: RTP stream on n8

On both graphs it is visible that during the call, voice was smooth, no packets were out of sequence and no inserted silence was experienced.

- Traces and logs recorded during the test:

Traces and recordings have been saved in 5Grail collaboration folder.

File Name:

WP3 Test Results/Voice test cases/Voice_021 Initiation of a multi-user voice communication from a train driver towards train drivers and ground users (FRMCS and GSM-R Users)/ test20230607_04_Voice_21.pcap

WP3 Test Results/Integration logs/10 N8 band/VOICE_019_DISP_init/G711_DISP_CAB_call.pcap

9.2 Measurement comparison with GSM-R

Despite different concepts in GSM-R and FRMCS some comparison was done on some KPI defined for GSM-R (ETCS over GPRS, refer to [S30] and voice (refer to [S31]) to get a first insight into the performance improvements of FRMCS:

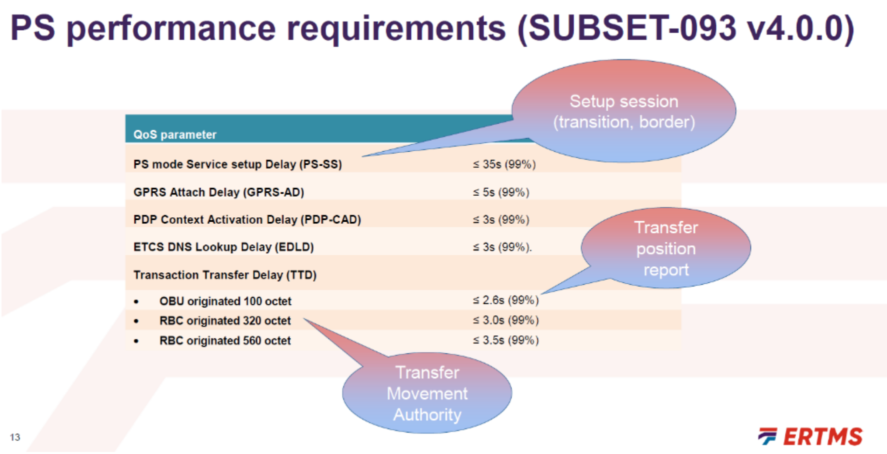


Figure 104 ETCS over GPRS Performance requirements

The following Table show the overview on select GSM-R KPI, example values from lab and measured 5GRail 5G values during the tests:

KPI ETCS	Value subset 093	Example lab values	5GRail measured 5G
GPRS Attache Delay	< 5sec (99%)	~2.5-3.2 sec	200 ms
GPRS PDP Context Activation	< 3 sec (99%)	~1.5-2 sec	80 ms

For voice & CAB radio following measurements have been done :

KPI Voice	Value EIRENE SRS/FRS		5GRail measured 5G
CAB SIP registration	N/A		40 ms
CAB Functional Address registration	< 30 sec / 5 number		60 ms per alias
CAB / Dispatcher REC / Group Call	<4 sec e2e, < 2.5 Sec network		KPI 2 400-800 ms
CAB Floor Request	Only for REC		

- SIP registration is not used in GSM-R but would be requested to setup MCX connectivity, therefore could be seen as a component of the overall Setup delay. Values of 40 ms were measured.
- The GSM-R standard requires the registration of Functional Number (5 numbers) below 30 sec
- REC comparable 5G MCX values were measured as KPI 2 requirement in chapter 9.1.2

The following chapter explain the test and measurements in more detail. Depending on test case different setup (e.g. using Band n8 or/and Band n78) have been selected.

9.2.1 5G Attach time

- Objective of the test:

The purpose of this test is to evaluate the 5G attach time using N78 band.

- Test description:

This test is described as a generic 5G mechanism required for FRMCS access to the 5G Transport layer. Smartphone device was used. The following simplified call flow was used (refer to [S32]). PCF is not used in 5GRail:

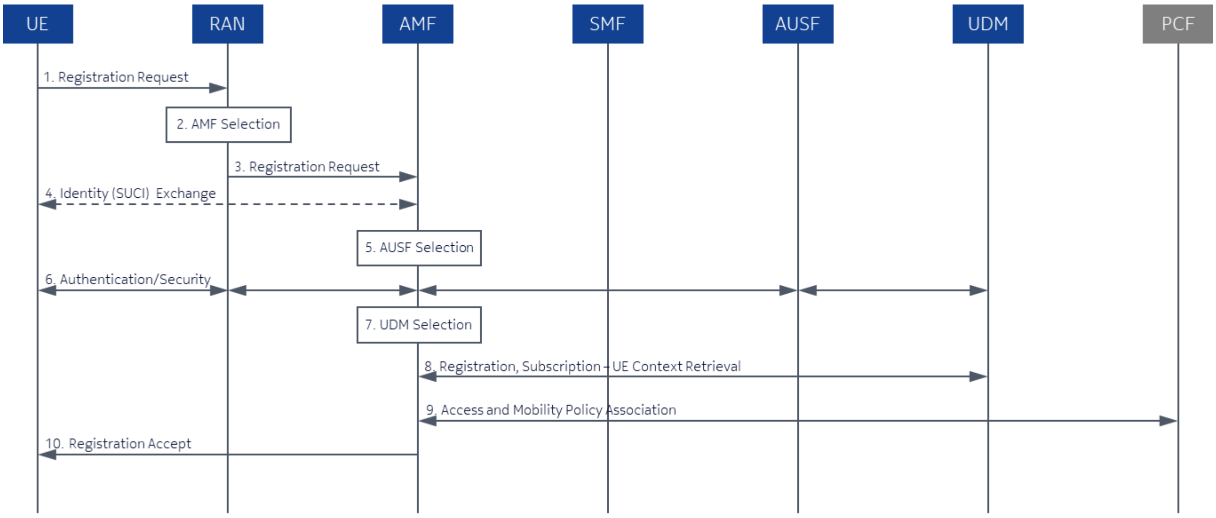


Figure 105: UE Registration Setup

- Test results and comments:

The 5G Attach delay time measurement was performed on N78 band.

In the GSM-R setup time comparison 5G RRC Setup time inclusion was included & excluded in the measurements. Folling samples have been taken:

5G Attach delay time [ms]										
Attach time with RRC setup time	243	243	242	242	243	242	263	222	226	222
Attach time without RRC setup time	202	202	201	201	202	184	184	181	185	181

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

9.2.2 5G PDP Context/Session setup time

- Objective of the test:

The purpose of this test is to evaluate the PDP context activation time using N8 band.

- <u>Test description:</u>

  This test is described as a generic 5G mechanism required for FRMCS access to the 5G Transport layer. Smartphone device was used. The call flow is used:

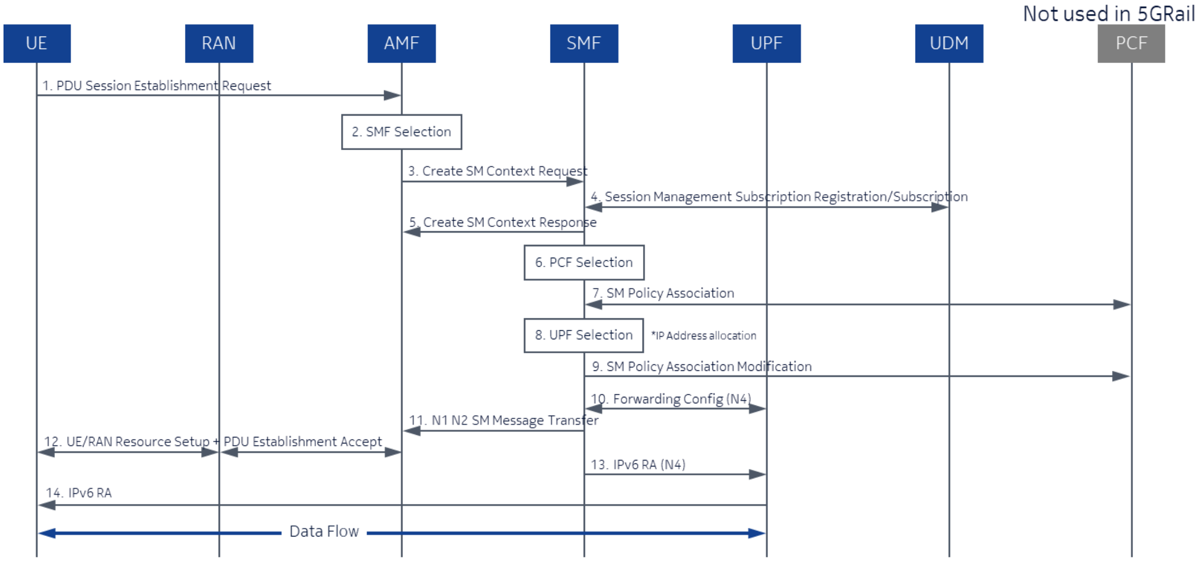


Figure 106: PDU Session Setup

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

  The KPI was evaluated from counters provided in the Nokia gNb for maximum and average time of (initial) Context Setup:

Counter name	NetAct name
Maximum time of Initial Context Setup	NG_MAX_TIME_INI_CTX_STP
Average time of Initial Context Setup	NG_AVG_TIME_INI_CTX_STP

- The test was: 10 times repeated attach (PDU session creation) with network user in 5 minutes timeframe. Following values have been achieved:
  - Max Initial Context Setup time: 87 ms
  - Average time: 84 ms

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

  The results of the tests were stored in WP3 Teams collaboration space (folder/file)

9.2.3 CAB Radio SIP registering time

- <u>Objective of the test:</u>

  The purpose of this test to test the performance for the SIP registration

- <u>Test description:</u>

  This test is described in. The following call trace has been evaluated:

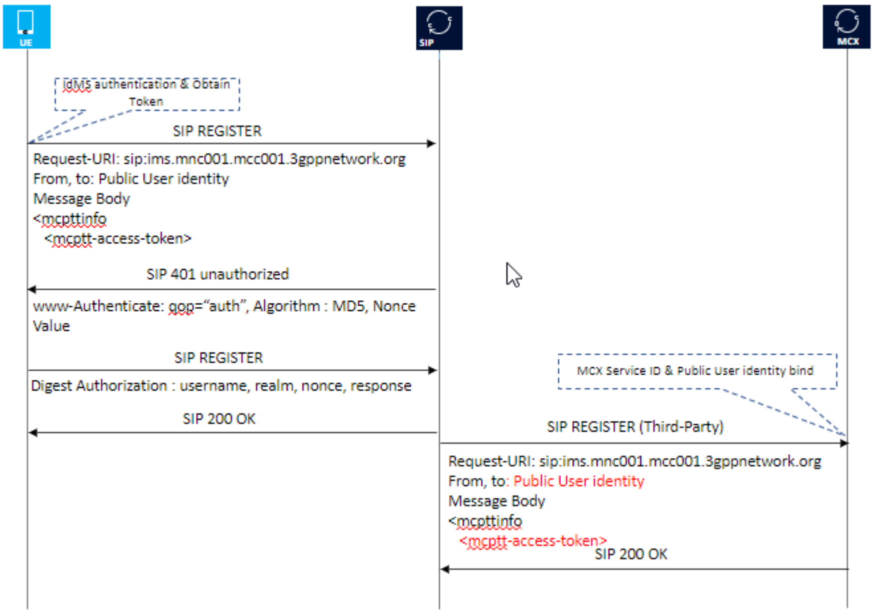


Figure 107: SIP Registration call flow

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

The following samples have been taken:

CAB Register: [ms]										
CAB register time (SIP REGISTER/SIP DEREGISTER)	48	35	34	34	34	36	33	34	36	35

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

  The results of the tests were stored in WP3 Teams collaboration space (folder/file)

9.2.4 CAB Radio Functional Alias registering time

- <u>Objective of the test:</u>

  The purpose of this test is to measure the time required for registration of functional alias.

- <u>Test description:</u>

  This test is described in chapter 4.2.1. In this test case the performance was evaluated.

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

The following detailed message flow is showing the measured call flow:

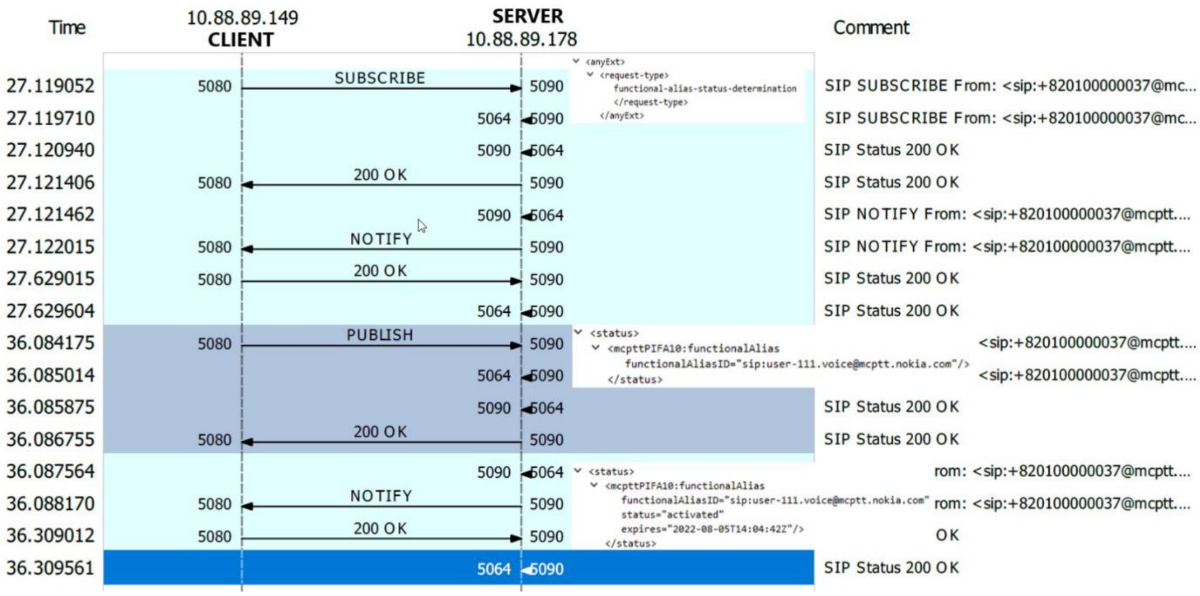


Figure 108: Functional Alias registration call flow

The measured sample showed following value:

CAB Register: [ms]	
CAB FA register time (FA REGISTER/SIP DEREGISTER)	60

- Traces and logs recorded during the test:

  The results of the tests were stored in WP3 Teams collaboration space (folder/file): test20220812_CAB_FA_reg_via_OBGW.pcap

9.2.5 CAB Radio Floor request-taken time

- Objective of the test:

  The purpose of this test to measure the time a CAB radio get's the floor granted , This is not directly comparable with GSMR but is part of the GSM-R requirement on Call setup for REC.

- Test description:

  This test measures the time between floor request and floor acknowledgement.

- Test results and comments:

Following time values have been measured and analysed from wireshark tracing:

CAB floor request-taken time [ms] (floor request/floor release in a private call towards Dispatcher)	40,0	39,8	40,1	39,8	39,8	39,8	39,9	40,5	40,0	39,8

- Traces and logs recorded during the test:

  The results of the tests were stored in WP3 Teams collaboration space (folder/file)

  test20231003_CAB_floor_request-taken-time.pcap

9.3 Cross Border

- Objective of the test:

  The purpose of this test is to measure time the handover takes (on network signalling level) for the building blocks Inter AMF handover, using Ng handover in the radio.

- Test description:

  This test is based on the 3GPP call flow described in [S32]. A simplified call flow is shown below:

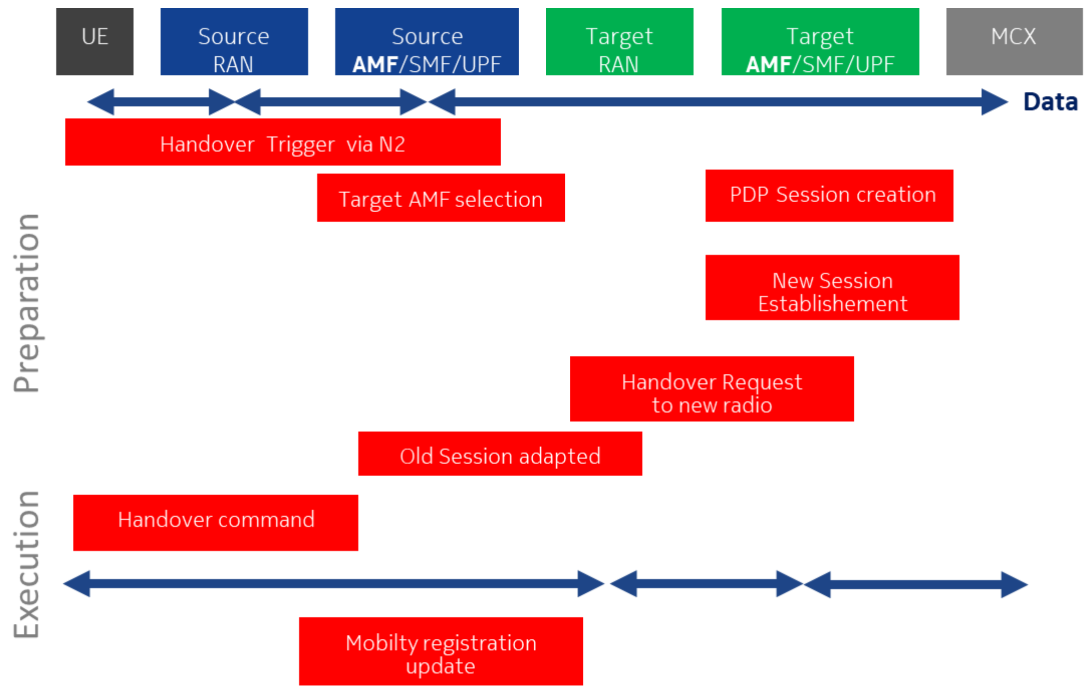


Figure 109 Inter AMF / Ng handover

- Test results and comments:

  Test with Iperf:

- Inter-AMF handover initial test was taken with Iperf data flow as emulation of constant video bitrate.
- Related to this information the Handover Interruption is the time taken between HandoverRequired and Handover Notify message, which is 154 ms:

```
[  5]  28.00-29.01  sec  1.88 MBytes  15.6 Mbits/sec
[  5]  29.01-30.01  sec  1.75 MBytes  14.7 Mbits/sec
[  5]  30.01-31.03  sec  1.88 MBytes  15.5 Mbits/sec
[  5]  31.03-32.01  sec  1.75 MBytes  14.9 Mbits/sec
[  5]  32.01-33.01  sec  1.88 MBytes  15.8 Mbits/sec
[  5]  33.01-34.01  sec  1.75 MBytes  14.6 Mbits/sec
[  5]  34.01-35.03  sec  1.75 MBytes  14.5 Mbits/sec
[  5]  35.03-36.03  sec  1.75 MBytes  14.7 Mbits/sec
[  5]  36.03-37.01  sec   640 KBytes  5.33 Mbits/sec
[  5]  37.01-38.01  sec  0.00 Bytes  0.00 bits/sec
[  5]  38.01-39.01  sec   640 KBytes  5.27 Mbits/sec
[  5]  39.01-40.01  sec  1.12 MBytes  9.40 Mbits/sec
[  5]  40.01-41.00  sec  1.25 MBytes  10.6 Mbits/sec
[  5]  41.00-42.01  sec  1.12 MBytes  9.38 Mbits/sec
[  5]  42.01-43.01  sec  1.12 MBytes  9.45 Mbits/sec
[  5]  43.01-44.01  sec  1.12 MBytes  9.41 Mbits/sec
[  5]  44.01-45.01  sec  1.12 MBytes  9.46 Mbits/sec
[  5]  45.01-46.01  sec  1.25 MBytes  10.5 Mbits/sec
[  5]  46.01-47.01  sec  1.12 MBytes  9.39 Mbits/sec
[  5]  47.01-48.01  sec  1.12 MBytes  9.50 Mbits/sec
[  5]  48.01-49.01  sec  1.12 MBytes  9.42 Mbits/sec
```

Handover

Figure 110: Iperf data flow during HO

Test with Voice:

- Cab radio towards Train controller speech path is continuous during handover, short crackling was hearable without any loss.
- Train controller towards Cab radio speech path is not continuous during handover, ~1 sec voice gap is hearable.

- Traces and logs recorded during the test:

The results of the tests were stored in WP3 Teams collaboration space (folder/file)

9.4 Radio related performance measurement (n8)

The purpose of this section is to provide a comprehensive overview of potential disparities in radio performance between n78 and n8 frequency bands. To give a clear view Voice and IPERF applications were used. Apart from the frequency band change, from n78 to n8, the test measurements and comparison were created in the same conditions, with the same already performed testcases.

9.4.1 Throughput in nominal conditions

- Objective of the test:

The purpose of this test is to compare the maximum data throughput between n78 and n8 band with the required radio configuration. Related to throughput measurement testing the employed tool was IPERF. With the same configuration of IPERF, uplink throughput measurement test was performed both on n78 and n8 band.

- Test description:

1. Thales MW31 modem attaches to 5G network - correct IP address is received
2. Modem registers on Iperf3 as server
3. PC registers on Iperf3 as client
4. Client sends TCP data flow request towards Server (iperf3 -c 10.88.89.148 -p 5002 -R -t 300) - data transfer starts correctly on uplink (server/Thales sends data)
5. Continue data transfer for 5 minutes
6. Modem disconnects from 5G network - UEContextRelease message is received on gNb

- Test results and comments:

Test is passed.

- Comments by Nokia

During test result comparison, no particular difference was experienced between n78 and n8 band. Both bands were performed around maximum 10mbits/sec.

Iperf throughput result on n78 and N8

Video/Constant Iperf measurement:									
Throughput in nominal conditions n78 [Mbps]	9,42	9,46	9,47	9,31	9,44	9,57	9,31	9,49	9,65
Throughput in nominal conditions n8 [Mbps]	10,40	10,80	10,40	9,90	10,90	10,50	11,00	10,70	9,99

Figure 111: Iperf throughput result on n8 and n78

Traces and logs recorded during the test:

Traces and recordings have been saved in 5Grail collaboration folder.

File Name:

WP3 Test Results/Integration logs/11 N78 Comparison/IPERF Throughput/iperf_tcp_throughput_n78.txt

WP3 Test Results/Integration logs/10 N8 band/IPERF_TC_001/IPERF_TC_001.txt

9.4.2 Throughput in degraded conditions

- Objective of the test:

The objective of this test is to measure and contrast throughput levels under degraded conditions across N8 and N78 frequency bands. This comparative analysis aims to provide insights into the impact of simulated movement on data throughput. The simulation is designed to replicate conditions at a speed of 120 km/h, incorporating relevant propagation models to accurately simulate fading effects. Simulation and propagation models are described in Chapter 3.4.

Employed applications during this comparison are Video Server and IPERF.

- Test description:

In alignment with the official Video_002 testcase, a bitrate restriction of 1 Mbit/s has been implemented for TCP video streaming, IPERF case has been adjusted correspondingly to utilize the same bitrate limitation.

On N78 band the following testcases were used:

- Video_TC_002 – This test is described in D1.1 v4 [S22] WP1 test plan, chapter 9.4.2.
- IPERF_N78_120kmh_1mps:
    1. Propagation and simulation file has to be uploaded to Vertex Channel Emulator
    2. Compile the simulation on Vertex – Ready to start state
    3. Thales modem attaches to 5G network – correct IP address is received
    4. Modem registers on Iperf3 as server
    5. PC registers on Iperf3 as client
    6. Start simulation on Vertex
    7. Client starts to send TCP data flow request towards Server with 1mbit/sec bitrate (iperf3 -c 10.88.89.148 -p 5002 -R -t 600 -b 1M) – data transfer starts correctly on uplink (server side/Thales modem sends data)
    8. Continue data transfer until simulation lasts – with 120 km/h it takes 2:00 mins
    9. After simulation stops, finish sending data on Iperf
    10. Modem disconnects from 5G network - UEContextRelease message is received on BTS

On N8 band the following testcase was used:

- IPERF_N8_120kmh_1mps:
    - Similar to the previously mentioned IPERF_N78_120kmh_1mps testcase description

- Test results and comments:

Test is passed.

- Comments by Nokia:

Upon analysing, it became evident that comparing degraded throughput performance between different frequency bands using different applications will not yield accurate results.

In order to ensure precision in performance assessment, an additional IPERF case was conducted specifically on N78 band. The subsequent section will provide a comprehensive review detailing the impact on throughput performance derived from these conducted scenarios.

Throughput result with Video server on N78 band with limited 1mbit/s bitrate:

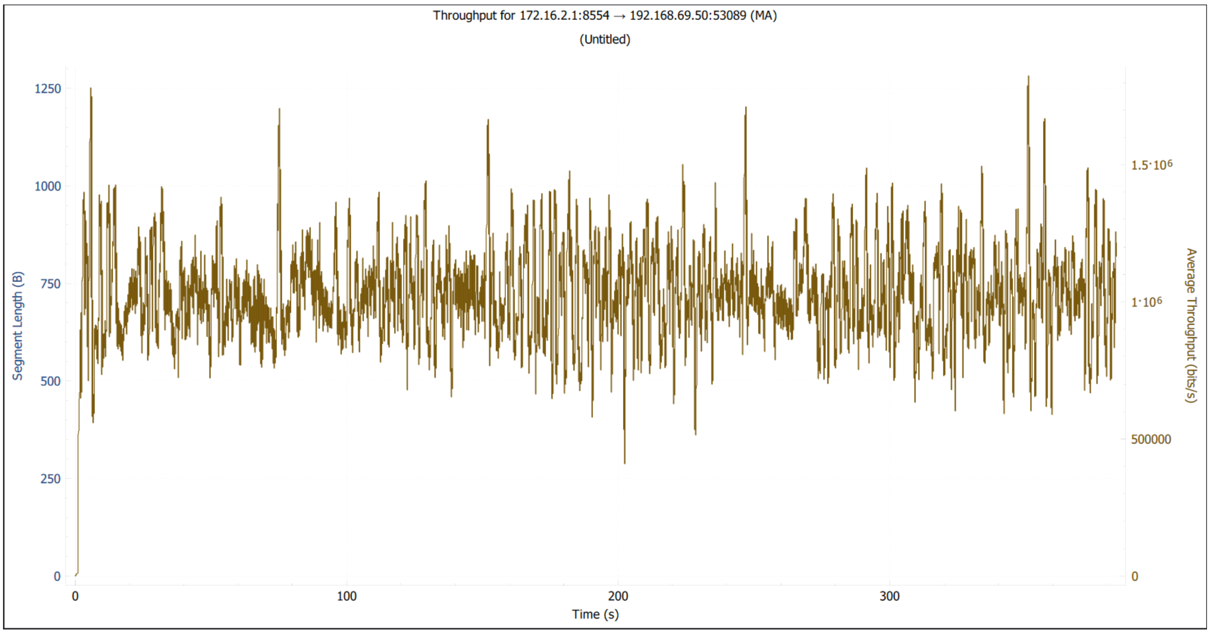


Figure 112: Throughput result on N78 with Video server

Statistics

Measurement	Captured	Displayed
Packets	103464	30802 (29.8%)
Time span, s	431.947	402.286
Average pps	239.5	76.6
Average packet size, B	605	1365
Bytes	62592819	42045753 (67.2%)
Average bytes/s	144 k	104 k
Average bits/s	1159 k	836 k

Figure 113: Average throughput on N78 with Video server

Average throughput rate for Video server during degraded conditions is 0,832 mbits/sec.

Throughput result with IPERF on N78 band with limited 1mbit/s bitrate:

Note: Despite IPERF was limited to 1 mbit/s bitrate, during data flow the tool applies a higher, 1,05 mbits/s bitrate which varies related to dynamic fading conditions.

```
c:\iperf3>iperf3 -c 10.88.89.148 -p 5002 -R -t 600 -b 1M
Connecting to host 10.88.89.148, port 5002
Reverse mode, remote host 10.88.89.148 is sending
[  4] local 10.154.164.141 port 52312 connected to 10.88.89.148 port 5002
[ ID] Interval           Transfer     Bandwidth
[  4]   0.00-1.00   sec   128 KBytes  1.04 Mbits/sec
[  4]   1.00-2.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   2.01-3.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   3.01-4.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   4.01-5.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   5.01-6.00   sec   128 KBytes  1.06 Mbits/sec
[  4]   6.00-7.00   sec   128 KBytes  1.05 Mbits/sec
[  4]   7.00-8.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   8.01-9.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   9.01-10.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  10.01-11.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  11.01-12.02  sec   128 KBytes  1.05 Mbits/sec
[  4]  12.02-13.02  sec   128 KBytes  1.05 Mbits/sec
[  4]  13.02-14.00  sec  95.2 KBytes   796 Kbits/sec
[  4]  14.00-15.00  sec   135 KBytes  1.11 Mbits/sec
[  4]  15.00-16.00  sec  96.3 KBytes   788 Kbits/sec
[  4]  16.00-17.00  sec   116 KBytes   949 Kbits/sec
[  4]  17.00-18.00  sec  86.5 KBytes   708 Kbits/sec
[  4]  18.00-19.00  sec   132 KBytes  1.08 Mbits/sec
[  4]  19.00-20.00  sec   107 KBytes   878 Kbits/sec
[  4]  20.00-21.00  sec   128 KBytes  1.05 Mbits/sec
[  4]  21.00-22.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  22.01-23.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  23.01-24.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  24.01-25.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  25.01-26.01  sec   128 KBytes  1.05 Mbits/sec
[  4]  26.01-27.02  sec   128 KBytes  1.05 Mbits/sec
[  4]  27.02-28.00  sec   128 KBytes  1.06 Mbits/sec
[  4]  28.00-29.01  sec   128 KBytes  1.04 Mbits/sec
[  4]  29.01-30.01  sec   107 KBytes   875 Kbits/sec
```

Figure 114: Iperf throughput result on N78 with Thales modem

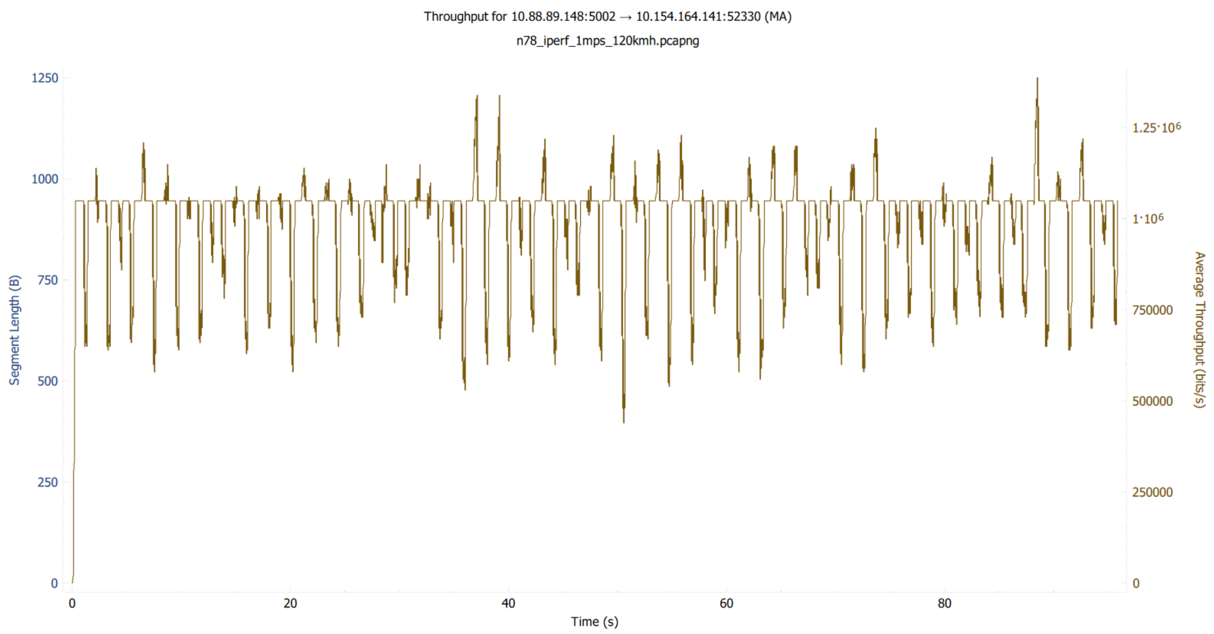


Figure 115: Throughput result on N78 with Thales modem

Statistics

Measurement	Captured	Displayed
Packets	9666	9666 (100.0%)
Time span, s	95.955	95.955
Average pps	100.7	100.7
Average packet size, B	1346	1346
Bytes	13005920	13005920 (100.0%)
Average bytes/s	135 k	135 k
Average bits/s	1084 k	1084 k

Figure 116: Average throughput on N78 with Thales modem

Average throughput rate for IPERF during degraded conditions is 1,08 mbits/s.

Throughput result with IPERF on N8 band with limited 1mbit/s bitrate:

```
c:\iperf3>iperf3 -c 10.88.89.148 -p 5002 -R -t 600 -b 1M
Connecting to host 10.88.89.148, port 5002
Reverse mode, remote host 10.88.89.148 is sending
[  4] local 10.154.164.141 port 50495 connected to 10.88.89.148 port 5002
[ ID] Interval           Transfer     Bandwidth
[  4]   0.00-1.01   sec   128 KBytes  1.04 Mbits/sec
[  4]   1.01-2.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   2.01-3.00   sec   128 KBytes  1.06 Mbits/sec
[  4]   3.00-4.00   sec   128 KBytes  1.04 Mbits/sec
[  4]   4.00-5.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   5.01-6.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   6.01-7.01   sec   128 KBytes  1.05 Mbits/sec
[  4]   7.01-8.00   sec   128 KBytes  1.06 Mbits/sec
[  4]   8.00-9.00   sec   128 KBytes  1.05 Mbits/sec
[  4]   9.00-10.00  sec  95.2 KBytes   782 Kbits/sec
[  4]  10.00-11.01  sec   161 KBytes  1.31 Mbits/sec
[  4]  11.01-12.00  sec   121 KBytes   994 Kbits/sec
[  4]  12.00-13.00  sec   132 KBytes  1.08 Mbits/sec
[  4]  13.00-14.00  sec  76.7 KBytes   627 Kbits/sec
[  4]  14.00-15.01  sec  98.7 KBytes   805 Kbits/sec
[  4]  15.01-16.00  sec   177 KBytes  1.45 Mbits/sec
[  4]  16.00-17.01  sec  91.4 KBytes   744 Kbits/sec
[  4]  17.01-18.01  sec   132 KBytes  1.08 Mbits/sec
[  4]  18.01-19.02  sec  68.2 KBytes   554 Kbits/sec
[  4]  19.02-20.00  sec   128 KBytes  1.07 Mbits/sec
[  4]  20.00-21.00  sec   129 KBytes  1.06 Mbits/sec
[  4]  21.00-22.00  sec   127 KBytes  1.04 Mbits/sec
[  4]  22.00-23.01  sec   117 KBytes   958 Kbits/sec
[  4]  23.01-24.01  sec   133 KBytes  1.09 Mbits/sec
[  4]  24.01-25.00  sec   138 KBytes  1.14 Mbits/sec
[  4]  25.00-26.01  sec   111 KBytes   900 Kbits/sec
[  4]  26.01-27.01  sec   113 KBytes   928 Kbits/sec
[  4]  27.01-28.00  sec   156 KBytes  1.29 Mbits/sec
[  4]  28.00-29.00  sec   128 KBytes  1.05 Mbits/sec
[  4]  29.00-30.00  sec   128 KBytes  1.05 Mbits/sec
```

Figure 117: Iperf throughput result on N8 with Thales modem

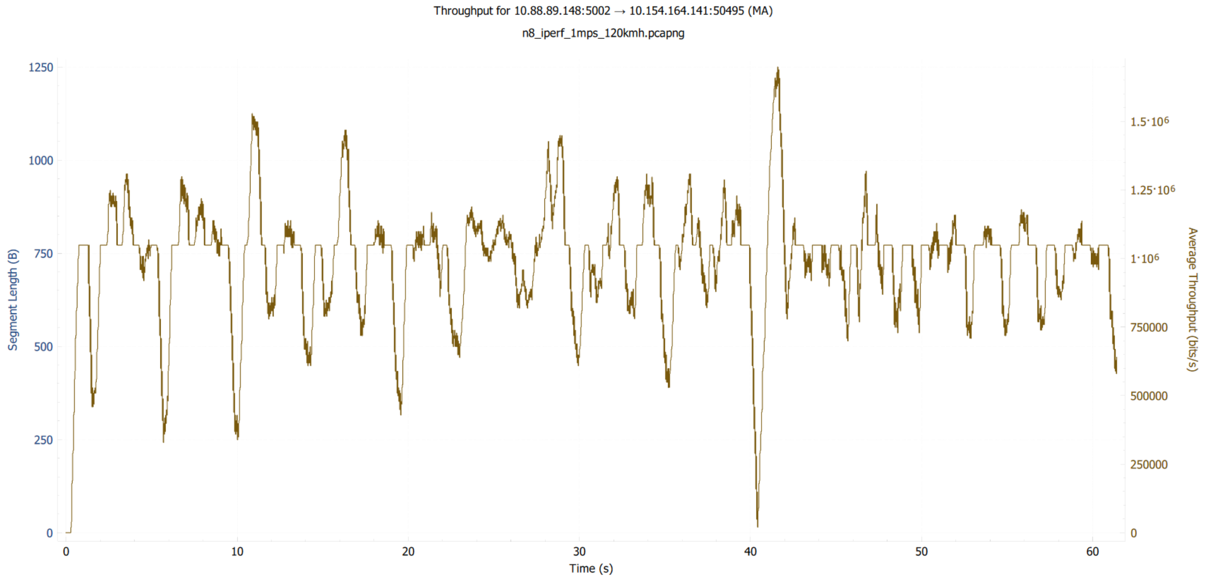


Figure 118: Throughput result on N8 with Thales modem

Statistics

Measurement	Captured	Displayed
Packets	6165	6165 (100.0%)
Time span, s	61.738	61.738
Average pps	99.9	99.9
Average packet size, B	1344	1344
Bytes	8286421	8286421 (100.0%)
Average bytes/s	134 k	134 k
Average bits/s	1073 k	1073 k

Figure 119: Average throughput on N8 with Thales modem

Average throughput rate for IPERF during degraded conditions is 1,072 mbits/s.

The conclusion of these results is that throughput related to Video server is slightly impacted in degraded conditions. Tests were performed with IPERF tool have behaved appropriately, data flow throughput rate have not been impacted by the simulated movement.

Comparing N8 and N78 band, IPERF scenarios worked very much the same. Neither of the testcase results showed negative effects by the degraded conditions and the average performance of the throughput was performed equally well.

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

Traces and recordings have been saved in 5Grail collaboration folder.

File Name:

WP3 Test Results/MC DATA testcases/Video/ 9.4.2. - Video_TC_002 (streaming with degraded radio)/ train speed 120kmph/ high quality _ full_HST switched on/ 2023-05-12-video-120-degraded-gnb1-filtered, 2023-05-12-video-120-degraded-gnb2-filtered

WP3 Test Results/Integration logs/11 N78 Comparison/IPERF_TC_1MPS_N78/ n78_iperf_1mps_120kmh.pcapng

WP3 Test Results/Integration logs/10 N8 band/ IPERF_TC_1MPS_120KMH_N8/ n8_iperf_1mps_120kmh.pcapng

9.4.3 Handover time

- Objective of the test:

The purpose of this test is to measure and compare the performance of handover during voice communication. This comparison can give a clear view about the performance of the handover time on different frequency brands (n78 and n8). During the test inter-gNb, intra-frequency Xn handover was performed.

- Test description:

For this test result comparison Voice_019 was used. This test is described in D1.1 v4 [S22] WP1 test plan, chapter 7.10.

- Test results and comments:

The following figures show the comparison of Inter AMF Handover times between N78 and N8:

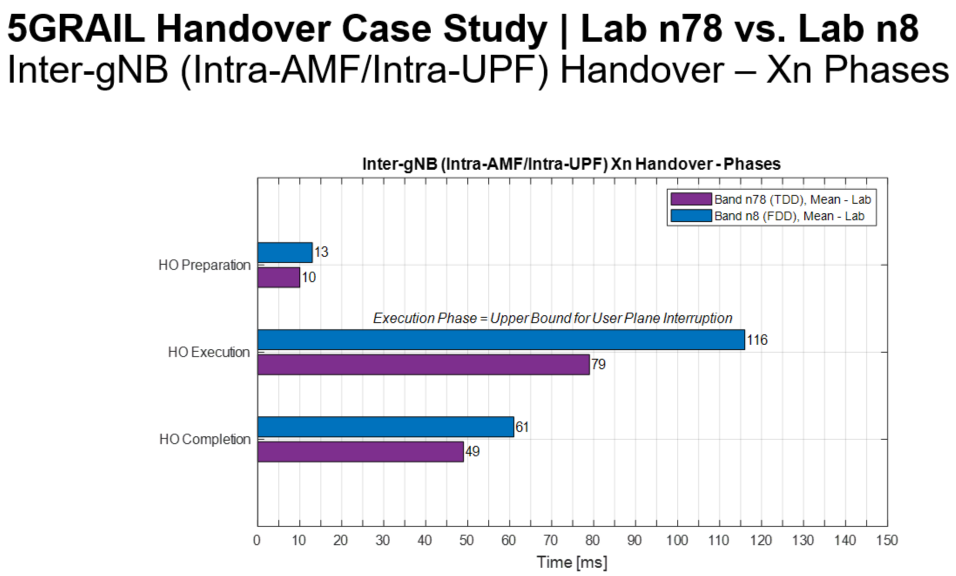


Figure 120: Handover phase times N78 vs. N8 (1)

5GRAIL Handover Case Study | Lab n78 vs. Lab n8
Inter-gNB (Intra-AMF/Intra-UPF) Handover – Xn Overall Time

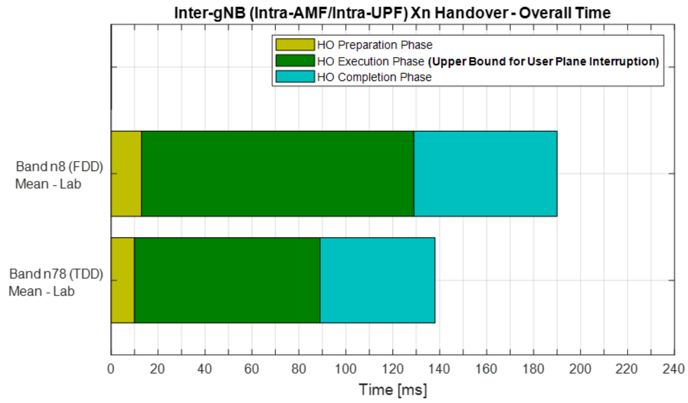


Figure 121: Handover Phase times N78 vs. N8 (2)

The next figure shows the measured values comparing Xn and N2/Ng handover:

5GRAIL Handover Case Study | Lab n78
Inter-gNB (Intra-AMF/Intra-UPF) Handover – Xn vs. NG

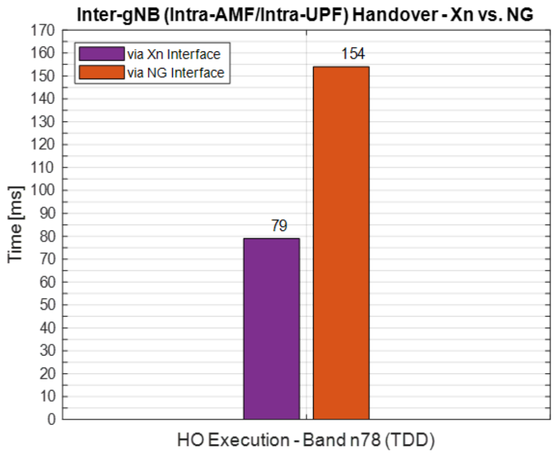


Figure 121: Handover time Xn vs Ng.

- <u>Comments by Nokia:</u>

During the test result comparison, difference was experienced related to handover time between n78 and n8 band inline with 3GPP.

Observations:

- NG Interface HO higher than Xn Interface HO
- Xn HO Execution time measured between *HandoverRequest/HandoverRequestAcknowledge (XnAP)* and *PathSwitchRequest (NGAP)* messages
- NG HO Execution time measured between *HandoverRequired (NGAP)* and *HandoverNotify (NGAP)* messages
- TDD is faster than FDD according 3GPP

Handover time on n78:

17650	*REF*	10.104.6.93	10.104.6.92	XnAP	598	HandoverRequest
17654	0.010	10.104.6.92	10.104.6.93	XnAP	778	HandoverRequestAcknowledge
17655	0.014	10.104.6.93	10.104.6.92	XnAP	158	SNStatusTransfer
17664	0.089	10.104.6.92	10.88.89.211	NGAP	146	PathSwitchRequest
17689	0.138	10.104.6.92	10.104.6.93	XnAP	102	UEContextRelease

Figure 122: Handover time on n78

Handover time on n78 band is 138 ms.

Handover time on n8:

9705	*REF*	10.104.6.90	10.104.6.91	XnAP	554	HandoverRequest
9711	0.013	10.104.6.91	10.104.6.90	XnAP	770	HandoverRequestAcknowledge
9714	0.018	10.104.6.90	10.104.6.91	XnAP	146	SNStatusTransfer
9722	0.129	10.104.6.91	10.88.89.211	NGAP	142	PathSwitchRequest
9778	0.188	10.88.89.211	10.104.6.91	NGAP	166	SACK (Ack=0, Arwnd=131072) , PathSwitchRequestAcknowledge
9780	0.190	10.104.6.91	10.104.6.90	XnAP	98	UEContextRelease

Figure 123: Handover time on n8

Handover time on n8 band is 190 ms.

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

Traces and recordings have been saved in 5Grail collaboration folder.

10 CONCLUSIONS

The several tests successfully integrated, supported by SW enhancements and finally executed are a major step forward on the way towards FRMCS realization, as the related lab and field experiments provide valuable feedback on the first set of specifications for railway operational communications and ongoing specification work. The joined work in the WP3 also created a clear momentum among all partners.

The developed and tested products - even if some are on prototype level – are the first step towards products that will use in the future to address customer's needs. Sure, further enhancements towards fully commercialized products needs to happen.

Teams today working mainly on GSM-R and other railway related solutions had to execute a technical ramp up as to execute the project engineers had to develop new critical skills on various subjects like 5G SA, IMS or MCx. And as specification have not been finalized during the project, assumptions or innovations have been provided, e.g. on the GSM-R IWF, the solution to solve requirements for bearer flexibility and border crossing or QoS treatment.

On of the main challenge is for sure to find solutions for testing based on the restrictions still in 5G SA technology in market, ecosystem and products leading to limited maturity of aspects related to Roaming, Handover or Interconnection. As example existing 5G SA solution was enhanced to achieve some of the important aspects of a smooth border crossing scenarios ((by testing the impacting Ng and Inter AMF/N14 Handover building blocks), MCPTT solutions related to Railway Emergency call have been provided as interim step towards final standardization.

The impact of COVID and the successful mitigation by implementing secure and stable remote cooperation and work was a main success factor to be able to execute WP3 tasks, which on the other hand requires more effort and time as originally planned at project start. However, this kind of cooperation is a valuable learning which definitely helps upcoming projects (like "MORANE 2.0") to be executed in an efficient way. manage future projects and it must be understood that efforts not panned.

The setup of WP3 supporting WP5 with remote connectivity of the lab with the field radio deployment causes on the one hand additional effort, but provided also a lot of benefits executing tasks and test of lab and field in parallel – again some learnings to be considered for future projects.

Under the above circumstances WP3 could achieve outstanding results in a 5G SA network setup using FRMCS concepts of Onboard and Trackside GW configuration with the most important railway applications as voice, ETCS, TCMS and Video where sone of them are listed below:

- First successful FRMCS Voice and with CAB radio, smartphones and dispatcher
- Railway Emergency Calls with innovative new dynamic group affiliation based on train position
- GSM-R Interworking and network transition IWF(which received the award by the EU as a key innovation (Innovation Radar > Discover great EU-funded innovations (europa.eu)))
- Evaluation and testing of QoS mechanism to control different application requirements.
- Measurement of e2e performance on data, video on voice
- Providing emulated train speed for performance measurements
- Testing various 5G radio configurations and handover scenarios incl. measurements on some characteristic 5G performance values
- Bearer Flexibility by using one modem access for different 3GPP (sub) bands
- Border Crossing building block test by adopting Radio Ng based handover with separate core setup for Inter AMF / N14 handover

Finally, 5Grail and the work done in WP3 helped to further accelerate the way towards FRMCS by not only testing important aspects, but also as the involved partner created exchanges opportunities for all stakeholders through conferences, advisory boards and lab visits.

11 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, Stage 1 (Release 16 & Release 17)	3GPP TR22.889 V17.4.0 3GPP TR22.889 V16.6.0
[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] First Lab Integration and Architecture Report	D3.1
[S21] First Lab Test Setup Report	D3.2
[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]	5GAA Technical Report: Cross-Working Group Work Item Network Reselection Improvements (NRI), 2020	www.5GAA.org
[S27]	GSM-R ENIR - EUROPEAN NETWORK INTEGRATION FOR RAILWAYS GROUP , O-8350 1.0, FFFS for Voice and Data Services Interconnection & Roaming between GSM-R networks , www.uic.org	
[S28]	3GPP TS 23.501, System Architecture for the 5G System; Stage 2	
[S29]	ETSI TS 103 792 Interworking with Legacy Systems (GSM-R - draft	
[S30]	Subset 093 v4.0	
[S31]	EIRENE SRS 8.16.1	
[S32]	3GPP TS 23.502 Procedures for the 5G System (5GS)	

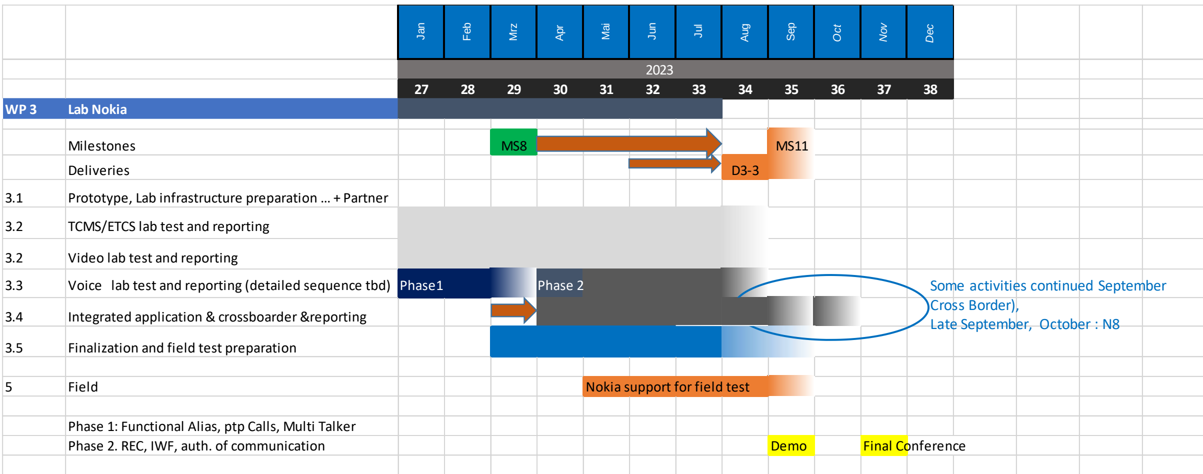
12 APPENDICES

12.1 Work Package 3 planning of activities

The activities have been structured as follows:

Task 3.1	Prototyping, Lab infrastructure preparation and integration, radio interface verification
Task 3.2	TCMS, ETCS and CCTV/Video lab test and reporting
Task 3.3	Voice lab test and reporting
Task 3.4	Integrated applications, cross-border lab testing & reporting, demonstration
Task 3.5	Finalisation and field preparation

WP3 continuously meet on ~monthly base to align the status of the overall planning with the involved partner. Following status was discussed and agreed on CW 34 :



Del Rel. No	Del No	Title	Description
D3.1	D9	First Lab Integration and Architecture Description	This document will provide a full description of environmental conditions for the achievement of tests, including integration considerations and technical architecture detailing all sub-systems.
D3.2	D10	First Lab Test Setup Report	This report outlines the lab setup, integration and verification of radio compatibility of 5G radio modules and other public band modules depending on spectrum. Based on WP1 definition, network functionality for GSM-R – FRMCS interworking will be simulated.
D3.3	D11	First Lab Test Report	The lab testing reports outlines and details the different lab test phases for each application. It documents the work done and details the achieved results for the integration of prototypes into the 5G infrastructure and the validation of the communication capabilities in the lab environment in line with the lab test strategy document elaborated in WP1. It covers Voice, TCMS, ETCS CCTV/Video test results, as well as cross-border testing.

Table 6: WP3 Overview Planning Status

12.2 List of tests cases that have been executed within Task 3.4

The following table shows the executed test cases (status CW 34) for voice, followed by data and video tests:

						OK		Mar	Mar	Mar	Mar	Apr	Apr	Apr	Apr	May	May	May	May	May	June	June	June	June	July	July	July	July	Aug	Aug	Aug	Aug	Aug	Sept	Sept	Sept	Sept
D1.1	TC number	TC name	optional	N8?	app type	ok?	pl	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
						OK	WP5				MS8																	MS11 →					D3.3				
7.2.1	Voice_001	Registration of a functional identity related to the user			Voice	OK											WP5																				
7.2.2	Voice_002	Deregistration of a functional identity			Voice	OK											WP5																				
7.2.3	Voice_003	Authorisation of communication	OPT?		Voice	OK?													no white/black list																		
7.2.4	Voice_004	Authorisation of application			Voice	OK											WP5																				
7.2.5	Voice_005	Multi - user talker control			Voice	OK?						OK?					WP5	no speech in			CAB		WP5		retest?												
7.2.6	Voice_006	Arbitration: ongoing P2P call, incoming normal emergency call			Voice	OK	WP5																WP5														
7.3.1	Voice_008	Initiation of a voice communication from a train driver (CAB) towards a train controller responsible for the train movement area - only FRMCS			Voice	OK	WP5										WP5						WP5														
7.4.1	Voice_009	Initiation of a voice communication from a train controller (disp) to the train driver - only FRMCS users			Voice	OK	WP5										WP5						WP5														
7.5.1	Voice_010	Initiation of a multi-user voice communication from a train driver (cab) towards train drivers (usage of smartphones only) - only FRMCS users			Voice	OK	WP5										WP5						WP5														
7.5.2	Voice_021	Initiation of a multi-train voice communication from a train driver (cab radio) towards train drivers (smartphone only), with IWF (FRMCS and GSMR users)			voice	OK	WP5						OK							small issues			WP5														
7.6.1	Voice_011	Railway Emergency Call initiated by a train controller - only FRMCS users			Voice	OK	WP5									OK	WP5	OK	outside REC area				WP5														
7.6.2	Voice_022	Railway Emergency Call initiated by a train driver (cab radio) w/o interworking - only FRMCS users			Voice	OK	WP5				XML format in CAB					OK	WP5						WP5														
7.6.3	Voice_12	Railway Emergency Call initiated by a train driver incl. interworking with IWF (FRMCS and GSMR users)			Voice	OK	WP5					disp initiated								small issues			WP5														
7.6.4	Voice_13	Joining an ongoing Railway Emergency Call (late join)	OPT.		Voice	optional																															
7.6.5	Voice_14	Leaving an ongoing Railway Emergency Call	OPT.		Voice	optional																															
7.6.6	Voice_15	REC call, FRMCS to GSM-R system transition with service continuation (inter-technology/inter- frequency test case, to replace the cross-border TC for voice)			Voice		WP5	Still to test									No Fw in CAB displ.					Test in WP5 field in CW34										WP5					
7.8	Voice_17	Combined scenario from train driver to dispatcher with voice p2p call (MCPTT, GBR, 5QI 2) and Video (non-GBR)			Voice/video	QoS WA	WP5	no DSCP/QoS in CAB						no QoS			Qos WA															WP5					
7.9	Voice_18	Combined scenario with voice p2p call (MCPTT, GBR, 5QI 2) and Video (noGBR) in degraded conditions (varying speed, high speed is used), QoS setting		N8	Voice/video	QoS WA		no DSCP/QoS in CAB						no QoS	Qos WA,50 kmph				175 kmph																	N8?	N8?
7.10	Voice_19	P2P private call (train driver) to dispatcher with Xn interface HO gNodeB (inter gNodedB and intra gNodeB), intra frequency		N8	Voice	N78 only	WP5																WP5													N8?	N8?
7.11	Voice_20	P2P private calls train driver) to dispatcher with degraded radio conditions (assume high speed)		N8	Voice	N78 only					50kmh			120, 150		175dd, 350d							WP5													N8?	N8?

Table 7 : Executed Test Cases – Overview Voice

						OK		Mar	Mar	Mar	Mar	Apr	Apr	Apr	Apr	May	May	May	May	May	June	June	June	June	July	July	July	July	Aug	Aug	Aug	Aug	Aug	Sept	Sept	Sept	Sept
D1.1	TC number	TC name	optional	N8?	app type	ok?	pl	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
						OK	WP5				MS8																	MS11 →					D3.3				
WP5		field test support DB (WP5 testweeks)					pl	W		OB							Siemens		CAF				Siemens		Teleste							Teleste		prep		DEMO	
WP5		shipping of partner eqipments (the latest)					pl		CAB2 OBGW2								ETCS TCMS						send Vide				rec Vid				send Vide						
		ETCS integration test - nominal comm. testing (onboard to trackside)			ETCS	OK			OK																												
8.1.1.3	ETCS-CAF_TC_001	Nominal communication between ETCS on board application and RBC			ETCS	OK	WP5				OK								WP5																		
8.1.1.4	ETCS-CAF_TC_005	Nominal communication between ETCS on board application and RBC, including BTS handover (same 5G network)			ETCS	OK	WP5				OK								WP5																		
8.1.2	ETCS-CAF_TC_002	Communication between ETCS on board application and RBC (same 5G network) in degraded radio mode			ETCS	OK					50kmh					120kmh																					
8.1.3	ETCS-CAF_TC_003	Increase data transferred in the ETCS communication			ETCS	OK					OK																										
8.1.4	ETCS-CAF_TC_004	ETCS onboard combined with other application (TCMS)	OPT		ETCS/TCMS	OK	WP5							OK					WP5																		
9.2.1.3	TCMS_TC_001	Nominal communication between MCG on board application and GCG (same 5G network)			TCMS	OK	WP5												WP5																		
9.2.1.4	TCMS_TC_004	Nominal communication between MCG on board application and GCG, including BTS handover (same 5G network)			TCMS	OK	WP5												WP5																		
9.2.2	TCMS_TC_002	Evaluate FRMCS On-Board System and impact on application with degrading radio conditions		N8?	TCMS	OK								50kmh		120kmh																					
9.2.3	TCMS_TC_003	Cross border scenario with TCMS – Telemetry	OPT		TCMS		WP5																														
9.3.1	TC_001	Nominal communication between GCG trackside application and onboard MCG (same 5G network) (remote control of equipment)			TCMS	OK																															
		Video integration test - nominal comm. testing			Video	OK		OK	Both streaming and CCTV offload are ok																												
9.4.1.3	Video_TC_001	Streaming of video from train to trackside		N8	Video	N78	WP5	OK	streaming with perfect quality on 1mbps									no N8 testing is possible							WP5												
9.4.1.4	Video_TC_003	Streaming of video from train to trackside (nominal conditions including BTS handover also)		N8	Video	N78 only	WP5	OK										no N8 testing is possible							WP5												
9.4.2	Video_TC_002	Degraded communication: streaming of video from train to trackside		N8	Video	N78			streaming quality OK					50, 120kmh			175km	no N8 testing is possible																			
9.4.2	Video_TC_004	Border crossing (with video!) from train to trackside - inter AMF handover			Video		WP5		Still to test							Ng-based inter-gNodeB Handover							intra-AMF Ng ho									WP5					
9.5.1	CCTV_TC_001	CCTV offload from train to trackside		N8	CCTV	N78	WP5	OK										no N8 testing is possible							WP5	on-off tput						WP5					
9.5.2	CCTV_TC_002	CCTV offload from train to trackside with bearer-flex		N8	CCTV	OK?	WP5											no N8 testing is possib					OK		WP5	on-off tput						WP5					

Table 8 Executed Test Cases – Overview Data, Video

The table reflects the status of calendar week 34, and can be updated later.

12.3 Documentation of integration results

A common Teams collaborator place is created to store the integration and test results. All partners have rights to upload their results to this folder.

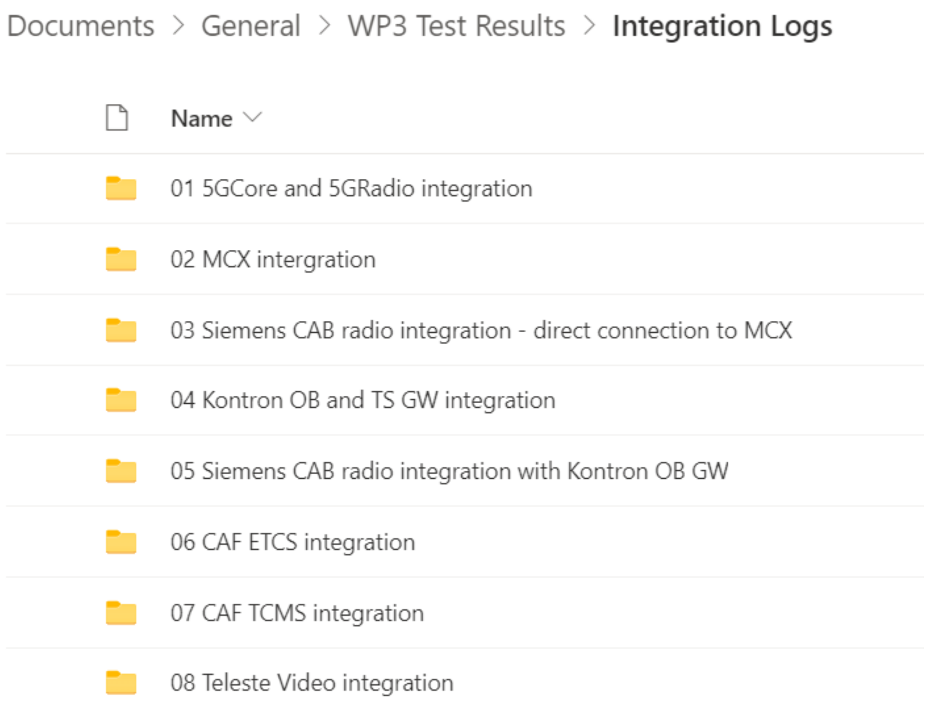


Figure 124: Folder structure of integration logs

12.4 Border crossing in 5G SA: Roaming architecture

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).

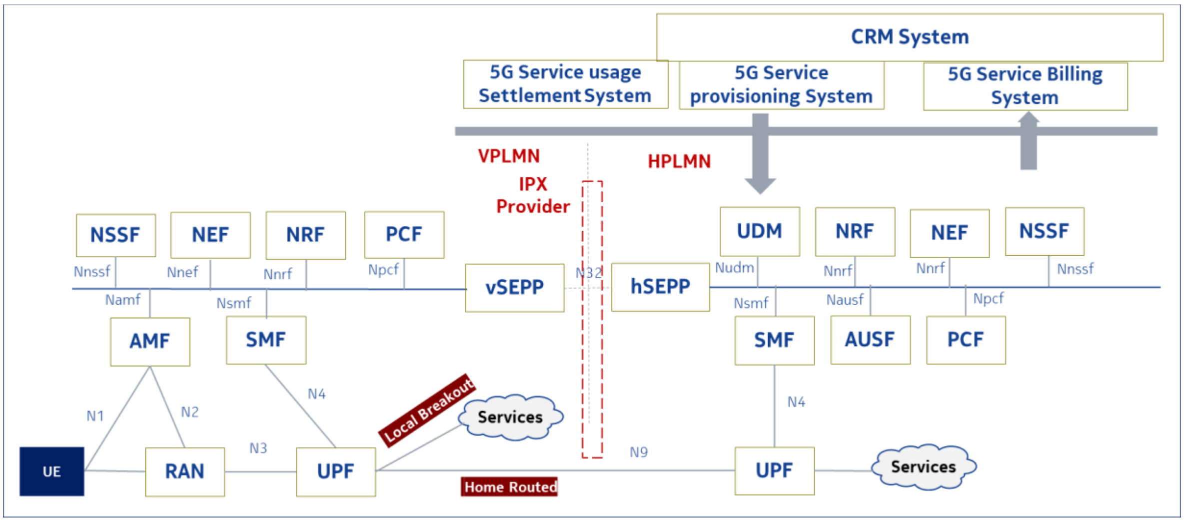


Figure 125: 5G SA Roaming Architecture

- In Local Break Out, roamer uses a visited network UPF to access a Data Network
- In Home Routed, roamer uses a home network UPF to access a Data Network

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.

Service based 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, i.e 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.

Service Session Continuity - SCC

The support for session and service continuity in 5G System architecture enables to address the various continuity requirements of different applications/services for the UE (refer to 3GPP TS 23.501). It is new concept in 5G to support URLLC and e.g. local UPF deployments as breakout for low latency.

It is mainly defined for Intra PLMN uses cases serving the needs for low latency enterprise scenarios.

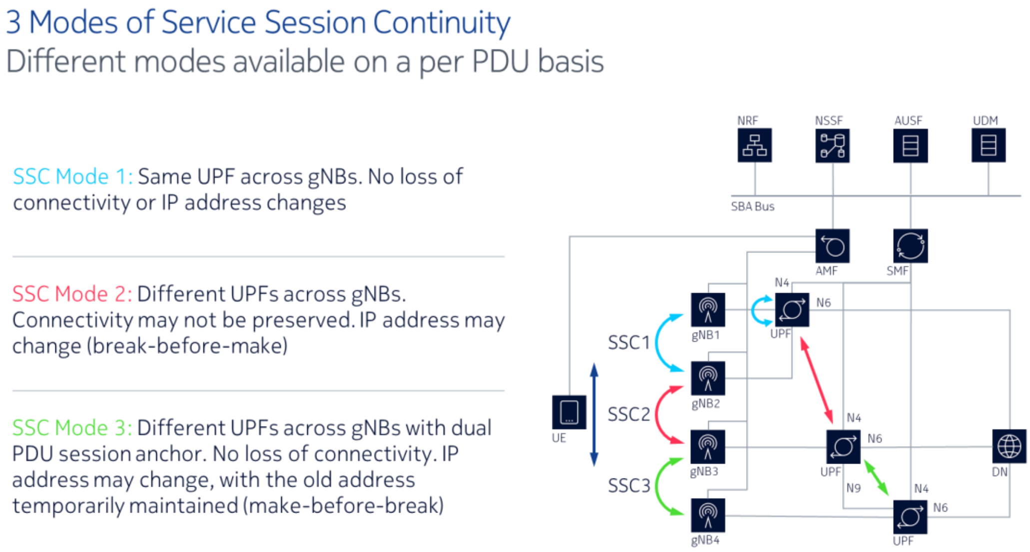


Figure 126: Overview on 5G Service Session Continuity

Especially Mode 3 provides low interruption by a make before break concept. However, several aspects needs further evaluation for railway environment

12.5 Border Crossing in related CAM projects

Horizon 2020 ICT CAM projects as 5GCroCo, 5G Carmen et al have evaluated in detail available measures and potential improvements to improve service continuity for the automotive sector when crossing borders (refer to [S26]). It is important to understand that – in contrast to railway – CAM services rely on public operator networks, and thus for automotive sector the cooperation of mobile operator between networks is required, which is expected to be more challenge compared to the cooperation models typically done in railway (where already in GSM-R close cooperation between railways are in place to achieve seamless interworking ad roaming across Europe (refer to GSM-R ENIR project [S27].

The following steps have been described and partly tested to improve service continuity between different mobile operator PLMNs with respect to the capabilities of the (4G and) and 5G NSA/SA core and radio network:

Scenario 1 / Basic	UE roaming with new registration
Scenario 2	UE roaming with AMF relocation (idle mode mobility)
Scenario 3	(Inter PLMN) Handover

The below architecture shows the two main interfaces where improvements have been evaluated:

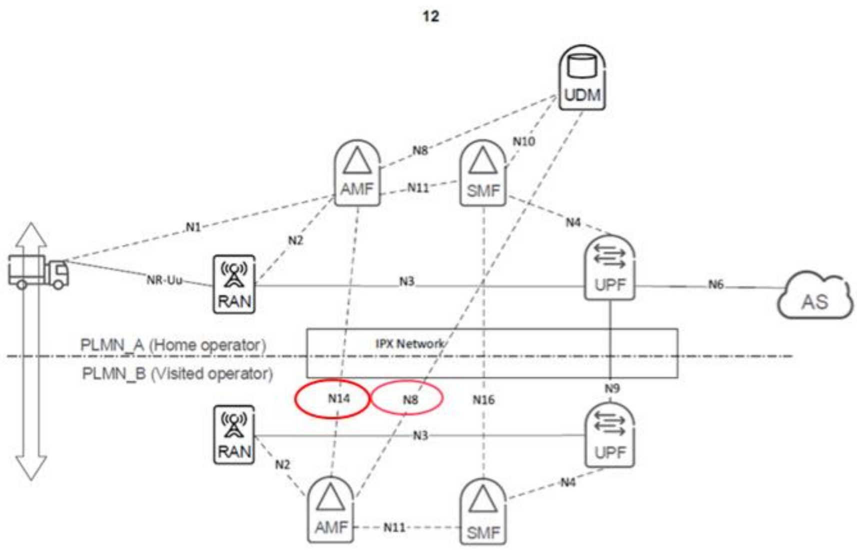


Figure 127 5G SA Reference architecture for cross border evaluations

The following scenarios have been studied:

Scenario 1: UE roaming with new registration

- Once a UE loses connection with a serving operator, the roaming procedure will take place. In particular, as described in [TS23.122], the UE will perform PLMN selection and identify the most suitable PLMN (according to its configuration).
- In any case, the delay to attach to a VPLMN is 100 seconds on average because of the sequential process and the context transfer procedure. In the case of the HPLMN the registration requires significant time as well – in the range of 9 seconds according to the same measurements' analysis.
- This solution is implemented using the N8 interface among the operators and does not require deployment of N14.

Scenario 2 . UE roaming with AMF relocation (idle mode mobility)

Following improvements have been evaluated in this scenario:

- Redirecting
  This is addressed by including redirect information in the release message. I.e. the controlling RAN is configured to the inform the UE (as part of the release) about available target frequency bands to allow the UE to immediate tune to a carrier (without the need to scan the spectrum).
- Use of the "Equivalent PLMN" function, i.e. the UE is informed about PLMNs it is allowed to use, removing the need for blind attachment attempts.
- Optimizing registration/authentication with the additional roaming interface between AMFs (N14), this interface allows the AMF in the Visited PLMN to fetch the UE context from the source AMF.

- Optimizing the user plane re-established on the new network also using N14 interface, since the new network is made aware of used UPF and UE IP address and that the user plane is re-established as part of the tracking area update in the new network.

Scenario 3 (Inter PLMN) Handover

An additional step to improve roaming would be to support handover, as defined by 3GPP between the networks. In this case, it would involve a core network type of handover, not using Xn between base stations (gNBs) because they are not normally used between networks. In this scenario the above architecture needs to be configured or factor in the handover functions.

In short, the source (controlling) network gets information from the UE about potential handover candidates in the target network, the source network contacts the potential target network and asks for resources. If granted, the source network sends a ‘handover command’ to the UE with information about the target network, the UE then tunes into and connects to the new network. The PLMNs need to be configured to execute the NG/N2 Handover between gNB AND PLMNs.

It is assumed that the 5G scenario can anticipate similar interruption times to 4G, i.e. around 100 ms.

12.6 MCx migration and interconnection

The 3GP standardization for MCX already define the concepts for Migration of context between MCX system, and interconnection uses cases. Special improvements for railway use cases – e.g. border crossing – are ongoing in 3GPP Rel. 18 (e.g. TS 23.280

- Interconnection
  Communication between MC systems whereby MC service users obtaining MC service from one MC system can communicate with MC service users who are obtaining MC service from one or more other MC systems. Interconnections between FRMCS domains is required.
- Migration
  MC service user is able to obtain MC services from a partner MC system e.g., the MCX of the roaming PLMN. Therefore, User Profile data is migrated and then accessible to partner network to migrate, especially in cross border scenarios

When it comes to the improvements for railway border crossing, on migration, the following figures explain the scope and call of the targeted specification for the some aspects of migration of group and private calls and interconnection:

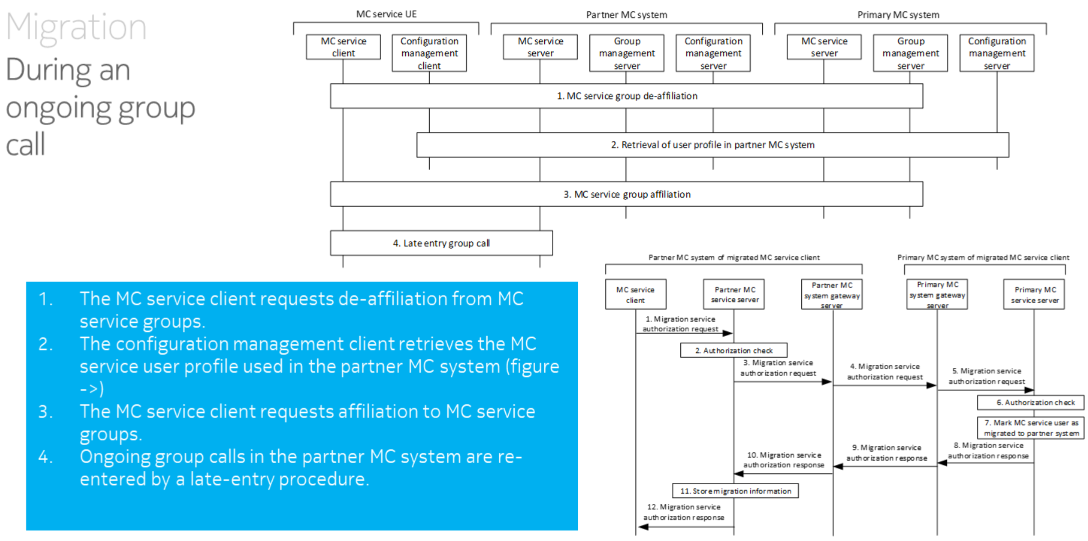


Figure 128: MCX Migration during ongoing group call

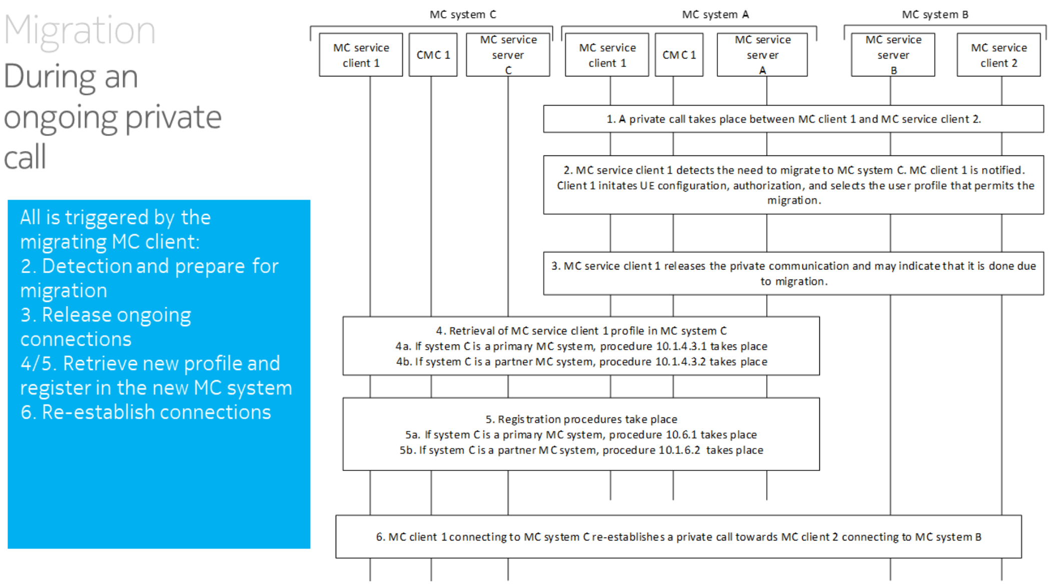


Figure 129 MCX Migration during ongoing private call

On Interconnection the following graphic shows how migrated subscriber are reached:

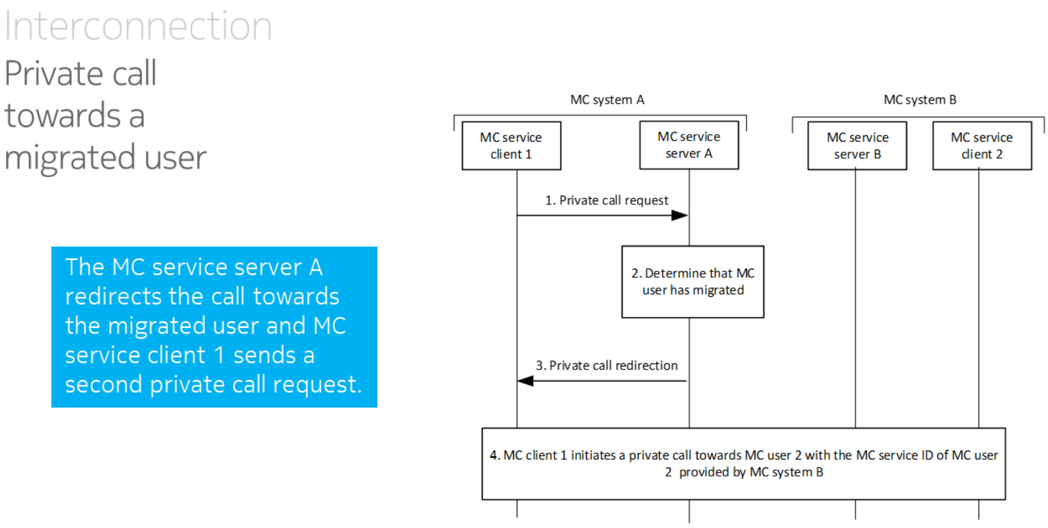


Figure 130 MCX Interconnection private call

12.7 Railway Emergency Call – UIC V1 Specification options

UIC FIS evaluated following 4 options for V1 in UIC FIS specification:

	Option 1	**Option 2** **Option 2A and Option 2B**	**Option 3**	**Option 4**
Type	Client based approach based on rules based affiliation done by the client	Server based approach. Server sends message to the clients based on rules that trigger the clients to perform an affiliation **Option 2A:** using continuous affiliation/de-affiliation after client movements based on Areas and Roles **Option 2B:** server triggered explicit affiliation of clients based on Area and Roles subsequent to client initiating a generic emergency alert.	User regroup method: Server determines based group and area definition the clients that have to be included in the call). Then originating client performs user regroup and initiates group call using the newly defined group Client based affiliation	Adhoc group method Server based area definition and user determination

Independent of the detailed solution the following high level flow chart shows the different phases required to realize a Railway Emergency Call setup fulfilling railway requirements:

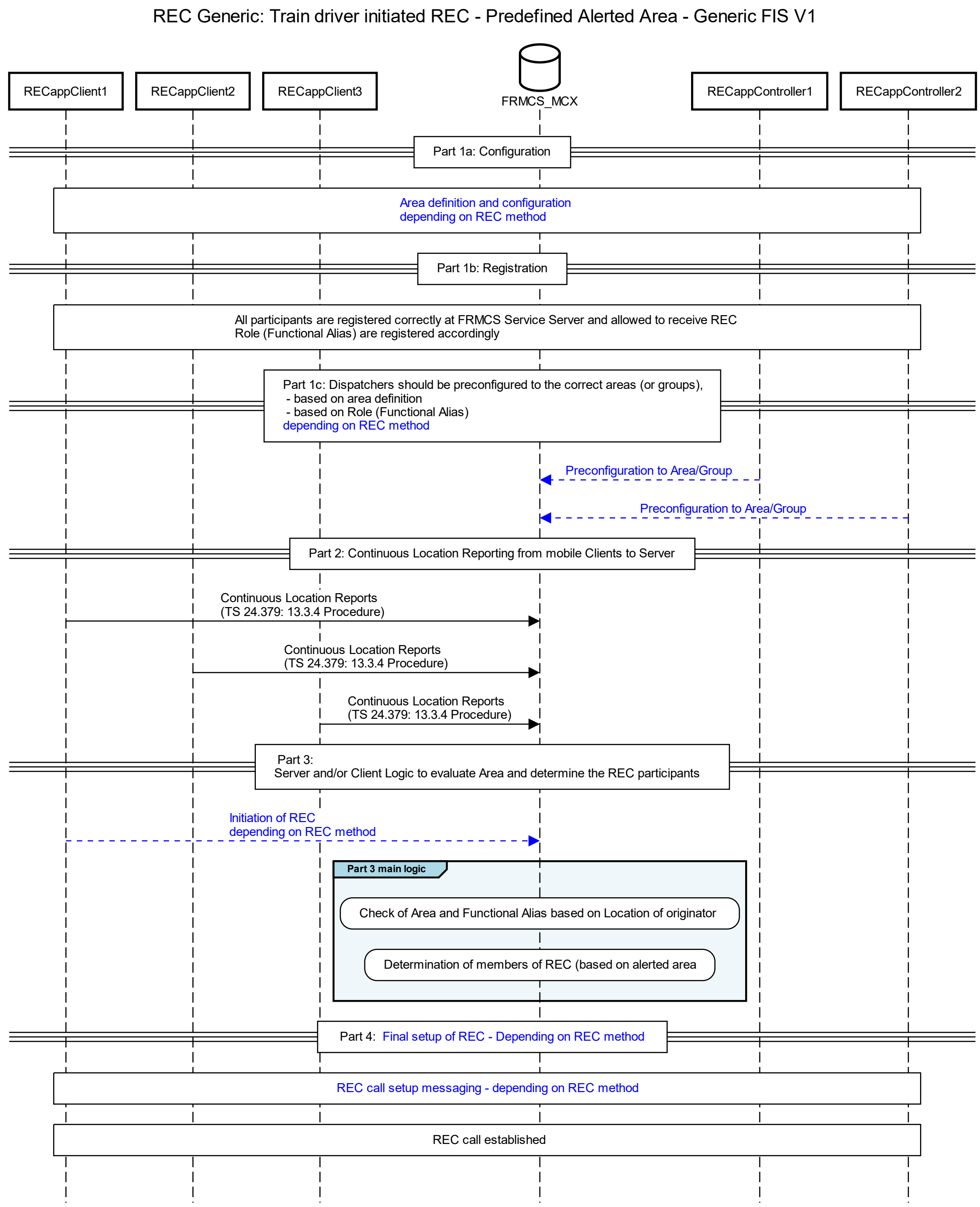


Figure 131: Generic Call Flow for REC

The following steps are described (only 5GRail functions are shown):

Part 1a: Configuration and Prerequisites

- System is configured with Area definition
- All participants are correctly configured in the FRMCS Service Server (MCX Server)

Part 1b: Registration

- All participants are registered correctly at FRMCS Service Server and allowed to receive REC

- Controller is registered in as controller identity

Part 1c: Dispatcher configuration

- Dispatchers should be preconfigured/registered to the correct areas (or groups),
  - based on area definition
- depending on REC method

Part 2: Continuous Location Reporting from mobile Clients to Server

- All mobile clients shall report continuously their location as defined in the Section
- Thus the FRMCS Service Server (MCX Server) is aware of current location of all mobile clients.

Part 3: Server and/or Client Logic to evaluate Area and determine the REC participants

- After initiation of the REC a logic shall
  - Shall check the area based on the location of the originator
  - Shall eventually determine the members of the REC (based on the above evaluations and the addressed area)

Part 4: Final setup of REC – depending on REC method

- Initiation of REC call setup signalling – depending on REC method

For 5GRail the option 2A was selected, where we have the following basic concepts and message flow:

Basic principles:

- **Operation:**
  - Clients sends continuous location reports to MC Server.
  - MC Server can determine client affiliation to Area specific group depending on the client locations
    - Client determination can use internal server rules which triggers the notification (3GPP TS 24.379 Section 6.3.2.4.2 procedure which triggers 3GPP TS 24.379 Section 12.1.1.4 procedure) and subsequent trigger the client based affiliation procedure.
  - Upon emergency initiated by user, the client automatically selects the last known emergency group (see affiliation step 0) and requests a standard MCPTT emergency group call request.
- **Clients configuration**:
  - all clients initiate emergency-group calls to the currently-selected group

The selected call flow for Option 2A is extracted from UIC FIS v1 specification and adapted to the 5GRail supported messages:

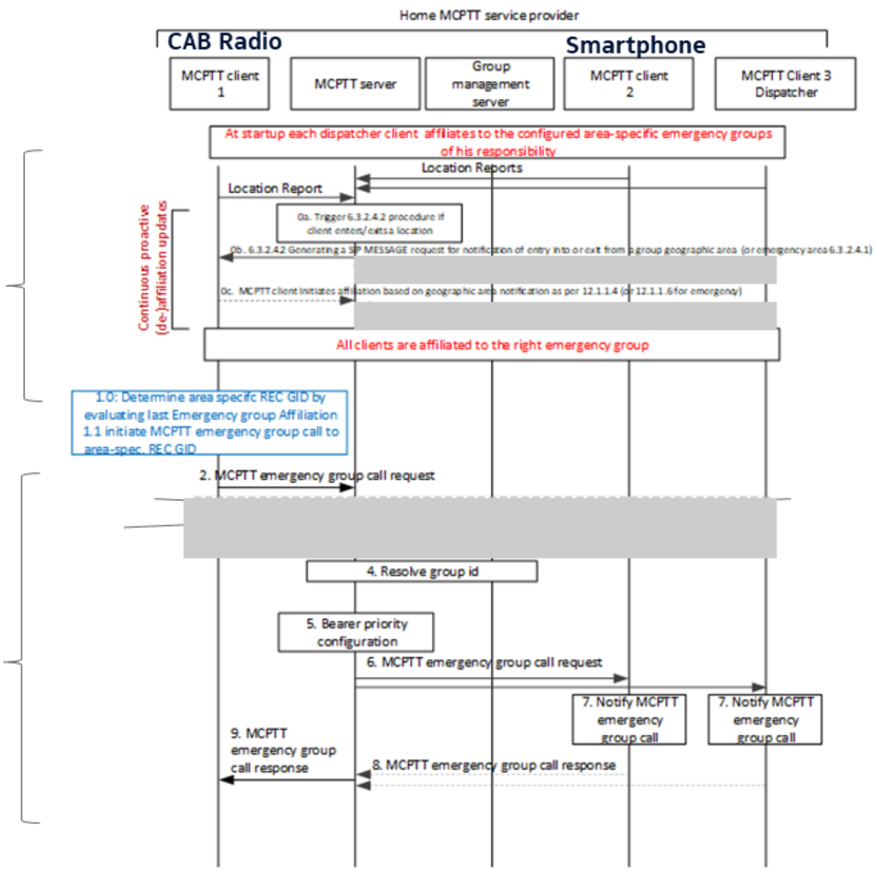


Figure 132: 5GRail call flow for REC

The additional functionality of Late Join and leave – triggered again by the location messages send by the client, and the corresponding server evaluation – has not been specified in detail, and has not been implemented in 5GRail. However, Leave and Late Join was realized based on existing MCX specifications, where client joins and leaves and already ongoing Emergency Communication, but the new dynamic affiliation process is replaced by pre-configuration of the client and implicit affiliation process of MCX.

12.8 Bearer Flexibility in 5G: ATSSS (Access Traffic Steering, Switching & Splitting)

Multi access capabilities by the 5G SA transport domain standardized in 3GPP defines the functionality required to serve different access using the ATSSS (Access Traffic Steering, Switching & Splitting). Current 3GPP Rel. 17/18 the solution is limited to serve a 3GPP and a non 3GPP (e.g. WiFi) access, but activities have been started for 3GPP Rel. 19 to evaluate enhancements of the ATSSS model to serve (at least) two different 3GPP access types as well.

To allow to serve non 3GPP access like WiFi using a 5G SA core network, mediation functionality (e.g. a N3IWF) is needed to map to 5G NSSAP signalling capable to be understood by the 5G Core. Following architecture from 3GPP TS 23.501 (see [S28] shows the concept:

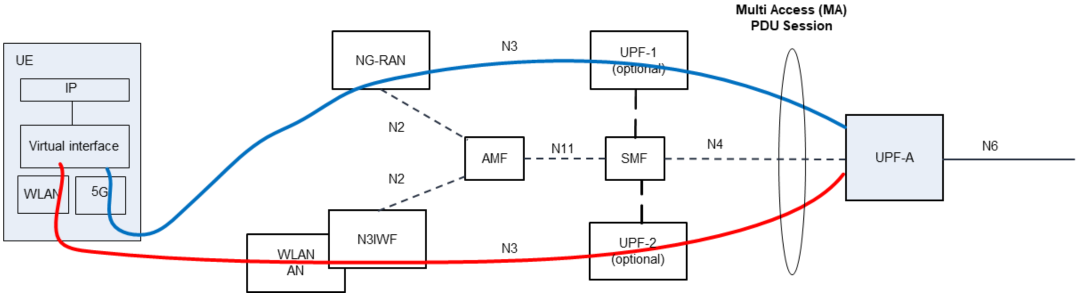


Figure 133: ATSSS architecture

ATSSS (Access Traffic Steering, Switching & Splitting) between one 3GPP access and one non-3GPP access encompasses following functions

- Access Traffic **Steering** (to one 3GPP access or to one non-3GPP access): Selecting an access network for a new data flow and transferring the traffic of this data flow over the selected access network.
- Access Traffic **Switching** (between one 3GPP access and one non-3GPP access): Moving all traffic of an ongoing data flow from one access network to another access network in a way that maintains the continuity of the data flow.
- Access Traffic **Splitting** (between one 3GPP access and one non-3GPP access): Splitting the traffic of a data flow across multiple access networks. When traffic splitting is applied to a data flow, some traffic of the data flow is transferred via one access and some other traffic of the same data flow is transferred via another access.
- ATSSS considers any type of access network, including untrusted and trusted non-3GPP access networks, wireline 5G access networks.

This is achieved by a Multi-Access PDU Session concept with a new type of PDU session to serve the two accesses. On the establishment of the sessions the UE includes an "MA-PDU capability" indication. User planes are established on each access when possible (either both at same time, or one first and the other when the UE registers to the access).

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