ETSI Plugtests Report V1.0.0 (2024-09)

4th ETSI C-V2X Plugtests
Malaga, Spain
10 – 13 September 2024

ETSI

Keywords
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1 Executive Summary

ETSI, in partnership with 5GAA, has organized the 4th C-V2X Plugtests™ interoperability events for C-V2X (Cellular Vehicle-to-Everything) using mobile communication technology for direct communication between vehicles, from vehicle to pedestrian and from vehicle to infrastructure. This event was hosted by DEKRA, from 10th to 13th September 2024 in Malaga, Spain. More than 170 test scenarios were executed between vendors and equipment, based on 3GPP and TC ITS standards.

The 4th ETSI C-V2X Plugtests attracted a total of 24 companies, with 82 participants (onsite + remote). Observers from different organizations witnessed the execution of more than 170 tests, based on a test plan with more than 60 test scenarios, with a 94 per cent success rate.

At this Plugtests event many C-ITS platforms and PKIs demonstrated their interoperability by participating at state-of-the-art safety use cases including CPM (Collective Perception Message) and VRU (Vulnerable Road Users). The activities enabled On-Board-Units (OBUs), Roadside-Units (RSUs) and public key infrastructure (PKIs) vendors to run interoperability test sessions to assess the level of interoperability of their implementation and validate the understanding of the standards.

5GAA organised a workshop on “C-V2X ecosystem and discuss the impact of ETSI Release 2 standards”, gathering key players of the C-V2X ecosystem, including governmental entities and companies, to discuss global perspectives on 5G-V2X, the progress made on 5G-V2X Direct, ETSI Release 2 messages, security and future integration of V2X and ADAS., concluding with an insightful panel discussion.

The following equipment was tested:

OBU vendors:

- COHDA WIRELES
- CTAG
- ETTIFOS
- KEYSIGHT
- MARBEN
- NFINIITY
- VECTOR

RSU vendors:

- CTAG
- MACH SYSTEMS
- MOVYON ELECTRONICS

PKI Providers:

- EVIDEN
- MICROSEC

CV2X Module + Dev Kit:

- ROLLING WIRELESS

Test Equipment Manufacturers:

- DEKRA
- TTA
- VECTOR
- WAYTIES

The Plugtests event was a pure testing event, and no products were certified.

2 References

The following documents have been used as references in the Plugtests. The participants in the Plugtests agreed on a set of specific documents and versions for the Plugtests. Please see also the test specification document for the references.

[1] ETSI TS 103 301 V1.1.1 (2016-11): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services".

[2] ETSI EN 302 636-4-1 (V1.4.0): "Intelligent Transport System (ITS); Vehicular communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to multipoint communications; Sub-part 1: Media independent functionalities".

[3] ETSI EN 302 637-2 (V1.4.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[4] ETSI EN 302 637-3 (V1.3.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[5] ETSI EG 202 798 (V1.1.1): "Intelligent Transport Systems (ITS); Testing; Framework for conformance and interoperability testing".

[6] ETSI TS 101 556-1 (V1.1.1): "Intelligent Transport Systems (ITS); Infrastructure to Vehicle Communication; Electric Vehicle Charging Spot Notification Specification".

[7] ETSI TS 102 894-2 (V1.3.1): " Intelligent Transport Systems (ITS); Users and applications requirements; Part 2: Applications and facilities layer common data dictionary"

[8] ETSI EN 303 613 (V 1.1.1): "Intelligent Transport Systems (ITS); LTE-V2X Access layer specification for Intelligent Transport Systems operating in the 5 GHz frequency band.

[9] ETSI TS 136 331 (V14.6.2): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC); Protocol specification (3GPP TS 36.331 version 14.6.2 Release 14)".

[10] ETSI TS 136 321 (V14.7.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA);

[11] Medium Access Control (MAC) protocol specification (3GPP TS 36.321 version 14.7.0 Release 14)".

[12] ETSI TS 136 322 (V14.1.0): "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Link Control (RLC) protocol specification (3GPP TS 36.322 version 14.1.0 Release 14)".

[13] 5GAA Technical Report: "C-V2X Interoperability Test Plan for Mode 4 PC5".

[14] ETSI CTI Plugtests Guide For Lab Based Test Plan: "ETSI Lab Based Interoperability Test Plan".

[15] ETSI CTI Plugtests Guide For Outdoor Based Test Plan: "ETSI Field Based Interoperability Test Plan ".

[16] ETSI EN 302 636-4-1 (V1.3.1): "Intelligent Transport System (ITS); Vehicular communications; GeoNetworking; Part 4: Geographical addressing and forwarding for point-to-point and point-to multipoint communications; Sub-part 1: Media independent functionalities".

[17] ETSI TS 103 097 (V1.3.1): ITS Security; Security header and certificate formats.

[18] ETSI TS 102 941 (V1.3.1): ITS Security; Trust and Privacy Management.

[19] ETSI TS 102 940 (V1.3.1): ITS Security; ITS communications security architecture and security management.

[20] IEEE 1609.2a-2017: IEEE Standard for Wireless Access in Vehicular Environments—Security Services for Applications and Management Messages.

[21] EU CP v1.1: EU Certificate Policy for Deployment and Operation of European Cooperative Intelligent Transport Systems (C-ITS).

[22] ETSI EN 302 637-2 (V1.4.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service".

[23] ETSI EN 302 637-3 (V1.3.1): "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 3: Specifications of Decentralized Environmental Notification Basic Service".

[24] ETSI TS 103 600 (V1.1.1):"Intelligent Transport Systems (ITS); Interoperability test specifications; Test descriptions for security".

[25] ETSI TS 103 096 (V1.4.1): ITS Security; Conformance test specifications for ITS Security.

[26] ETSI TS 103 525 (V1.1.1): ITS Security; Conformance test specifications for ITS PKI management.

[27] ETSI TR 103 099 (V1.4.3, draft): Intelligent Transport Systems (ITS); Architecture of conformance validation framework (draft for PKI conformance tests).

[28] ETSI TS 103 324 V2.1.1: Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Collective Perception Service; Release 2.

[29] ETSI TS 103 926 (V0.0.1, draft): Intelligent Transport System (ITS); Testing; Cooperative Perception Services; Interoperability tests specification.

[30] ETSI TS 103 300-2 V2.1.1: Intelligent Transport System (ITS); Vulnerable Road Users (VRU) awareness; Part 2: Functional Architecture and Requirements definition; Release 2.

[31] ETSI TS 103 300-3 V2.2.1: Intelligent Transport Systems (ITS); Vulnerable Road Users (VRU) awareness; Part 3: Specification of VRU awareness basic service; Release 2.

[32] ETSI TS 103 925 (V0.0.1, draft): Intelligent Transport Systems (ITS); Vulnerable Road Users (VRU) awareness; Interoperability tests specification.

3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
AA	Authorization Authority
ATS	Abstract Test Suite
CA	Certification Authority
CAM	Cooperative Awareness Message
CMS	Cooperative Mobility Services
CPM	Collective Perception Message
CPS	Collective Perception Service
CRL	Certificate Revocation List
CTL	Certificate Trust List
DENM	Decentralized Environmental Notification Message
DNS	Domain Name System
EUT	Equipment Under Test
GPSD	Daemon that receives data from a GPS receiver. It provides a unified interface to receivers of different types, and allows concurrent access by multiple applications
GN	GeoNetworking
HV	Host Vehicle
ICRW	Intersection Collision Risk Warning
ITS	Intelligent Transport System
ITS-S	ITS Station. Can be either RSU or OBU
LCRW	Longitudinal Collision Risk Warning
LTE	Long Term Evolution
MAC	Media Access Control layer of the access layers
NO	Test is recorded as NOT successfully passed
NA	Test is not applicable
NAT	Network address translation
OBU	On Board Unit
OK	Test is recorded as successfully passed
OT	Test is recorded as not being executed due to lack of time
PHY	The Physical layer of the access layers
PKI	Public Key Infrastructure
PSID	Provider Service Identifier
RSU	Road Side Unit
RWW	Road Works Warning
Test Session	A paring of vendors that test together during a given time slot
TRT	Test Reporting Tool
TSR	Test Session Report. Report created during a test session
TTCN-3	Testing and Test Control Notation Version 3
VRU	Vulnerable Road Users
V2V	Vehicle to Vehicle
V2X	Vehicle to Anything

4 Technical and Project Management

4.1 Scope

The main goal of the fourth C-V2X Plugtests was testing the interoperability of the V2X ecosystem for ITS Security, CPS and VRU ITS Release-2 features. The 4th C-V2X Plugtests event enabled vendors to run interoperability test sessions to assess the level of interoperability of their implementation and validate the understanding of the standards. Different topics were addressed, including PKI security testing, Vulnerable Road Users, Conformance testing and Collective Perception Message.

4.2 Timeline

Registration to the C-V2X Plugtests event was open from 14th May 2024 to 07th June 2024 to any organisation willing to participate in testing the C-V2X Services Ecosystem. After registering to the C-V2X Plugtests event, participating organisations had to sign the Rules of Engagement (RoE) and Non-Disclosure Agreement (NDA) they received upon registration. Upon signature of the Rules of Engagement (RoE) and Non-Disclosure Agreement (NDA) sent to the official contact, the participants received their credentials for the C-V2X Plugtests WIKI and invitations to the preparation conference calls.

	April	May					June				July					August				September	
	wk 17	wk 18	wk 19	wk 20	wk 21	wk 22	wk 23	wk 24	wk 25	wk 26	wk 27	wk 28	wk 29	wk 30	wk 31	wk 32	wk 33	wk 34	wk 35	wk36	wk 37
Conference Calls	X (Open)				X		X		X		X		X		X		X		X	X	
Registration		13/05 - 07/06/2024																			
Equipment Registration								10/06 - 28/06/2024													
Pre-Testing/Travel for Onsite Installation																				02/09 - 06/09/2024	
Plugtests																					10/09 - 13/09/2024

A total of 82 people were finally involved in the 4th C-V2X Plugtests event.

The following clauses describe the different phases of the Plugtests event preparation. It is worth noting that since the start of the documentation phase until the first week of the face-to-face Plugtests event, weekly conference calls were run among organisers and participants to discuss and track the progress, anticipate and solve technical issues, review the test plan, etc.

4.3 Test Scheduling

The preliminary test schedule was developed during the Plugtests week and was circulated to all the participants in advance for comments. ETSI test reporting tool was used to schedule the test session between all the devices. The test schedule allowed for each ITS vendor to test against all ITS stations. Each day was organized in a morning test sessions from 9.00 to 13.00 and in an afternoon test sessions from 14.00 to 18.00.

During the test event the test schedule was constantly updated according to the progress of the test sessions. This was done during the daily wrap-up meetings at the end of each day and during face-to-face meetings with the participants.

4.3.1 Documentation

Once the registration to the Plugtests event was closed, the following documentation activities were launched in parallel:

1) EUT Documentation

Participants registered their EUTs, by providing the information directly to the Plugtests event team. The Plugtests event team compiled the final EUT table for all the participating vendors and was appended to the Plugtests event Test Plan.

All the information described above was made available in the Plugtests event WIKI, so that it could be easily maintained and verified by the participants.

2) Test Plan Development

The Test Plan development was led by ETSI Centre for Testing and Interoperability following the methodology defined by 3GPP TSGs and ETSI TC ITS. The Test Plan was scoped around ITS Services Release -2 capabilities and concentrated on the features supported by the implementations attending the Plugtests event.

The Test Plan was developed and consolidated in an iterative way, taking into account input and feedback received from Plugtests event participants. See details in clause 8.

4.3.2 Plugtests event

From 10th September to 13th September 2024, participants sent representatives to the host premises in DEKRA to collaboratively run the Interoperability Test Sessions. The Plugtests were kindly hosted by the DEKRA at their facilities in Malaga, Spain.

This one-week on-site face-to-face event was scheduled as follows:

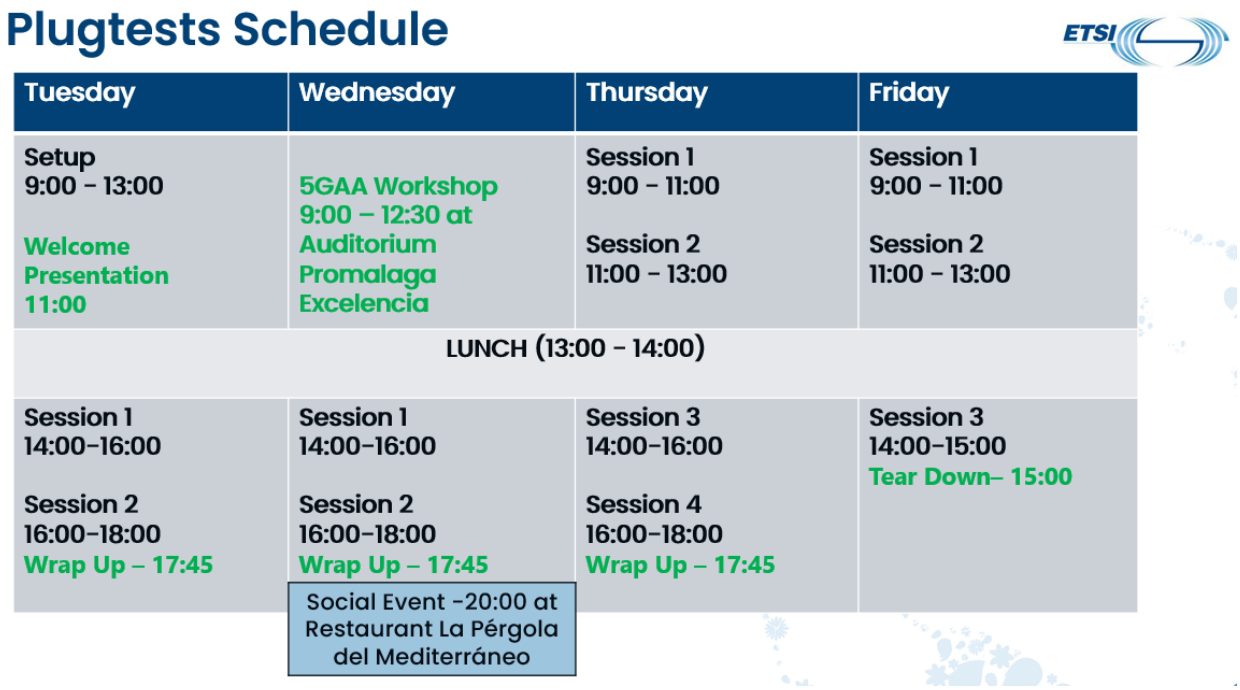

Figure 1. High-level schedule for Plugtests event on-site

First half of Monday was dedicated to local installation and pre-testing continuation, this time also including local implementations. A number of EUTs were installed and connected locally to the IT infrastructure, as well as some test and support functions.

The following 4 days were dedicated to on-site interoperability test sessions involving all the participating EUTs organised in several parallel tracks.

The scheduling of individual test combinations was done dynamically using ETSI Test reporting tool with the inputs and requests from the participants. The schedule was adapted during the test session slots on a per need basis.

4.4 Tools

4.4.1 Plugtests event WIKI

The Plugtests event WIKI was the main source of information for the C-V2X Plugtests event, from logistics aspects to testing procedures. Access to the WIKI was restricted to participating companies.

The main technical information provided in the wiki was organised as follows:

- **Event Information** – Logistics aspects of the Plugtests event.

- **Host Information** – Information from the host.
- **Free Shuttle Bus** – Information on the free shuttle bus for the participants.
- **Visa Information** – Information regarding Visa to Spain.
- **Shipment of Equipment** - Logistics information for shipping the equipment.
- **Test Tools** – Information related to testing tools available during the event.
- **Network Information** – IT Network Infrastructure of the Plugtests event.
- **PKI Certificates –** Security certificates provided by PKI vendors.
- **GPSD Server –** For simulating positions on the test track.
- **Test Specifications** - Test Plans and base specifications used for EUTs Testing.
- **Equipment Registration** - Participating EUTs overview.
- **Conference Calls** - Calendar, logistics, agendas and minutes of the weekly conference calls run during the remote integration and pre-testing phase.
- **Networking Event** – Information regarding social event.
- **List of Participants** – Name of the participants of the Plugtests event.
- **5GAA Workshop** - Presentations from the 5GAA workshop.
- **Observations**– Issues seen during the event are documented.

In addition, the embedded WIKI Chat and Slack was used among the participants to communicate with each other during the pre-testing phase and Test Sessions, include their remote colleagues (back-office support) in the discussions.

4.4.2 Test Reporting Tool (TRT)

The Test Reporting Tool guides participants through the Test Plan test cases during the on-site Test Sessions. It allows creating Test Session Reports compiling detailed results for the individual scheduled Test Sessions.

Only the companies providing the EUTs for each specific Test Session combination have access to their Test Session Reports contents and specific results. All companies involved in a specific session and who have entered the test results were required to verify and approve the reported results at the end of each session. Only test report which has been approved by all involved parties are considered as valid.

Another interesting feature of this tool is the ability to generate real-time stats (aggregated data) of the reported results, per test case, test group, test session or overall results. These stats are available to all participants and organisers and allow tracking the progress of the testing with different levels of granularity, which is extremely useful to analyse the results.

6497		2024-09-11 14:00	120	II	Config-Security	Microsec - PKI CohdaWireless - ITS-S	
6498		2024-09-11 14:00	120	III	Config-Security	Eviden - PKI CTAG - ITS-S	
6501		2024-09-10 14:00	120	IV	Config-Security	Microsec - PKI Movyon - ITS-S	
6502		2024-09-10 16:00	120	IV	Config-CPS	CohdaWireless - ITS-S Keysight - ITS-S	
6504		2024-09-10 14:00	120	III	Config-CPS	Nfiniity - ITS-S Vector - ITS-S	
6507		2024-09-11 14:00	120	V	Config-CPS	Keysight - ITS-S Nfiniity - ITS-S	
6509		2024-09-11 14:00	120	I	Config-CPS	Mach-systems - ITS-S Movyon - ITS-S	
6511		2024-09-11 14:00	120	IV	Config-CPS	Marben - ITS-S Vector - ITS-S	
6515		2024-09-11 16:00	120	V	Config-VRU	CTAG - ITS-S Mach-systems - ITS-S	

Figure 2. Test Reporting Tool – example screen shot

5 Equipment Under Test

The tables below summarise the different EUTs provided by the Plugtests event participants:

5.1 OBU vendors

Organisation	Comment
COHDA WIRELES	
CTAG	
ETTIFOS	
KEYSIGHT	
MARBEN	
NFINIITY	
VECTOR	

Table 1. On Board Units Under Test

5.2 RSU vendors

Organisation	Comment
CTAG	–
MACH SYSTEMS	–
MOVYON ELECTRONICS	–
ROLLING WIRELESS	CV2X Module + Dev Kit

Table 2. Road Side Units Under Test

5.3 PKI providers

Organisation	Comment
EVIDEN	–
MICROSEC	–

Table 3. PKI Under Test

5.4 Test Equipment Manufacturers

Organisation	Comment
DEKRA	–
TTA	–
VECTOR	–
WAYTIES	–

Table 4. Test Equipment Manufacturers Under Test

Test Scope Participation

Lab testing - Security V1	Lab testing - Security V2	Lab testing - CPS	Lab testing - VRU	Outdoor testing	ITS Services over 5G sidelink
Eviden PKI	Microsec PKI	Movyon	CTAG	CTAG	Ettifos
Microsec PKI	CTAG	Vector	Marben	Nfiniity	Vector
Movyon	Mach	CTAG	Nfiniity		Keysight
CTAG	Keysight	Marben	Mach		
Marben	Rolling	Nfiniity			
Mach	Vector	Mach			
Cohda		Keysight			
Rolling		Vector			
Vector		Cohda			

Figure 3. Test Scope Participation

6 Test Infrastructure

6.1 Local Test Infrastructure

The face-to-face testing phase were enabled by the setup as shown in Figure 3:

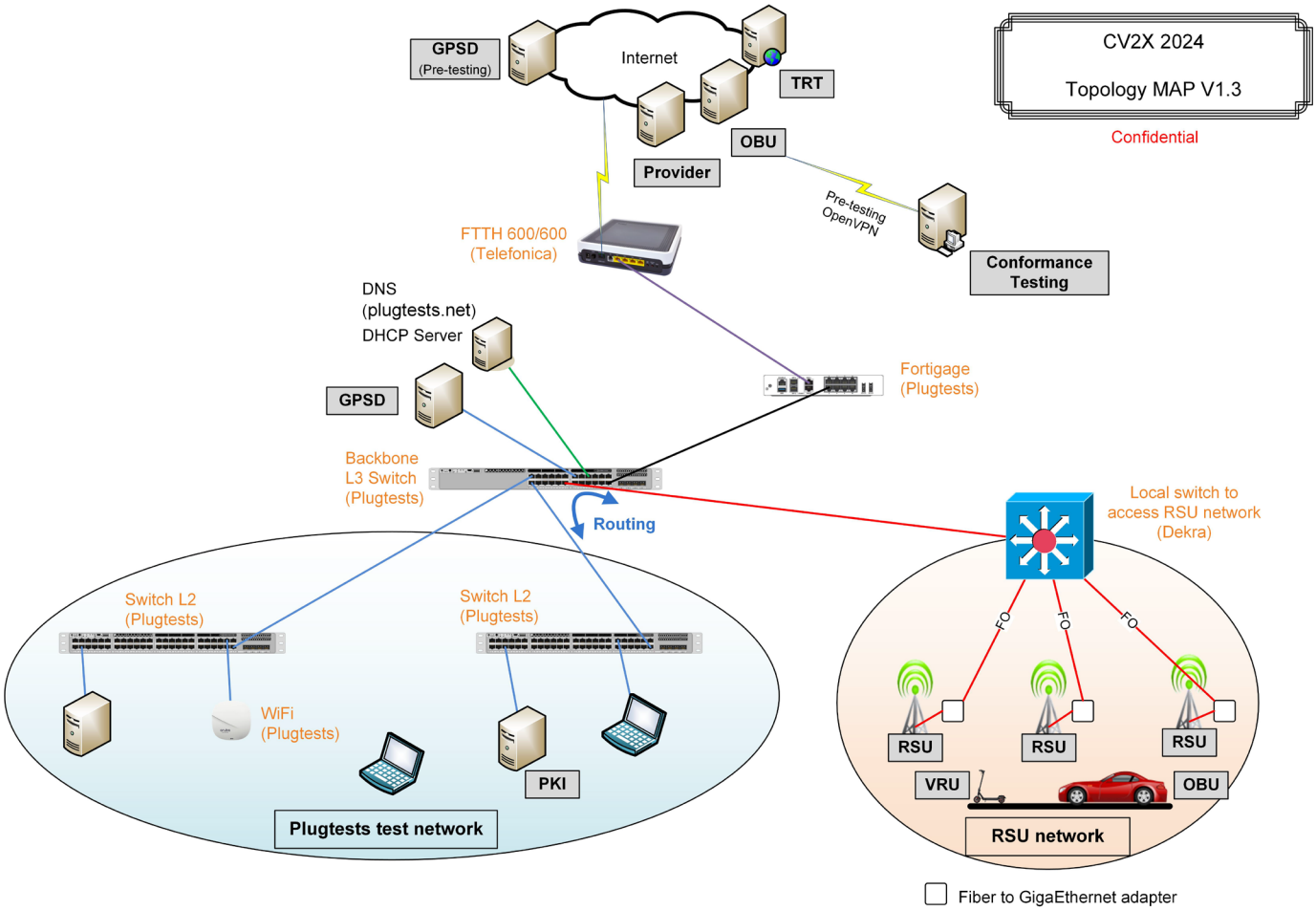

Figure 4. Local Test Infrastructure

6.3 GPSD Server Configuration

The GPSD server emulated the movement of cars on the test track. It provided different positions for each vendor in order to avoid position collisions. All positions and port allocations were presented at the GPSD server web interface. The GPSD server was synchronized with the local NTP server on time.windows.com.

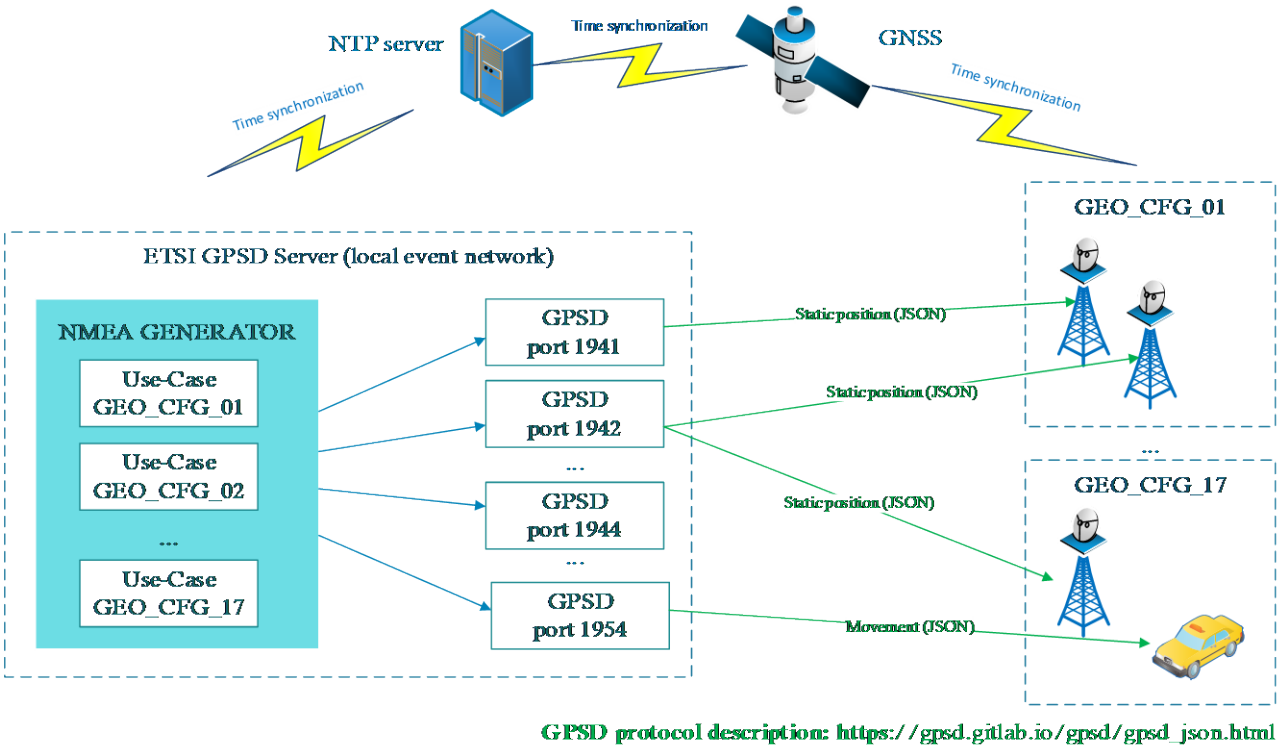

Figure 5. GPSD Server Configuration

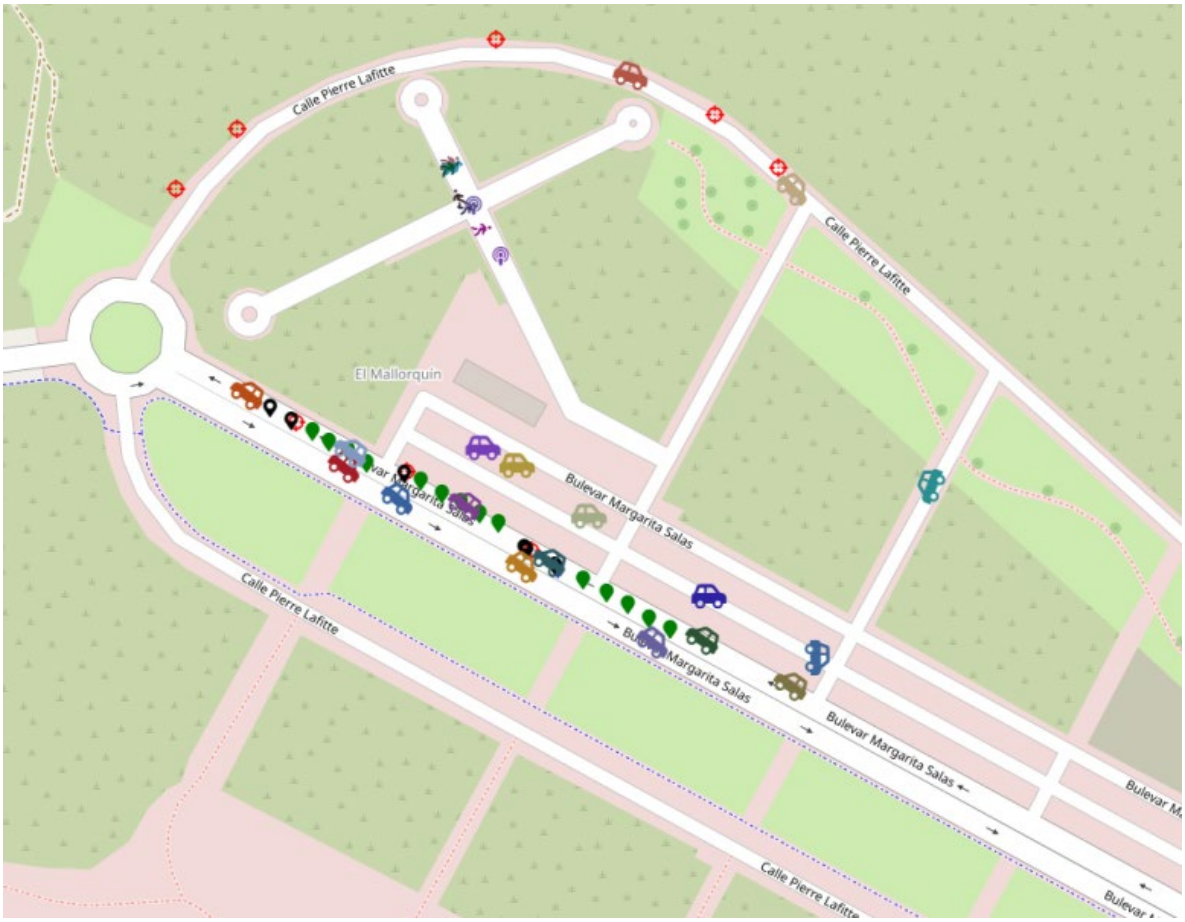

Figure 6. GPSD Web Interface

7 Test Procedures

7.1 Interoperability Testing Procedure

During the on-site face-to-face part of the Plugtests event, a daily Test Session Schedule was produced and shared via the WIKI. Test Sessions were organised in several parallel tracks, ensuring that all participants had at least one Test Session scheduled any time. The different test configurations were used for the main event.

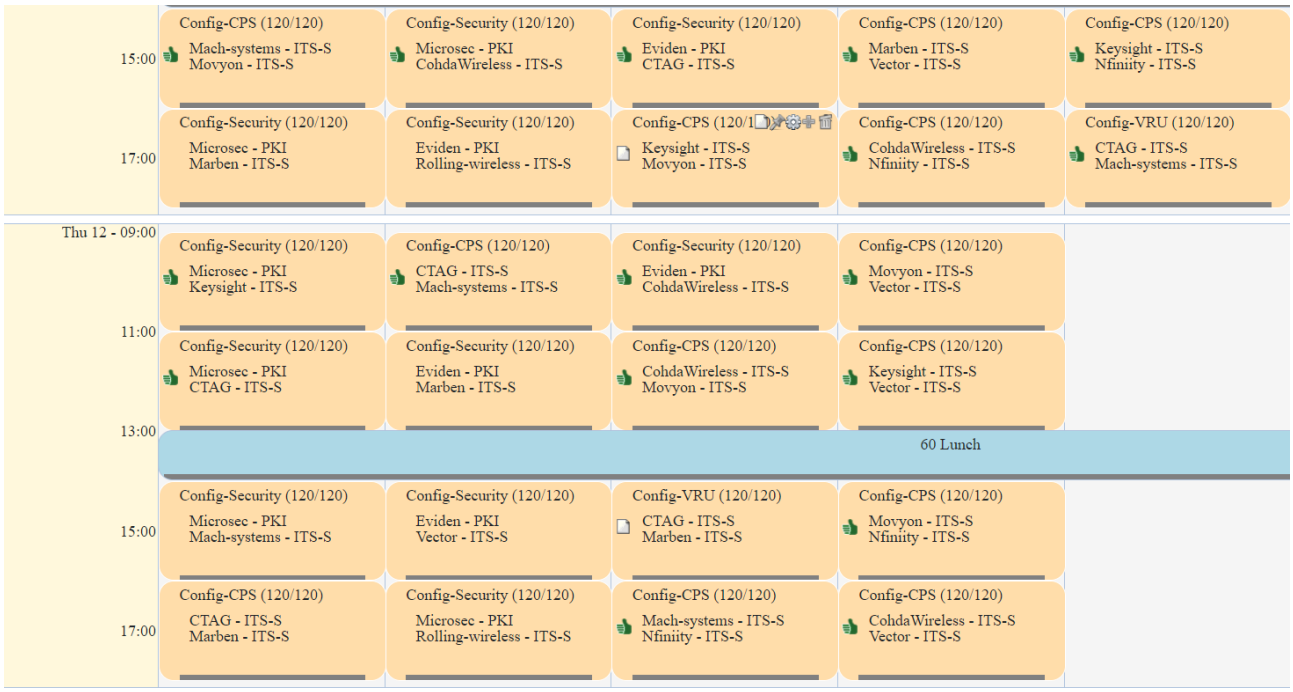

Figure 7. Daily Schedule & Test Sessions – example excerpt

Config Name	Main Test Configuration
Config-ABTS	Test Tool + ITS-S
Config-Conformance	Test tool + ITS
Config-CPS	ITS-S + ITS-S
Config-ITS-Services	ITS-S + ITS-S
Config-Outdoor	ITS-S + ITS-S
Config-Security	ITS-S + PKI
Config-VRU	ITS-S + ITS-S

Table 5. Main Test Configurations

During each test session, for each tested combinations the Interoperability testing procedure was as follows:

1. The participating vendors opened the Test Session Report and the Test Plan.

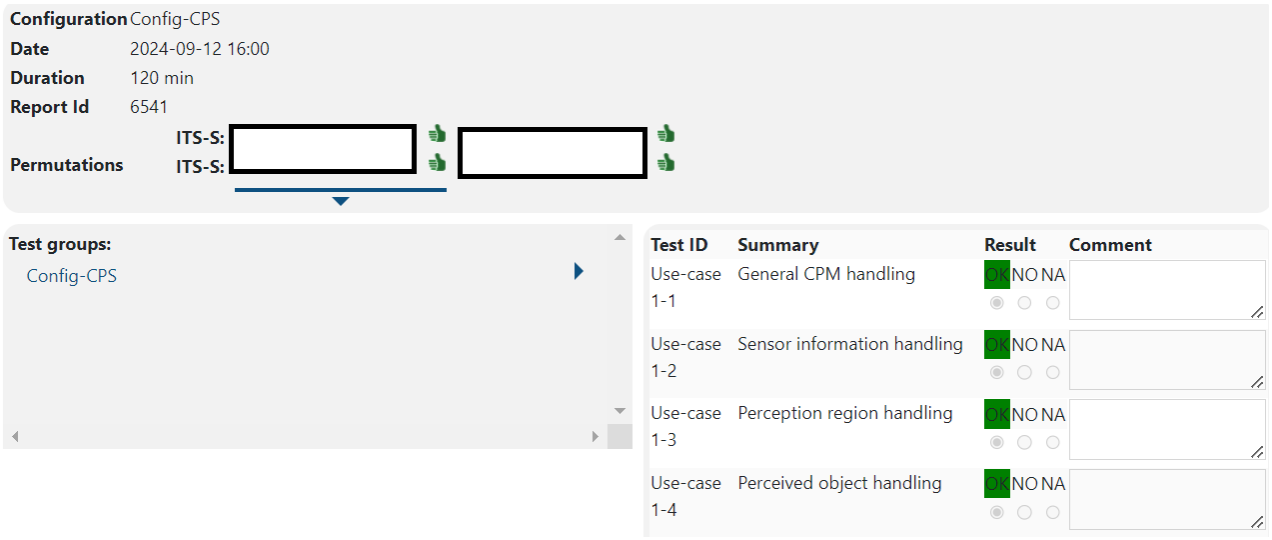

Figure 8. Test Session Report example excerpt

2. For each Test in the Test Plan:

    a. The corresponding Test Description and EUT Configuration were followed for CPM Handling

Figure 9. System Under Test (SUT) Configuration – CPM Handling example excerpt

6.1 Use-case 1-1 General CPM handling

Interoperability Test Description			
Identifier:	TC_ITS_CPS_UC1-1		
Objective:	Check that EUT can correctly encode and decode the CPM with all allowed DEs and DFs.		
Configuration:	EUT1 shall be capable of transmitting CPMs as specified in [1] with all allowed DEs and DFs. EUT2 shall be capable of receiving and decoding CPMs as specified in [1] with all allowed DEs and DFs. Both EUTs are configured to use the same communication channel for the transmission and reception of CPMs. The load of the communication channel shall be below 10 % CBR. EUT1 and EUT2 shall be positioned at a distance of less than 100 m in direct line of sight conditions.		
Pre-test conditions:	Neither EUT1, EUT2 nor any other ITS-S transmits CPMs.		
REQ /PICS	**Tested Requirements**	**PICS**	
	1.1		
Step	**Type**	**Description**	**Result**
1	Stimulus (by Sender)	EUT1 transmits CPMs periodically with a generation event periodicity of T_GenCpm = 100 ms, using all available message fields in each generated CPM.	
2	Verify (by Receiver)	EUT2 receives the CPMs transmitted by EUT1	EUT2 forwards the decoded CPM to IF.APP or IF.CPM. All data fields of the decoded CPM are equal to the corresponding data fields in the encoded CPM by EUT1.
NOTE: EUT1 may fill the data fields with meaningful or random data, as long as the allowed ranges are obeyed. This includes *segmentationInfo* and *messageRateRange*, in the *ManagementContainer, pitchAngle, rollAngle* and *trailerDataSet* in the *OriginatingVehicleContainer* (needed only for ITS-S_Type = Vehicle or Trailer), *mapReference* in the *OriginatingRsuContainer* (needed only for ITS-S_Type = RSU), instances of *SensorInformation* each described by another *perceptionRegionShape* in the *SensorInformationContainer*, instances of *PerceptionRegion* each described by another *perceptionRegionShape*, *sensorIdList* and *numberOfPerceivedObjects* or *perceivedObjectIds* in the *PerceptionRegionContainer*, and instances of *PerceivedObject* of different *ObjectClassificationDescription*, including the entire kinematic and attitude state vector with variances and correlations, as well as *mapPosition* (for PICS=RSU).			

Figure 10. CPM Handling example excerpt

3. C-V2X equipment providers jointly executed the different steps specified in the test description and evaluated interoperability through the different IOP Checks prescribed in the Test Description

   b. The C-V2X equipment provider recorded the Test Result in the Test Session Report, as follows:

      i. OK: all IOP Checks were successful

      ii. NOK: at least one IOP Check failed. A comment was requested.

      iii. NA: the feature was not supported by at least 1 of the involved EUTs. A comment was requested.

4. Once all the tests in the Test Session Report were executed and results recorded, the participants reviewed the Report and approved it.

8 Test Plan Overview

8.1 Introduction

This 4th C-V2X Plugtests Test Plan was developed following ETSI guidelines for interoperability. There were different test plans available for testing which are attached with the report.

- Collective Perception Services (CPS) - ETSI TS 103 324 [28] and 103 926 [29].
- Vulnerable Road Users (VRU) - ETSI TS 103 300-2 [30], 103 300-3 [31] and 103 925 [32].
- PKI Security Interoperability Testing ETSI TS 103 600 [24].
- Conformance and RF test plan offered by TE vendors.

The Test Plan was reviewed and discussed with participants during the preparation and pre-testing phase. Considering the huge number of resulting test cases and difference expected maturity of the implementations.

8.2 Group of test cases

As described in the Subclause 4.1 of this document, different test objectives were considered. Please refer to test plans attached with the report.

The following tables collect the test cases grouped by test objective following the structure of the test specification document itself.

Test Id	Test Purpose
CPS-USE-CASE 1	General CPM handling
CPS-USE-CASE 2	Sensor information handling
CPS-USE-CASE 3	Perception region handling
CPS-USE-CASE 4	Perceived object handling
CPS-USE-CASE 5	Correlation matrix handling
CPS-USE-CASE 6	Non-line-of-sight perception
CPS-USE-CASE 7	Resource-aware data rate adaptation
CPS-USE-CASE 8	Resource-aware channel offloading
CPS-USE-CASE 9	Cluster deactivation

Table 6. Test Group for the Test Plan CPS [29]

Test Id	Test Purpose
VRU-USE-CASE 1	Cluster deactivation
VRU-USE-CASE 2	Cluster activation
VRU-USE-CASE 3	Cluster leader break cluster up
VRU-USE-CASE 4	Creating a cluster
VRU-USE-CASE 5	Stop sending VAMs after cluster joining
VRU-USE-CASE 6	Cluster Breakup triggered by leader
VRU-USE-CASE 7	Failed joining a cluster
VRU-USE-CASE 8	Increase cluster after successful cluster joining
VRU-USE-CASE 9	Cluster leader does not change cluster properties on aborted cluster joining attempt
VRU-USE-CASE 10	Leave VAM cluster
VRU-USE-CASE 11	Leave cluster in case of connection loss
VRU-USE-CASE 12	Leave cluster on Safe Distance Violation
VRU-USE-CASE 13	Leave cluster after cluster ID change
VRU-USE-CASE 14	Decrease of cluster size after a cluster leaving
VRU-USE-CASE 15	Stop sending VAM if ITS-S is part of CPM

Test Id	Test Purpose
VRU-USE-CASE 16	Start sending VAM if ITS-S is not a part of CPM anymore
VRU-USE-CASE 17	Increased safe distance after adverse weather warning
VRU-USE-CASE 18	Trajectory interception probability

Table 7. Test Group for the VRU Test Plan [32]

Test Id	Test Purpose
PKI-Use-case 1-1	Both ITS-S authorized by the same AA
PKI-Use-case 1-2	Different AAs of the same PKI
PKI-Use-case 1-3	Peer-to-peer distribution of AA certificate
PKI-Use-case 1-4	Participating ITS-S are registered in different RCAs
PKI-Use-case 1-5	Pseudonym changing
PKI-Use-case 2-1	Invalid certificate region
PKI-Use-case 2-2	Invalid ValidityPeriod of ATs
PKI-Use-case 2-3	PSID exceptional behaviour
PKI-Use-case 2-3a	CAM PSID missing in ATs - rejected sending
PKI-Use-case 2-3b	DENM PSID missing in ATs - rejected sending
PKI-Use-case 2-4	Using of AT issued by AA included in the CRL
PKI-Use-case 2-5	Unknown RCA
PKI-Use-case 3-1	Valid enrolment behavior
PKI-Use-case 3-2	Enrolment behaviour with already enrolled station
PKI-Use-case 3-3	Enrolment behaviour when ITS-S is not registered on the EA
PKI-Use-case 3-4	Enrolment behaviour when EA is on the CRL
PKI-Use-case 4-1	Valid authorization behaviour
PKI-Use-case 4-2	Authorization behaviour with optional privacy requirements
PKI-Use-case 4-3	Authorization behaviour when AA and EA are from different PKI
PKI-Use-case 4-4	Authorization behaviour when AA is on the CRL
PKI-Use-case 4-4a	Authorization behaviour with AA from another PKI when AA is on the CRL
PKI-Use-case 4-5	Check renewal of expired AT certificates
PKI-Use-case 5-1	Initial CA certificate request
PKI-Use-case 5-2	Re-keying of CA certificate

Table 8. Test Group for the ETSI PKI Security Interoperability Test Plan [24]

Test Id	Test Purpose
1.1	Range Test < 500 m
1.2	Range Test < 600 m
1.3	Range Test < 700 m
1.4	Range Test < 800 m
1.5	Range Test < 900 m
2.1	CPM with Stereo Camera Object Detection - Detect Pedestrian
2.2	CPM with Stereo Camera Object Detection - Detect Bicycle
2.3	CPM with Stereo Camera Object Detection -Generate CPM for Pedestrian
2.4	CPM with Stereo Camera Object Detection - Generate CPM for Bicycle

Table 9. Test Group for the ETSI Outdoor Test Plan

Test Id	Test Purpose
UC1	This test verifies that the devices under test can transmit and

Test Id	Test Purpose
	receive C-V2X messages (one semi-persistent scheduling (SPS) flow with 100 ms periodicity) over PC5 interface.
UC2	This test verifies that the devices under test can transmit and receive C-V2X messages (two SPS flows each with 100 ms periodicity) over PC5 interface.
UC3	This test verifies that the devices under test can transmit and receive C-V2X messages (two SPS flows each with 100 ms periodicity and multiple event-driven flows) over PC5 interface.
UC4	This test verifies that the devices under test can transmit and receive C-V2X messages (two SPS flows each with 100 ms periodicity, IP-based and multiple event-driven flows non-IP) over PC5 interface.
Bench Test - LSD 02	Traffic Condition - Local Slow Down
Bench Test - SPD 01	Traffic Condition - Sudden Speed Drop

Table 10. Test Group for the ETSI lab-based ITS Services Interoperability Test Plan

9 Interoperability Results

9.1 Overall Results

During the face-to-face Plugtests event at Dekra, Malaga, 175 test executions were conducted, and interoperability results were reported in the Test reporting tool.

The table below provides the overall results (aggregated data) from all the Test Cases run during all the Test Sessions with all the different combinations of Equipment Under Test from all the participating companies.

Among the executed Test Cases, the possible results were “OK”, when interoperability was successfully achieved and “NO” (Not OK) when it was not.

Interoperability		Totals
OK	**NO**	**Run**
164 (93.7%)	11 (6.3%)	175

Table 11. Overall Results

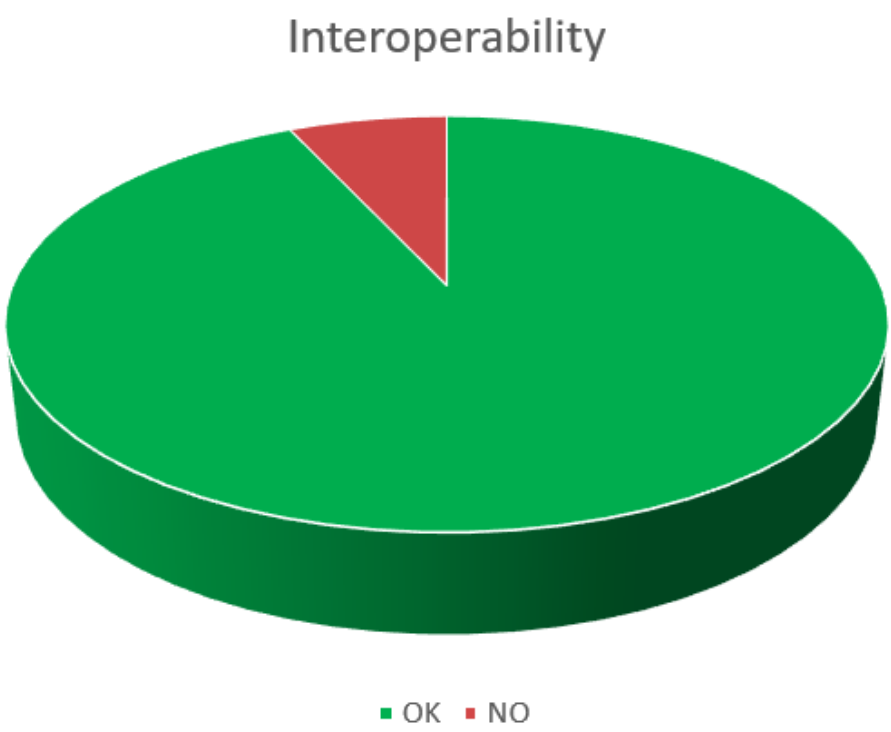

Figure 11. Overall results (%)

An overall interoperability success rate of 93.7% was achieved, which indicates a very high degree of compatibility among the participating implementations (EUTs) in the areas of the Test Plan where features were widely supported, and the test cases could be executed in most of the Test Sessions. In the next clauses, we will see that this high rate is also a consequence of the good preparation and involvement of participants during the preparation phase of the Plugtests.

9.3 Results per Group

The table below provides the results for each test configuration in the scope of the Plugtests event.

Configuration	Interoperability		Total
	OK	NO	Run
Config-CPS	87 (89.7%)	10 (10.3%)	97
Config-VRU	4 (100.0%)	0 (0.0%)	42
Config-Security	58 (98.3%)	1 (1.7%)	26
Config-Conformance	6 (100.0%)	0 (0.0%)	41
Config-Outdoor	9 (100.0%)	0 (0.0%)	0
Config-ITS-Services	0 (0.0%)	0 (0.0%)	2
Config-ABTS	0 (0.0%)	0 (0.0%)	109

Table 12. Results per Group

9.3 Results per Test Case

The table below provides the results for each test case in the scope of the Plugtests event.

	Interoperability		Total
	OK	NO	Results
CPS-Use-case 1-1	26 (78.8%)	7 (21.2%)	33
CPS-Use-case 1-2	29 (96.7%)	1 (3.3%)	30
CPS-Use-case 1-3	9 (90.0%)	1 (10.0%)	10
CPS-Use-case 1-4	23 (95.8%)	1 (4.2%)	24
CPS-Use-case 1-5	0 (0.0%)	0 (0.0%)	0
CPS-Use-case 1-6	0 (0.0%)	0 (0.0%)	0
CPS-Use-case 1-7	0 (0.0%)	0 (0.0%)	0
CPS-Use-case 1-8	0 (0.0%)	0 (0.0%)	0
CPS-Use-case 1-9	0 (0.0%)	0 (0.0%)	0
VRU-Use-case 1-1	4 (100.0%)	0 (0.0%)	4
VRU-Use-case 1-2	0 (0.0%)	0 (0.0%)	0
VRU-Use-case 1-3	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-4	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-5	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-6	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-7	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-8	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-9	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-10	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-11	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-12	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-13	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-14	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-15	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-16	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-17	0 (0.0%)	0 (0.0%)	0
VRU-Use-Case 1-18	0 (0.0%)	0 (0.0%)	0
PKI-Use-case 1-1	3 (100.0%)	0 (0.0%)	3
PKI-Use-case 1-2	2 (100.0%)	0 (0.0%)	2

PKI-Use-case 1-3	1 (100.0%)	0 (0.0%)	1
PKI-Use-case 1-4	1 (100.0%)	0 (0.0%)	1
PKI-Use-case 1-5	2 (100.0%)	0 (0.0%)	2
PKI-Use-case 2-1	1 (100.0%)	0 (0.0%)	1
PKI-Use-case 2-2	1 (100.0%)	0 (0.0%)	1
PKI-Use-case 2-3	2 (100.0%)	0 (0.0%)	2
PKI-Use-case 2-3a	2 (100.0%)	0 (0.0%)	2
PKI-Use-case 2-3b	2 (100.0%)	0 (0.0%)	2
PKI-Use-case 2-4	0 (0.0%)	0 (0.0%)	0
PKI-Use-case 2-5	1 (100.0%)	0 (0.0%)	1
PKI-Use-case 3-1	6 (100.0%)	0 (0.0%)	6
PKI-Use-case 3-2	4 (100.0%)	0 (0.0%)	4
PKI-Use-case 3-3	5 (100.0%)	0 (0.0%)	5
PKI-Use-case 3-4	1 (50.0%)	1 (50.0%)	2
PKI-Use-case 4-1	5 (100.0%)	0 (0.0%)	5
PKI-Use-case 4-2	3 (100.0%)	0 (0.0%)	3
PKI-Use-case 4-3	1 (100.0%)	0 (0.0%)	1
PKI-Use-case 4-4	1 (100.0%)	0 (0.0%)	1
PKI-Use-case 4-4a	1 (100.0%)	0 (0.0%)	1
PKI-Use-case 4-5	4 (100.0%)	0 (0.0%)	4
PKI-Use-case 4-1 V2	5 (100.0%)	0 (0.0%)	5
PKI-Use-case 4-3 V2	0 (0.0%)	0 (0.0%)	0
PKI-Use-case 3-1 V2	4 (100.0%)	0 (0.0%)	4
Conformance CAM	2 (100.0%)	0 (0.0%)	2
Conformance DENM	2 (100.0%)	0 (0.0%)	2
Conformance Security	2 (100.0%)	0 (0.0%)	2
1.1	1 (100.0%)	0 (0.0%)	1
1.2	1 (100.0%)	0 (0.0%)	1
1.3	1 (100.0%)	0 (0.0%)	1
1.4	1 (100.0%)	0 (0.0%)	1
1.5	1 (100.0%)	0 (0.0%)	1
2.1	1 (100.0%)	0 (0.0%)	1
2.2	1 (100.0%)	0 (0.0%)	1
2.3	1 (100.0%)	0 (0.0%)	1
2.4	1 (100.0%)	0 (0.0%)	1
UC1	0 (0.0%)	0 (0.0%)	0
UC2	0 (0.0%)	0 (0.0%)	0
UC3	0 (0.0%)	0 (0.0%)	0
UC4	0 (0.0%)	0 (0.0%)	0
Bench Test - LSD 02	0 (0.0%)	0 (0.0%)	0
Bench Test - SPD 01	0 (0.0%)	0 (0.0%)	0

Table 13. Results per Test Case

10 5GAA Workshop on C-V2X Interoperability and Deployment

5GAA organised a workshop on “C-V2X ecosystem and discuss the impact of ETSI Release 2 standards.”, gathering key players of the C-V2X ecosystem, including governmental entities and companies, to discuss global perspectives on 5G-V2X, the progress made on 5G-V2X Direct, ETSI Release 2 messages, security and future integration of V2X and ADAS. The workshop will be structured in two parts: a series of presentations, starting with a global outlook on 5G-V2X adoption and deployments, followed by an open discussion with industry experts.

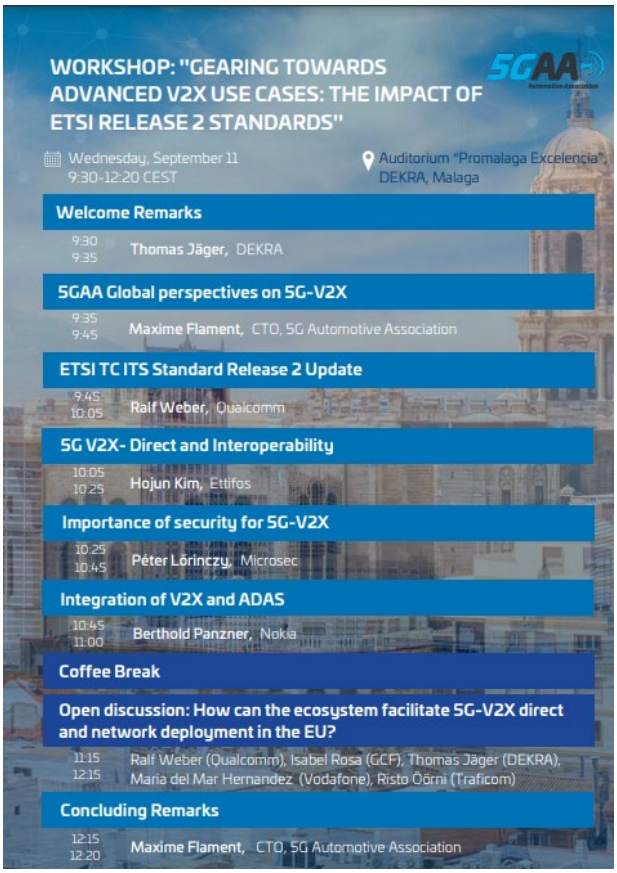

Figure 12. 5GAA Workshop Agenda

11 Observations

11.1 CPS use-case 1-2 Sensor information handling

In this use case, Sensor Information 1 has the following fields:

- horizontalOpeningAngleStart** = -30
- verticalOpeningAngleStart** = -20

However, according to the ASN.1 module ETSI-ITS-CDD, the value range for both fields cannot be less than 0.

11.2 CPS use-case 1-5 Message Assembly Configuration

To detect the Message Assembly configuration of a received message, I considered two approaches, but both have limitations:

1. **Matching perceived object IDs in the perception regions with those sent:** The issue here is that the perceived object ID field is optional, so it might not always provide a reliable match.
2. **Verifying if all sent perceived objects are within the sent perception regions:** This approach has the flaw that, by coincidence, the condition could be true even if the sender used a utility function-based assembly, leading to false positives.

11.3 PKI ETSI TS 102 941 V2.2.1 (2022-11)

Clause 6.2.3.5.2 Butterfly Authorization request

Key generation for encryption/decryption is not explicitly mentioned.

Key generation for verifyKeyIndicator is mentioned here:

" An ECC private key is randomly generated, the corresponding public key (verifyKeyIndicator) is to be used as caterpillar key for the butterfly key expansion."

And placement in the structure is mentioned as well:

"- the verifyKeyIndicator shall contain the generated caterpillar key."

But the key used in the butterfly expansion is not mentioned.

"the original option with the ButterflyParamsOriginal containing a signingExpansion containing a freshly generated 16 Byte string to be used as a key for the expansion function for signing, **an encryptionKey containing the caterpillar public key for encryption**, and an encryptionExpansion containing a freshly generated 16 Byte string to be used as a key for the expansion function for encryption;"

11.4 Usage of unsecuredData as a top-level container

Currently ETSI specification doesn't prevent usage of unsecuredData as a top-level container of Secured packet.

GN spec says: "*The overall packet structure may be protected by security services as specified in ETSI TS 102 723-8 [i.2] and ETSI TS 103 097 [10], i.e. by digital signatures and certificates and by encryption.* " (**implying that signed or encrypted messages are used but only using "i.e." wording, which can’t be considered as a requirement.)**

Security spec says: "*A secure data structure shall be of type EtsiTs103097Data as defined in annex A, which corresponds to a Ieee1609Dot2Data as defined in IEEE Std 1609.2™ [1], clause 6.3.2, with the constraints defined in this clause, in clause 5.2 and in clause 5.3. The type Ieee1609Dot2Data shall support the following options in the component content: • The option unsecuredData shall be used to encapsulate an unsecured data structure. • The option signedData, corresponding to the type SignedData as defined in IEEE Std 1609.2™ [1], clause 6.3.4, shall be used to transfer a data structure with a signature. • The option encryptedData, corresponding to the type EncryptedData as defined in IEEE Std 1609.2™ [1], clause 6.3.30, shall be used to transfer an encrypted data structure.*" (**implying that, additionally, unsecured messages are used**.)

Using unsecuredData as a top-level container doesn't have any rational reason.

11.5 UPER bit incompatibility in CPM message

During the event, a **UPER (Unaligned Packed Encoding Rules)** encoding incompatibility was confirmed in **CPM (Collective Perception Message)** messages, as initially highlighted in the **DLR**.

The encoding inconsistency can cause **interoperability issues** between different systems or devices, potentially affecting the accurate exchange of sensor data critical for cooperative perception. Given that CPM messages play a key role in enabling vehicles to share detected object information for enhanced situational awareness, this **UPER encoding incompatibility** poses a significant challenge for ensuring seamless communication in **V2X (Vehicle-to-Everything)** environments.

11.6 Fixed CAM rate in PC5 channel

According to the **ETSI ITS CAM** (Cooperative Awareness Message) standard, CAMs are designed to be sent with flexible rates and sizes, adapting to various traffic conditions and network needs. This flexibility allows the message frequency and size to dynamically adjust based on factors like vehicle speed, density, and surrounding environment, ensuring efficient use of the communication channel.

However, the **PC5 policy** (used in LTE-V2X) mandates that messages be sent at a **fixed size and at a fixed rate**, which directly contradicts the flexibility defined in the CAM specification. This discrepancy creates a challenge, as the rigid requirements of PC5 can limit the adaptive capabilities of CAM messages, reducing their overall efficiency and responsiveness to real-time conditions.

In essence, the **PC5 policy's fixed size and rate** transmission violates the **ETSI ITS CAM standard**'s core principle of adaptability, potentially undermining the effectiveness of vehicular communication systems in certain scenarios. This conflict highlights the need for harmonizing the two standards or developing workarounds to maintain the intended functionality of CAMs within the constraints of PC5.

History

Document history		
V0.1.0	16/09/2024	First Draft
V0.2.0	19/09/2024	Stable Draft
V0.3.0	20/09/2024	Stable Draft
V1.0.0	25/09/2024	Report published