5GMOBIX

5G for cooperative & connected automated MOBIlity on X-border corridors

D4.3 Report on the corridor and trial site test activities

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Control sheet

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ABBREVIATIONS

Abbreviation	Definition
5G NR	5G New Radio
ADAS	Advanced Driver Assistance System
APN	Access Point Name
CAM	Cooperative Awareness Message
CAM	Connected and Automated Mobility
CBC	Cross-Border Corridor
C-ITS	Cooperative Intelligent Transport System
CN	China
CPM	Collective Perception Message
CS	Considered Solutions
CV	Connected Vehicle
C-V2X	Cellular Vehicle to Everything
DE	Germany
DENM	Decentralized Environmental Notification Message
DNS	Domain Name System
E2E	Edge-to-edge
EDM	Edge Dynamic Map
ES	Spain
FI	Finland
FR	France
gNB	gNodeB
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GR	Greece
GRX	GPS Roaming exchange
GTP	Tunnelling Protocol

HO	Handover
H-PLMN	Home Public Land Mobile Network
HR	Home Routed
HSS	Home Subscriber Server
ITS	Intelligent Transport System
KPI	Key Performance Indicator
KR	Korea
LBO	Local Breakout
LTE	Long-Term Evolution
MCM	Manoeuvre Coordination Message
MCS	Manoeuvre Coordination Service
MEC	Multi-access/Mobile Edge Computing
MME	Mobility Management Entity
mmWave	Millimetre Wave
MNO	Mobile Network Operator
MQTT	Message Queuing Telemetry Transport
MTU	Maximum Transfer Unit
NL	Netherlands
NSA	Non-Standalone Architecture
OBU	On Board Unit
PDU	Protocol Data Unit
PGW	Packet Gateway
PLMN	Public Land Mobile Network
PT	Portugal
QoS	Quality of Service
RSI	Roadside Infrastructure
RSU	Roadside Unit
RTP	Real-time Transfer Protocol
RTT	Round Trip Time

SA	Standalone Architecture
SAE	Society of Automotive Engineers
SGW	Serving Gateway
SIM	Subscriber Identity Module
SMF	Session Management Function
TCP	Transmission Control Protocol
TR	Turkey
TS	Trial Site
UE	User Equipment
UP	User Plane
V2X	Vehicle to Everything
VM	Virtual Machine
V-PLMN	Visited Public Land Mobile Network
VPN	Virtual Private Network
VRU	Vulnerable Road User
WP	Work Package
XBI	Cross-border Issue

EXECUTIVE SUMMARY

This document entitled "D4.3: Report on the corridor and trial site test activities" presents the work on trials performed within WP4 since 2021 with the two Cross border corridors, Spain-Portugal and Greece-Turkey, and in the six local Trial sites, namely the French TS, the Finnish TS, the Dutch TS, the German TS, the Korean TS and the Chinese TS.

This deliverable presents the results of the application of the methodology defined by T4.1 which has been adapted and specified by each local site. Throughout the project, 11 Cross border issues (XBIs) were defined and addressed by 26 Considered solutions (CSs). Around 180 5G test cases were developed in all sites to address the XBIs in different context (locally or at the borders, open or closed roads, closed tracks…) network configurations and environments. Each site was able to test between 2 and 6 XBIs and to address them by testing from 4 to 11 5G solutions.

The data and results collected during these trials were then transferred and analysed within the framework of WP5 "Evaluation", and whose deliverables will allow a detailed and technical analysis of the data collected.

The 5G-MOBIX project and WP4 were strongly impacted and delayed by different elements such as the COVID-19 pandemic, 5G deployment delays in different sites. As a result, the extension of the project timeline and the adaptation of the sites to the circumstances made it possible to carry out these trial activities.

1 INTRODUCTION

1.1 5G-MOBIX concept and approach

5G-MOBIX aims to showcase the added value of 5G technology for advanced Connected and Automated Mobility (CAM) use cases and validate the viability of the technology to bring automated driving to the next level of vehicle automation (SAE L4 and above). To do this, 5G-MOBIX will demonstrate the potential of different 5G features on real European roads and highways and create and use sustainable business models to develop 5G corridors. 5G-MOBIX will also utilize and upgrade existing key assets (infrastructure, vehicles, components) and the smooth operation and co-existence of 5G within a heterogeneous environment comprised of multiple incumbent technologies such as ITS-G5 and C-V2X.

5G-MOBIX will execute CAM trials along cross-border (x-border) and urban corridors using 5G core technological innovations to qualify the 5G infrastructure and evaluate its benefits in the CAM context. The Project will also define deployment scenarios and identify and respond to standardisation and spectrum gaps.

5G-MOBIX will first define critical scenarios needing advanced connectivity provided by 5G, and the required features to enable some advanced CAM use cases. The matching of these advanced CAM use cases and the expected benefits of 5G will be tested during trials on 5G corridors in different European countries as well as in Turkey, China and Korea.

The trials will also allow 5G-MOBIX to conduct evaluations and impact assessments and to define business impacts and cost/benefit analysis. As a result of these evaluations and international consultations with the public and industry stakeholders, 5G-MOBIX will identify new business opportunities for the 5G enabled CAM and propose recommendations and options for its deployment.

Through its findings on technical requirements and operational conditions 5G-MOBIX is expected to actively contribute to standardisation and spectrum allocation activities.

1.2 Purpose of the deliverable

The present document, D4.3 "*Report on the corridor and trial site test activities*", is delivered as part of WP4 and will be provided by all site and cross-border corridors leaders to document their actual trials activities. Based on the methodology discussed within task 4.1 of WP4, detailed in Deliverable D4.1 "*Report on the Corridor and Trial Sites Plans"* [1] and further implemented in D4.2 "*Report on the methodology and pilot site protocol"* [2], this deliverable gives the vision on the actual trials sessions led between 2021 and June 2022.

1.3 Intended audience

The deliverable D4.3 is a public document (PU) and it is addressed to any interested reader, hence it will be used publicly to inform all interested parties about 5G-MOBIX trialling activities. However, knowing the trials activities is relevant for WP5 Evaluation and WP6 on Exploitation partners.

2 OVERALL VISION AND TRIALS METHODOLOGY

This chapter gives an overall vision of the trials and of their execution and aims to provide update on the planning and methodology that has been described in the previous WP4 deliverables.

Task 4.1 of WP4 implemented an overall methodology that has been adopted by the TSs and the CBCs to prepare and execute their trials. The Figure 1 below gives an overview of this methodology that has slightly evolved over the project to better take into account the evolution and extensions of the project.

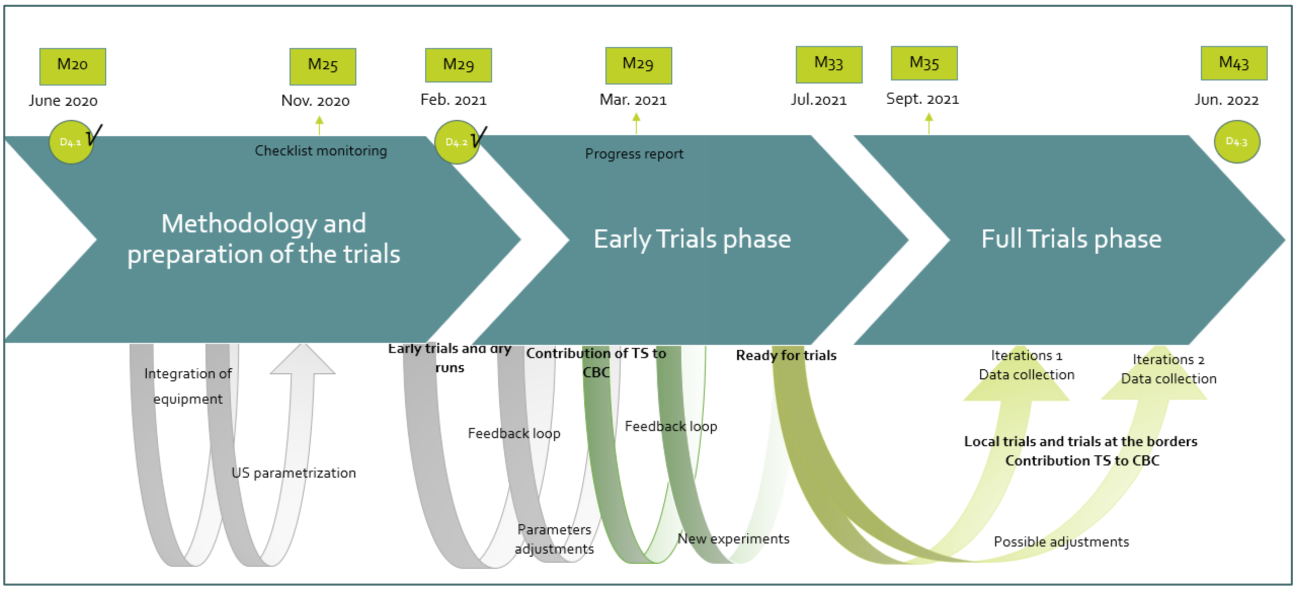

Figure 1: WP4 trials methodology

As stated in the previous WP4 deliverables, the Full trials phase was supposed to begin mid from August-September 2021. This date had to be postponed allowing the Early trials phase to conclude correctly, to allow the last integrations and deployments, and to properly synchronize the different sites and CBCs, in particular, to carry out the contributions that the TSs transferred to the CBCs.

Thus the "Methodology and preparation of the trials" phase finally lasted until February 2021. The Early trials phase lasted from February 2021 until August 2021. Finally, the actual trials started from September 2021 to June 2022. During this phase, the contributions of the TSs to the CBCs (initially scheduled for the end of 2021), took place between March 2022 and April 2022.

The annexes presented page 90 present the complete view of the scheduled trials sessions for each CBC and TS.

The Table 1 below summarizes the number of XBIs, CSs and test cases trialled by each sites gives an overview of the number of trials sessions that were finally executed at each trial sites (locally and at the borders). During each trials sessions several runs and iterations were performed to test different 5G solutions, configurations and environments. These trials sessions allowed the collection of data for WP5. We can see from the Table 1 below that around 100 trials sessions were successfully organised to test around 170 test cases.

Table 1: Trials overview per XIBs, CSs, Test cases

	# XBIs	# CSs	# Test cases trialled	# Trials sessions
ES-PT	6	8	60	≈ 30
GR-TR	6	11	35	≈ 8
NL	5	5	19	≈ 13
FR	5	7	22	≈ 18
DE	3	6	9	≈ 10
FI	2	4	11	≈ 10
KR	1	1	2	≈ 2
CN	2	4	9	≈ 4

The Table 2 below shows the number of XBIs and of CSs trialled by each site. The solutions implemented by each site are further detailed in the following sections. Both the ES-PT and GR-TR CBC addressed 6 XBIs and they respectfully implemented 8 and 11 5G solutions. The European TSs tested from 2 to 5 XBIs and implemented between 4 and 7 solutions each.

Table 2: Number of XBIs and CSs addressed per CBC/TS

3 SPAIN-PORTUGAL (ES-PT) CROSS-BORDER CORRIDOR

3.1 Test cases trialled at ES-PT CBC

Table 3: Specific test cases for baseline purposes in ES-PT

Test Case	Location	Vehicles/OBUs	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
ES-PT-1.1 **Related UC:** Advanced Driving / Lane Merge	A55 motorway	CTAG autonomous vehicle 2 CTAG connected vehicles CTAG legacy vehicle IT connected vehicle	Telefónica	CTAG MQTT hosted in Nokia ES MEC on ES side CTAG RSI for radar	Latency and reliability at the network and the application layers	XBI_0: CS_0	7/10/2021 (6 test runs) 3/11/2021 (6 test runs)
ES-PT-1.10 **Related UC:** Advanced Driving / Lane Merge	A28 motorway	CTAG legacy vehicle CTAG autonomous vehicle CTAG connected vehicle IT connected vehicle	NOS	IT MQTT hosted in Nokia PT MEC on PT side IT RSI for radar	Same as above	XBI_0: CS_0	2/06/2022 (6 test runs)
ES-PT-1.11 **Related UC:** Advanced Driving / Lane Merge	A28 motorway	CTAG legacy vehicle CTAG autonomous vehicle CTAG connected vehicle IT connected vehicle	NOS	IT MQTT hosted in Nokia PT MEC on PT side IT RSI for radar	Same as above	XBI_0: CS_0	2/06/2022 (6 test runs x 4 stress levels)

Test Case	Location	Vehicles/OBUs	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
ES-PT-2.1 **Related UC:** **Advanced Driving / Overtaking**	A55 motorway	CTAG autonomous vehicle 2 CTAG connected vehicles IT connected vehicle	Telefónica	CTAG MQTT hosted in Nokia ES MEC on the ES side	Same as above	XBI_0: CS_0	28/09/2021 (4 test runs) 28/10/2021 (11 test runs)
ES-PT-3.1 **Related UC:** Extended Sensors / HDMaps Vehicle	A55 motorway	CTAG autonomous vehicle CTAG connected vehicle IT connected vehicle	Telefónica	CTAG server on the ES side	Same as above	XBI_0: CS_0	30/09/2021 (11 test runs)
ES-PT-6.1 **Related UC:** Remote Driving / Remote Control Crossing	CTAG's tracks	Shuttle autonomous vehicle	Telefónica	Nokia ES control center on the ES side	Same as above	XBI_0: CS_0	09/01/2022 (6 test run)

Table 4: Agnostic test cases for baseline purposes in ES-PT

Test Case	Location	Vehicles/OBUs	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
KPI_AG1 (TCA-GEN_01)	CTAG's tracks. Motorway A55 and A28. New Bridge. Old Bridge.	CTAG connected vehicles.	Telefónica/ NOS	Served hosted in MECs	DL Throughput	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28
KPI_AG2 (TCA-GEN_01)	Same as above	CTAG connected vehicles	Telefónica/ NOS	Served hosted in MECs	UL Throughput	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28
KPI_AG3 (TCA-GEN_02)	Same as above	CTAG connected vehicles.	Telefónica/ NOS	Served hosted in MECs	Same as for KPI_AG1 but for cell edge	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28
KPI_AG4 (TCA-GEN_02)	Same as above	CTAG connected vehicles	Telefónica/ NOS	Served hosted in MECs	Same as for KPI_AG2 but for cell edge	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28
KPI_AG5 (TCA-GEN_03)	Same as above	CTAG connected vehicles.	Telefónica/ NOS	Served hosted in MECs	DL Data Throughput of Single User (Mbps) - mobile	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28

Test Case	Location	Vehicles/OBUs	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
KPI_AG6 (TCA-GEN_04)	CTAG's tracks. Motorway A55 and A28. New Bridge. Old Bridge.	CTAG connected vehicles	Telefónica/ NOS	Served hosted in MECs	UL Data Throughput of Single User (Mbps) - mobile	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28
KPI_AG7	Same as above	CTAG connected vehicles.	Telefónica/ NOS	Served hosted in MECs	User Plane Latency (e2e)	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28
KPI_AG8	Same as above	CTAG connected vehicles	Telefónica/ NOS	Served hosted in MECs	UL Packet Loss Rate (%) - mobile	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28
KPI_AG9	Same as above	CTAG connected vehicles.	Telefónica/ NOS	Served hosted in MECs	DL Packet Loss Rate (%) - mobile	XBI_0: CS_0	From September 2021 to December 2021 in CTAG's tracks and A55. From January 2022 to March 2022 in New and Old Bridge. May and June 2022 in A28
KPI_AG10	CTAG's tracks. Motorway A55 New Bridge. Old Bridge.		Telefónica/ NOS	For HR and for LBO	DL Throughput	XBI_0: CS_0 XBI_1: CS_8	From January 2022 to March 2022 in New and Old Bridge.

Table 5: Agnostic test cases using home routed NSA with release and redirect using S10 interface

Test Case	Location	Vehicles/OBUs	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
TCA-GEN-33_INterPLMN_HO	New Bridge between ES and PT	2 CTAG Connected vehicles	NOS and Telefónica	CTAG MQTT hosted in Nokia ES MEC on the ES side IT MQTT hosted in Nokia PT MEC on the PT side	Latency, reliability	XBI_3: CS_8	April 2022
		DEKRA TACS4 measurement tool		Servers in MECs and behind MECs	Mobility interruption time	XBI_1: CS_3	16-18 March 2022
TCA-ES-PT-02	Old Bridge between ES and PT	ISEL Connected vehicles	NOS and Telefónica	Servers in MECs and behind MECs	Latency	XBI_3: CS_8	April 2022
TCA-ES-PT-03	New and Old Bridge between ES and PT	ISEL Connected vehicles	NOS and Telefónica	Servers in MECs and behind MECs	HO success rate	XBI_1: CS_3	April 2022
TCA-ES-PT-04	Old Bridge between ES and PT	ISEL Connected vehicles	NOS and Telefónica	Servers in MECs and behind MECs	Throughput	N/A	April 2022
TCA-ES-PT-05	Old Bridge between ES and PT	ISEL Connected vehicles	NOS and Telefónica	Servers in MECs and behind MECs	Throughput	N/A	April 2022
TCA-ES-PT-06	New and Old Bridge between ES and PT	DEKRA TACS4 measurement tool	NOS and Telefónica	Servers in MECs and behind MECs	Throughput, Latency, Reliability, RSRP, SNR	XBI_3: CS_8	16 – 18 March 2022
TCA-ES-PT-07	New and Old Bridge between ES and PT	DEKRA TACS4 measurement tool	NOS and Telefónica	Servers in MECs and behind MECs	Throughput, Latency, Reliability, RSRP, SNR	XBI_3: CS_8	16 – 18 March 2022
TCA-ES-PT-08	New and Old Bridge between ES and PT	DEKRA TACS4 measurement tool	NOS and Telefónica	Servers in MECs and behind MECs	Throughput, Latency, Reliability, RSRP, SNR	XBI_3: CS_8	16 – 18 March 2022

Test Case	Location	Vehicles/OBUs	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
TCA-ES-PT-09	New and Old Bridge between ES and PT	DEKRA TACS4 measurement tool	NOS and Telefónica	Servers in MECs and behind MECs	Throughput, Latency, Reliability, RSRP, SNR	XBI_3: CS_8	16 – 18 March 2022
TCA-GEN-12_TCP_DL_No Load	New and Old Bridge between ES and PT	DEKRA TACS4 measurement tool	NOS and Telefónica	Servers in MECs and behind MECs	Throughput, RSRP, SNR	N/A	16 – 18 March 2022
TCA-GEN-13_TCP_UL_No Load	New and Old Bridge between ES and PT	DEKRA TACS4 measurement tool	NOS and Telefónica	Servers in MECs and behind MECs	Throughput, RSRP, SNR	N/A	16 – 18 March 2022
TCA-GEN-14_TCP_DL_Loaded	New and Old Bridge between ES and PT	DEKRA TACS4 measurement tool	NOS and Telefónica	Servers in MECs and behind MECs	Throughput, RSRP, SNR	N/A	16 – 18 March 2022
TCA-GEN-15_TCP_UL_Loaded	New and Old Bridge between ES and PT	DEKRA TACS4 measurement tool	NOS and Telefónica	Servers in MECs and behind MECs	Throughput, RSRP, SNR	N/A	16 – 18 March 2022

Table 6: Agnostic test cases using local breakout NSA with release and redirect using S10 interface

Test Case	Location	Vehicles/OBU	Network	MECs/Edge	KPIs	XBI/CS	Planning
TCA-GEN-24_INterPLMN_HO	New Bridge between ES and PT	CTAG onnected ehicles	NOS and Telefónica	CTAG MQTT hosted in Nokia ES MEC on the ES side IT MQTT hosted in Nokia PT MEC on the PT side	Latency, RSRP, SNR	XBI_3: CS_8	June 2022
TCA-GEN-34_INterPLMN_HO	New Bridge between ES and PT	CTAG onnected ehicles	NOS and Telefónica	CTAG MQTT hosted in Nokia ES MEC on the ES side IT MQTT hosted in Nokia PT MEC on the PT side	Latency, reliability	XBI_3: CS_8	June 2022

Table 7: Specific tests cases using home routed NSA with release and redirect using S10 interface

Test Case	Location	Vehicles/OBU	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
ES-PT-1.2 to ES-PT-1.9 **Related UC:** Advanced Driving / Lane Merge	New Bridge between ES and PT	CTAG autonomous vehicle 2 CTAG connected vehicles IT connected vehicle	NOS Telefónica	CTAG (ES side) and IT (PT side) RSIs for radar CTAG MQTT hosted in Nokia ES MEC on the ES side IT MQTT hosted in Nokia PT MEC on the PT side	Latency, reliability and mobility interruption time at the network and the application layers	XBI_1: CS_3 XBI_3: CS_8 XBI_5:CS_14 XBI_5: CS_17 XBI_9: CS_23	ES-PT-1.2: March 30, 2022 (6 test runs) ES-PT-1.4: March 30, 2022 (7 test runs)
ES-PT-2.2 to ES-PT-2.9 **Related UC**: Advanced Driving / Overtaking	Same as above	Same as above	NOS Telefónica	CTAG MQTT hosted in Nokia ES MEC on the ES side IT MQTT hosted in Nokia PT MEC on the PT side	Same as above	XBI_1: CS_3 XBI_3: CS_8 XBI_5: CS_14 XBI_5: CS_17 XBI_9: CS_23	ES-PT-2.2: March 3, 2022 (12 test runs) and March 15, 2022 (7 test runs) ES-PT-2.3: April 7, 2022 (8 test runs) ES-PT-2.4: April 7, 2022 (2 test runs) ES-PT-2.5: April 7, 2022 (6 test runs) ES-PT-2.6: March 17, 200 (6 test runs)

Test Case	Location	Vehicles/OBU	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
ES-PT-3.2 to ES-PT-3.4 **Related UC:** Extended Sensors / HDMaps Vehicle	New Bridge between ES and PT	CTAG autonomous + connected vehicles IT connected vehicle	NOS Telefónica	CTAG server on the ES side AtoBe server on the PT side	Throughput, latency, reliability and mobility interruption time at the network and the application layers	XBI_1: CS_3 XBI_3: CS_8 XBI_5: CS_17 XBI_5: CS_15	ES-PT-3.2: May 5, 2022 (6 test runs) ES-PT-3.3: April 21, 2022 (6 test runs) ES-PT-3.4: May 5, 2022 (6 test runs)
ES-PT-5.2 to ES-PT-5.9 **Related U**: Advanced Driving / Cooperative Automated	Old Bridge between ES and PT	Shuttle autonomous vehicle	NOS and Telefónica	CTAG RSI for pedestrian detector system CTAG RSI for Siemens pedestrian detector system CTAG MQTT hosted in Nokia ES MEC - IT MQTT hosted in Nokia PT MEC	Latency, reliability and mobility interruption time at the network and the application layers	XBI_1: CS_3 XBI_3: CS_8 XBI_5: CS_14 XBI_5: CS_17 XBI_9: CS_23	ES-PT-5.6: May 12, 2022 (6 test runs) ES-PT-5.7: May 12, 2022 (6 test runs)
ES-PT-6.2 - ES-PT-6.9 **Related UC:** Remote Driving/Remote Control Crossing	Old Bridge between ES and PT	Shuttle autonomous vehicle	NOS and Telefónica	Nokia ES control center on the ES side	Same as above	XBI_1: CS_3 XBI_3: CS_8 XBI_5: CS_17	ES-PT-6.3: May 3 and May 12, 2022 (6 test runs) ES-PT-6.6: April 4, 2022 (6 test runs)
ES-PT-7.1-ES-PT-7.4 **Related UC:** Vehicle QoS Support media public transport	Old Bridge between ES and PT	ALSA connected public transport	NOS and Telefónica	CTAG control center ALSA multimedia server	Throughput and reliability	XBI_1: CS_3 XBI_5: CS_17	April 21 and May 9, 2022 (6 test runs)

Table 8: Specific tests cases using local breakout NSA with release and redirect using S10 interface

Test Case	Location	Vehicles/OBUs	Network	MECs/Edge	Measured KPIs	XBI/CS	Trials
ES-PT-2.10 - ES-PT-2.13 Related UC: Advanced Driving / Overtaking	New Bridge between ES and PT	2 CTAG connected vehicles	NOS and Telefónica	CTAG MQTT hosted in Nokia ES MEC on the ES side IT MQTT hosted in Nokia PT MEC on the PT side	Latency, reliability and mobility interruption time at the network and the application layers	XBI_1: CS_3 XBI_3: CS_8 XBI_5: CS13 XBI_5: CS_14 XBI_5: CS_16 XBI_9: CS_23	June 2022
ES-PT-3.2 - ES-PT-3.4 Related UC: Sensors / HD Maps Public Transport	New Bridge between ES and PT	CTAG autonomous vehicle ALSA connected public transport	NOS and Telefónica	CTAG server on the ES side AtoBe server on the PT side	Throughput, latency, reliability and mobility interruption time at the network and the application layers	XBI_1: CS_3 XBI_3: CS_8 XBI_4: CS_10 XBI_5: CS_15 XBI_5: CS_16	June 2022

3.2 ES-PT XBI_0: Baseline

3.2.1 ES-PT CS_0: Tests on the national side (no mobility issues)

Baseline tests were executed on the national sites in Spain and in Portugal to check the performing of the CAM applications by isolating them from the mobility issues. The test cases describing the different features and configuration are listed in the Table 3: Specific test cases for baseline purposes in ES-PT and in Table 4: Agnostic test cases for baseline purposes in ES-PT.

3.3 ES-PT XBI_1: NSA Roaming interruption

3.3.1 ES-PT CS_3: Release and redirect with S10 interface using an NSA network

When the target eNodeB is not under the control of the source MME and S10 interface is configured, the handover procedure is performed inter-MME handover over the S10 interface. The source eNodeB triggers the handover via S1-MME to the source MME. The source MME performs a DNS query to obtain the target MME. The source MME sends a Forward Relocation Request over the S10 interface to the target MME, providing the UE data.

3.4 ES-PT XBI_3: Inter-PLMN interconnection latency

Currently operators interconnect using a GRX network used for both signalling and user plane data. This network extends over multiple countries and operators and is typically designed for high continuity and throughput, this at the expense of low latency. Moreover, GRX connectivity may redirect traffic through far-away nodes (based on the GRX operator architecture) further increasing E2E latency, which is unsuitable for CAM applications. In the ES-PT corridor we decided to use a dedicated line between the operators that can guarantee the latency of the messages interchanged between the 5G Core Components, and between the MECs. Given that the latency by 200 km of direct fibre connection is around one millisecond one-way, and that the interconnection routers introduces additional latency in each interface, (in the range of 0.2 to 0.8 milliseconds per interface) we considered that improving radio handovers by using GRX or Internet Access from the operators will prevent any acceptable services quality for CAM.

3.4.1 ES-PT CS_8: Direct Interconnection

Direct interconnection between the operators in the border of Spain and Portugal is using a direct optical fibre with three different VLANs for the following purposes:

- VLAN 215: S6A + S10 Signaling.. epc_ext_core_mobix (PT) <-> VRF SIG – S6A + S10 (ES)
- VLAN 216: S8-C/U. epc_ext_core_mobix (PT) <-> VRF Core Control – S8-U/C (ES)
- VLAN 217: Inter-MEC Apps connectivity towards NOS Portugal. inter_mec_mobix (PT) <-> VRF – Inter MEC (ES)

By using this fibre, we have provided an RTT of less of 5 ms between MECs. By using international GRX or International Internet Access this latency increases in a factor in the range of X2 – X10. This dedicated fibre line provides stability to the latencies implemented in the related tests cases.

3.5 ES-PT XBI_4: Low coverage Areas

Looking at current border areas we see very low coverage areas because of sparse populations at the border. In addition, given the current regulations, operators must comply with consider the max field strengths allowed at the border. On both sides of the borders the same frequencies are in use. Operators need to try and limit the interference. In addition, border areas are often sparsely populated, giving little incentives to provide for increased capacity or coverage in those areas. As a result, areas of low or no coverage may appear close to the border, threatening the CAM application continuity.

3.5.1 ES-PT CS_10: MEC service discovery and migration using enhanced DNS support

A vehicle's trajectory on the road/highway may cross the serving areas of different cross MEC systems of different PLMNs both within nation's border and at cross-border areas. Consequently, service continuity between the vehicle and the distributed MEC system(s) needs to be maintained in such operational conditions (ref. European Telecommunications Standards Institute (ETSI) GS MEC 030, 5GAA white paper #32). In (current) XBI definitions this links to XBI_5. For the FI TS, the implemented solution for service continuity in terms of MEC service discovery and migration is based on enhanced DNS support through association of MEC with DNS edge servers for low latency applications (DNS-based solutions are surveyed in this ETSI ISG MEC white paper https://www.etsi.org/images/files/ETSIWhitePapers/etsi-wp39-Enhanced-DNS-Support-towards-Distributed-MEC-Environment.pdf)

Test cases: ES-PT-3.2 and ES-PT-3.4 as in Table 8 above.

3.6 ES-PT XBI_5: Session & Service Continuity

In addition to network selection and the triggering of a handover (HO) event, minimizing service disruption during cross-border mobility further depends on the actual HO sequence followed. This sequence has important implications on connectivity during and after a HO event. In understanding these implications, it is important to first distinguish between service continuity and session continuity. While the first refers to service-level user experience, session continuity considers preservation of network attachment parameters, such as the IP address, during a HO process.

3.6.1 ES-PT CS_13: Double MQTT client

This solution aims to address the service disruption expected due to the interruption time inquired by the MQTT client-server session establishment/tear down procedures i.e, upon a handover event, an MQTT client is typically required to gracefully tear down its session with the MQTT server at the home PLMN and then establish a new one with the MQTT server at the visited network. The signaling process is time consuming resulting in service disruption. The double MQTT client solution employs two client instances e.g., A and B, with A being connected to the home PLMN server. Upon HO, client B initiates the session establishment procedure with the visited PLMN server, while A is in the process of tearing down the original session.

Test cases: ES-PT-2.10 – ES-PT-2.13 in Table 8 above.

3.6.2 ES-PT CS_14: Inter-MEC exchange of data

To address service continuity challenges when the service requiring a low latency connection with a MQTT server is upon a handover event, two instances of the server MQTT are created and deployed at the MEC of the home and the visited PLMNs. The home MQTT is directly publishing the messages in the visited one (and vice versa), managing both MQTTs the same information in every moment avoiding its segmentation in two MQTT servers upon the HO event.

Test cases: ES-PT-1.2 – ES-PT1.9, ES-PT2.2 – ES-PT-2.9, ES-PT-5.2 – ES-PT-5.9 in Table 7 above and ES-PT-2.10 – ES-PT-2.13 in Table 8.

3.6.3 ES-PT CS_15: Inter-server exchange of data

To address service continuity challenges when the service requiring a high throughput (but not very strict latency requirements) is upon a handover event, two instances of the same application are created and deployed in a server behind the MEC (connected via high-speed fibre) of the home and the visited PLMNs. Hosting the application in a server, instead of the MEC, the MEC saturation is avoided and gives the service provider direct control over its application. Duplicating the server applications, the different regulatory issues in both PLMNs can be managed if needed and the latency is also minimized.

Test cases: ES-PT-3.2 – ES-PT3.4 in Table 7 and Table 8 above.

3.6.4 ES-PT CS_16: LBO NSA

In local breakout for NSA 5G networks, the User Plane (UPU) traffic of a roaming UE is served directly by the V-PLMN, while authentication and handling of subscription data is managed by the H-PLMN. Specifically, only signaling data is routed to the H-PLMN, which allows more efficient routing in terms of latency, whereas the IP address of a roaming user is obtained from the V-PLMN.

Test cases: the same test cases as in Table 6 and Table 8 above.

3.6.5 ES-PT CS_17: HR NSA

In home routed for NSA 5G networks, the H-PLMN provides the IP address for the roaming users. The user plane (UP) traffic of the roaming UE is always served by H-PLMN, thus giving more control over the users' traffic. The MME in the V-PLMN contacts the HSS in the subscribers' H-PLMN to obtain subscriber data. When the subscriber is accepted by the V-PLMN, the user plane to the Packet Data Gateway (PGW) is established in the H-PLMN where the subscriber's IP address is anchored. The main drawback of this model is the high latency incurred since UP traffic must be tunnelled towards the H-PLMN.

Test cases: the same test cases as in Table 5.

3.7 ES-PT XBI_9: Geo-Constrained Information Dissemination

3.7.1 ES-PT CS_23: Uu geobroadcast

The architecture used for the ES-PT trials uses a distributed MQTT integration at the MEC level. MECs are present at the 5G antenna sites near the border of Spain and Portugal. Each MEC hosts its own MQTT Server.

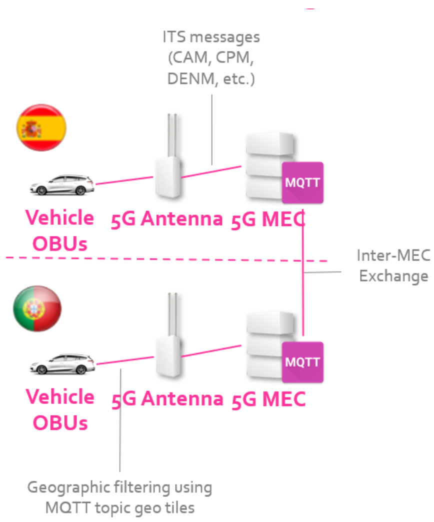

Figure 2: Simplified distributed MQTT integration architecture at the ES-PT CBC

The architecture is depicted above in Figure 2.

The messages published on the brokers are organized by topics according to each message type: CAM, DENM, CPM or MCM (Manoeuvre Cooperation Message). Besides the MQTT broker itself, there is also a GeoServer application running in each MEC node, which is responsible for handling the messages published by all connected elements.

<general_topic_header>/<message_type>/<tile>/<StationID>.

The tiling structure allows the calculation of the relevant geographic tiles for a specific location. The maximum level of zoom used in the project is 18, corresponding approximately to a 150-meter square tile side. The quadtree to publish in will be computed by the connected device (vehicles, RSUs, etc.) based on the position of the cooperative alert/message that is needed to notify. These messages are published in the in-queue topics of the broker, for instance:

its_center/inqueue/cam/0/3/1/3/3/2/2/1/3/3/2/3/2/3/3/3/3/3/986

After the messages are published to the broker, they will be received and processed by the GeoServer application that subscribes to all in-queue topics. Then, the GeoServer calculates the adjacent tiles, and republishes the message in all of them, making it available for the connected vehicles that are in that tile surroundings (Figure 3 (b)). However, in this case, the messages will be published in the out-queue topics.

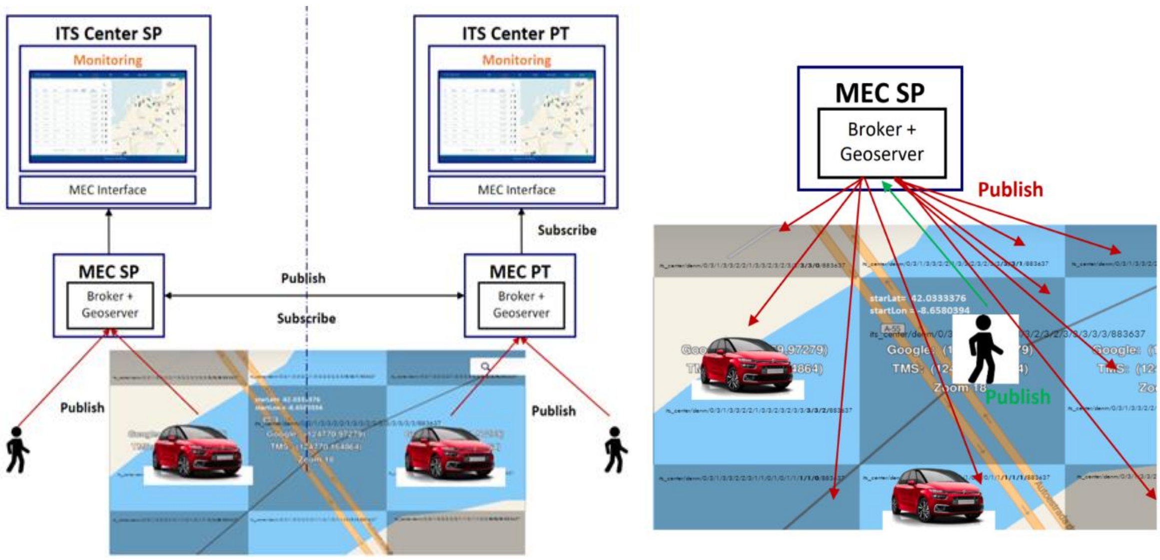

Figure 3: (a) MEC Brokers and GeoServers in ES-PT CBC; (b) GeoServer republishing strategy

There is also exchange of messages between MEC nodes, to provide service continuity in the cross-border areas, so that vehicles and VRUs connected to one of the MQTT brokers can also receive information published in the broker of the other country. This interconnection is attained through the GeoServer application that subscribes to specific topics called "inter_mecs" in the other's country MQTT broker and republishes those received messages in outqueue topics of the co-located broker. This is a simple but efficient solution for inter-MEC connection.

Test cases: ES-PT-1.2 – ES-PT1.9, ES-PT2.2 – ES-PT-2.9, ES-PT-5.2 – ES-PT-5.9 in Table 7 and ES-PT-2.10 – ES-PT-2.13 in Table 8.

3.8 Contributions of Trial Sites to CBCs

3.8.1 NL contribution to ES-PT

Figure 4: NL-TS team during OVT Trials in ES-PT CBC

Table 9: NL contribution to ES-PT CBC

Test case ID	Test Description	Related XBIs / CSs	Trials
NL-2.2	OBUs installed in vehicles from CTAG, participation in tests for user story USS1.1b. MEC MCS application installed in Spanish MEC.	XBI_9 / CS_23	2-5/11/2021, 13-17/3/2022

Lessons learnt from the NL contribution to ES-PT CBC:

- Modems, which have been tested and deployed in 5G NSA test networks in Finland (Huawei CPE), could not connect to either one or both of the ES-PT networks. The performance of 5G modems (Netgear Nighthawk), which have good performance in test networks in Netherlands and Finland, was poor in the ES-PT corridor.
- Prior to make the decision to travel to the test site the proper functioning of the network and all the functionalities needed for the tests should be guaranteed.

3.8.2 FR Contribution to ES-PT

Figure 5: FR and FI team during contribution trials in ES-PT CBC

Table 10: FR contribution to ES-PT CBC

Test case ID	Test Description	Related XBIs / CSs	Trials
TCA-FR-03	Test handover between network operators of the two countries at the border crossing	XBI_1/CS_1	March 2022 with 8 runs
TCA-FR-6 **TCA-FR-7**	Test service continuity with multi-SIM solution at the border crossing	XBI_5/CS_4 XBI_5/CS_5	March 2022 with 6 runs for each TC.
TCA-FR-14	Test exchange of data with MEC servers and interoperability of CAM services with ES-PT	XBI_5/CS_14	March 2022 with 10 runs

Lessons learnt from the FR contribution to ES-PT CBC:

- Even if we did not face any issue when using our OBU with Spanish and Portuguese SIM, the results obtained, in terms of throughput, delay, jitter, packet loss rate, are much poorer compared to those obtained in France, due to the high mobility, less maturity of the experimental networks, and the use of the single-SIM solution.

- For service continuity, it has been seen from the results an average of 26 seconds with maximum value of 74 seconds, for service interruption under the current single-SIM solution.

- Although it was planned to install the data fusion server at the NOS premises, NOS had administrative and technical difficulties to prepare the placeholder for the server on time. For this reason, the FR TS vehicle had built a connection with a data fusion server installed in France at VEDECOM server room, thus contributing to increase latency and reduce the effective throughput

3.8.3 DE Contribution to ES-PT

Figure 6: DE TS team during Trials in ES-PT CBC

Table 11: DE contribution to ES-PT CBC

Test case ID	Test Description	Related XBIs / CSs	Trials
TCS-DE-EDM-01-Adaptive-Video **TCS-DE-EDM-02-Constant-Video**	The DE TS's Extended Sensors user story was trialled in the New Bridge area. EDM and WebRTC instances were integrated into Telefonica's MEC and NOS' MEC. VICOM's vehicle, an additional connected vehicle, and two dual modem solutions were transferred to the CBC.	XBI_5 - CS_4, CS_13, CS_14 XBI_8 - CS_21 XBI_9 - CS_23, CS_24	28/02/2022 - 04/03/2022

Lessons learnt from the DE contribution to ES-PT CBC:

- The networks should support a bitrate of 10 Mbps required for the 4-camera video streaming. This means roughly 50 Mbps DL and 30 Mbps UL, to get steady performance. The Adaptive Bitrate feature decreases this bitrate if necessary, to mitigate or avoid interruptions.
- The ping pong cell handover needs to be under control from the network perspective.
- Experimenting with the network as a black box makes the debugging more difficult.
- The handover restricted to one direction or to a specific combination of SIM and direction, limits the experimentation possibilities.
- The KPI logging tool needs to be prepared for IP changes.

3.8.4 FI Contribution to ES-PT

Table 12: FI contribution to ES-PT CBC

Test case ID	Test Description	Related XBIs/CSs	Trials
TCA-FI-11	Test service continuity with multi-SIM solution at the cross-border area of the New Bridge between ES and PT	XBI_5/CS_4	March 2022 (10 runs)

Lessons learnt from the FI contribution to ES-PT CBC:

The testing of service continuity using the FI TS multi-SIM solution at the ES-PT cross-border area encountered a number of challenges which also generated some notable lessons. These included the following:

- The operation of the FI-TS multi-SIM solution relies on the deployment of a mobile IP (MIP) gateway server to provide an anchoring point for switching between MIP tunnels created on different PLMNs (when doing link selection). The plan to deploy the MIP gateway either ES or PT did not materialise, the trials to utilise the MIP gateway server deployed in the FI TS. This created excessive delays as traffic had to be routed to the distant gateway. The performance of some multi-SIM OBUs will be limited by the placement of such supporting platforms (and not just the OBU itself).
- The connectivity of the FI TS multi-SIM OBU to the ES 5G network (by Telefonica) was not possible as the commercial core network kept forcing the modem in the OBU to revert to vendor specific Access Point Name (APN) rather that the APN of 5G-MOBIX used for the project. A solution would have been to set the APN Type configuration in the OBU to APN Type = default,ia which would have forced APN to remain as 5G-MOBIX. This meant that the tests had to proceed only with the 5G test network from NOS (PT) and a secondary roaming SIM card from Finland. It is noted here that OBU and modems from different vendors may not always be guaranteed to work when encountering such local or regional settings with constraints with some of the parameters.

3.9 General conclusion from the perspective of the ES-PT CBC

In the ES-PT CBC there have been 5 different scenarios for the execution of trials:

- CTAG runways equipped with their own 5G antenna and where the validations of the different use cases could be carried out and a baseline established in a controlled environment.
    - For the validation of each use case and its behaviour with 5G network before going out to real controlled environments.

Figure 7: Trials in ES-PT CBC

- Real scenarios where road closures were necessary:
  - National in both countries for Advanced Driving, Extended Sensors and QoS:
    - A55 on the Spanish side to establish a baseline in a real environment.
    - A28 on the Portuguese side to establish a baseline in a real environment.
  - Border scenarios, where in addition to testing all the use cases, the contributions of the TSs were tested:
    - New Bridge for the use cases of Advanced Driving, Extended Sensors and QoS.
    - Old Bridge for the use cases of Remote Driving Vehicle and Extended Sensors.

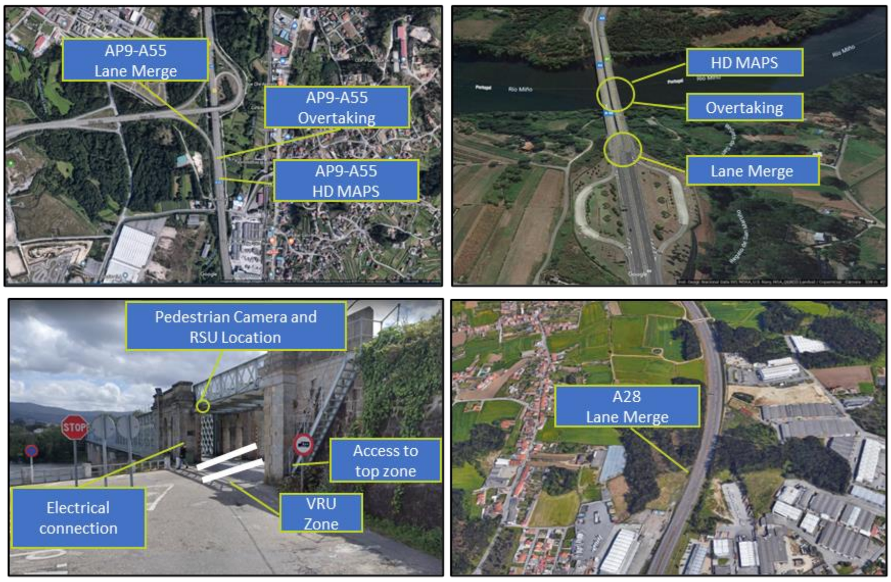

Figure 8: ES-PT CBC Real road Scenarios

These real road scenarios are located on high traffic highways, so the closures have always had to be carried out at night, with the authorisation of several public authorities in both countries and under a very complicated coordination of all those involved. The execution of these tests involves mobilising the authorities of two countries, which, although close to each other, each have their own procedures and legislation, as well as a different timetable. Another major challenge was to execute high-speed manoeuvres in a very small space and to be able to control the HOs in such a way that they happened in that space to evaluate their impact on the different manoeuvres. As for example in the case of Lane Merge in the New Bridge where there were about 200m for the execution of the manoeuvre and the location of the HO. This does not happen under natural conditions, but it is necessary for testing purposes.

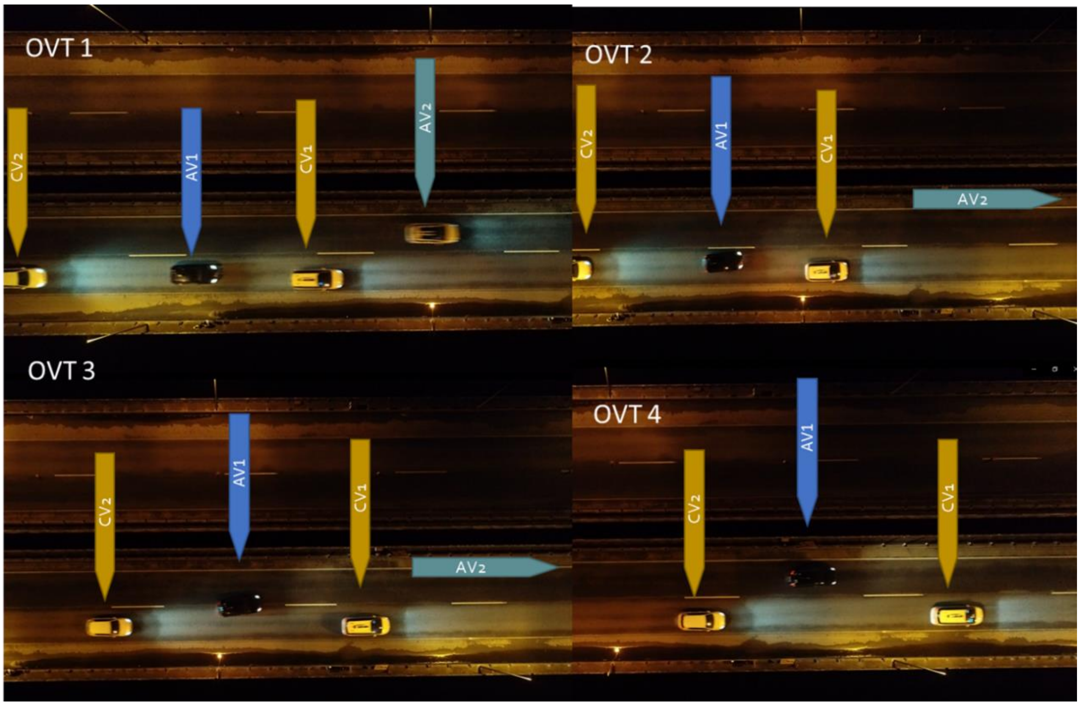

Figure 9: OVT manouvre in New Bridge PT --> ES direction with autonomous (AV) and connected (CV) vehicles

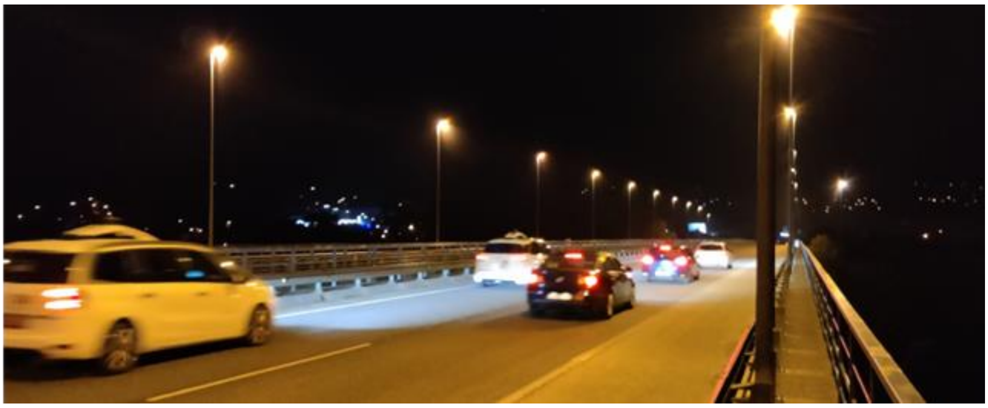

Figure 10: OVT manouvre in New Bridge PT --> ES direction with autonomous (AV), connected (CV) and legacy vehicles

During the testing period, the impact of COVID-19 was felt through occasional border closures that prevented people from entering and leaving the two countries and led to changes in the testing dates. Occasional absences of team members due to illness also led to small delays and the need to recalculate the tests. Some contributions also had to be postponed (in addition to network problems) due to international travel difficulties and restrictions.

It should be noted that during the trials, not only the aforementioned specific tests were carried out, but also user acceptance tests. These were carried out on the A55 and on the Old Bridge with non-project participants from both countries.

Following are some of the main lessons learnt and some of the technical conclusions (with more detail and data support to be presented in D5.2 "*Report on technical Evaluation*" [3]).

With the Home Routed (HR) Network Configuration:

- In all cases where the HO happened it could be verified that it is compatible with the execution of the tested functions. The interruption time is sufficiently low so that there is no impact on the function and there are no disconnections at any time.

With the Local Breakout (LBO) Network Configuration:

- HO is NOT compatible with the correct execution of the tested functions due to the reattach that must be performed on the 5G modem and that generates an interruption time that breaks the connection. To avoid this disconnection after the HO, the network would need to provide a trigger that facilitates this reconnection in the shortest possible time. This does not currently happen and to solve this problem, work is being done to ensure that the OBU itself carries out this reset and re-attach after the change of network.
- At the time of submitting this document, the ES-PT CBC is still carrying out tests with LBO since a script has been created that allows this reattach from the vehicle. Ongoing tests are aimed at improving these interruption times and reducing them as much as possible so that they have no impact on the function.

It is considered that in border areas the most logical configuration will possibly be HR while LBO could be used in areas far from the border, applying there a latency reduction since the equipment of the country where the user is located will be used. In any case, it is very important to consider the physical position of the MEC centre before establishing one configuration or the other, since it has also been shown that if it is very far away from the area where the manoeuvres have been carried out, it has a negative effect on the function of the MEC centre.

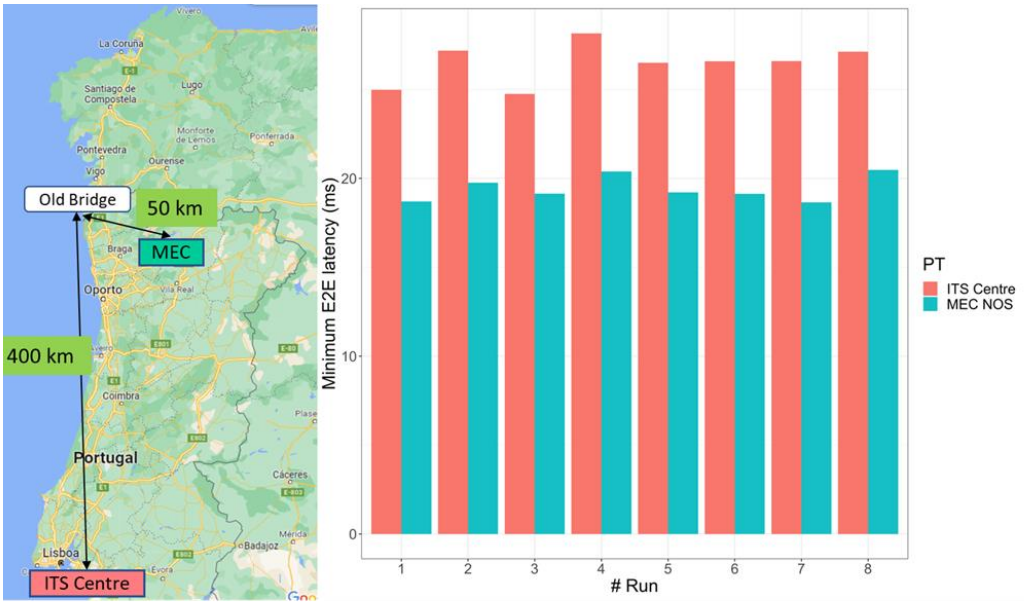

Figure 11: The minimum value of the latency in each test run provides a measurement of the distance between OBU and server.

For the handover to take place, two conditions must be met:

- The coverage value must be lower than a certain value on the antenna to which it is connected.
- The coverage value with the antenna to which the change would take place must be higher than another value.

Setting these 2 values gives the point at which the handover will occur. However, due to the fluctuation of coverage values due to several factors (user equipment, weather, physical obstructions...) this location of the HO fluctuates so that rather than a fixed point it is a variable area where the HO can "jump".

Not all handovers were implemented, in Home Routed they only worked if the SIM was that of the country being entered, and in Local Breakout if the opposite was the case. When the HO conditions were met, only the first one was produced. To perform another HO, it was necessary to restart the equipment. This is not a problem in real use conditions, but it was a difficulty when carrying out the trials. Due to the need for the handover to occur during the execution of the functions to be tested, in the area cut off for this purpose. To achieve this, it was necessary to find a specific configuration for each function so that, using the trial equipment, the handover would occur at a very specific point, for which an extensive process of coverage measurement and trial and error with different handover configurations was necessary.

In addition to this process, having to test in both directions led to unusual situations such as overlapping of the two handover zones (ES --> PT and PT --> ES), which would be avoided in a real situation. This causes problems with high latencies when the equipment was in a handover candidate area in both directions. There was also an area of pin pong effect when in the case of the Lane Merge function, due to the location of the radars and the merging lanes, it was necessary to place the handovers backwards from what was expected. In other words, when going from Portugal to Spain, for example, the handover from Portugal to Spain came first and then from Spain to Portugal. Due to the aforementioned problem whereby only the first handover takes place without restarting the teams, the ping pong effect did not take place. However, there was a problem of high latencies when the teams were in an area that met the hopping conditions of both handovers.

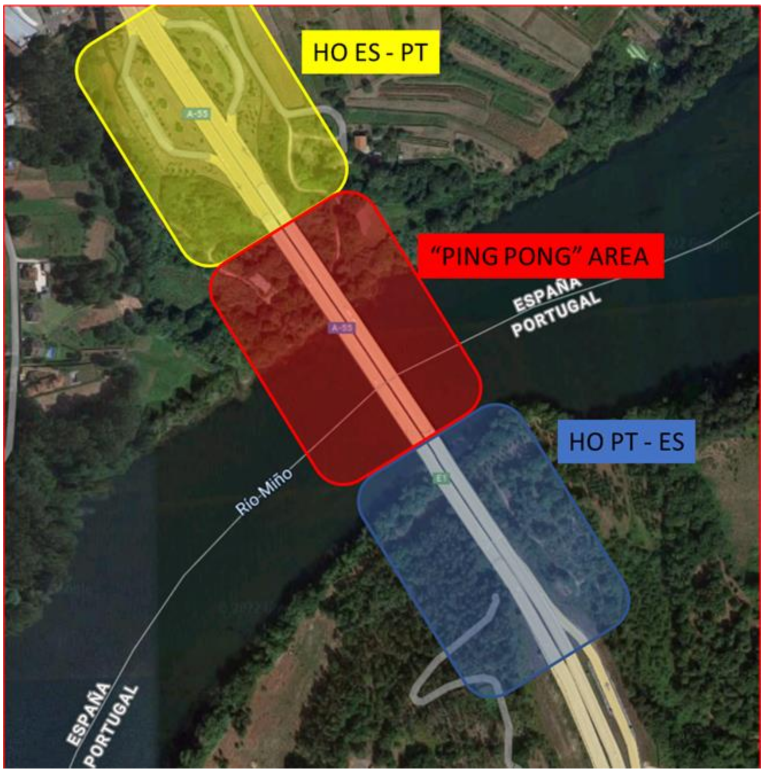

Figure 12: HO in ES-PT CBC location

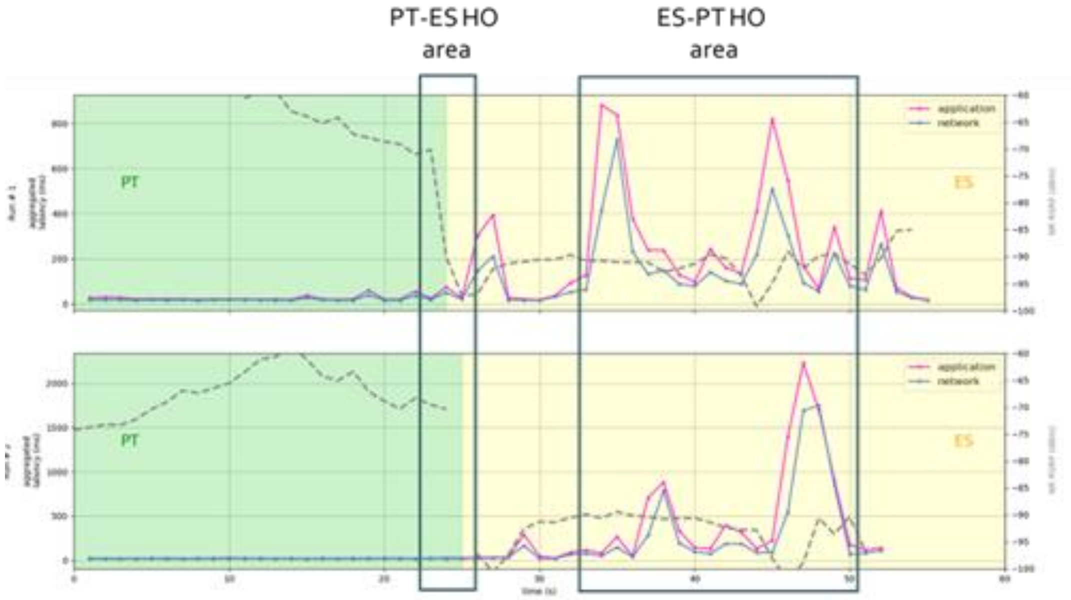

Figure 13: ES-PT and PT-ES handovers overlapping

Other factors that have affected the execution of the road trials and which have been observed in the field have been the alterations in the network reception and communications of the different equipment, creating areas of low or no coverage affected by elements of the road infrastructure. The impact of metal signage panels on the A28 and Puente Nuevo was very noticeable. In both scenarios these panels caused the blocking and bouncing of signals from both the antennas and the radar of the IT equipment (in the case of the A28). For example, during the A28 Lane Merge tests some of these panels were covered and indeed the radar signals improved and the merging effect of vehicles identified with these panels was minimised. Autonomous functions require much more precision than other functions. To achieve this requires a combination of highly accurate equipment, equipment and vehicle calibration and a suitable environment, i.e., free of obstacles that can cause signal deviations or disturbances in the case of radar for example (fusion problems) and in the network coverage.

Finally, in the case of the ES-PT CBC, it must always be taken into account that the tests were carried out with a shared network, as in the case of ES it is a commercial network and the changes and modifications to it were constant, which caused the tests to vary from one day to the next, an effect that is shown later in the results obtained.

All of the above has been very useful and is knowledge gained by all partners through testing that can be taken into account in future deployments. However, this also meant that there were delays in the execution of the trials and that some of the tests initially planned could not be executed.

- The deployment of the network for the main home routing configuration was done within the expected time, with the network performance being fully adequate for the execution of all use cases on the national territory (or baseline). However, the correct operation of the HO in the border scenarios did pose a challenge whose solution took a long time, causing several delays in the tasks and tests in the corridor and of the TSs whose contributions had to be tested in the corridor.

- Manoeuvre coordination deployments were planned with the TSs of NL, DE and FR-FI for joint testing in the corridor. The state of the network at that time (between February and April) did not allow the planned tests to be carried out with the different TSs as initially planned. In fact, the contribution of FI (Services Discovery) is being tested at the time of this deliverable with the LBO configuration.

For the preparation of the tests of each TS in the ES-PT CBC, continuous support was provided by checking the equipment that the TSs were sending in advance to CTAG and checking their connections. During the stay of each TS in the corridor, this support was maintained and the necessary network contacts were provided for the management of access to the network, servers and resolution of doubts and problems.

The ES-PT CBC is compiling all this knowledge and is planning to continue with more tests as part of the final demonstration and other projects in connected mode (since requesting more road cuts is complex due to all the implications it entails, including pedestrian and road users' safety).

4 GREECE-TURKEY (GR-TR) CROSS-BORDER CORRIDOR

4.1 Test cases trialled at GR-TR CBC

Table 13: Agnostic Test cases trialled at GR-TR CBC for baseline purposes

Test Case	Location	Vehicle	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
TCA-GEN-01_TCP_DL	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	Peak DL TCP Data Throughput of Single User	XBI_0: CS_0	21-24.12.2021 (3 runs)
TCA-GEN-02_TCP_UL	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	Peak UL TCP Data Throughput of Single User	XBI_0: CS_0	21-24.12.2021 (3 runs)
TCA-GEN-03_TCP_DL _Avg Speed	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	User Average Data TCP DL Throughput, TCP UL Throughput in Mobile Use. Loaded and Unloaded conditions (Average Speed)	XBI_0: CS_0	21-24.12.2021 (3 runs)
TCA-GEN-04_TCP_DL _High Speed	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	User Average Data TCP DL, TCP UL Throughput in Mobile Use. Loaded and Unloaded conditions (High Speed)	XBI_0: CS_0	21-24.12.2021 (4 runs)
TCA-GEN-11_TCP_DL _x% load **TCA-GEN-11_TCP_UL _x% load**	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	User Average Data TCP DL, TCP UL Throughput at the cell edge LTE SINR for TCP DL test NR SINR for TCP DL test LTE SINR for TCP UL test NR SINR for TCP UL test	XBI_0: CS_0	21-24.12.2021 (1 run)

Test Case	Location	Vehicle	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
TCA-GEN-16_DL_Cell Capacity	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	User Average Data TCP DL Throughput at the cell edge PDSCH Average RBs LTE SINR for TCP DL test NR SINR for TCP DL test	XBI_0: CS_0	21-24.12.2021 (1 run)
TCA-GEN-17_UL_Cell Capacity	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	User Average Data TCP UL Throughput at the cell edge PUSCH Average RBs LTE SINR for TCP UL test NR SINR for TCP UL test	XBI_0: CS_0	21-24.12.2021 (1 run)
TCA-GEN-18_PING_No load_MTU size	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	User Plane Latency in Unloaded Cell with MTU Size 32 and MTU Size 1500	XBI_0: CS_0	21-24.12.2021 (3 runs)
TCA-GEN-19_PING_x% load_MTU size	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	User Plane Latency in loaded Cell with MTU Size 32 and MTU Size 1500	XBI_0: CS_0	21-24.12.2021 (3 runs)
TCA-GEN-20_CP Latency	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	Control Plane Latency (NR RRC Idle -> NR Connected)	XBI_0: CS_0	21-24.12.2021 (7 runs)

Test Case	Location	Vehicle	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
TCA-GEN-23_TCP_DL_speed, TCA-GEN-23_TCP_UL_speed, TCA-GEN-23_TCP_DL&UL_speed	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	LTE Serving SINR_speed (50kmph; 90kmph) LTE Serving RSRP_speed (50kmph; 90kmph) NR Serving SS-RSRP_speed (50kmph; 90kmph) _50kmph NR Serving SS-SINR_speed (50kmph; 90kmph) NR DL PDCP Throughput (Mbit/s)_speed_50kmph ; 90kmph NR UL PDCP Throughput (Mbit/s)_speed_50kmph ; 90kmph	XBI_0: CS_0	21-24.12.2021 (3 runs)
TCA-GEN-24_TCP_DL	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	Mobility Interruption Time (where Intra MeNB mobility: MeNB same, SgNB different)	XBI_0: CS_0	21-24.12.2021 (1 run)
TCA-GEN-25_Handover	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	Mobility Interruption Time (where Inter-MeNB handover without SgNB change triggered by MeNB)	XBI_0: CS_0	21-24.12.2021 (1 run)
TCA-GEN-26_Handover	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul	Mobility Interruption Time (where Inter-MeNB handover no SgNB scenario)	XBI_0: CS_0	21-24.12.2021 (1 run)

Table 14: List of specific Test cases trialled at GR-TR CBC

Test Case	Location	Vehicle	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
GR-TR-4.1, GR-TR-4.2, GR-TR-4.4, GR-TR-7.1, GR-TR-7.2, GR-TR-7.4	Assisted "zero-touch" border crossing	2 Ford Trucks	2Networks (Cosmote and Turkcell)	1 WINGS OBU, 1 Cloud server & 2 application servers on edge	User experienced data rate E2E Latency Mobility Interruption Time	All Test cases: XBI_1: CS_1 GR-TR-4.4_7.4: XBI_6-CS_16	12/04/2022 13/04/2022 10/05/2022 02/06/2022 15/06/2022
GR-TR-4.2, GR-TR-4.4 GR-TR-7.2, GR-TR-7.4	Assisted "zero-touch" border crossing	2 Ford Trucks	2Networks (Cosmote and Turkcell)	1 WINGS OBU, 1 Cloud server & 2 application servers on edge	User experienced data rate E2E Latency Mobility Interruption Time	XBI_3:CS_8	12/04/2022 13/04/2022 10/05/2022
GR-TR-4.1, GR-TR-4.2 GR-TR-7.1, GR-TR-7.2	Assisted "zero-touch" border crossing	2 Ford Trucks	2Networks (Cosmote and Turkcell)	1 WINGS OBU, 1 Cloud server & 2 application servers on edge	User experienced data rate E2E Latency Mobility Interruption Time	All Test cases: XBI_6-CS_17 GR-TR-4.1, GR-TR-7.1 : XBI_3:CS_7	12/04/2022 13/04/2022 10/05/2022 15/06/2022
GR-TR-10.1 GR-TR 10.2	Truck Routing	1 Ford Truck	1 network (Turkcell)	1 cloud 3 IMEC RSUs	Throughput End to End Latency Reliability	XBI_3: CS_8 XBI_4: CS_4	May 2022 (7 runs) June 2022: (9 runs)
GR-TR-11.1	See-What-I-See	2 Ford Trucks 2 IMEC OBUs,	2Networks (Cosmote and Turkcell)	2 application servers on edge	User experienced data rate End to End Latency Reliability Application Level Handover Success Rate	XBI_1: CS_1 XBI_3: CS_7 XBI_3: CS_8 XBI_5:CS_17 XBI_5:CS_19 XBI_6CS_19	March 2022 April 2022
TCS-GR-TR-Plat-5GPlat-Platoon-Maintain_Split_Merge-Manoeuver	5G platooning	2 Ford Trucks	2 networks (Turkcell-Cosmote)	2 IMEC OBUs 1 cloud application	Throughput End to End Latency Reliability	XBI_4: CS_4 XBI_5: CS_4	May 2022 (5 runs) June 2022 (5 runs)

Test Case	Location	Vehicle	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
TCS-GR-TR-Plat-5GPlat-Platoon-Create_Search_Join-Manoeuver	5G platooning	2 Ford Trucks	2 networks (Turkcell-Cosmote)	2 IMEC OBUs 1 cloud application	Throughput End to End Latency Reliability	XBI_4: CS_4 XBI_5: CS_4	May 2022 (5 runs) June 2022 (5 runs)
TCS-GR-TR-Plat-5GPlat-Platoon-Dissolve-Manoeuver	5G platooning	2 Ford Trucks	2 networks (Turkcell-Cosmote)	2 IMEC OBUs 1 cloud application	Throughput End to End Latency Reliability	XBI_4: CS_4 XBI_5: CS_4	May 2022 (5 runs) June 2022 (5 runs)

Table 15: List of agnostic Test cases trialled at GR-TR CBC

Test Case	Location	Vehicles	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
TCA-GR-TR-04_InterPLMN_HO_LBO	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul Indirect Connection between MNOs	In LBO configuration, it does not matter whether the connection between MNOs is over the Internet or Direct. Results will be the same as TCA-GR-TR-05_InterPLMN_HO_LBO.	XBI_6:CS_16	11-13 May 2022 (4 runs)
TCA-GR-TR-05_InterPLMN_HO_LBO	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul Indirect Connection between MNOs	User Experienced DL throughput, E2E Latency, ICMP packet loss rate	XBI_6:CS_16	11-13 May 2022 (4 runs)
TCA-GR-TR-06_InterPLMN_HO_HR	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul Indirect Connection between MNOs	User Experienced DL/UL throughput, E2E Latency, Mobility Interruption Time, ICMP packet loss rate	XBI_6:CS_17	21-25 February 2022 (4 runs)
TCA-GR-TR-07_InterPLMN_HO_HR	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul Indirect Connection between MNOs	User Experienced DL/UL throughput, E2E Latency, Mobility Interruption Time, ICMP packet loss rate	XBI_6:CS_17	28March – 1 April 2022 (4 runs)

Test Case	Location	Vehicles	Network	MECs/Edge	KPIs	XBI/CS	Trials carried out
TCA-GR-TR-01_Handover TCA-GR-TR-02_Handover	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul Indirect Connection between MNOs	User Experienced DL Throughput, Mobility Interruption Time, LTE handover and NR leg addition procedure success	XBI_6:CS_17	11 May 2022 (1 run)
TCA-GR-TR-03_Handover	Ipsala/ Edirne-Turkey	1 Drive Test vehicle	Turkcell	Option3x NSA Access NW (3 deployed sites) Core NW located Kartal-Istanbul Indirect Connection between MNOs.	User Experienced DL Throughput, Mobility Interruption Time, LTE handover and Secondary Node Release success	XBI_6:CS_17	11 May 2022 (1 run)

4.1 GR-TR XBI_0: Baseline

4.1.1 GR-TR CS_0: Tests on the national side (Intra PLMN Tests)

These are the tests in which basic functions are checked within the same country. No border crossing was made in these tests. Each cell has been tested and reported separately. The test cases describing the different features and configuration are listed in the Table 13.

4.2 GR-TR CBC XBI_6: Data Routing

4.2.1 GR-TR CS_16: LBO NSA

LBO (Local Break Out) is one of the roaming solutions between mobile operators which requires additionally configuration on hosted MME and PGW. Visited UE entering to Home Network, eNB/NR is directing to UE to Home Operator MME, then home MME sent visited UE attached request visited HSS. After a successfully authentication period, home MME selects home SGW and PGW to complete control plane part of attachment. Visited UE uses its original APN (this was configured before in PGW) and takes IP address from IP pool of Home PGW. As a result, Visited UE attached home network and exiting to internet or application server through Home PGW (For Home Routed (HR) solution, PGW must be Visited PGW). With this solution, leased line costs between operators can be reduced and Jitter/Delay will be low between UE and application servers when compared with Home Routed (HR) solution.

4.2.2 GR-TR CS_17: HR NSA

Commercial networks usually do not allow Inter PLMN handovers. When leaving a country, a UE will stay connected to the Home Network until it lost synchronization of the last cell which is connected. For a long time, the quality of the radio link drops to very low levels, and the establishment of speech and the simplest data service is not allowed by the network. After losing the synchronization, the UE starts searching for the appropriate cell in the visited country. It will then establish a new PDN connection usually resulting in a new Internet Protocol (IP) address. Being served by a different network than the home one is called "roaming". When the UE attaches to the visited NW it will usually still use a P-GW in its home network. This will be the same P-GW as before the roaming process. The S-GW in the visited network and the P-GW in the home network communicate over the S8-interface. The MME in the visited network and the HSS in the home network communicate over the S6a interface. Interfaces S8 and S6a are realized over an IP Exchange (IPX) network. This could be either the public Internet or direct connection. All above definitions addressing to the Home Routing Inter PLMN handover scenario.

4.3 Technical conclusion for the Inter PLMN tests:

Within the scope of the agnostic test, three different configurations were tested in the border region.

- In the Inter PLMN_HO Home Routed + S10 configuration, the configuration where the connection between MNOs is made over the Internet has been tested as Config1. In this configuration, it was observed that the latency values changed after Inter PLMN HO.
- In the Inter PLMN_HO Home Routed + S10 configuration, the configuration where the connection between MVOs is made directly has been tested as Config2. In this configuration, it was observed that the latency values decreased after Inter PLMN HO compared to Config1. For the Config1 and Config2 UE/OBU IPs have assigned by Home NW PGW. It has been observed that after Inter PLMN HO user IPs have not change which is correct behaviour of the NW.
- In the Inter PLMN_HO Local Breakout + S10 configuration, the configuration where the connection between MNOs is made directly has been tested as Config3 (in LBO configuration, it does not matter whether the connection between MNOs is over the Internet or Direct.) Tests have been done while the home network was shut down after HO, to prevent the phone to reconnect to the home network. This is normal behaviour since a complete new attach and registration is needed using flight mode. If you only close down the data session and keep the phone registered to the network, we expect that the phone won't try to reconnect to the home network. After being re-attached to the visited NW, the new IP was assigned by the visited NW PGW. It means OBU/UE get service like home network.
- Current networks are able to apply Session and Service Continuity (SSC) mode 1 and 2:
    - Mode 1: session is always preserved
    - Mode 2: network may release a data session, instructing the UE to establish a new session

  With future implementations it will be possible to keep the UE connected using mode 3: a new data session is set up before the old one is released. LBO configuration is not suitable for the seamless CAM services.

4.4 Contributions of Trial Sites to GR-TR CBC

For the "See–What–I–See" (SWIS) video streaming application of GR-TR CBC trials, there was the significant and substantial contribution of FI TS. For the required LEVIS transfer and remote installation to our equipment (both clients and server), many preliminary tests were gradually realized. Before the final trials of the GR-TR CBC corridor, our partners participated in numerous sessions for the successful installation and functionality test of the configuration applied to the "See– What – I– See" application. More particularly, the tests took place in many different settings for checking the application's response to our scenarios. The equipment consisted of one server and two client devices configured to be in the follower and leader truck of our cross-border tests. The client devices were initially tested with sender (leader truck client device) being in Finland and sending the stream to the receiver (follower truck client device) in Greece using the Greek server in ICCS premises. Alternatively, the same test was done with FI server and then the complete integrated solution tested before the final trials and the associated measurements.

The SWIS application was properly tested on field at both Home Routed network configurations. Specifically for the Local Breakout scenario, the application was not able to realize the tests from a traditional LBO perspective as it works with one server only. However, the device IP changes management when the trucks change network, while crossing the borders takes place in client device level giving extreme flexibility to the system and its deployment. The application was successfully tested for the IP change scenario in laboratory test bed.

The features were tested with the video streaming service continuity when the trucks cross the borders and the Mobile Network Operator changes. During the trials, the client devices were behind the IMEC OBUs in the trucks which had COSMOTE sim cards. The involved server was the Greek in Alexandroupoli edge server. During the measurements both GR server with COSMOTE sim cards and TR server with Turkcell sim cards were used. The transferred asset was the LEVIS video streaming binaries installed at both edge servers and the client devices.

Apart from the preliminary tests on the lab (February 2021 – July 2021), the additional integration with the trucks and on the site tests took place on October 2021. The measurement tests took place between March 2022 to June 2022 and they included 3 network configurations (2 HR and 1 LBO). The test runs which were finally managed to complete were 3 complete routes (TR-GR-TR and GR-TR-GR) for both edge servers (at total 12 measurement rounds). The successful application functionality and its required outcomes were proven during the trials at the 9th-10th May 2022.

Figure 14: The follower truck road view with the leader truck in its front

Figure 15: The SWIS screen on the follower truck presents the leader driver's view

Lessons learnt:

There were not any significant hindrances referring to the FI TS contribution and LEVIS binaries transfer. However, the strict firewall rules from the MNOs perspective kept the initial deployment back from its initial schedule. During the on-site deployment new communication flows were on request and further delays emerged for their activation.

4.5 General conclusions from the perspective of the GR-TR CBC

In GR-TR corridor, 4 user stories were tested. General view of test location for all user stories can be seen in Figure 16 below.

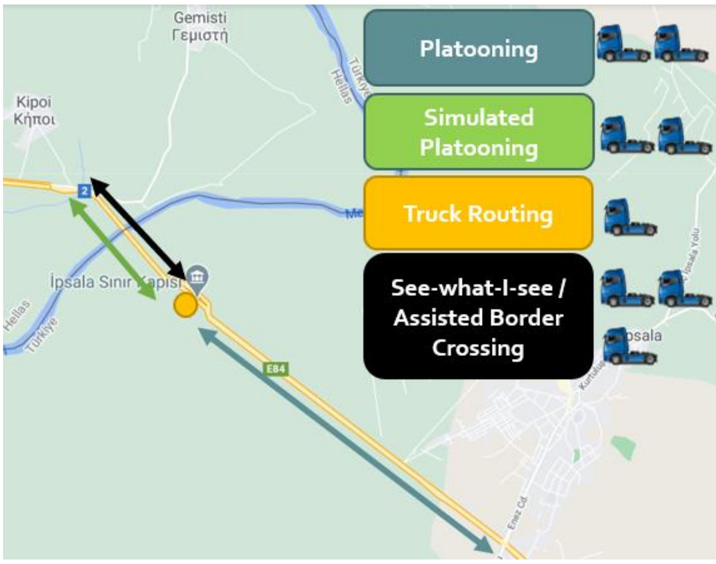

Figure 16: Overall View of Trial Locations

The 5G Platooning user story was tested in two different locations with two vehicles. The first location is just before the entrance of Ipsala – Turkish Border Gate, road E84 and it is approximately 4.5km. In this area, Platooning was performed with all manoeuvres and physical distance was maintained by autonomous trucks (see below Figure 17, left picture). The second location used, is the bridge on buffer zone between GR – TR. This area is strictly controlled by militaries of both countries, and it is impossible to maintain gap between two trucks with autonomous mode, due to speed limits (the maximum allowed speed is 30km/h). Additionally, road width is too narrow, and huge truck queues exist in this area (see below Figure 17 right picture). Due to these restrictions, in this area the two trucks exchanged related 5G Platooning messages but were not operated autonomously.

Figure 17: Road Before the Ipsala – Turkish Border Area (left picture)- Bridge on Buffer Zone Between GR-TR Border (right picture)

Autonomous Truck Routing user story tested in Ipsala – Turkish Border Area and picture from field can be seen in Figure 18, and the used route in this area is shown with a red arrow that also illustrates the trial area. The See What I See and Assisted Border Crossing user stories were also tested in the same location with Simulated 5G Platooning (see Figure 18). While two trucks were used for the See What I See user story, one truck was used for the Assisted Border Crossing.

Figure 18: Ipsala – Turkish Border Gate (top) - Illustration of Ipsala – Turkish Border Gate (bottom)

The GR-TR border area is defined as hard border with many control points and presence of militaries from both countries. To perform any test in this area, permissions must be granted from the Greek, Turkish military, and customs officials. For our trials, these permissions were granted for ICCS and TÜBİTAK, by Greek and Turkish officials respectively.

COVID-19 pandemic affected our trial time plans. It was impossible to travel to border area and pass from one country to another. Hence, the team had to update the time plan on a weekly basis.

The two Ford F-MAX trucks that were used during the trials were carried on another truck trailer since these trucks are not ready yet for untrained truck drivers, due to the fact that the developed software is aimed to be only for proof-of-concept studies. Pictures of the trucks that were carried on trailer can be seen below in Figure 19.

Figure 19: Trucks on Trailer at Ipsala

Since this is a multi-partners project and every partner developed different parts of the user stories, mainly a remote support was provided by partners via meeting calls except for Ericsson TR, Turkcell, Ford Otosan, TÜBİTAK and WINGS. Listed partners were on the field for each new network configuration tests. Ford Otosan team handled truck shipment, truck driving during every user story tests, completion of paperwork to pass the border, performing responsible user story tests (mainly 5G Platooning and supportive for Autonomous Truck Routing), and equipping vehicle with shipped user story equipment such as OBU, camera, processing unit. Ericsson TR and Turkcell teams took care of network configuration tests, TÜBİTAK and WINGS teams handled their user story tests.

Lessons learnt:

- 5G modems are not fully ready for common usage. Due to software bugs, the team on the field had to restart modems so many times to have remote and 5G connection.
- NSA LBO is not useful for seamless connectivity. The service continuity was problematic, since to change operator from Turkcell to Cosmote or vice versa, 5G modem had to be restarted and/or flight mode activated.
- Bureaucracy, paperwork was a big burden on the field and it slowed down the teams to complete planned tests.

5G Non-Stand Alone (NSA) 3GPP Rel. 15 networks have been deployed on Turkey and Greece covering a total of 9.9 kms of Highway with 4 eNB/gNBs. Core NW equipment's installed at Alexandroupoli in Greece and Kartal in Turkey.

Network tests are very important for the US test performing correctly in the field. For this purpose, many test cases were carried out during the network verifications. During the tests, a test car specially designed by Turkcell was used. In the vehicle, there was a power unit providing energy to the test devices and a table on which we could put the test devices it is shown in Figure 20 and Figure 21.

Figure 20: GR-TR CBC drive testing team

Figure 21: Figure Agnostic test vehicle

Commercial smart phones (Huawei P40 Pro, Xiaomi Mi10) and softwares (Tems Investigation, Probe) were used during the tests.

Lessons learnt:

- Delays at border crossings are inevitable, not only due to the Covid-19 pandemic, but also due to the corridor's important and intensive use in terms of commercial transportation.
- Since all of these sites are located on the tower, the control of the radio signals has created a significant difficulty. We had to change some antenna directions and separate LTE antennas from commercial NW (for NR anchoring commercial LTE antennas were used).
- Commercial smart phones used are designed for normal subscribers. There were many stability problems on UE during the long test's durations.
- Since the UEs used during the agnostic tests were inside the vehicle, some problems were experienced in the signal levels. In addition, the use of metal fences close to the custom area had an impact on the heavy truck traffic test results.
- NW parameters are set to specific values for all UEs. During the tests, it was observed that the OBUs and UEs behaved differently compared to each other. A special parameter set has been created for OBUs with the support of IMEC and Ford so that OBUs can handover in the right place. The parameter set used for the agnostic tests was adjusted before the US tests.
- Since Turkey is not a member of the European Union, project workers are required to obtain a visa at border crossings. Issuing a visa is a time-consuming procedure and Visa applications should have been made quite in advance.
- While the project tests are being conducted, the police and military authorities must be informed before the border crossing. The authorities in the project organization have made great efforts on the subject and have helped to solve many problems. However, although these permits were obtained, a lot of time was lost during border crossings due to various coordination problems.The difficulty of carrying out such projects in high security areas was seen in this project.

5 NETHERLANDS (NL) TRIAL SITE

5.1 Specific Test cases trialled at NL TS

Table 16: List of Specific Test Cases trialled by NL TS

Test Case	Location	Networks	Vehicles/OBUs	MEC/Edge	KPIs	XBIs/CSs	Trials carried out
NL-1.1	Helmond & Eindhoven, A270/N270	5G NSA KPN network (commercial)	TNO 5G SA OBU (Fibocom FM-150AE unit) Siemens vehicle with 5G SA capable OBU	Siemens edge infrastructure (with LBO for 5G SA networks) Message brokers in edge to support use-cases: edge interconnect (MQTT federation) Remote station (Remote driving specific)	Latency PDR	XBI_0: CS_0	04-08-2021: 4 runs 02-09-2021: 6 runs
NL-1.2	Helmond & Eindhoven, A270/N270	5G SA TNO network	TNO 5G SA OBU (Fibocom FM-150AE unit) Siemens vehicle with 5G SA capable OBU	Siemens edge infrastructure (with LBO for 5G SA networks) Message brokers in edge to support use-cases: edge interconnect (MQTT federation) Remote station (Remote driving specific)	Latency PDR	XBI_0: CS_0	22-07-2021: 7 runs 02-09-2021: 6 runs
NL-1.3	Helmond & Eindhoven, A270/N270	5G SA TNO network	TNO 5G SA OBU (Fibocom FM-150AE unit) Siemens vehicle with 5G SA capable OBU	Siemens edge infrastructure (with LBO for 5G SA networks) Message brokers in edge to support use-cases: edge interconnect (MQTT federation) Remote station (Remote driving specific)	Latency PDR	XBI_0: CS_0	22-07-2021: 12 runs 02-09-2021: 7 runs

Test Case	Location	Networks	Vehicles/OBUs	MEC/Edge	KPIs	XBIs/CSs	Trials carried out
NL-1.4 **NL-1.5** **NL-1.6** **NL-1.7** **NL-3.4**	Helmond Eindhoven A270/N270	5G SA TNO 5G SA KPN	TNO 5G SA OBU (Fibocom FM-150AE unit) AIIM - TU/e vehicle with 5G SA capable OBU	Siemens edge infrastructure (with LBO for 5G SA networks) Message brokers in edge to support use-cases: edge interconnect (MQTT federation) Remote station (Remote driving specific)	Latency PDR	XBI_5:CS_14 XBI_6:CS_14 XBI_11:CS_26	**NL-1.4**: 22/07/2021 (7 runs); 4/08/2021 (6 runs) **NL-1.5:** 22/07/2021 (3 runs); 4/08/2021 (6 runs); 02/09/2021 (12 run) **NL-1.6**: 4/08/2021 (3 runs); 02/09/2021 (8 runs) **NL-1.7**: 15/12/2021 (20 runs)
NL-1.8	Helmond & Eindhoven, A270/N270	5G SA TNO 5G SA KPN	TNO 5G SA OBU (Fibocom FM-150AE unit) AIIM - TU/e vehicle with 5G SA capable OBU Siemens vehicle with 5G SA capable OBU	Siemens edge infrastructure (with LBO for 5G SA networks) Message brokers in edge to support use-cases: edge interconnect (MQTT federation) Remote station (Remote driving specific)	Latency PDR	XBI_2:CS_6	02/09/2021 (6 runs) 04/08/2021: (4 runs)
NL-1.1 t/m NL-1.8	Helmond Eindhoven A270/N270	5G SA TNO 5G SA KPN	TNO 5G SA OBU (Fibocom FM-150AE unit) AIIM - TU/e vehicle with 5G SA capable OBU Siemens vehicle with 5G SA capable OBU	Siemens edge infrastructure (with LBO for 5G SA networks) Message brokers in edge to support use-cases: edge interconnect (MQTT federation) Remote station (Remote driving specific	Position accuracy based on 5G localisation	XBI_9:CS_23	21/07/2021 (10 runs) 22/07/2021 (20 runs) 4/08/2021 (9 runs) 2/09/2021 (36 runs) 15/12/2021 (20 runs) 16/042022 (18 runs)

Test Case	Location	Networks	Vehicles/OBUs	MEC/Edge	KPIs	XBIs/CSs	Trials carried out
NL-2.1	Tampere	Commercial 4G/5G network in Finland.	2 OBUs	MQTT broker and MCS application in local server in Tampere	Latency	XBI_0: CS_0	Tests performed in September 2021
NL-2.2	Tampere	Commercial 4G/5G network in Finland.	2 OBUs	MQTT broker and MCS application in local server in Tampere	Latency	XBI_0: CS_0	Tests performed in September 2021, and April 2022.
NL-2.3	Tampere	Commercial 4G/5G network in Finland.	2 OBUs	MQTT broker in local server in Tampere	Latency	XBI_0: CS_0	Tests performed in September 2021.
NL-2.1 **NL-2.2** **NL-2.3**	Vaarle	5G SA TNO 5G SA KPN	VTT OBU with Netgear Nighthawk modem	Siemens edge infrastructure, MCS application installed on VM (for NL-2.3) Message brokers in edge to support use-cases: edge interconnect (MQTT federation) Remote station (Remote driving specific)	Latency	XBI_6:CS_14 XBI_9: CS_23	7/9/2021 (10 test runs for NL-2.1, 30 for NL-2.2, 10 for NL-2.3) 4-5/4/2022 (8 test runs for NL-2.1)
NL-2.1(2), NL-2.2(1)	Helmond Eindhoven A270/N270	5G SA TNO 5G SA KPN	VTT OBU with Netgear Nighthawk modem	Siemens edge infrastructure, Message brokers in edge to support use-cases: edge interconnect (MQTT federation)	Latency	XBI_9:CS_23	5/4/2022 (5 runs for NL-2.1(2), 5 runs for NL-2.2(1)). Additionally, 3 test runs stored at Automotive Campus (NL-2.1(2))
NL-3.1	Helmond	5G SA KPN	Siemens vehicle with 5G SA capable OBU	Siemens edge infrastructure (with LBO for 5G SA networks) Message brokers in edge to support use-cases: edge interconnect (MQTT federation)	Latency Reaction time of remote driver	XBI_0: CS_0	64 test runs

Test Case	Location	Networks	Vehicles/OBUs	MEC/Edge	KPIs	XBIs/CSs	Trials carried out
				Remote station (Remote driving specific)			
NL-3.2	Vaarle	5G SA KPN	AIIM - TU/e vehicle & Siemens vehicle with 5G SA capable OBU	Siemens edge infrastructure (with LBO for 5G SA networks) Message brokers in edge to support use-cases: edge interconnect (MQTT federation) Remote station (Remote driving specific)	Latency Position accuracy w.r.t. reaction time of remote driver	XBI_0: CS_0	Positioning tests executed Mar/Apr 2021 and Sept. 2021: 184 test runs on 4G (Benchmark tests) 304 tests runs on 5G
NL-3.3	Helmond	Virtual network configuration using HIL setup with Siemens PreScan on different communication	Siemens PreScan vehicle (software)	Siemens PreScan with OBU in HiL setup	Latency Position accuracy with respect to reaction time of remote driver	XBI_0: CS_0	Positioning tests executed Mar/Apr 2021 and Sept. 2021: 110 test runs
NL 3.5	TU/e campus (both simulation as well as outdoor testing)	5G SA TU/e	mm-wave antenna setup	TU/e dedicated setup for mm-wave processing	Position accuracy based on 5G localisation	XBI_7: CS_20	Outdoor network testing: 2 days of testing (see D3.7 [4]) - 25 & 26 April 2022 (& prior lab testing in March/April 2022) Localisation simulations: >50 runs)

5.2 NL XBI_0: Reference case for cross-border issues

5.2.1 NL CS_0: Reference case for cross-border issues

The NL Trial site has three 5G SA networks as depicted in Figure 22 below. The cross-border related trials have been executed using the KPN network (with 6 base stations) and TNO network (only one base station), while the TUE network is specifically setup for mmWave trials.

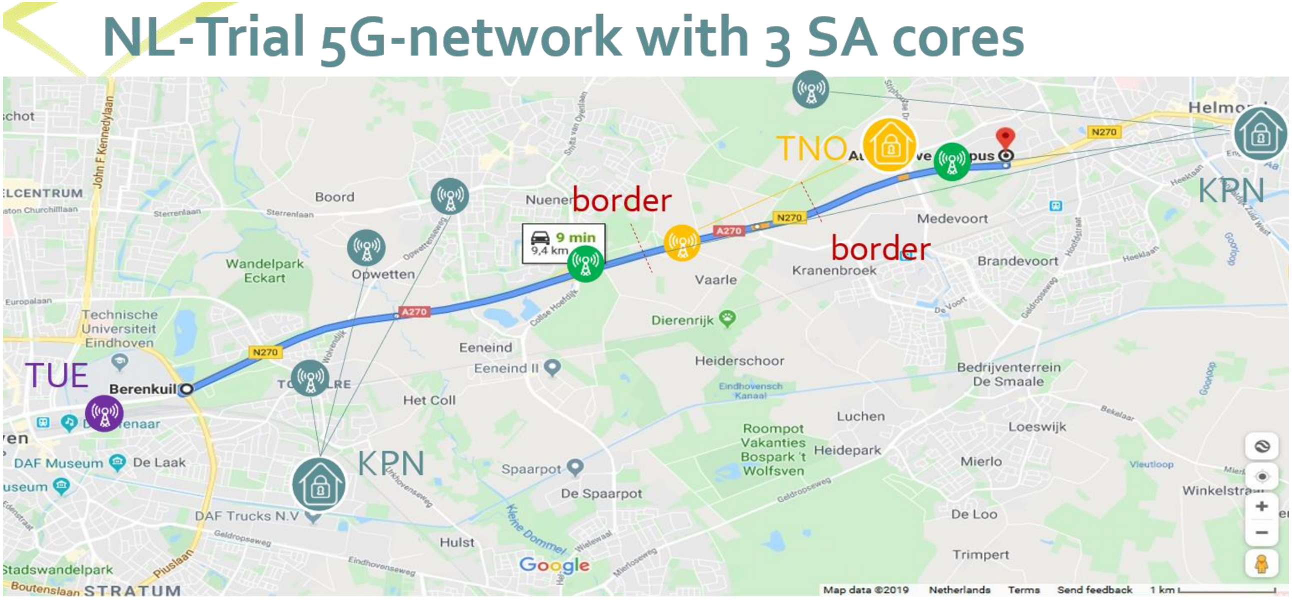

Figure 22: Network configuration of 5G-MOBIX in The Netherlands

The NL TS executed baseline tests for the different considered solutions addressing different XBIs. The following test cases were executed: NL-1.1: tests with KPN's commercially available 5G NSA network. Traffic to MEC/Edge components was routed through KPN's APN exit point, over the internet, to an entry point in the Siemens network. NL-1.2: tests with TNO's 5G SA network while doing 'core routing'. Traffic to MEC/Edge components was routed through TNO's APN exit point (in The Hague) over a VPN connection, back again over the VPN connection, towards the MEC/Edge applications. NL-1.3: tests with TNO's 5G SA network while doing LBO: Traffic to MEC/Edge components was routed through LBO towards the MEC/Edge applications. NL-3.1: tests with KPN's 5G SA network on remote driving – perception tests, to evaluate remote driving vs. normal manual driving and influence of low vs. high bandwidth requirements on remote driving performance. NL-3.2: tests with KPN's 5G SA network on remote driving – position accuracy tests, to evaluate remote driving vs. normal manual driving and discrepancy in vehicle position. Tested on both 4G LTE as well as KPN 5G SA network. NL-3.3: tests with simulated 5G SA network on remote driving – position accuracy tests, to evaluate remote driving vs. normal manual driving and influence of (simulated) communication delay on the use case performance.

5.2.2 CS_6: Release and redirect using an SA network

The Release and Redirect functionality was not fully implemented, as explained in deliverable D3.7 [4]. However, roaming tests were performed without this functionality. This is what we call 'basic roaming'. The different test cases were performed using a 5G SA network. This is a setup where the UE has no PLMN pre-configured in the SIM other than its H-PLMN. The UE is not configured to search in a specific frequency/band. No mechanisms are in place on the gNB or core to reduce the interruption time.

5.3 XBI_5: Session & Service Continuity

5.3.1 CS_14: Inter-MEC exchange of data

The MQTT-federation allows data to be exchanged between two PLMN's. A UE connected to the TNO network is connected to TNO's MQTT instance, the other UE is connected to KPN's network and its MQTT instance.

5.4 XBI_6: Data routing

5.4.1 CS_14: Inter-MEC exchange of data

The MQTT-federation allows data to be exchanged between two PLMN's. A UE connected to the TNO network is connected to TNO's MQTT instance, the other UE is connected to KPN's network and its MQTT instance. Three test cases were implemented to address this XBI: NL-1.7, NL-2.2 and NL-2.3.

5.5 XBI_7: Insufficient Accuracy of GPS Positioning

5.5.1 CS_20: Compressed sensing positioning

Augmenting positioning by taking advantage of the properties of 5G mmWave signals, which provide large bandwidth combined with multiple antenna-technology at both network and UE sides. Using compressed sensing techniques on the OFDM signal, this can improve localization accuracy beyond the accuracy available from GNSS-type positioning even when only few reference stations are available. Taking advantage of information for angle of arrival/departure available from the multi-antenna systems and the sparsity of mmWave channels, highly accurate relative positions between base station and UE can be derived by UE-based positioning.

5.6 XBI_9: Geo-Constrained Information Dissemination

5.6.1 CS_23: Uu geobroadcast

Use quadtrees to define the geolocation of interest and use those quadtrees to determine whether an OBU (or subscriptor) should receive data. The quadtrees are calculated on the OBU's which directly translate to the MQTT topic(s) for which the OBU must subscribe or publish to. The quadtrees can be configured to have a specific zoom-level, which corresponds to the size of the area of interest.

5.7 XBI_11: Network slicing applicability

5.7.1 CS_26: Network slicing

Network slicing is used to create multiple virtual network slices and set absolute priorities between them. This means that a specific slice and its traffic can have absolute priority over another slice by influencing the scheduler in the gNB. In this way we can guarantee specific QoS to specific services (or slices).

5.8 General conclusions from the perspective of the NL TS

The trials in the Netherlands in general were executed as expected. The impact of COVID-19 has been minor since there were little restrictions on working outdoors, while indoor activities could be done remotely. It did affect timing trials executed by VTT due to international travel restrictions, however all trials were completed within the available time frame.

Concerning the contribution to the cross-border site a deployment of manoeuvre coordination by VTT was planned at the ES-PT site, aiming for providing data of using the MCM protocol. Due to delays in the network provision at the ES-PT cross-border site, this was unsuccessful even though an unplanned second attempt was made several months after the first attempt.

The MCM trials in the Netherlands shows clear improvement due to evolution of KPN's and TNO's networking configuration. It is also believed that presence or absence of leaves on trees affects performance, especially in the TNO network due to the antenna being installed at tree-level height.

During the trials in The Netherlands there was a breakdown of the VTT vehicle which had a strict timeline to return to Finland, resulting in tests for 3 days instead of planned 5 days.

For the application of extended sensors by TNO it appeared that the TNO network coverage at the planned lane merging location was insufficient to do trials on handover/roaming between the KPN network and TNO network. As a result, a switch was made to an overtaking scenario, which can be executed at any location within the network range. The application for overtaking is very similar to merging since for both scenarios it is required to identify the gaps in traffic to allow vehicle to enter on a lane. As a result, the merging application could relatively easily be translated to a lane-changing application with some extra effort in developments of the application. Therefore, this has no impact on the assessment of the networking capabilities and assessing the impact of handover effects on the application.

In addition to the initial plan, roaming tests were executed under real-life conditions and not just in simulation or lab environments. Various iterations of the networking functionality have been tested (planning adjusted to availability), as well as three different networking cores and UE's from three different suppliers, before settling on the Open5GS (core) and Fibocom (UE).

For remote driving the tests were executed at a different location than initially planned due to authorisation of the automated vehicles on the public road. This has had no impact on the results. It even enabled making a video with a professional drone.

As an unplanned addition, trials have been executed using slicing technology.

As part of remote driving mmWave trials were planned as part of the scientific work at the Eindhoven University, which in the end were executed in simulation instead of as a real-time in-vehicle application. The simulation models have been setup using the results of laboratory unit tests, and a limited amount of outdoor tests. Setting up a mmWave network with sufficient coverage for diving tests proved to be infeasible within the constraints of 5G-MOBIX. The result is a proof-of-concept application that can be used in future on-road experiments.

6 FRENCH (FR) TRIAL SITE

6.1 Specific and Agnostic test cases trialled at FR TS

Table 17: List of Specific Test Cases trialled by FR TS

Test case	Location	Vehicle/OBU	Network	MEC	KPIs	XBI/CS	Trials carried out
FR-1.1 **FR-1.2**	Paris, Versailles Satory	Connected Vehicle with VEDECOM OBU (Zoe) and C-ITS Stack	**FR-1.1** Bouygues Public 4G Network **FR-1.2** Bouygues Public 5G NSA Network	MEC Server with MQTT broker	Total Throughput End-to-end latency Packet loss rate CAM End-to-end latency CAM data rate CPM End-to-end latency CPM data rate MCM End-to-end latency MCM data rate	XBI_10: CS _25	Trails executed in November 2021 5 iterations recorded without collision risk not necessitating lane change manoeuvre 5 iterations recorded with collision risk (necessitates lane change manoeuvre)
FR-1.3	Versailles	Connected Vehicle with VEDECOM OBU (Zoe) and C-ITS Stack	TDF Private 5G NSA Network (mmWave)	MEC Server with MQTT broker	Total Throughput End-to-end latency Packet loss rate CAM End-to-end latency CAM data rate	XBI_10: CS _25	Trails executed in May/June 2022 5 iterations recorded
FR-1.4	Versailles	Connected Vehicle with VEDECOM OBU	Bouygues Public NSA and TDF Private NSA (mmWave)	MEC Server	Data rate End-to-End latency	XBI_5: CS_5	Trials executed early June 2022
FR-1.5	ES-PT CBC (New Bridge)	Connected Vehicle with VEDECOM OBU (Citroen C4)	NOS and Telefónica	2 MEC Server (ES-PT CBC)	Data rate End-to-End latency	XBI_5: CS_14	Trials executed on 24/03/2022
FR-1.6	Versailles	Connected Vehicle with VEDECOM OBU	LEO Satellite (Iridium)	MEC Server	Data rate End-to-End latency	XBI_4: CS_9	Trials executed early June 2022

Table 18: List of Agnostic Test Cases trialled by FR TS

Test case	Location	Vehicles/OBUs	Networks	MECs	Measured KPIs	Linked XBI/CS	Trials carried out
TCA-FR-01	Paris, Versailles, Satory Trial Site	Connected Vehicle with VEDECOM OBU (Zoe)	Bouygues Public 5G NSA Network	MEC Server with iperf	NR RSRP NR SINR Throughout Latency Packet Loss	XBI_10: CS_25	Multiple early trials performed in 2021 and 2022 Trials in May 2022: 2 runs
TCA-FR-02	Paris, Versailles, Satory Trial Site	Connected Vehicle with VEDECOM OBU (Zoe)	TDF Private 5G mmWave Network	MEC Server with iperf	NR RSRP NR SINR Throughout Latency Packet Loss	XBI_10: CS_25	Trials performed in April/May 2022 2 runs
TCA-FR-03	ES-PT CBC (New Bridge)	Connected Vehicle with VEDECOM OBU (Citroen C4)	NOS and Telefónica	VPN Server	NR RSRP NR SINR Throughput End-to-End latency Jitter Packet Loss Rate Service Interruption Time	XBI_1: CS_1	Trial executed on 23/03/2022 5 runs
TCA-FR-04 **TCA-FR-05**	Versailles, Buc area, open road	Connected Vehicle with VEDECOM OBU	Public 5G NSA networks (Orange and Bouygues)	VPN Server	NR RSRP NR SINR Throughput End-to-End latency Jitter Packet Loss Rate	**TCA-FR-04** XBI_5: CS_5 **TCA-FR-05** XBI_5: CS_4	Trials executed on 02/02/2022 6 runs
TCA-FR-06 **TCA-FR-07**	ES-PT CBC (New Bridge)	Connected Vehicle with VEDECOM OBU (Citroen C4)	NOS and Telefónica	VPN Server	NR RSRP NR SINR Throughput End-to-End latency Jitter Packet Loss Rate Service Interruption Time	**TCA-FR-06** XBI_5: CS_4 **TCA-FR-07** XBI_5: CS_5	Trials executed on 22/03/2022 5 runs

Test case	Location	Vehicles/OBUs	Networks	MECs	Measured KPIs	Linked XBI/CS	Trials carried out
TCA-FR-08 **TCA-FR-09**	Versailles, Buc area, open road.	Connected Vehicle with VEDECOM OBU	Orange and Bouygues 5G NSA networks	Iperf server	NR RSRP NR SINR Throughput End-to-End latency Jitter Packet Loss Rate	**TCA-FR-08** XBI_5: CS_5 **TCA-FR-9** XBI_5: CS_4	Trials executed on 25/02/2022
TCA-FR-10	Paris, Versailles, Satory Trial Site	Connected Vehicle with VEDECOM OBU (Zoe)	Bouygues Public 5G NSA Network and TDF Private 5G mmWave Network	MEC Server with iperf	Throughout Latency Packet Loss	XBI_10: CS_25	Trials performed in April/May 2022 (2 runs) June 2022 (2 runs)
TCA-FR-11	Paris, Versailles, Satory Trial Site	Connected Vehicle with VEDECOM OBU (Zoe)	Bouygues Public 5G NSA Network and TDF Private 5G mmWave Network	MEC Server with iperf	Throughout Latency Packet Loss	XBI_10: CS_25	Trials performed in April/May 2022 (2 runs) June 2022 (2 runs)
TCA-FR-12 **TCA-FR-13**	Versailles Satory Test Tracks	Connected Vehicle with VEDECOM OBU	TDF 5G NSA Network and LEO Satellite (Iridium)	Iperf Server	End-to-end latency Throughput	XBI_4: CS_9	Trials executed in May/June 2022 (2 runs)
TCA-FR-14	ES-PT CBC (New Bridge)	Connected Vehicle with VEDECOM OBU (Citroen C4)	NOS and Telefónica	2 MEC Server (ES-PT CBC)	NR RSRP NR SINR Throughput End-to-End latency Jitter Packet Loss Rate	XBI_5: CS_14	Trials executed on 24/03/2022
TCA-FR-16 **TCA-FR-17**	Versailles, Buc area, open road.	Connected Vehicle with VEDECOM OBU	Orange and Bouygues 5G NSA networks	Iperf server	NR RSRP NR SINR Throughput Packet Loss Rate	XBI_8: CS_22	Collection of data for model training from last quarter of 2021 to March 2022. Test of the model and demonstration done in April 2021 during FR site event.

6.2 XBI_1: XBI_1: NSA Roaming interruption

6.2.1 CS_1: S1 handover with S10 interface using an NSA network

This solution has been tested in ES-PT CBC with ES Telefonica and PT NOS networks. Here, a connected vehicle uses a single SIM from one of the two operators. Multiple runs which consist in crossing the border from one side to the other in the different directions have been done.

6.3 XBI_4: Low coverage area

6.3.1 CS_9: Satellite connectivity

Satellite fall back solution has been tested in use case agnostic and use case specific test cases. With agnostic test cases (TCA-FR-12 and TCA-FR-13), this solution has been tested in addition to 5G terrestrial communication to validate handover in case 5G network is not available. The executed trials have shown that when multi-SIM link aggregation is done (TCA-FR-13), handover between the technologies is possible as it fails when the feature is deactivated (TC-FR-12). Use case specific test case (FR1.6) consists in transmission of messages to assess performance of satellite connectivity to support CAM service.

6.4 XBI_5: Session service continuity

6.4.1 CS_4: Multi-modem / multi-SIM connectivity - Passive Mode

FR TS used an intelligent router solution, connected to its OBU, which allows the UE to keep multi-SIM connections with PLMNs ensuring continuity and communication quality between the application endpoints. The tested configuration consists in assigning priorities to the different technologies in used so that the router can select among the available links, the one with highest priority. Different tests have been performed statically (TCA-FR-05) and dynamically (TCA-FR-09) in FR TS and in ES-PT CBC (TCA-FR-06).

6.4.2 CS_5: Multi-modem / multi-SIM connectivity - Link Aggregation

FR TS used an intelligent router solution, connected to its OBU, which allows the UE to keep multi-SIM connections with PLMNs ensuring continuity and communication quality between the application endpoints. it performs link aggregation and load balancing across different PLMN connections and use these connections in a combined manner. Both sims are from different PLMN's. Different tests have been performed statically (TCA-FR-04) and dynamically (TCA-FR-08) in FR TS and in SP-PT CBC (TCA-FR-07). Use case specific test case (FR1.4) consists in transmission of messages to assess performance of the solution to support CAM service.

6.4.3 CS_14: Inter-MEC exchange of data

During the trials executed in ES-PT CBC, connectivity with different MEC and the handover between these MEC at the border crossing. There trials have been executed to complete agnostic test case (TCA-FR-14) and use case specific test case (FR 1.5).

6.5 XBI_8: Dynamic QoS Continuity

6.5.1 CS_22: Predictive QoS

FR TS has developed an algorithm to dynamically adjust transmission data rate for the CAM applications depending on the network conditions. To train this model, data have been collected at the access and network levels during different test sessions in the end of 2021 and beginning of 2022. Then, predictive QoS model has been trained based on the collected dataset and could be tested offline.

6.6 XBI_10: mmWave applicability

6.6.1 CS_25: mmWave 5G

A mmwave experimental network has been deployed in Satory site during Q1/2022. It includes LTE eNB and radio and 5G gNB and mmWave radio access (band n258). Performances of the deployed infrastructure has been tested and results are to be compared with baseline performances obtained with other radio access (LTE and 5G sub 6GHz). Performance tests of networks have been carried out (TCA-FR-01 and TCA-FR-02) and applicability of mmWave in combination with sub 6GHz technology for cross-border conditions has been tested (TCA-FR-10 and TCA-FR-11). Finally, use case specific test cases have been executed to test the capability of 5G mmWave to support CAM service of FR UC.

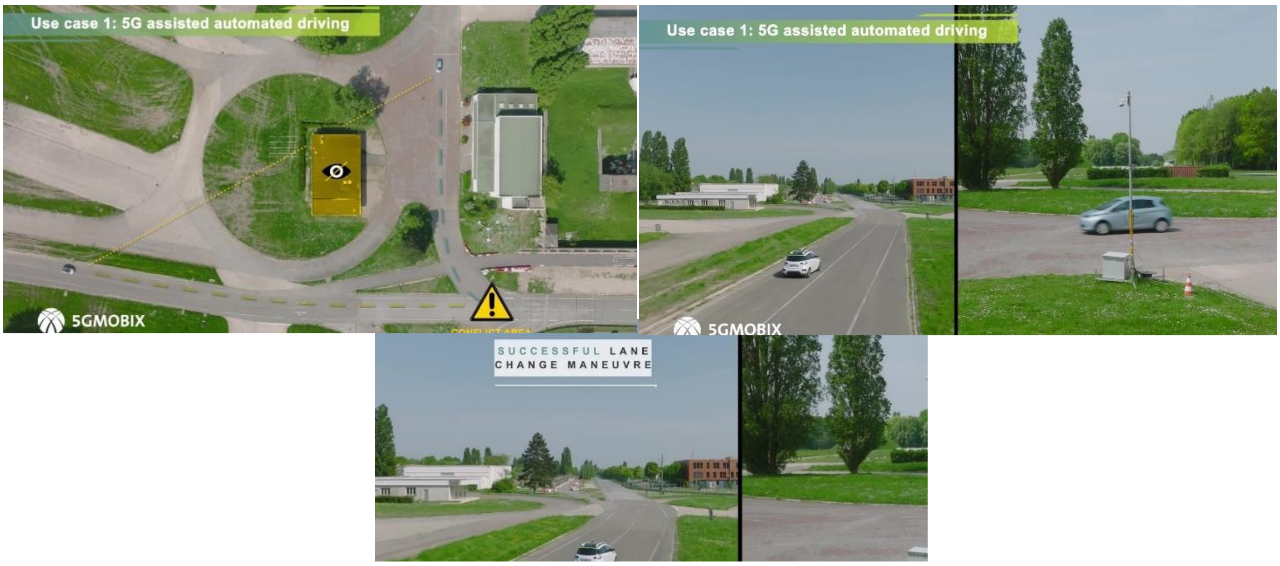

Figure 23: Photos of the Use Case Advanced driving tested in the French TS

6.7 General conclusions from the perspective of the FR TS

Within the scope of FR site, we have been able to perform most of the testcases that were committed. To some extent we were forced to perform more iterations than expected due to rework associated with lack of maturity of the technology. Some results were not possible to be recorded as networks and prototypes of UEs did not provide the tools to capture the performance indicators. Consequently, FR site has allowed lot of tests with sometimes limited relevant results.

As per main drawbacks we have faced:

- 5G technology still is at an early stage:
  - 5G NSA (3GPP Rel15) remains an intermediate step towards real 5G and we were not able to take benefits of of any SA network (Rel16)
  - C-V2X chipsets for 5G are not ready yet
  - 5Gmm configurations very limited in 3GPP
- Adjustments of settings are very complicated to put in place both at network side and UE side and fine tuning is needed to reach the performances announced for 5G such as:
  - Positioning of the antenna in Network and with 5G OBU
  - Design of cells especially with 5Gmm
  - Beamforming parameters
- Nevertheless, the testcases performed have permit to experiment real key benefits of 5G technology:
  - End to end latency improvement for V2X communications with 5G-NR and MEC
  - Effectiveness of adaptive QoS
  - High throughput not essential for V2X messages but offering potential for raw date exchanges (video flows from cameras or cloudpoints from lidars)
  - High reliability is there
  - Computation in MEC is an efficient solution.

7 GERMAN (DE) TRIAL SITE

7.1 Specific and Agnostic test cases trialled at DE TS

Table 19: List of Specific Test Cases trialled by DE TS

Test case	Location	Vehicle	Network	MEC	KPIs	Linked XBIs / CS	Trials carried out
TCS-DE-1.1	Straße 17 Juni, Berlin	DAI Labor VW Tiguan Valeo VW 2 x Cohda Mk6c OBUs	O2 NSA DT NSA	MobiledgeX MEC TUB Data Center 2 x NUVO far edge MEC 2 x Cohda Mk6c RSUs Sensors infrastructure deployment	Throughput e2e latency Reliability	XBI_5: CS_14	Test Number: 10 runs Dates of trials sessions: End May 2022
TCS-DE-1.2	Straße 17 Juni, Berlin	DAI Labor VW Tiguan Valeo VW 2 x Cohda Mk6c OBUs	O2 NSA DT NSA	MobiledgeX MEC TUB Data Center 2 x NUVO far edge MEC 2 x Cohda Mk6c RSUs Sensors infrastructure deployment	User experienced data rate e2e latency Reliability Mobility interruption time	XBI_5: CS_4; CS_13; CS_14 XBI_9 :CS_23 ; CS_24	Test Number: 10 runs Dates of trials sessions: May/June 2022
TCS-DE-1.3	Straße 17 Juni, Berlin	DAI Labor VW Tiguan Valeo VW 2 x Cohda Mk6c OBUs	O2 NSA DT NSA	MobiledgeX MEC TUB Data Center 2 x NUVO far edge MEC 2 x Cohda Mk6c RSUs Sensors infrastructure deployment	User experienced data rate e2e latency Reliability Mobility interruption time	XBI_5: CS_4; CS_13; CS_14 XBI_9 :CS_23 ; CS_24	Test Number: 10 runs Dates of trials sessions: Beginning May 2022
TCS-DE-2.1	Straße 17 Juni, Berlin	DAI Labor VW Tiguan Valeo VW 2 x Cohda Mk6c OBUs	O2 NSA DT NSA	MobiledgeX MEC TUB Data Center 2 x NUVO far edge MEC 2 x Cohda Mk6c RSUs	User experienced data rate e2e latency Jitter Reliability	XBI_5: CS_4; CS_13; CS_14 XBI_8: CS_21 XBI_9 :CS_23 ;CS _24	Test Number: 10 runs Dates of trials sessions: January, March 2022

Test case	Location	Vehicle	Network	MEC	KPIs	Linked XBIs / CS	Trials carried out
				Sensors infrastructure deployment	Application Level Handover Success Rate Mobility interruption time		
TCS-DE-2.2	Straße 17 Juni, Berlin	DAI Labor VW Tiguan Valeo VW 2 x Cohda Mk6c OBUs	O2 NSA DT NSA	MobiledgeX MEC TUB Data Center 2 x NUVO far edge MEC 2 x Cohda Mk6c RSUs Sensors infrastructure deployment	User experienced data rate e2e latency Jitter Reliability Application Level Handover Success Rate Mobility interruption time	XBI_5: CS_4; CS_13; CS_14 XBI_8: CS_21 XBI_9 :CS_23 ;CS _24	Test Number: 10 runs Dates of trials sessions: January, March 2022

Table 20: List of Agnostic Test Cases trialled by DE TS

Test case	Location	Vehicle	Network	MEC	KPIs	XBIs / CS	Trials carried out
TCA-DE-02	Straße 17 Juni, Berlin	DAI Labor VW Tiguan Valeo VW 2 x Cohda Mk6c OBUs	O2 NSA DT NSA	MobiledgeX MEC TUB Data Center 2 x NUVO far edge MEC 2 x Cohda Mk6c RSUs Sensors infrastructure deployment	e2e latency Reliability	XBI_9: CS_24	June 2022 (10 runs)
TCA-DE-05	Straße 17 Juni, Berlin	-	O2 NSA DT NSA	TUB MobiledgeX AWS	e2e latency	XBI_5: CS_14	June 2022 (10 runs)
TCA-DE-06	Straße 17 Juni, Berlin	DAI Labor VW Tiguan	O2 NSA DT NSA	-	Mobility interruption time	XBI_5: CS_4	June 2022 (10 runs)
TCA-DE-08	Straße 17 Juni, Berlin	-	DT NSA	MobiledgeX	e2e latency	XBI_9: CS_23	June 2022 (10 runs)

7.2 XBI_5: Session service continuity

7.2.1 CS_4: Multi-modem / multi-SIM connectivity

In the DE TS, two 5G modems with Quectel modules are connected to the OBU, allowing the UE to keep multi-SIM connections with two different MNOs and ensuring service continuity within the application. First the application connects using the interface from the modem with an O2 SIM card, and after crossing the virtual border, as the DE TS is located in the center of Berlin, this interface is disconnected and the traffic is re-routed to the second available interface, which is provided by the modem with the Deutsche Telekom SIM card. The following test cases were performed in order to measure the interruption time generated when changing between the 2 interfaces used : TCS-DE-1.2, TCS-DE-1.3, TCS-DE-2.1, TCS-DE-2.2 (the detailed KPIs and configuration are listed in Table 19 and Table 20 above). The Agnostic test cases using Multi-SIM configuration are the following were TCA-DE-06.

7.2.2 CS_13: Double MQTT client

In this case, there are two different MQTT clients in each vehicle, with the aim to make the communication interruption shorter when switching to the second 5G modem in a cross-border scenario. When crossing the border, the first MQTT client disconnects from its associated broker in MEC 1, and the second MQTT client connects to its broker in MEC 2. Following this approach, results regarding interruption time are optimized.

7.2.3 CS_14: Inter-MEC exchange of data

Regarding considered solution 14, in the DE TS there are two MECs available, each of them is "in charge" of the infrastructure elements (sensors, traffic cameras, object detection, RSUs, etc.) deployed in one of the two areas divided by the border. Thanks to the exchange of all messages generated by the infrastructure elements between the two MECs, the information from the whole area is available anywhere. The MECs will forward the messages to the vehicles according to their driving direction.

7.3 XBI_8: Dynamic QoS Continuity

7.3.1 CS_21: Adaptive Video Streaming

Depending on the quality of the received video, in the surround view User story in the DE TS, the transmitted video data rate can be adjusted to the current capacity of the network in that location and time. This will ensure a suitable representation of the video that guaranties the correct functionality of the application.

7.4 XBI_9: Geo-Constrained Information Dissemination

7.4.1 CS_23: Uu geobroadcast

The information of standard ETSI C-ITS messages is disseminated via Uu interface. Using a MQTT broker and publisher/subscriber architecture, the broker filters the information and forwards to the vehicles only messages from the infrastructure that are relevant for their driving direction and their current location/area. Brokers in contiguous areas, for example in a cross-border scenario, exchange the information produced in their areas. Therefore, a broker can forward relevant information from other broker to a vehicle in its area if the conditions are the right ones (e.g. a vehicle driving towards the border will receive information from the other side of the border).

7.4.2 CS_24: PC5 geobroadcast

This considered solution takes advantage of the PC5 interface's geo-localized characteristics by design. The RSUs broadcast infrastructure information (ITS messages) which are received only by the UEs in their PC5 coverage area, without the need of an MQTT broker. This solution is also used in specific use cases only requiring short-range communications, e.g., platooning messages between vehicles close by. In a cross-border scenario, the information is received independently of the actual border side or registered MNO. If the UEs are in the PC5 coverage area of the RSUs, they will receive the information.

7.5 General conclusions from the perspective of the DE TS

The deployment challenges and lessons learnt about technological, legal and regulatory aspects are described in detail in deliverable D3.7 "Final Report on Development, Integration and Roll-out" [4]. The results of the trials are described in detail in the deliverable D5.2 "Report on technical Evaluation" [3]. To avoid repetitions, this section describes the specific learnings and difficulties found during the execution of the 5G-MOBIX trials in DE TS that are not described in deliverables D3.7 or D5.2.

Regarding the restrictions caused by the COVID-19 pandemic, some partners from the DE TS Consortium whose residence is not Berlin, did face some difficulties to travel to Berlin for trials during 2020 and 2021, due to their company restrictions or to travel restrictions among different countries. This fact caused several delays in the overall testing.

Regarding technical issues, there have been several complications along the trialling phases. Most of them happened to collect the metrics needed for the calculation of the KPIs or for the upload to the CTS.

In the physical layer, metrics are directly retrieved from the Quectel modems with the QLog tool. This tool crashes several times without a known reason, thus, needing to restart the OBUs computer and set up all the elements involved in the test again. Every time this happened, lot of testing time was lost.

In the network layer, the DEKRA tool also produced delays. Agents for this tool are deployed in the different components of the network used by the DE TS, OBUs, RSUs and MECs. These agents also crashed without a known reason till the moment of writing. In that case, the agents needed to be restarted to start the tests.

In other occasions, at the end of a good test, the tool controller failed to collect all the information produced in the different agents, and no data for that test was available. All these facts made the testing phase more complicated than planned and caused several delays.

Although facing all these difficulties, the planned DE TS trials were finally successfully executed. The results can be checked in deliverable D5.2 "Report on technical Evaluation" [3].

8 FINLAND (FI) TRIAL SITE

8.1 Specific and agnostic test cases trialled at FI TS

Table 21: List of Specific Test Cases trialled by FI TS

Test Case	Location	Vehicle/OBU	Networks	MEC	KPIs	XBI/CS	Trials carried out
FI-1.1 **FI-1.2**	Otaniemi campus, Espoo, Finland	AALTO connected vehicle (Ford Focus)	Telia 5G NSA Elisa 5G NSA	Edge controller and 2 LDNS servers 2 MEC servers	User experienced data rate End to end latency Reliability Mobility Interruption Time Application Level Handover Success Rate	XBI_5: CS_4; CS_10	9/12/2021(12 runs) 18/05/2022 (15 runs)
FI-2.1 **FI-2.2**	*Primary target for extended sensors user story trials has been on NSA networks, SA networks briefly considered but later dropped due to limitations of SA devices and outdoor SA networks in FI-TS.*						
FI-3.1 **FI-3.2**	Otaniemi campus, Espoo, Finland	SENSIBLE4 automated vehicle (Renault Twizy SAE L4)	Telia 5G NSA Elisa 5G NSA	LEVIS video streaming server Remote operations centre fleet control server	User experienced data rate End to end latency Reliability Mobility Interruption Time	XBI_5: CS_4 XBI_2: CS_18	15 /09/2021 (12 runs) 25-28 /04/2022 (26 runs)
FI-4.1 **FI-4.2**	*Primary target for remote driving user story trials has been on NSA networks, SA networks briefly considered but later dropped due to limitations of SA devices and outdoor SA networks in FI-TS.*						
FI-5.1 **FI-5.2**	Otaniemi campus, Espoo, Finland	SENSIBLE4 automated vehicle (Renault Twizy SAE L4)	Telia 5G NSA Elisa 5G NSA	LEVIS video streaming server Remote operations centre fleet control server	User experienced data rate End to end latency Reliability	XBI_5: CS_5;	25-28/04/2022 (17 runs)
FI-6.1 **FI-6.2**						XBI_5: CS_0;	25-28/04/2022 (22 runs)

Table 22: List of Agnostic Test Cases trialled by FI TS

Test Case	Location	Vehicle/OBU	Networks	MEC	KPIs	XBI/CS	Trials carried out
TCA-FI-11	Otaniemi campus, Espoo, Finland	AALTO connected vehicle (Ford Focus)	Telia 5G NSA Elisa 5G NSA	iPerf server	User experienced data rate End to end latency	XBI_5: CS_4	15/03/2022 (9 runs)
TCA-FI-12	Otaniemi campus, Espoo, Finland	AALTO connected vehicle (Ford Focus)	Telia 5G NSA Elisa 5G NSA	iPerf server	User experienced data rate End to end latency	XBI_5: CS_5;	22/06/2022 (6 runs)
TCA-FI-13	Indoor lab, Otaniemi campus, Espoo, Finland	No vehicle used (indoor lab walk test	AALTO SA (PLMN-ID – 999 99) AALTO SA (PLMN-ID – 999 40)	N/A	User experienced data rate End to end latency Mobility Interruption Time	XBI_2: CS_18 XBI_5: CS_18	*Trials yet to be conducted at time of reporting*

8.2 XBI_5: Session & Service Continuity

8.2.1 CS_0: Features off

The FI TS has been trialling the Multi-SIM approach for addressing service continuity challenges (XBI-5) for V2N connectivity in any geographical location where connectivity to two (or more) PLMNs is possible a multi-SIM OBU solution. The CS_0 case is a benchmark scenario whereby the OBU has the multi-SIM features turned off and OBU is only operating with a single SIM card (rather than two SIM cards for the CS_4 and CS_5 cases). The trials with this scenario were conducted in 5G NSA-mode within the remote driving user story (test cases FI-6.1, FI-6.2) and in agnostic testing.

8.2.2 CS_4: Multi-modem / multi-SIM connectivity - Passive Mode

In the FI TS case a multi-SIM OBU solution (based on mobile IP-tunnelling) with two SIM cards was utilized, whereby, the multi-SIM OBU device selected the 'best or high priority' 5G connection based on criteria including latency, signal strength and RAT priority. The trials with this multi-SIM OBU link selection solution were conducted in 5G NSA-mode within the extended sensors user story (test cases FI-1.1, FI-1.2), remote driving user story (test cases FI-3.1, FI-3.2) and in agnostic testing (TCA-FI-11).

8.2.3 CS_5: Multi-modem / multi-SIM connectivity - Link Aggregation

In the FI TS case, a multi-SIM OBU solution with two SIM cards was utilized, whereby, the multi-SIM OBU device simultaneously utilized both 5G connections associated with each SIM card. The trials with this multi-SIM OBU link aggregation solution were conducted in 5G NSA-mode within the remote driving user story (test cases FI-3.1, FI-3.2) and in agnostic testing (TCA-FI-12).

8.2.4 CS_10: MEC service discovery and migration using enhanced DNS support

A vehicle's trajectory on the road/highway typically traverses serving areas of different cross MEC systems of different PLMNs both within nation's border and at cross-border areas. The FI TS, the implemented and trials a solution for service continuity in terms of MEC service discovery and migration is based on enhanced DNS support through association of MEC with DNS edge servers for low latency applications. The trials with this MEC service discovery and migration solution were conducted in 5G NSA-mode within the extended sensors user story (test cases FI-1.1, FI-1.2).

8.2.5 CS_18: LBO SA

In FI TS, service continuity when moving between two 5G SA networks is being experimentally trialled using SA-SA roaming implementation in local breakout (LBO) architecture. With this LBO architecture the UE sets up a Protocol Data Unit (PDU) session with a User Plane Function in the visited network. This in contrast to Home routed (the current default) where data is routed back to the home network. To setup a LBO PDU session the Session Management Function (SMF) in the visited network needs to contact the Unified Data

Management (UDM) in the home network over the N10 interface. All the other roaming interfaces are also utilized, with the exception of the N9 and N16 interface since the data stays local. Although the primary focus of the FI TS trials has been on NSA networks, the trials with this SA-SA LBO solution where also briefly within the extended sensors user story (test cases FI-2.1, FI-2.2) and remote driving user story (test cases FI-4.1, FI-4.2). However, these trials were postponed due to unavailability of outdoor AALTO 5G SA networks within the required trialling time window. This unavailability was mainly attributed to faults in the baseband equipment for one of the radio sites and excessive delays in shipment of replacements. As an alternative scaled plan, SA-SA LBO roaming architecture implementation was done in the indoor lab test environment and targeted for agnostic testing (test case TCA-FI-13).

8.3 XBI_2: SA Roaming interruption

8.3.1 CS_18: LBO SA

In FI TS, service continuity and potential roaming interruptions when moving between two 5G SA networks is being experimentally trialled using SA-SA roaming implementation in local breakout (LBO) architecture. With this LBO architecture the UE sets up a PDU session with a User Plane Function in the visited network. This in contrast to Home routed (the current default) where data is routed back to the home network. To setup a LBO PDU session the SMF in the visited network needs to contact the UDM (Unified Data Management) in the home network over the N10 interface. All the other roaming interfaces are also utilized, with the exception of the N9 and N16 interface since the data stays local. The trials with this SA-SA LBO solution where to be conducted within the extended sensors user story (test cases FI-2.1, FI-2.2) and remote driving user story (test cases FI-4.1, FI-4.2). However, these trials were postponed due to unavailability of outdoor AALTO 5G SA networks within the required trialling time window. This unavailability was mainly attributed to faults in the baseband equipment for one of the radio sites and excessive delays in shipment of replacements. As a fallback plan, SA-SA LBO roaming architecture implementation was done in the indoor lab test environment and targeted for agnostic testing (test case TCA-FI-13).

8.4 General conclusions from the perspective of the FI TS

The FI TS trials have provided a range of interesting lessons and insights. First and foremost, it was noted the elaborate setups and storyboards for the remote driving and specific user story trials required multiple (iterative) verification and pre-trialling phases before running the full trials. For instance, for the remote driving user story, the first full trials were conducted in September 2021. However, these trials were preceded by pre-trials in February 2021 and early trials in April/May 2021, which allowed for testing of different parts of the overall setup (including KPI measurement setup) and various configurations (e.g. OBU network selection parameters), as well as, understanding the level of resources, effort and time required on average for each test run. This approach allowed more careful planning and execution of the full trials in September 2021. The first full trials allowed for preliminary evaluation of measurement data and re-planning of some aspects for next full trials (which were conducted in April 2022 for remote driving user story). An example of this is the introduction of a benchmark single SIM OBU test cases for comparison with multi-SIM approaches.

The FI TS provided a useful trialling environment due to the access to multiple-PLMNs that allow experimental studies on service continuity when transitioning between PLMNs. These PLMNs have been a combination of AALTO research testbeds deployed in both indoor and outdoor environments, as well as multiple 5G networks commercial mobile network operators with coverage in the Otaniemi. The main FI TS trials were conducted using outdoor commercial NSA networks from two different operators. While the use of outdoor commercial networks prevented experimental study of peak performances (without resource sharing in same network) or ability to test different network parameters, the use of these production provided a more realistic insight of what is feasible for CAM applications in contemporary 5G networks (e.g. understanding the how the achievable performance varies between busy hour and off-peak periods). The AALTO research networks also include configurations in standalone (SA) mode, which provides a useful complement to the CBC test networks which only operate in NSA mode. While outdoor deployments where initially considered, the eventual focus of experimenting with SA-SA roaming implementations was limited to indoor lab-based setups.

Another useful insight from the trials was the differences in how the user stories were executed for each test run as the open road scenarios vary, which may in some cases also have a bearing on the observed KPI results from one test run to another. It is noted once again that the trials were carried out on open roads of the designated FI TS test route and with mixed traffic, e.g., public buses, service trucks, and pedestrians, and sometimes under challenging winter conditions (e.g. temperatures as low as -18 degrees Celsius). Some of these road conditions (see examples in Figure 24) change the way in which the user story is executed in practice (e.g. when video streams are triggered in remote driving). This also impacts how the user story utilises network resources. These varying conditions provides an understanding of the bounds of required network performance for each CAM user story.

Figure 24: Example of different challenges encountered whilst trialling in open roads

The trials also provided some useful insights on the constraints that could be encountered 5G devices in terms of the availability, regional settings and so on. Moreover, regulatory aspects also presented limits in what could be feasible in the trials due to factors, such as, limited spectrum allocations, number of PLMNs that could be support given a pool of available PLMN-IDs. The additional details on these challenges and lessons learnt in FI TS in the deployment and post-trials evaluation phases can be found in deliverables D3.7 "Final Report on Development, Integration and Roll-out" [4] and D5.2 "Report on technical Evaluation" [3].

9 KOREAN (KR) TRIAL SITE

9.1 XBI_10: mmWave applicability

9.1.1 CS_25: mmWave 5G

A mmWave 5G NR vehicular communication system can provide a wider spectrum and shortened latency. Leveraged by such capabilities, the system is eligible for realizing two V2X applications, Remote Driving (US#4.5) and Tethering via Vehicle (US#5.2), whose test cases correspond to KR-1.1 and KR-1.2, respectively. To the best of our knowledge, experimental trials conducted with 5G systems so far have been focused on sub-6GHz bands. Therefore, implementing a testbed and validating that the system has the potential to realize the V2X applications is meaningful in terms of giving valuable insights into the applicability of mmWave-band systems.

Field trials for KR-1.1 and KR-1.2 have been completed successfully, and the information is summarized as follows:

Table 23: Specific test cases using mmWave 5G in KR TS

Test Case	Test Configuration	KPIs	Trials carried out
KR-1.1	**Vehicle**: One remote-control vehicle equipped with mmWave OBU **Network**: mmWave-band 5G NR network **Infrastructure**: one gNodeB, one remote control driving system in the remote-control vehicle, and one remote control station by which a remote operator controls the vehicle via the mmWave 5G NR network. **Location**: autonomous vehicle proving ground located at KATECH premises in Cheonan-Si, South Korea	Uplink data rate: 49.1 Mbps Round-trip time: 6.8 ms	Field trial took place on May 3, 2022
KR-1.2	**Vehicle**: One vehicle equipped with mmWave OBU **Network**: mmWave-band 5G NR network **Infrastructure**: one video server, one BenchBee server for Wi-Fi speed test, and five gNodeBs installed along the test track **Location**: highway test track in Yeoju, Korea	Downlink backhaul data rate: 1.5 Gbps Wi-Fi speed of onboard user: 400 Mbps	Field trial took place on Nov. 26, 2020

9.2 General conclusions from the perspective of the KR TS

While the final demonstration regarding key functionalities of the mmWave communication such as beam switching and handover were successfully tested and validated, three challenges were identified during the field trial from a deployment perspective.

- The first challenge observed is signal blockage by the road bridge which resulted in unreliable communication, especially just before the test vehicle approaches to the road bridge. We found out that there is a very serious received power loss occurred in the NLOS region before the bridge and it gives an insight that in which a road bridge exists, a gNB DU should be deployed lower than the bridge or much higher than and close to the bridge.
- The second challenge observed during the PoC of KR TS was a strong interference from adjacent cells. It made unexpected interference effects on the reception of the serving cell signal during the field trial. It needs to address before multi-UE communication scenarios are implemented in terms of commercialization. To resolve this issue, it is necessary to test and validate different frequency planning strategies or inter-gNB DU scheduling/resource allocation algorithms to minimize the interference effect.
- The last challenge is real time HD video streaming via mmWave communication. In the remote-control vehicle, the V2X modules stream four HD videos to the remote-control station based on the real-time transfer protocol (RTP) packetization. The V2X module makes the HD videos to the RTP payload with a maximum transfer unit (MTU) of 1500 and transmits it to the remote-control station through the vehicle UE via the mmWave vehicular communication link that adds an additional header such as a general packet radio service (GPRS) tunnel protocol (GTP) header to the RTP payload. Since the MTU of the packet is 1500 bytes, the last 40 bytes of the received payload are dropped when transmitted to the 5G core network which is an undesired behaviour. To avoid this, the V2X module is designed to confine the MTU size when it packetizes the HD videos to the RTP payload.

Figure 25: Autonomous vehicle proving ground located at KATECH premises in Cheonan-Si, South Korea

10 CHINA (CN) TRIAL SITE

10.1 Specific test cases trialled at CN TS

Table 24: List of Specific Test Cases trialled by CN TS

Test Case	Vehicle/OBU	Networks	MEC	KPIs	XBI/CS	Trials carried out
CN-1.1 **CN-1.2** **CN-1.3**	SDIA vehicle with multi-band OBU supporting R15 5g NSA/SA (GNSS, ADAS, DMS)	5G SA China Mobile 5G SA China Unicom	MQTT broker, TCP server, and web server in edge cloud to support use cases	Post encroachment time	XBI_4: CS_4 XBI_5: CS_5 XBI_5: CS_13 XBI_5: CS_14	15 runs, June 5, 2022 10 runs June 20, 2022
CN-2.1 **CN-2.2** **CN-2.3**	Sinotrucks with multi-band OBU supporting R15 5g NSA/SA (GNSS, ADAS, DMS)	5G SA China Unicom 5G SA China Mobile	MQTT broker, TCP server, and web server in edge cloud to support use cases MQTT broker	Number of perception message failure	XBI_4: CS_4	15 runs, June 5, 2022
CN-3.1 **CN-3.2** **CN-3.3**	SDIA vehicle with multi-band OBU supporting R15 5g NSA/SA (GNSS, ADAS, DMS)	5G SA China Mobile 5G SA China Unicom	Remote control center (Remote driving specific), MQTT broker, TCP server, and web server in edge cloud to support use cases	Remote driving session outage	XBI_4: CS_4 XBI_5: CS_5 XBI_5: CS_13 XBI_5: CS_14	15 runs, June 5, 2022 15 runs, June 15, 2022 10 runs June 20, 2022

10.2 XBI_4: Low coverage Areas

10.2.1 CS_4: Multi-modem / multi-SIM connectivity - Passive Mode

In order to address technical challenges when a vehicle crosses the low coverage areas, CN TS adopted a router redundancy solution connected to the OBU, which allows the UE to keep multi-SIM connections with PLMNs ensuring continuity and communication quality between the vehicle and MEC sever. It performs best link selection with high priority across different PLMN connections and uses these connections in a combined manner. This solution was tested during the trials of the test cases CN-1.1, CN-1.2, CN-1.3 to measure the KPI post encroachment time. The test cases CN-2.1, CN-2.2, CN-2.3, measured the number of perception of message failure KPI and finally the test cases CN-3.1, CN-3.2, CN-3.3 measured Remote driving session outage.

10.3 XBI_5: Session & Service Continuity

10.3.1 CS_5: Multi-modem / multi-SIM connectivity - Link Aggregation

In order to address service continuity challenges when a vehicle crosses the cross-border areas, CN TS adopted a solution with double SIM cards for the test vehicle, which allows the UE to keep multiple connections in the same session, ensuring continuity and communication quality between the vehicle and MEC server. The test vehicle will keep more than one 5G connection to MEC server, the routing link will be decided according to the better connection with high priority. This solution was conducted within remote driving and advanced driving (test cases CN-1.3, CN-3.3) and in agnostic testing (TCA-CN-04).

10.3.2 CS_13: Double MQTT client

This solution aims to address the service disruption expected due to the interruption time inquired by the MQTT client-server session establishment/tear down procedures, i.e., upon a handover event, an MQTT client is typically required to gracefully tear down its session with the MQTT server at the home PLMN and then establish a new one with the MQTT server at the visited network. The signaling process is time-consuming, resulting in service disruption. CN TS will use the double MQTT client solution that employs two client instances, e.g., A and B, with A being connected to the home PLMN server. Upon HO, client B initiates the session establishment procedure with the visited PLMN server, while A is in the process of tearing down the original session.

10.3.3 CS_14: Inter-MEC exchange of data

In order to address service continuity challenges when the service requiring a low latency connection with a MQTT server is upon a handover event, two instances of the server MQTT will be created in CN TS and deployed at the MEC of the home and the visited PLMNs. The home MQTT is publishing the messages directly in the visited one (and vice versa), managing both MQTTs with the same information at every moment, avoiding its segmentation in two MQTT servers upon the HO event.

10.4 General conclusions from the perspective of the CN TS

In CN TS, Shandong Institute of Automation (SDIA) built the cloud server, and Dalian University of Technology (DLUT) made the application on this server. And the Jinan-2-SDHS test site has completed a 2km expressway by SDHS (Shandong High-Speed Information Group Co., Ltd.) in the northern part of Miaoshan, with three full-width gantry and Hawkeye cameras with a spacing of 500 meters. In the two parts of CN trial sites, we contributed to simulating the problem-solving of 5G cross-border issues in the Jinan. Two challenges were identified during the field trial from a deployment perspective:

- In our initial test results, the vehicle relied on one R15 5G module solution to support the communication of control plane. When the vehicle crossed the simulated cross-border areas, the OBU was switched to another MNO, the communication was interrupted due to signaling redialing. We cannot guarantee the required service continuity.
- We rely on the public link aggregation mode in the started test, the 5G network performance are affected significantly by the public 5G network condition, like the network congestion at peak period.

To tackle the technical challenges above, we deployed the test vehicle with double 5G communication modules to provide redundancy to complete signaling process and minimize session interruption time when moving multiple MNOs coverage areas. We deployed a dedicated 5G shared MEC in the enclosed site to provide more bandwidth for use cases, and we learnt the following lessons:

- The trigger time of handover procedure must be configured in both OBU and gNB to ensure the coordination between two the communication modules.
- In order to ensure the better service continuity, the handover location needed to be obtained in advance.

Deployment of 5G gNB for dedicated MEC **Double 5G communication modules for multi-SIM solution**

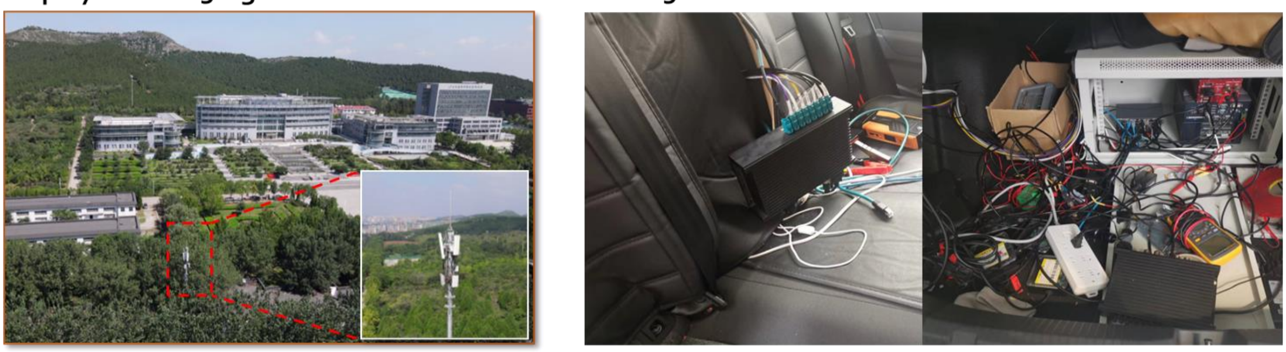

Figure 26: Trials in CN TS

According to the dynamic zero-COVID policy of China, we have many cooperation issues on our site. Firstly, the CN team worked in different cities, such as DLUT researchers in Dalian city, the SDIA, SDHS and CNHTC (China National Heavy Duty Truck Group Co.,Ltd) researchers in Jinan city and DATANG in Beijing city. Thus, the verification processes had been delayed as originally planned. The full test cases were conducted in the mid of June. In order to promote the project's progress, we made online meetings and field coordination to solve cooperation issues. Also, we got remote help from our partner at Aalto University.

11 CONCLUSION

After having defined and described the common methodology for the preparation and execution of the trials within WP4 activities and reported in D4.1, the CBCs and TSs specified and adapted this trialling methodology to their site, depending on their needs and specificities in D4.2. Now the trials sessions have ended and this deliverable D4.3 reported all the different trialling sessions performed by each CBC and TS locally and at the borders.

The trials activities took place from early 2021 (for the early trials phase) to June 2022 (for the Full trials phase). Almost 100 trials sessions in total were recorded for this project at each site, locally and at the borders. Each CBC and TS organised its own sessions to perform the defined test cases that were based on XBIs and collect the data for evaluation purposes. During the project it was agreed that the trials phase would be extended along with the evaluation results reports to give more time to adapt to the project objectives and redefinition. In parallel, the project and trials preparation were also affected importantly by the COVID-19 pandemic, resulting in delays in the deployments of 5G network and configurations. Thanks to the extension and constant mobilisation of the 5G-MOBIX teams (either remotely or in presence) the project managed to conduct most of the defined test cases and to create meaningful data for WP5 activities. Although, some test cases could not be trialled in WP4 timeframe due to delays or unavailability in networks deployments. All the data collected has now been transferred for analysis to WP5 and the technical evaluation is currently occurring, and more details will be delivered in WP5 D5.2 "Report on technical evaluation" [3].

During the trial's activities, we faced multiple situations from coordination to technical challenges. Below is the non-exhaustive list of the main challenges that all the TSs and CBCs had to address to successfully performed their trials:

- COVID-19 impacted the trials by causing delays (impact on coordination, remote trials, difficulties to travel or to cross the borders for tests; delays in the networks deployment…).
- Bureaucracy and authorizations (especially for the trials ah the borders).
- Delays in a CBC can impact the trials and TS contribution.
- 5G technologies are still at early stage (some 5G modems or chipset not yet ready preventing us from testing some test cases).
- Adjustments settings can be complicated to put in place: antenna and 5G OBUs position matter, MEC configuration and physical position also.
- Environment settings can impact the signal and coverage area (weather, season, position on the road and road materials…).

12 REFERENCES

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[2] *5G-MOBIX Deliverable D4.2, "Report on the methodology and pilot site protocol", December 2021..*

[3] *5G-MOBIX Deliverable D5.2, "Report on technical Evaluation", July 2022.*

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[5] Masaki Suzuki, Takuya Miyasaka, Debashish Purkayastha, Yonggang Fang, Qiang Huang, Jinguo Zhu, Balendu Burla, Xiaopeng Tong, Dan Druta, Jane Shen, Hanyu Ding, Guo Song, Marco Angaroni and Viscardo Costa, *Enhanced DNS Support towards Distributed MEC Environment*, https://www.etsi.org/images/files/ETSIWhitePapers/etsi-wp39-Enhanced-DNS-Support-towards-Distributed-MEC-Environment.pdf).

13 ANNEXES

13.1 General trials planning of the ES-PT CBC

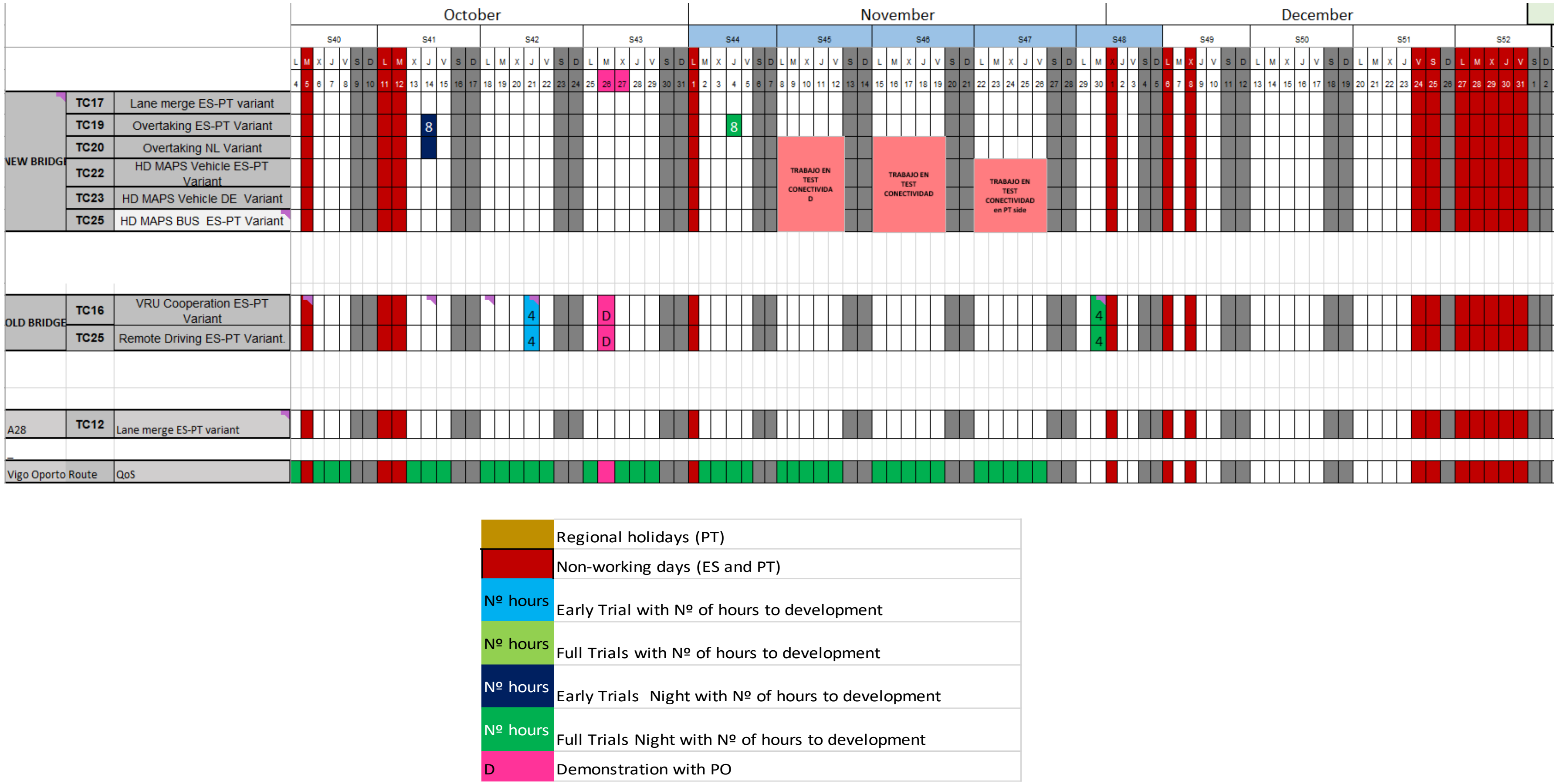

Figure 27: ES-PT CBC Trials planning (part 1)

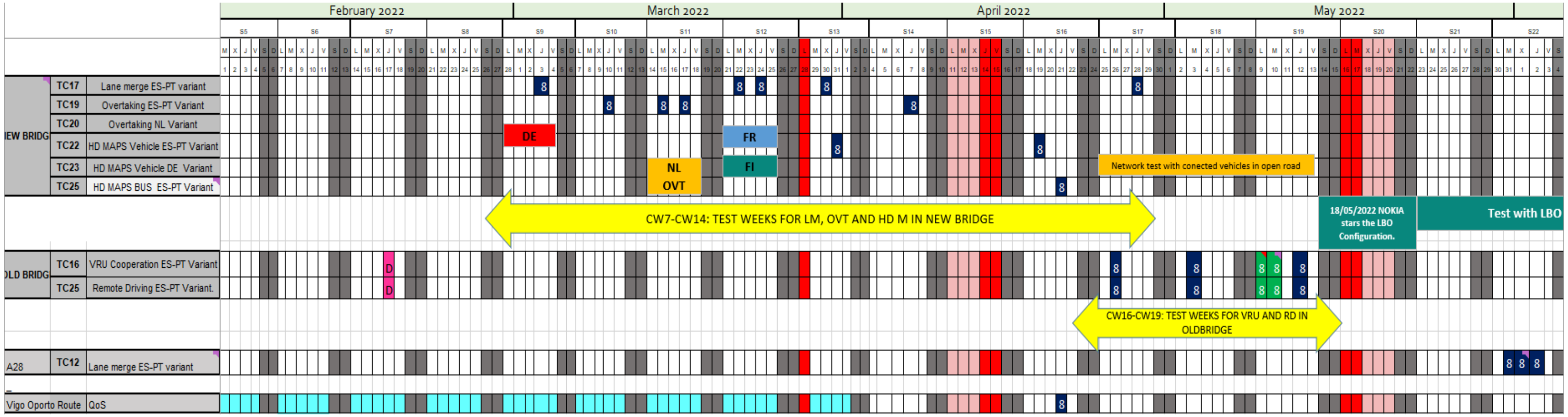

Figure 28: ES-PT CBC trials planning (part 2)

13.2 General trials planning of the GR-TR CBC

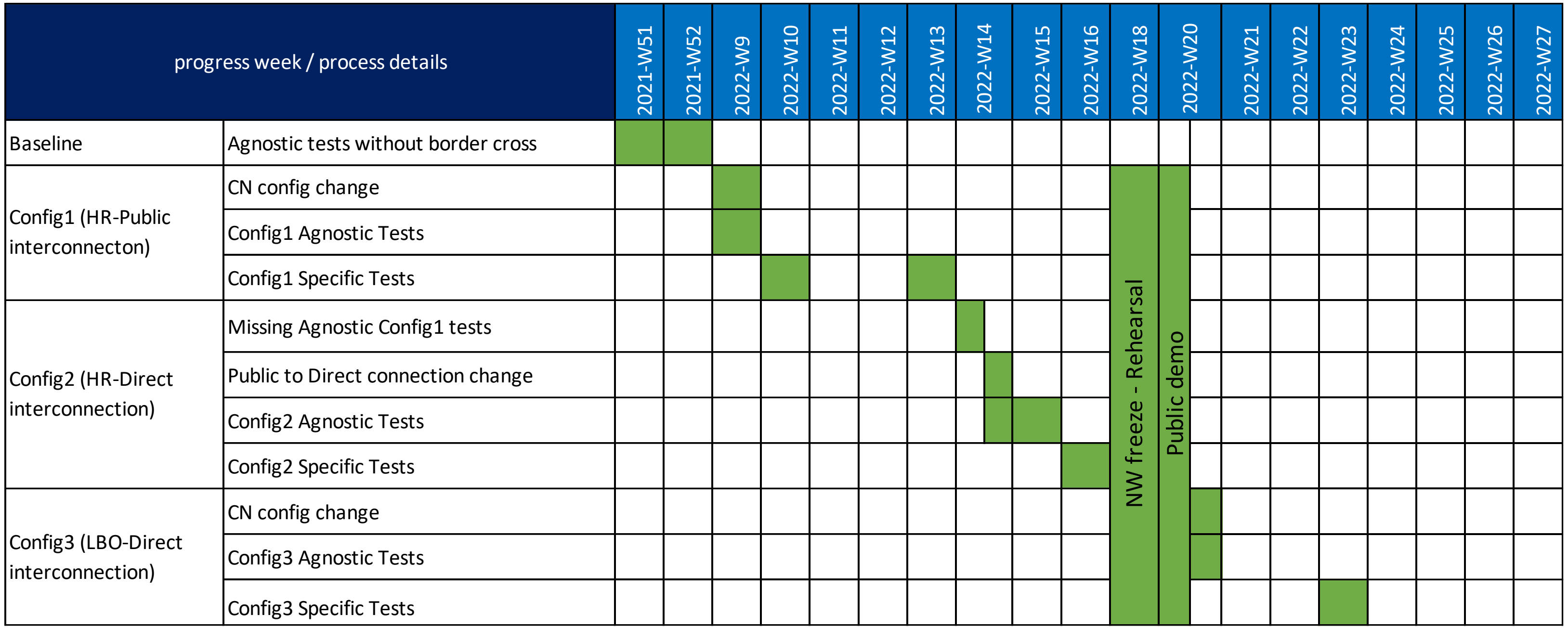

Figure 29: GR-TR CBC Trial Planning

13.3 General trials planning of the TSs

		Early Trials																									
	Year	2021																									
	Months	January				February				March					April				May				June				
UCC	Activity title	M27				M28				M29					M30				M31				M32				
	Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
GERMAN TRIAL SITE																											
Platooning	AsseRSU													LT								LT					
Extended sensors	EDM													LT								LT					
Contribution to CBC	DE contribution to ES-PT																										
FINLAND TRIAL SITE																											
Extended sensors	Edge Processing					LT (FI)													LT (FI)							LT (FI)	
Remote Driving	Redundant NE					LT (FI)											LT (FI)										
Contribution to CBC	FI Contribution to ES-PT (Edge discovery service)					LT (FI)																					
Contribution to CBC	FI contribution to ES-PT (Multi PLMN/ Multi-SIM)					LT (FI)																					
Contribution to CBC	FI contribution to GR-TR (LEVIS)					LT (FI)										T (GR-TF											
FRENCH TRIAL SITE																											
Advanced Driving	AssInfrastructure									LT FR																	
Contribution to CBC	FR contribution to ES-PT (5G connected car)																				LT (FR)						
Contribution to CBC	FR contribution to ES-PT (Multi PLMN/ Multi-SIM)																						LT (FR)				
NETHERLANDS TRIAL SITE																											
Advanced Driving	CCA (VTT)																										
Extended sensors	CPM (TNO)															LT					LT						
Remote Driving	5GPositioning (TU/e + KPN)													LT													
Contribution to CBC	NL contribution to ES-PT (VTT + TNO)														LT (fi)							LT					
CHINA TRIAL SITE																											
Advanced Driving	CloudAssisted														LT												
Platooning	AssCloud																	LT									
Remote Driving	DataOwnership																										
KOREA TRIAL SITE																											
Remote Driving	mmWave									LT	LT	LT				LT	LT	LT									
Vehicle QoS Support	Tethering									LT	LT	LT				LT	LT	LT									

Figure 30: Trial sites Early trials planning

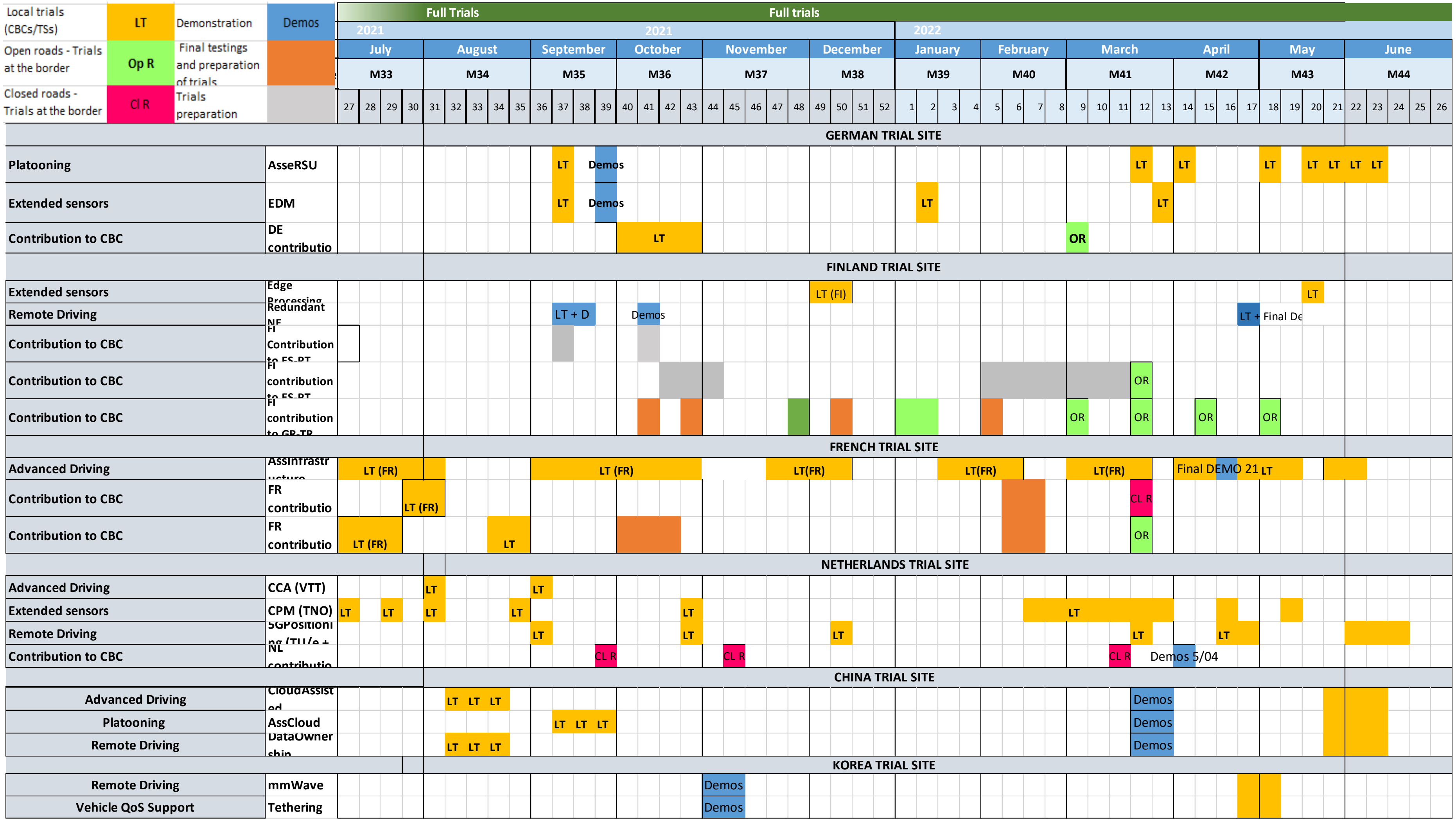

Figure 31: Trial sites Full trials planning