V2X and Connected Infrastructure – V2X2

Public report

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FFI Fordonsstrategisk Forskning och Innovation

VINNOVA Energimyndigheten TRAFIKVERKET FKG VOLVO SCANIA VOLVO

Content

FFI in short
FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which about €40 is governmental funding.
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1. Summary

This project has served to increase the knowledge and skillset of AstaZero in the area of connectivity in general and WLAN-based communication to and from vehicles in particular. The purpose was to prepare AstaZero to better serve both its clients and researchers within the field of the connected transport system.

A number of roadside units and onboard units have been procured and used in experiments, both at the AstaZero test track and in open traffic, in the city of Gothenburg, rural roads, and on the E4 highway. Much experience has been gained on the intricacies of V2X messaging security and the PKI system, with focus on EU.

In collaboration with Halmstad University, a system was developed for tracking vulnerable road users (VRUs) and sending warnings to equipped vehicles. Initially, the system was intended to build on WLAN devices, but since there were no suitable hardware available for purchase, an app for cellular phones was developed. The functionality has been proven in filmed demonstrations and a research paper published.

Furthermore, the project has developed interfaces for steering specific features of the networks, both 802.11p and cellular, with the intention of facilitating interesting future connectivity tests, both for research and clients.

2. Sammanfattning på svenska

Detta projekt har bidragit till att öka kunskapen och kompetensen hos AstaZero inom området uppkoppling i allmänhet och WLAN-baserad kommunikation till och från fordon i synnerhet. Syftet var att förbereda AstaZero för att bättre kunna serva både sina kunder och forskare inom området det uppkopplade transportsystemet.

Ett antal vägenheter, roadside units, och ombordenheter, onboard units, har upphandlats och använts i experiment, både på testbanan AstaZero och i öppen trafik, i Göteborgs stad, på landsvägar och på E4:an. Mycket erfarenhet har vunnits om krångligheterna med V2X-meddelandesäkerhet och PKI-systemet, med fokus på EU.

I samarbete med Högskolan i Halmstad togs ett system för att spåra oskyddade trafikanter (VRU) och skicka varningar till utrustade fordon fram. Ursprungligen var systemet tänkt att bygga på WLAN-enheter, men eftersom det inte fanns någon lämplig hårdvara att köpa utvecklades en app för mobiltelefoner. Funktionaliteten har bevisats i filmade demonstrationer och en forskningsartikel publicerad.

Vidare har projektet utvecklat gränssnitt för att styra specifika egenskaper hos nätverken, både 802.11p och mobilnät, med avsikt att underlätta intressanta framtida tester kring uppkoppling, både för forskning och kunder.

3. Background

A car of today has 30-40 antennas. They are used for many different systems, such as broadcasting (FM, DAB, AM, DVB…), cellular (2G, 3G, 4G, 5G), Wi-Fi (802.11 a, b, g, n, ac, ax), GNSS (GPS, Galileo, GLONASS, Beidou), Bluetooth, NFC, wireless key systems and so on.

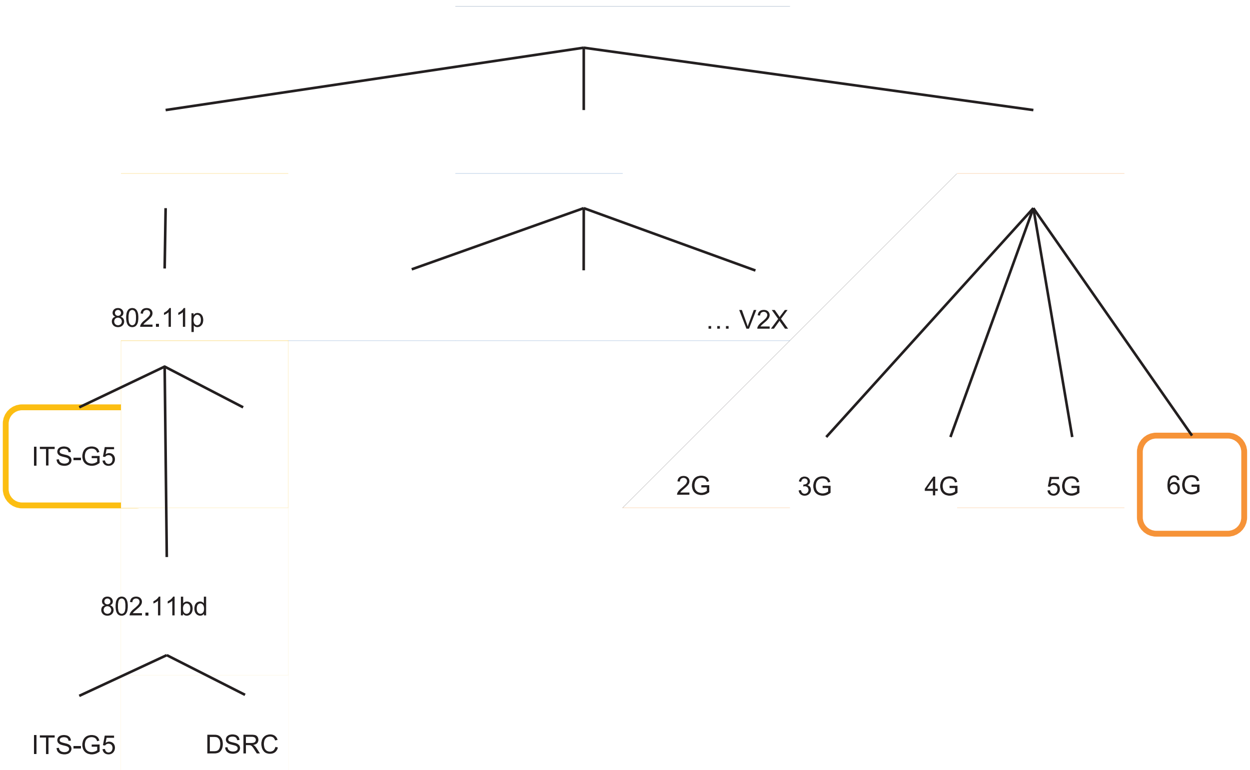
AstaZero already has access to a private 5G network and with this project, it is preparing to serve as a test bed for both vehicles and infrastructure that support ITS-G5. In this way, a unique opportunity is created for Swedish academia, industry, and authorities/government to research, develop and conduct studies at home.

3.1 What is V2X?

Vehicle to everything (V2X) – "communication between a vehicle and any entity that may affect, or may be affected by, the vehicle" – designates communication between a vehicle and its surroundings [1]. V2X uses two types of communication technology, WLAN-based 802.11p (DSRC and ITS-G5) or cellular-based 3GPP (C-V2X).
Among the categories of V2X are:

- Vehicle-to-Device (V2D) - Bluetooth / WiFi-Direct, e.g., Apple’s CarPlay and Google’s Android Auto.
- Vehicle-to-Grid (V2G) - information exchange with the smart grid to balance loads more efficiently.
  - Vehicle-to-Building (V2B), also known as Vehicle-to-Home (V2H)
  - Vehicle-to-Load (V2L)
- Vehicle-to-Network (V2N) - communication based on cellular (3GPP) / 802.11p.
  - Vehicle-to-Cloud (V2C) - e.g., over the air (OTA) updates, remote vehicle diagnostics (DoIP).
  - Vehicle-to-Infrastructure (V2I) - e.g., traffic lights, lane markers and parking meters.
  - Vehicle-to-Pedestrian (V2P) - e.g., wheelchairs and bicycles.
  - Vehicle-to-Vehicle (V2V) - real-time data exchange with nearby vehicles.

The standards and access technologies are illustrated in Figure 1.



chnologies and their related standards.

3.2 V2X History in Brief

The history of V2X spans several decades and involves multiple technologies and standards. In 1980s, an early example of V2X technology is the Radio Data System (RDS), which is a broadcast system that uses FM radio to transmit digital information, including traffic updates, weather reports, and emergency alerts. In 1990/2000s, early efforts were made toward inter-vehicle communication with the development of various Vehicular Ad-hoc Networks (VANETs). In 2010, the IEEE (Institute of Electrical and Electronics Engineers) developed the 802.11p standard, a variation of Wi-Fi that operates in the 5.9 GHz frequency band, included in the Dedicated Short Range Communication (DSRC) and ITS-G5 protocol suites. It is designed specifically for V2X communication and enables vehicles to exchange information.

In 2014, 3GPP introduced LTE sidelink, which enables V2X communication over cellular networks. This supports direct communication between nearby user equipment/vehicles without requiring a connection to the core network.

In 2014, the European Telecommunications Standards Institute (ETSI) introduced the ITS-G5 standard, which is based on 802.11p and is designed for V2X communication in Europe. In 2015, Toyota released a proprietary V2X system called ITS (Intelligent Transport System) Connect. It uses DSRC technology (760 MHz) to enable vehicles to communicate with each other and with roadside infrastructure. In 2019, Volkswagen (VW) equipped the new ID.x series with V2X (ITS-G5).

3.3 V2X Standards

There are unfortunately many standards for V2X in the world, Figure 2. Vehicle manufacturers intending to sell products globally will need to comply with all these standards unless a unification takes place. This work has focused on EU and 802.11p.

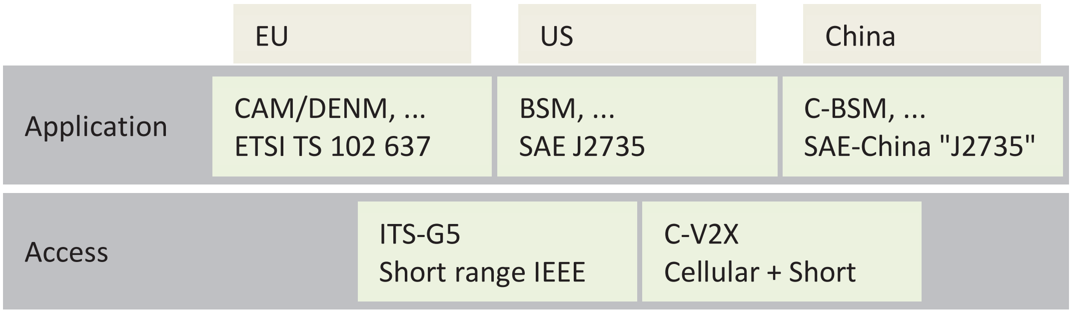


Figure 2. V2X standards over the world, and their related access networks.

3.4 Common V2X Messages (EU)

In EU there are various V2X messages in use. The most frequent ones are Cooperative Awareness Messages, CAMs. They contain information on kinematic data and dimensions of the vehicle and are sent periodically. The send frequency is determined by the change of the vehicle's own status (change of position or speed) and the radio channel load in the access layer, Decentralized Congestion Control (DCC).
Also in common use are Decentralized Environmental Notification Messages, DENMs. DENMs send information (often cause and position) related to a road hazard or an abnormal traffic condition and are triggered when needed. Examples of scenarios and their related messages are shown in
Table 1.

Table 1. Examples of scenarios and their related V2X messages.

Scenario	V2X Message
Static or variable road signs or road works	IVIM
Collision Risk Warning	CAM: Basic + HF
Emergency electronic brake light systems	CAM: Basic + HF + LF
Emergency Vehicle	CAM: Basic + HF + Special
Weather Warning	DENM
Road Work	DENM
Intersection Collision	CAM: Basic +HF +LF
Blind Spot Warning, Lane Change Warning	CAM: Basic +HF +LF
Green light optimal speed advisory	SPaT + Map
Cooperative perception	CPM

IVIM, Infrastructure to Vehicle Information Message
CAM, Cooperative Awareness Message
DENM, Decentralized Environmental Notification Message
CPM, Collective Perception Message
SPaT: Signal Phase and Timing
MAP: Map Data (intersection geometry)
Basic, HF (high frequency), LF (low frequency), Special, different types of data/containers

3.5 V2X Security (EU)

The V2X messages can be received and read/parsed by anyone. The message's integrity and transmitter's authenticity are ensured by digitally signing of every message using a private key. The receivers use the transmitter's public key contained in the certificate to verify the digital signature attached to the message. This means that if someone wants to send an illicit message, e.g., pretending to be an ambulance to get priority at a red light, the message will be rejected if the sender is not trusted.

Certificates are used to prevent unauthorized parties from interfering with the exchange of data. There are Enrolment Certificates (EC) which are long-term certificates for identification and accountability of ITS stations (ITS–S), and pseudonym certificates (Authorization Tickets, AT) which are short-lived, anonymized certificates for V2V/V2I communications. An AT protects vehicle and user identities and are used to authenticate messages such as CAM or DENM. ATs are frequently changed. The station-id is also changed at certain distance or time intervals).
A hierarchical structure of Public Key Infrastructure (PKI) manages the security credentials of the ITS Stations. In Europe, the PKIs can be operated by various

stakeholders, such as governments (EU/National), IT service providers, vehicle manufacturers, telecommunication providers, etc. An overview of the certificate handling in EU is given in Figure 3.

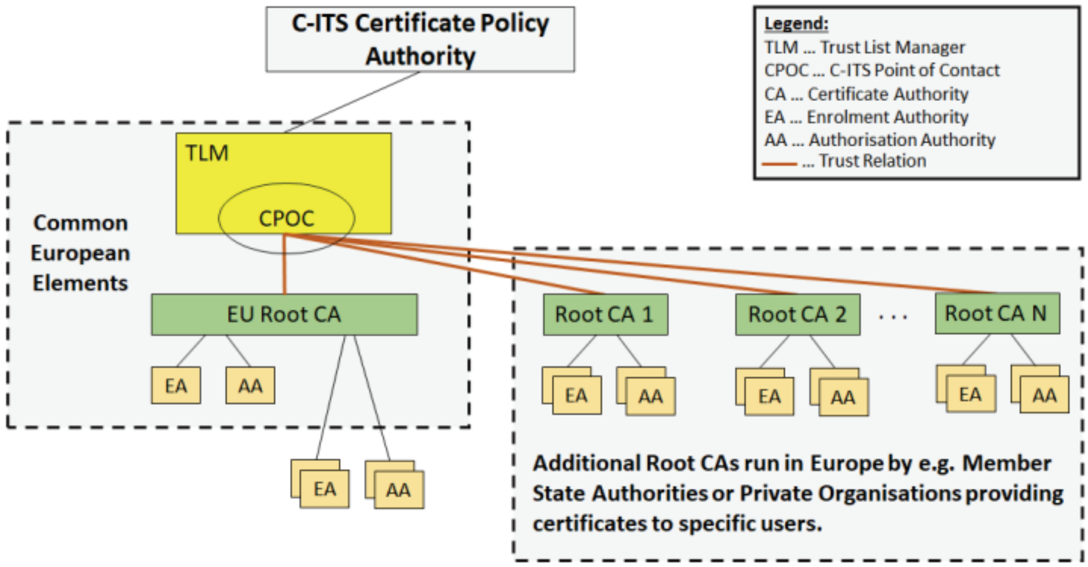


Figure 3. C-ITS certificate handling in EU. Image from [2].

Some of the most important features that are handled in the PKI are

- Access control to C-ITS
- Authentication and integrity of V2X messages
- Revocation of entities
- Privacy – not allowing any tracking of users

The European Certificate Trust List (ECTL) has different levels for different purposes. ECTL L0 is offered for interoperability testing and has an easy registration process. ECTL L1 handles stable pilot operation, longer validities of certificates and has an intermediate registration process. No audits are needed but requirements and processes must be close to full compliance. At ECTL L2, systems operate according to the certificate policy with no exceptions, there is a strict registration process and full audits are required.
As of mid-March 2023, the status in EU is that the European central PKI, Atos, operates on L0. AstaZero is authorized to use Atos C-ITS PKI L0 service. ECTL L1 will be audited after the summer 2023 and the certification, and this is expected to be ready in Q4 2023. Atos is ready to operate on L1. Regarding ECTL L2, the V2X ecosystem waits for validation of stations' protection profiles. Atos is ready to operate on L2 too.

However, there are some caveats, limitations when testing with VW cars in production. VW's trust list is not directly coupled to ECTL and EU-PKIs. VW's trust list is managed by VW and their rules for enrolment exclude (Level 0) test systems. This means that when

AstaZero gets to ECTL L1 or L2, VW might consider enrolment of the AstaZero units, but the requirements for L1/L2 basically exclude test systems. In the long term, all parties should be included in the ECTL L1/L2 for the system to become functional. Governing documents are found in references [3] and [4].

4. Purpose, Research Questions and Method

The first two work packages in this project aimed to ensure that infrastructure elements are connected to the test control system, and to establish routines and methods to influence connection and performance of said devices.
The last two packages were focused on demonstrating that the right routines and skills have been obtained in various scenarios.

4.1 WP 1 V2X Installation

This work package has procured and installed roadside units (RSUs) and onboard units (OBUs). The supplier was chosen after scrutiny of the suppliers and products available at the time of purchase (spring 2021), in accordance with the Swedish rules of public procurement. The selection criteria included the possibility to use the hardware for both 802.11p and cellular connections and, above all, product availability during the pandemic.

The roadside units can be placed at any desired location, mounted on movable poles with concrete base. The onboard units have been mounted in AstaZero R&D vehicles and used in testing.

Digital road signs that can display dynamic content and provide information such as speed limits and the direction of travel and be used to regulate traffic between different test tracks and other specific sections have been installed. The ability to display the direction of travel is especially useful as it allows AstaZero to perform test with both right and left-handed traffic.

4.2 WP 2 Method Description for Connected Infrastructure

The control system which comes with the roadside units and onboard units is relatively easy to use. It has been complemented with a graphical user interface (GUI) which was developed for controlling selected features of the cellular networks and the V2X RSUs at AstaZero’s test track.

4.3 WP 3 VRU Warning

This work package involved informing vehicles about vulnerable road users, VRUs, by having the VRUs connected with, for example, a safety vest used in road construction. At the test track, this application also creates an opportunity for the test management to ensure that no people are in close proximity to ongoing testing activities, which can be very dangerous.

Work on the connection of the high-visibility vest was slightly modified from the project description. Since the V2X equipment available today is not portable due to its size, weight, and battery requirements, two other solutions were explored. The first is to procure and test simpler Wi-Fi modules that are portable, and the second to develop an app for mobile phones (iOS and Android). The idea is that people who are present at AstaZero's test track should be able to use the app on their own phone, or a phone lent to them by AstaZero during their stay, to allow the app to communicate the person's position to test control and traffic management, and to receive alerts for potentially dangerous situations. This communication can be both cellular and Wi-Fi based. The app development work was done in collaboration with senior researchers at Halmstad University and the requirements were set in consultation with customers and employees of AstaZero.

4.4 WP 4 Infrastructure Status

This work package demonstrated the reporting of maintenance needs or traffic hazards, with the help of connectivity and information exchange. It was widened to include tests with vehicles reporting on other vehicles hindering the traffic or posing risks to traffic safety.

The OBUs procured in WP1 mounted in AstaZero R&D vehicles, along with Volkswagen vehicles equipped with V2X transceivers were used in these tests, which were conducted both at the AstaZero test track, in the city of Gothenburg, and on highway stretches in central Sweden.

5. Objective

The project objective was to explore and implement relevant WLAN-based V2X hardware and functions at AstaZero’s test track. During the course of the project, the interest in WLAN as a connectivity technology further decreased in Sweden, in favour of cellular based technology.

Hence, the project objective was shifted slightly, after approval from Vinnova. The amount of testing using 802.11p was reduced, and focus was instead directed to using the test control system for steering the networks, both 802.11p and cellular. This will enable interesting test cases for future connectivity tests, both for research and client tests.

However, it is very important that there is a national test site able to assist industry and researchers with testing of both types of connectivity technology, and therefore AstaZero may consider expanding its offerings on both cellular and WLAN-based V2X in the future.

6. Results and Deliverables

6.1 WP 1 Requirements and Procurement

In its initial phase, the work focused on mapping the stakeholders' needs and requirements. This in combination with a survey of relevant equipment available on the market, its expected performance and suitability for the upcoming testing at AstaZero served as preparation for procurement of road-side and on-board units, RSU and OBU.

Requirements were set in consultation with the AstaZero research group in Gothenburg and the test engineers and management at the test track. Four potential suppliers were selected and offered the opportunity to present themselves and their products in online meetings with the project team. Of these, three companies responded, and one was not heard from. The three held separate presentations with Q&A sessions and where then sent a formal request for a quotation. All three have been treated equally and under public procurement rules. Procurement of equipment according to LOU, the Swedish Public Procurement Act, was completed and the equipment delivered.
Unfortunately, the equipment was significantly more expensive than what was estimated in the project application, which led to that only equipment from one supplier could be procured. It is therefore impossible to compare different equipment brands as originally hoped.

6.2 WP 2 GUI for Control of Network Functions

The GUI was built using Node-RED, a programming tool for wiring together hardware devices, APIs and online services, and can be run on a server or locally. It is mostly used to control Ericsson base stations, and it has a button to enable and disable the RSU Wi-Fi signal. The button sends an MQTT message which the RSU is subscribed to, which runs a C program that enables/disables Wi-Fi on the device, Figure 4

This will be a very useful feature in upcoming test scenarios where the dependence on connectivity plays a role. A similar approach could be used to control other aspects of the RSU in the future.

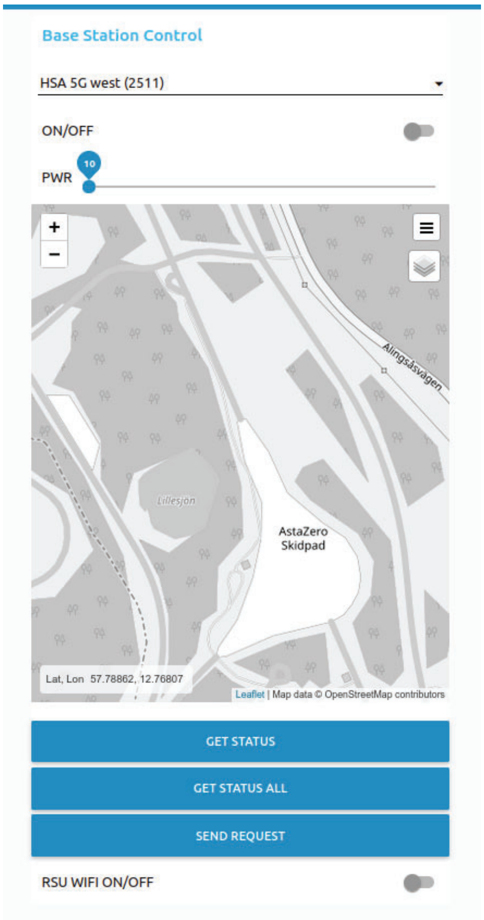


Figure 4. An image of the web-based GUI controlling network features.

6.3 WP 3 Practical VRU Warning

Figure 5. V2X VRU app screenshot.

A proof of concept (PoC) for a hybrid system (LTE and DSRC) for VRU protection was presented in collaboration with Oscar Molina at Halmstad University. An app was developed with the purpose of warning drivers of VRUs. It has a very simple interface with one button to start/stop broadcasting the phone's position, Figure 5.

A practical demonstration of the system was carried out using one of AstaZero's R&D vehicles equipped with an OBU. An RSU was connected to the MQTT server to relay the messages.

A person with the Halmstad app activated on a regular Android cellular phone was positioned behind vehicles in a way that he was not visible to the driver of the car approaching, Figure 6 top left. As the person started walking, Figure 6 top right, the screen in the car was displaying his approach, Figure 6 bottom left, and finally the person became visible to the driver, Figure 6 bottom right. A short film of this demonstration can be found on YouTube [5]. The PoC system was also tested in an urban scenario.

In this PoC, the RSU was configured to communicate with the messages defined in the Society of Automotive Engineers (SAE) J2735 202007 standard, specifically the Personal Safety Message (PSM). In EU, this type of warning could be sent as DENM via RSUs as the standardised message "V2X_E_CAUSE_CODE_HUMAN_PRESENCE". This DENM is then received by OBUs in cars, visualized as warnings and or icons on the screens in the cars. Although the RSU sends these types of messages, possibly signed, the messages will not necessarily be processed by cars or other vehicles , due to vendor specific trust chains/list as described earlier.

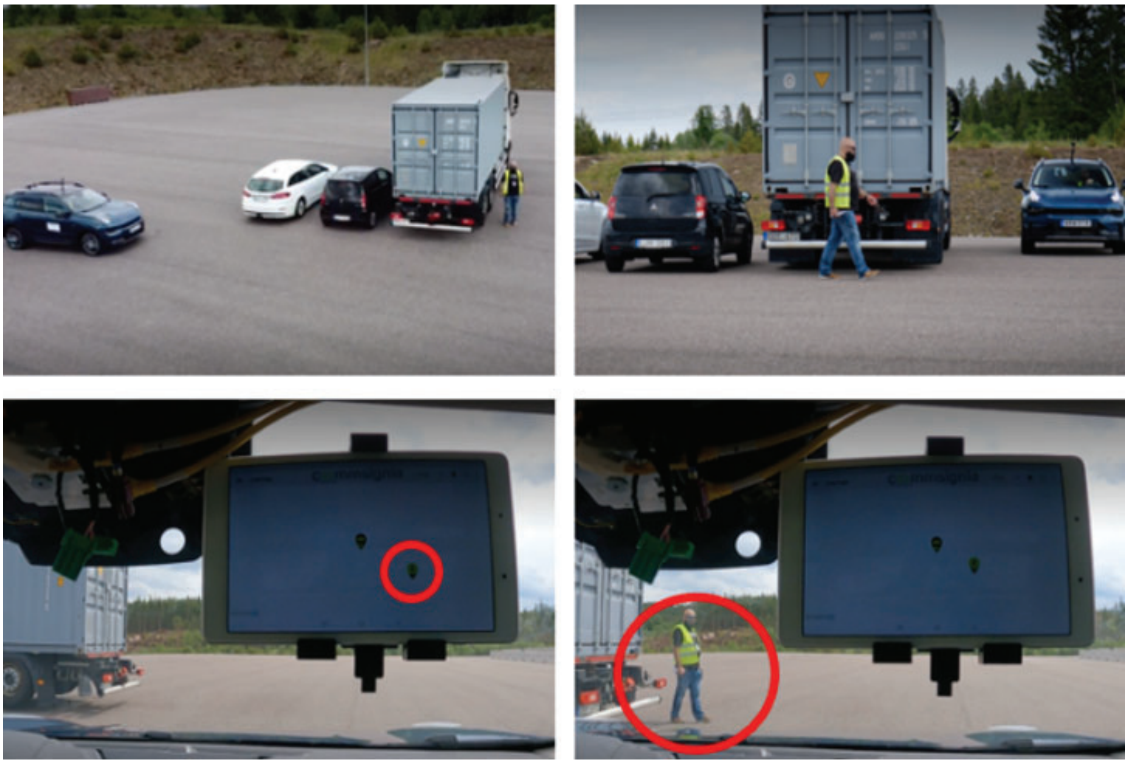


Figure 6. The VRU app test setup.

A scientific paper “Protection of Vulnerable Road Users using Hybrid Vehicular Networks” describing this app and test was presented at IEEE International Conference on Vehicular Electronics and Safety (ICVES), Bogotá, Colombia, November 2022 [6]. The paper also includes a discussion of the future stages for the system considering design principles and the availability of access technologies.

6.4 WP 4 Live Tests using 802.11p in Vehicles

Tests have been carried out both at the AstaZero test track and in the city of Gothenburg using VW cars which have active 802.11p connections. Some examples are listed below. One very important conclusion is that AstaZero cannot send trusted messages to production vehicles, since the devices transmitting are not on the EU PKI list, Public Key Infrastructure. How to solve this is currently being investigated. AstaZero is currently authorized to use AtoS C-ITS PKI Level 0 service, see section 3.5 above for details.

Tests were conducted using V2X in Volkswagen (VW) iD3 and iD4. 12 test cases were obtained from VW, of which three were selected for testing at AstaZero and two are described below. DENMs were triggered for Stationary Vehicle Warning, Dangerous Situation, and Traffic Jam.

Test Case 1 Stationary Vehicle – Local Hazard Warning

This test case involves a vehicle that has stopped for some reason. It could be for example a broken-down vehicle, post-crash. The range of the 802.11p signals (5.9 GHz) were approximately 300-400 meters, line of sight. The VW cars used the V2X communication themselves to give the driver early warnings in the following use cases:

- When the car approaches another car on the shoulder with hazard lights on
- The approaching car must have a speed of 80 km/h or more
- The approaching car and the car on the shoulder must be headed in the same direction

Test case 1 is illustrated in Figure 7.

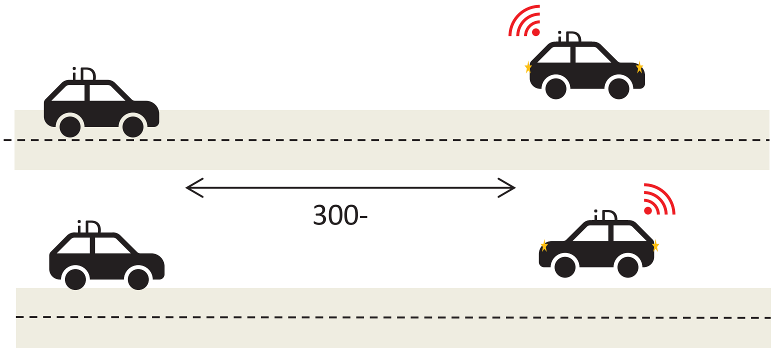


Figure 7. Test case 1, stationary vehicle - local hazard warning.

Test Case 2 Dangerous Situation

This test is based on the electronic emergency brake light and automatic brake intervention, etc. An example of when this can happen is in a traffic jam, a so-called dangerous end of queue. The traffic jam warning is sent when a car ahead makes an emergency brake, with a deceleration over 3.5 m/s^2. This test case is illustrated in Figure 8.

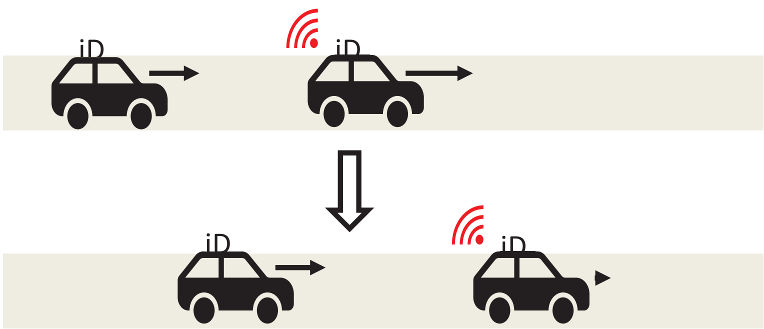


Figure 8. Test case 2, traffic jam.

6.5 WP4 V2X radio/signal reconnaissance

While driving from Eskilstuna to Gothenburg, Figure 9, all received messages were logged with the OBU in the vehicle,
Table 2. Only CAM messages were received. At this point in time, only VW ID.x cars transmit V2X messages, to our knowledge. All V2X messages can be received and read/parsed. However, each message is signed, which means that its authenticity can be established (See section 3.5 for details.). The two AstaZero R&D vehicles have OBUs installed.

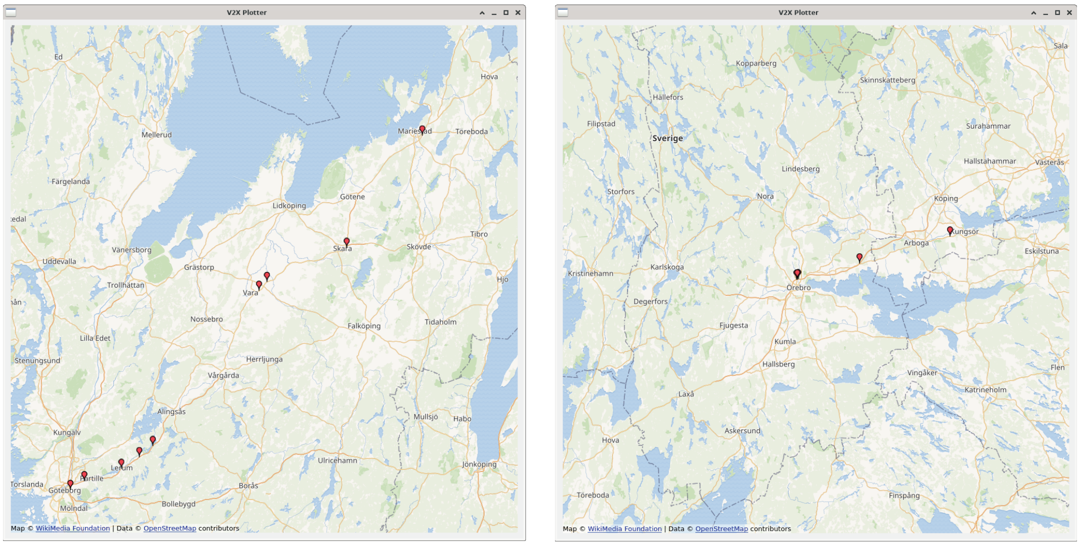


Figure 9. Map showing the locations where V2X signals were received, more prevalent near cities.

Table 2. Example of logged data from OBU.

Message	Station ID	Lat	Lon	Alt	Speed	Curve	Heading	Yaw	Time
CAM	2131168855	594099732	160100384	3250	2984	30001	909	-20	2022-09-21-15-15-02-275
CAM	2131168855	594099712	160102488	3250	2985	30001	910	-25	2022-09-21-15-15-02-582
CAM	2131168855	594099706	160103011	3250	2981	30001	910	-41	2022-09-21-15-15-02-603
CAM	2131168855	594099690	160104589	3250	2984	30001	910	-24	2022-09-21-15-15-03-007
CAM	2131168855	594099677	160105641	3250	2980	30001	912	-45	2022-09-21-15-15-03-100
CAM	2131168855	594099671	160106167	3250	2988	30001	912	-2	2022-09-21-15-15-03-402
CAM	2131168855	594099659	160107213	3250	2988	30001	913	-2	2022-09-21-15-15-03-402
CAM	2131168855	594099652	160107743	3250	2986	30001	913	-41	2022-09-21-15-15-03-499
CAM	2131168855	594099652	160107743	3250	2984	30001	913	-9	2022-09-21-15-15-03-602
CAM	2131168855	594099640	160108791	3250	2990	30001	913	4	2022-09-21-15-15-03-700
CAM	2131168855	594099634	160109313	3250	2990	30001	912	4	2022-09-21-15-15-03-914
CAM	2131168855	594099634	160109313	3250	2990	30001	912	4	2022-09-21-15-15-03-914
CAM	1927768617	593344713	155318128	5550	3128	18	462	43	2022-09-21-15-35-35-375
CAM	1927768617	593345807	155320349	5550	3129	12	460	44	2022-09-21-15-35-35-893
CAM	1927768617	593346081	155320899	5550	3127	12	459	38	2022-09-21-15-35-35-959
CAM	1927768617	593346288	155321317	5550	3127	12	459	38	2022-09-21-15-35-36-091
CAM	1927768617	593346470	155321686	5550	3125	12	459	37	2022-09-21-15-35-36-166

7. Dissemination and Publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	
Be passed on to other advanced technological development projects	X	
Be passed on to product development projects		
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions	X	May be used in, e.g., Euro NCAP testing when protocols so demand

7.2 Publications

The collaboration with Halmstad University has led to a scientific paper “Protection of Vulnerable Road Users using Hybrid Vehicular Networks” [6] which was presented at the 2022 IEEE International Conference on Vehicular Electronics and Safety (ICVES) by HU’s Oscar Amador Molina. This work was also documented and shared in a YouTube video [5].
The project was also an essential contributor to the large demonstration at AstaZero in March 2023, where many FFI co-funded projects combined its findings. A summary film is available on YouTube [7].

8. Conclusions and Future Research

The two technologies for V2X based on WLAN and cellular networks respectively will coexist for many years to come. Some nations have built up road infrastructure with ITS G5 roadside units, for example Austria and parts of Germany, but most have not. It is in general seen as poor economy to invest in ITS G5 where there is a good existing or planned coverage of 5G. There is also not a clear business case for the tentative subscription services which will be related to the data usage and data transfer.

In conclusion, the project has completed demonstrations of information exchange with short-range communication technology and cellular technology. The RSUs and OBUs chosen support IEEE802.11p and PC5, but not simultaneously. Changing between the radios requires firmware re-flashing. The RSUs have cellular modems, whereas the OBUs do not.

The VW group vehicles supports only IEEE 802.11p. The AstaZero RSU/OBU supplier is not aware of any car manufacturers with C-V2X/PC5 OBUs. Furthermore, operation of 802.11p and C-V2X/PC5 (in the 5.9 GHz band), in the same geographic area without an agreed coexistence solution, results in harmful co-channel interference.

Due to the lack of suitable hardware, the VRU warning vest became an app on cellular phones, and this may be a permanent feature in the future for protecting humans at AstaZero's test track.

9. Participating Parties and Contact Persons

This project had only AstaZero as partner. Project manager initially was Erik Frick and as of April 2021, Dr Katarina Boustedt, katarina.boustedt@astazero.com, has served as project manager.

10. List of Abbreviations

ITS-G5	Intelligent Transport System Generation 5, defined in ETSI EN 302 663 [8]
IEEE	Institute of Electrical and Electronics Engineers
5G	Fifth Generation cellular networks
3GPP	3rd Generation Partnering Project
ITS	Intelligent Transport System
ITS-S	Intelligent Transport System Station
DSRC	Dedicated Short-Range Communication, defined in a series of IEEE and SAE standards [9]
V2X	Vehicle to everything/anything
C-V2X	Cellular V2X
V2V	Vehicle to vehicle
V2P	Vehicle to pedestrian
V2D	Vehicle to device
V2G, V2L	Vehicle to grid, Vehicle to load
V2B, V2H	Vehicle to building, Vehicle to home
V2N	Vehicle to network
V2I	Vehicle to infrastructure
V2C	Vehicle to
DoIP	Diagnostics over Internet Protocol
OTA	Over the air
LTE	Long-term evolution, a standard for wireless broadband communication

ETSI	European Telecommunications Standards Institute
CAM	Cooperative Awareness Message
DENM	Decentralized Environmental Notification Message
IVIM	Infrastructure to Vehicle Information Message
CPM	Collective Perception Message
SPaT	Signal Phase and Timing
MAP	Map Data
HF	High Frequency
LF	Low Frequency
OBU	Onboard Unit
RSU	Roadside Unit
VRU	Vulnerable Road User
LOU	Lagen om offentlig upphandling, Swedish law of public procurement
PC5	Device-to-device communication, without the need for a base station, in C-V2X
PKI	Public Key Infrastructure
C-ITS	Cooperative Intelligent Transport System
MQTT	MQ Telemetry Transport, a machine-to-machine network protocol
GUI	Graphical User Interface
ECTL	European Certificate Trust List

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