SHared automation Operating models for Worldwide adoption

SHOW

Grant Agreement Number: 875530

D8.2: Solutions for on-site digital and communication infrastructure

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Executive Summary

This document describes the Digital and Communications Infrastructure used at the test sites of the SHOW project. This description consists of three parts:

- The introductory parts provide:
    - A high-level overview of DCI deployed at sites is introduced very briefly by means of referring to a description in the Annex "Super Spreadsheet". Descriptions of both Mega sites (bigger) and Satellite sites (smaller) are provided. Based on the analysis of this description, high level recommendations to sites are then given.
    - A definition of DCI is then provided in more detail; this definition comprises a set of components; the definition is compared to other definitions of infrastructure from external sources, including attribute definitions for ODD.
    - To characterize the DCI a new scale of values is proposed combining existing scales related to automated driving (ISAD levels, SAE Levels, SAE Cooperation Classes and Platooning scale).
- Detailed descriptions of deployed DCIs at test sites in SHOW are then provided.
- Finally, a site-independent part describes in theory more details about:
    - Sensors for traffic management
    - Traffic lights control for cooperative intersection
    - Analysis and recommendations for Internet use and GNSS RTK with V2X communications.

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Version	Date	Reason	Editor
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Version	Date	Reason	Editor
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Abbreviation List

Abbreviation	Definition
2G, 3G, 4G, 5G, 6G, 7G	Second generation of global systems for mobile communications, third generation and so on.
2G..5G, 2G to 5G	All generations from the second to the fifth.
5G/6G/7G	Some of the generations from the 5^{th} to the 7^{th}
5GAA	5G Automotive Association
AD	Automated Driving
AI	Artificial Intelligence
API	Application Programmer's Interface
AV	Automated Vehicle
C-ITS	Cooperative ITS
C-V2X	Cellular Vehicle to everything
CAM	Cooperative Awareness Message
CAV	Connected Automated Vehicle
CCAM	Cooperative, Connected, Automated and Autonomous Mobility
CEDR	Conference of European Directors of Roads
CIRCABC	Communication and Information Resource Centre for Administrations, Businesses and Citizens
CP	Collective Perception
Day1, Day1.5	Terms used by the Car to Car Communications Consortium to designate specific sets of services that are to be deployed in a first day immediate deployment (Day 1), or later.
DCI	Digital and Communications Infrastructure
DDNS	Dynamic Domain Name System
DDT	Dynamic Driving Task
DENM	Decentralised Event Notification Message
DI	Digital Infrastructure
DRT	Demand Responsive Transport
DVR	Digital Video Recorder
ECA	European Coverage Area
EDC	European Driving Cycle
ESCoS	EcoSystem Cooperative System
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
GHz	Giga Hertz
GNSS	Global Navigation Satellite-based System
GPC	GNSS Positioning Correction
GPS	Global Positioning System
HA	High Accuracy, High Availability
HAD	Highly-Automated Driving
HDMAP	High-Definition Map
HTTPS	Hyper Text Transfer Protocol Security
I2C	Undefined, but used in the CCAM SP WG3 Digital Infrastructure attributes table.
I2V	Infrastructure to Vehicle
IP	Internet Protocol
IPv6	IP version 6
ITS	Intelligent Transportation Systems

Abbreviation	Definition
ITS-G5	Intelligent Transportation Systems (ITS) working in the 5.9 Gigahertz band (G5)
IVIM	In-Vehicle Information Message
iVMS 4200	Intelligent Video Management System 4200
KPI	Key Performance Index
LTE-V2X	Long Term Evolution – Vehicle to everything
M2M	Machine to Machine
MAC	Medium Access Control
MAP	MapData Messages
MAPEM	MAP (topology) Extended Message
MHz	Mega Hertz
mmWave	Millimetre wave
MQTT	Message Queuing Telemetry Transport
NTRIP	Networked Transport of RTCM via Internet Protocol
OBU	On Board Unit
OCB	Outside the Context of a BSS identifier
ODD	Operational Design Domain
OS	Operating System
PDI	Physical and Digital Infrastructure
PHY	Physical layer
PI	Physical Infrastructure
PoI	Point of Interest
PPP	Precise Point Positioning
QoS	Quality of Service
RCC	Remote Control Center
RFC	Request for Comments
RFID	Radio Frequency Identification
RLT	Road and Lane Topology
RSU	Roadside Unit
RTC	Real-Time Clock
RTCEM	RTCM Extended Message
RTCM	Radio Technical Commission for Maritime Service, or Real-Time Correction Message
RTK	Real-time Kinematics
RTP	Real-time Transport Protocol
RTT	Round Trip Time
RTTI	Round Trip Time information(?) shown in Figure 1.
SAE	Society of Automotive Engineers, SAE International
SAPOS	Satellite-Positioning Service
SNMP	Simple Network Management Protocol
SP	Single Platform (used in CCAM SP)
SPAT	Signal Phase And Timing
SPATEM	SPAT Extended Message
SRM	Signal Request Message
SREM	SRM Extended Message
SSM	Signal State Message
SSEM	Signal request Status Extended Message
TBV	To be Validated
TL	Traffic Lights
TLC	Traffic Lights Controller
TLM	Traffic Light Manoeuvre
TMC	Traffic Management Center

Abbreviation	Definition
UC1.2	Use Case number 1.2
UDP	User Datagram Protocol
UHF	Ultra High Frequency
V2I	Vehicle to Infrastructure, Vehicle to Internet
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to everything (X stands for V or to I or to VRU or to P)
VMS	Variable-length Message Signs
VRU	Vulnerable Road User
WAN	Wide Area Network
WG	Working Group
WiFi	Wireless Fidelity
WiFi 6	WiFi in a spectrum band near the frequency of 6 GHz
WiFi 6E	WiFi 6 Extended
WiFi 7	WiFi Extremely High Throughput, 802.11be EHT

1 Introduction and Recommendations to Sites

This document presents the Digital and Communication Infrastructure (DCI) solutions used at the test sites of the SHOW project. It also provides recommendations for their consideration.

The document defines the DCI and proposes a scale of levels. It describes in detail the DCI at sites and finally a site-independent part describes more details about sensors for traffic management, traffic lights control for cooperative intersection, analysis and recommendations for Internet use and GNSS RTK with V2X communications.

A summary of the main characteristics of the deployed DCI at approximately 20 sites in SHOW has been collected in a “super spreadsheet”. This sheet is presented in the annex of this document.

Chapter 2 provides the definition of DCI. This comprises a set of components; the definition is compared to other definitions of infrastructure from external sources, including attribute definitions for ODD. To characterize the DCI, a new scale of values is proposed combining existing scales related to automated driving (ISAD levels, SAE Levels, SAE Cooperation Classes and Platooning scale). Following this, Chapter 3 describes the key 2 DCI components.

In Chapter 4, the DCI solutions at SHOW test sites are described. A high-level overview of DCI deployed at sites is also introduced briefly by means of the Annex “Super Spreadsheet”. Based on the analysis of this description, high level recommendations to sites have been concluded (in Chapter 5).

Finally, a site-independent part follows, providing in theory more details about:

- sensors for traffic management (Chapter 6)
- traffic lights control for cooperative intersection (Chapter 8)
- analysis and recommendations for Internet use and GNSS RTK with V2X communications (Chapter 7 and Chapter 9 respectively).

1.1 Intended Audience

The Deliverable is public, referring to all site administrators, public and private transport operators, researchers and developers that work in CCAM area and wish to deploy CCAM solutions in the Public Transport domain.

1.2 Interrelations

The key interrelations are with the SHOW test sites goals and experimental plans, as being worked out in WP9, as well as to the WP4 Architecture and WP5 data backend systems of the project. More specific interrelations are by nature existing with the other tasks of WP8, on physical infrastructure (A8.1) and Traffic Management (A8.3).

The following documents are related to D8.2:

- D4.2 “Architecture”,
- D5.1 “Platform”,
- D8.1 “Physical Infrastructure”,
- A8.3 “Traffic Management”.

1.3 High-level recommendations

In a generic manner, a high-level recommendation is that each site works towards progressing the ISAD Level. Where a site is on level D, if appropriate, it should be progressed to ISAD Level A.

Further, the features mentioned in the superspreadsheet (see annex 'Super Spreadsheet') should be used as starting points by sites. Sites should be deploying the features which are not checked on the respective row in the super spreadsheet, when appropriate. In the particular case of 3G..5G and V2X DCI components, the recommendations are the following:

- Aachen should deploy 3G..5G; Carabanchel, Carinthia, Brussels, Salzburg, Graz and JRC Ispra should all deploy 5G.
- The sites Brno, Rouen city centre, Lindholmen, Linköping, Belle Idée and Brussels should deploy V2X messages on ITS-G5.

The desires of sites, as expressed in the columns 'Gaps', 'Challenges' and 'Needs' of the "super spreadsheet", should be taken into consideration by all partners in project. The partners should work towards the realization of these needs.

Additional high-level recommendations to sites are the following:

- Sites that have already deployed DCI for trials, experimentation or dedicated professional use of automated shuttles should consider adapting the DCI for use by the public at large. For example:
    - Where DCI sends DENM messages for road operator professional during intervention, that same DENM message should also be sent to users at large, on their smartphones or in their vehicles capable of understanding them.
    - Where automated shuttles transmit video from inside to a specialized control center (see Trikala) the same capability should be offered to normal passengers with WiFi onboard, to be able to stream the video to Internet. Deployments of DCI should move, generally, from trial to production to being productive.
    - Where smartphone applications (apps and data are part of DCI) are developed for demonstration purposes (see Trikala) of mobility services such as reservation of itinerary or VRU warnings, the applications should be deployed at-large by making them available in respective smartphone stores (Google, Apple and others like Samsung).

      Where applications for new automated mobility services are demonstrated only on smartphones they should be developed and deployed for access from normal desktop PCs as well.
- The ongoing radio spectrum allocations strategies at regulators guide the possibilities of deploying various wireless communications technologies. The current strategy of a site must be to look closely at the ongoing developments of allocation strategies: if the allocation balance towards cellular technologies then new investments should be considered to that direction, and old trials ramped down towards an abandonment. If on the other hand the existing allocations at 5.9GHz are maintained as currently, then the strategic deployment plans of DCI should consider more evolutionary paths of evolving current RSU deployments.
- Sites should develop, to the extent of the possible, digital representations of their deployments: Digital Twins for DCI. The digital twins help in quicker and

better understanding and advancement of the DCI towards more innovative use-cases needed by users.

- Sites should make more use of Internet-related technologies. Road-Side Units connected to the Internet, traffic lights connected to the Internet, as well as other IoT paradigms, should be further integrated in DCI. DCI at sites should permit and help AVs to connect to the Internet in extensive ways: offer highest possible bandwidths to AVs, and most reliable communication technologies for AVs.

  Sites that have deployed DCI for use of Internet in the vehicles, or whose vehicles use the DCI that is deployed by other means (e.g. the DCI deployed for the public at large, not necessarily for vehicles: 3G..5G networks) should consider that vehicles will offer WiFi hotspot access inside, for passengers of these vehicles. To accommodate that, the DCI at sites should consider necessary adaptation to the DCI such that WiFi hotspots inside vehicles are possible. Currently no automated shuttle in SHOW offers WiFi hotspots inside the vehicles but in the future that will change.

- Sites should use mechanisms of direct communications between the Traffic Lights controllers and the vehicles and VRUs. The use of direction communications with IP is advantageous in terms of bandwidth utilization, latency, and more. The risk of single point of failure constituted by the intermediary cloud platform will be avoided.

  At a higher level, the market of traffic lights controller should be uniformised. Manufacturers from different countries should be allowed and encouraged to sell equipment in any *other* country. A uniformisation effort is necessary and that passes by creating interoperable communication systems.

- Sites should make more use of Galileo-first localisation technology, in complement to GPS. Currently most sites rely extensively on GPS and some have fallback on Galileo, whereas the situation should be the other way around: Galileo-first and fallback on GPS when necessary. Galileo correction technologies should be communicated over the Internet.
- Sites should deploy more DCI features in support to direct V2V communications, but should avoid becoming a mandatory requirement for V2V to work: the direct V2V communications should continue working without DCI if necessary.
- Sites should extend the wireless radio coverage to cover 100% of all places where automated shuttles are present, whenever possible. When radio coverage is not possible, new V2V mechanisms should be in place to reach to these areas.
- Sites should deploy DCI for automated shuttles according to relevant Ethics considerations, and within relevant considerations of Ecology.

In more detail, the rest of the document defines the DCI, proposes a scale of levels, describes in detail the DCI at sites and finally a site-independent part describes more details about sensors for traffic management, traffic lights control for cooperative intersection, analysis and recommendations for Internet use and GNSS RTK with V2X communications.

1.4 Methodology

This methodology is proposed for the development of this document. This aims at successfully executing the plan described initially in the activity A8.2 “On-site digital and communication infrastructure” in the Description of Work document (DoW).

First, a preliminary description of the on-site digital and communication infrastructure is given. The criteria used for ensuring quality are then described. Subsequently, a set of iterative steps are described as being constantly executed during the lifetime of A8.2. Finally, a workplan with proposed dates is given.

The **on-site digital and communication infrastructure** is defined – in a preliminary manner – by a few high-level characteristics:

- The digital and communication infrastructure at a pilot site is used to connect the Connected and Automated Vehicles (CAVs). This infrastructure will provide an additional layer of support for automated driving and connectedness for CAVs; this layer is in addition to the layer of data produced on-board of vehicles; the two layers are complementary: the infrastructure helps enhancing the data produced on-board and, at the same time, the on-board system ensures continuous operation even in cases where the wireless coverage offered by the infrastructure might be blind-spotted.
- The digital and communication infrastructure will be deployed mainly at a site (on-site), and typically very near the route. When considering a conceptual hierarchy *cloud-fog-mist*, the on-site digital infrastructure is situated in the mist: very near the road and vehicles (e.g. Roadside Units), whereas the cloud servers are situated in a Traffic Management Centre. The TMC is less in-focus for A8.2.
- The digital and communication infrastructure is constituted, among others, by digital equipment such as computers, networking equipment, antennae for wireless communications and, in some cases, electricity supply such as power lines, solar panels and batteries.
- The digital and communication infrastructure is a companion to the physical infrastructure. For example, a Roadside Unit, which is plainly a component of a digital and communication infrastructure, absolutely needs a physical support such as a pole; this pole is a component of the physical infrastructure. This component is situated at a vantage point whose physical coordinates are calculated precisely in function of road shape and other purely physical characteristics. The physical infrastructure is less in-focus for A8.2.

Criteria: the methodology applied will be subject to criteria of quality of the execution. These criteria will be:

- Quality of deliverables; the deliverables will be written with a high level of technical soundness; the different parts of the text will be as much as possible inter-related by transparent interfaces. The text will be reviewed by persons that are not the authors and their feedback will lead to improving the quality. The deliverables will be submitted on time.
- Close relationship to deployments at pilot sites: this criteria will be periodically checked to ensure there is not too much distance between the textual description and the deployed matters.
- Close relationship to other Activities in the WP8 and in other WPs. This will be ensured by participation of WP leader organisation in other groups.
- Synchronisation between partners; This will be achieved by regular tele-conferences (at least once a month) and other virtual meetings; when possible, face-to-face meetings will be used to present advancements of each partner and to facilitate interaction.

In the initial phases of the execution of the Activity, the following steps will be performed **iteratively**:

- Review the definition of the use-cases in the project.

- Perform continuous analysis of the State-of-the-Art (SoTA); this includes active research in the scientific literature and intellectual property databases, following of industry announcements, of new items proposed in standards development organisations, of EU project events and generally the events reported in the press that are relevant to the project topic.
- Review the features exhibited at pilot sites, and that are relevant to the on-site digital and communication infrastructure technical topics (*super* spread-sheet).

Workplan: the timeline of execution of A8.2 has followed closely the dates defined in the DoW. The A8.2 starts March 2020 and ends December 2021. The following steps have been performed:

1. Collect descriptions of existing digital infrastructure at Pilot Sites - March 2020 to September 2020.
2. Work on design and installation of sensors for Traffic Monitoring - Sept. 2020 to March 2021.
3. Work on analysis and recommendations on Internet connectivity - Sept. 2020 to March 2021.
4. Work on traffic lights control and cooperative intersection - Sept. 2020 to March 2021.
5. Work on roadside-based GNSS corrections - March 2021 to May 2021.
6. Edit deliverable D8.2 - March 2021 to September 2021.

2 Definition of Digital and Communication Infrastructure

The Digital and Communications Infrastructure (DCI) is a set of components consisting of the data-oriented physical entities (RSUs and base stations, sensors, cameras, antennas, other), the stored data, and the messages, that are all used for realizing Connected and Cooperative Automated Mobility (CCAM) for shuttles, logistics delivery vehicles (cargos) and robo-taxis. The DCI also contains the operational road infrastructure; the concept of operational road infrastructure is described in the section titled “Definition of DI from CCAM SP WG3”.

As opposed to the Physical Infrastructure (PI), the DCI has a strong digital characteristic. It offers digital computation and communication capability. The PI and DCI components have an inclusion relationship; in some cases a PI component might include a DCI component (e.g. a physical traffic sign that is painted a number corresponding to the speed limit and also emits a CAM message), and in other cases the reverse is true (e.g. a Road-Side Unit might contain a physical pole on which it is attached). This inclusion relationship is further described in section titled “Inclusion Relationship between PI and DI”.

Several components are part of the DCI. The list of the DCI components is the following:

1. 5G Base Station, potentially with 2G, 3G and 4G
2. Road-Side Unit for ITS-G5, potentially providing Internet connectivity (IP)
3. Fixed camera, lidar, situated on masts along the road.
4. Traffic Lights and TL controller
5. In-pavement and proximity digital sensor, magnetic loop
6. WiFi hotspot, bluetooth
7. GNSS signal augmentation station
8. Variable Message Signs (VMS)
9. Traffic Management software from A8.3
10. Real-time weather data of the road

The benefits of these DCI components for Automated Driving are, respectively:

1. Connection to Internet for all computers in a shuttle. Connecting to the Internet serves the process of Automated Driving in several potential ways. For example:
    a. the remote software update process of an onboard computer executing robotic guidance software is updated from a server situated in the Internet.
    b. obtaining the HDMAPS via the servers in the Internet.
    c. automated guidance process loop may use direct interactions with other computers in AD vehicles, via the Internet.
    d. automated enforcing of rules of traffic lights involve interactions between the TLC and the AD computers in the vehicle, via the Internet.
2. V2X messaging to the shuttle: CAM, DENM, SPAT, MAP and other related messages. Additionally, the ITS-G5 RSUs are potentially used to offer Internet access to the AD vehicle. The V2X messaging may influence directly, or indirectly the process of automated driving.
3. Identification of zone occupancy; help the AD process in the shuttle for less visible corners of the route. Leverage the costs of lidar deployment by sharing the lidar data from one mast (or one vehicle) to several other vehicles and the control center.

4. Direct braking suggested by the TL to shuttle.
5. Detection of space occupancy to assist the AD process.
6. Offer Internet access to devices of passengers in a shuttle, or waiting at the bus stop.
7. Improve timing and precision needed by the AD process of in-shuttle computers.
8. AD process in general, and the shuttles in particular, must obey legislation. The information the VMSs and other real-time information signs, as well as the 'metal' (solid, fixed) signs, display must be made available to the AD process. And real-time information signs.
9. The advantages of traffic management software for the AD are analysed and described in the deliverable documents of the Activity A8.3.
10. The weather data is of paramount importance for AD. When the AD process is aware of weather data such as fog, or snow on road, or similar, from other servers in the Internet, then that data helps extensively the video recognition software. For example, if the camera detects fog with a certain level of confidence, that confidence is improved if the same data of presence of fog is received from a server in the Internet.

2.1 Generic example of DCI with minimal features

The following figure depicts a generic example of DCI. This DCI has been developed for illustration purposes. It contains a minimum set of required features. Some features might be deployed at some sites, while other aspects at other sites.

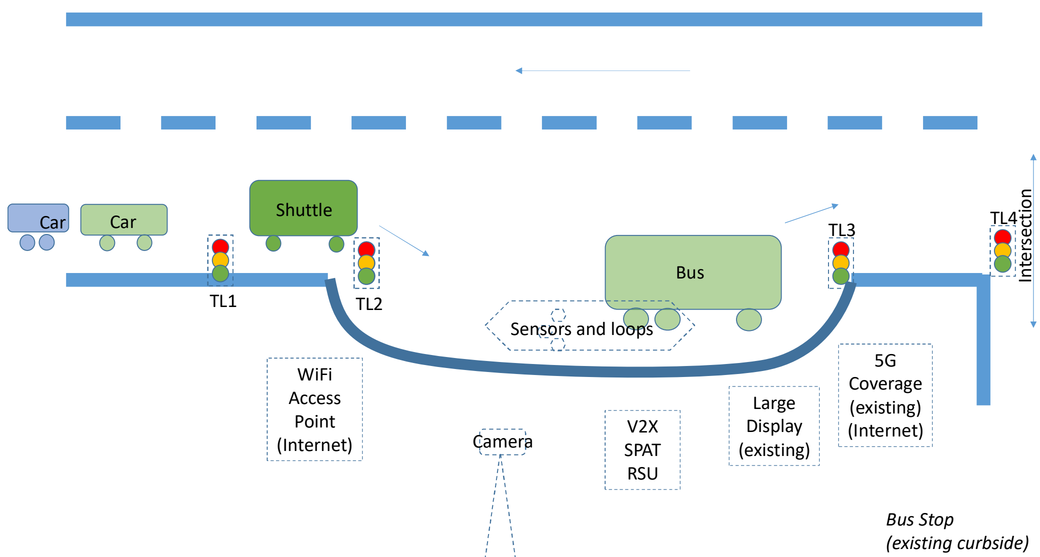


Figure 1: Generic example of DCI (dotted lines)

In this figure, the dotted lines delimit the components of DCI as deployed at a fictitious site. The figure depicts a small part of a road in an urban area with two directions delimited by a dashed line: above is the direction from right to left, and below it one can see the direction from left to right. In the middle of the figure a bus stop is depicted (a PI feature).

The DCI is composed of TL1..TL4 (Traffic Lights), WiFi Access Point, sensors and loops, Camera, RSU, large display and is under 5G coverage. The TLs guide the mobility of vehicles ensuring safety. The WiF Access Point offers Internet access for passengers waiting in the bus stop. The camera films the entire scene and sends the video to a control center. The sensors and loops in the gound detect the presence of vehicle on that area. The RSU sends V2X messages such as SPAT to vehicles in order to inform them about the status of TLs. The Large Display informs visually the passengers in the bus stop about the arrival hours. The entire area is under 5G coverage that is offered by means outside.

The use case is the following: it is assumed that the bus stop already exists for existing buses. A bus is present in the stop. An automated shuttle is arriving and there are a few normal cars behind it. The DCI must help orchestrating the mobility of vehicles such that the movements are safe and that traffic jams are not created. For example, based on information streamed by the camera the control center transmits information to RSU to be further sent to the automated shuttle and to the bus in order to synchronize their movements. Other mechanisms are possible, but the important aspect to consider is the presence and use of DCI components.

2.2 Definition of DI from CCAM SP WG3

The Digital Infrastructure (DI) for roads is described by the Working Group 3 of the Cooperative, Connected, Automated and Autonomous Mobility Single Platform expert group (CCAM SP). One of the main goals of the WG3 is to define how the Physical and Digital Infrastructure (PDI) can help advancing the CCAM, and in particular to extend the Operational Design Domain (ODD). An ODD is a description of the particular environment where a vehicle, and presumably a shuttle, operates safely at a given level of automation [SAE J3016].

A detailed description of the DI concept is provided, as seen from several points of view; but a formal definition of the DI is not provided. A description of the DI is provided by a “scoping paper”, which is the private document titled “CCAM platform Pre-deployment of Connected, Cooperative and Automated Mobility (CCAM) WG – 3 – Physical and digital road infrastructure” and dated November 4th, 2020. The scoping paper is available to the group members only, on the CIRCABC server, at the time of editing this deliverable.

The detailed description of the DI from CCAM SP WG3 has the following characteristics:

- Relies on an earlier description from the “C-ITS Platform” group of experts. This description is publicly available in the document titled “C-ITS Platform, Phase II; Cooperative Intelligent Transport Systems towards Cooperative, Connected and Automated Mobility; Final Report” dated September, 2017.

  In particular, that document mentions that DI means:

  > “[…] accurate, dynamic and live digital representation of the physical infrastructure and its traffic conditions, including additional information which cannot or is not presented by the physical infrastructure.”

- Considers the basis of DI to be the data, in the form of HD maps, representations of physical objects, and traffic-related data.
- Extends that basis with further DI elements such as:
  - Hybrid communications equipment, sensors;
  - Inter-vehicle communications, protocols;
  - Rules of roads.
- Adds a notion of ‘operational road infrastructure’ to the DI, such as to become a ‘Digital and Operational Infrastructure’. This notion of Digital and Operational Infrastructure was introduced in [Amditis, A., Lytrivis, P., Papanikolau, E., Carreras, A. and Daura, X., “Road infrastructure taxonomy for connected and

automated driving", chapter 14]. It states that the operational road infrastructure means:

> "Traffic management functions which facilitate the traffic flow by providing information or guidance. Operational road infrastructure highly depends on the physical and digital one, but its definition also implies the interaction with cloud services from, e.g., authorities, Original Equipment Manufacturers (OEMs), service providers or even mobility as a service."

The operational infrastructure is used, for example, for sending individual messages to individual automobiles; these automobiles will be *operated* and thus traffic management will be realized.

- Separates the notion of 'communications network infrastructure' out of the DI.

The following illustration depicts several elements of the DI described by the earlier C-ITS Platform. On the right hand side are pictured the DI elements such as map data and traffic management data. These elements are inter-related with the physical infrastructure, situated on the left hand side, by using the depicted 'V2I' bi-directional arrows (Vehicle to Infrastructure). These V2I arrows are communications on hybrid media: ITS-G5, cellular and more.

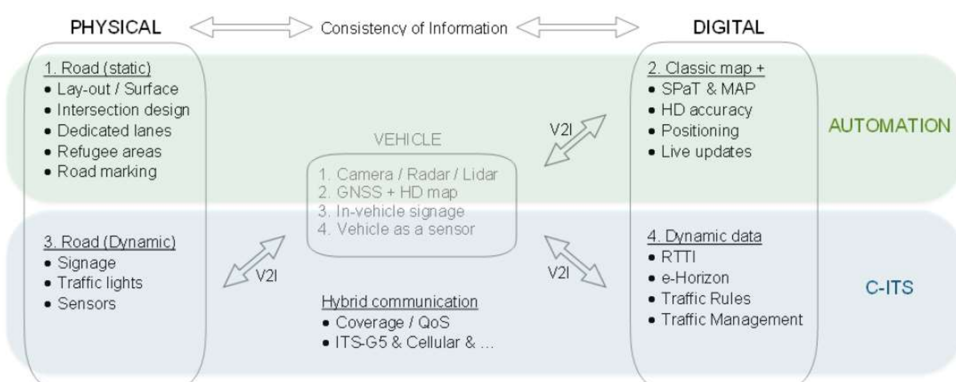


Figure 2: Illustration of the Digital Infrastructure in the C-ITS Platform (from the C-ITS Platform document titled "C-ITS Platform…" mentioned earlier in the text)

The following illustration depicts the digital infrastructure as described by the CCAM SP WG3 scoping paper:

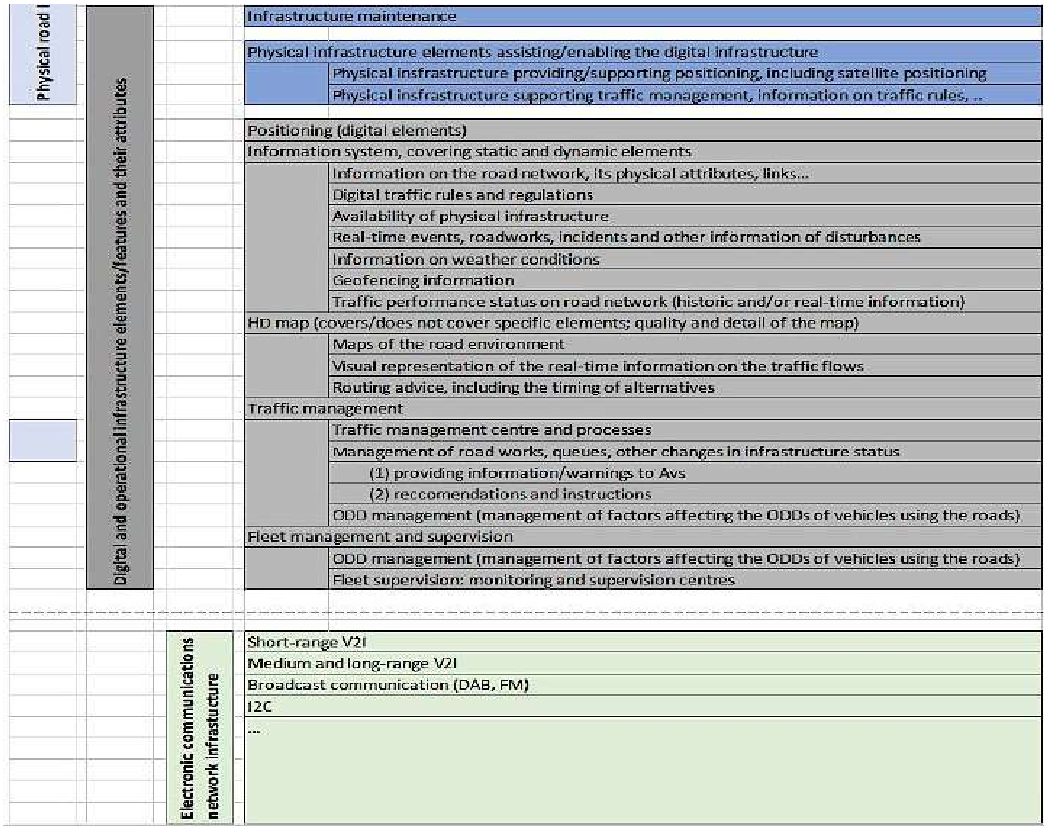


Figure 3: Digital and Operation Infrastructure described in CCAM SP WG3 (from the scoping paper mentioned in the text)

In the figure above, it can be seen that the DI is considered to be a set of information elements for: positioning, HD maps, traffic management and fleet management (the grey lines in the previous figure), all accompanied by a set of electronic communication network infrastructure features (short range V2I, long-range V2I, broadcast communications (DAB, FM), I2C (presumably I2V – Infrastructure to Vehicles) and more).

The final report of the CCAM Single Platform is in draft stage at the time of writing of this deliverable. The document can be referred to by its title: “DRAFT FINAL REPORT OF THE SINGLE PLATFORM FOR OPEN ROAD TESTING AND PRE-DEPLOYMENT OF COOPERATIVE, CONNECTED AND AUTOMATED AND AUTONOMOUS MOBILITY PLATFORM (CCAM Platform)”, Bruxelles, Juin 2021, Contact: frederic MARCHAL, E-mail: EU-CCAM-SINGLE-PLATFORM@ec.europa.eu Frederic.marchal@ec.europa.eu.

The final report of the CCAM Single Platform contains a final table. This table lists on the first column attributes of the PI; for each of these attribute it associates a DI attribute. For example, for a PI attribute named ‘Lanes dedicated to automated vehicles’ there is a DI attribute, or a ‘digital twin physical attribute’, that is named ‘element in HD map / C-ITS message (MAP)’. There are more columns explaining this relationship. For the sake of conciseness only the first columns are presented below for illustration:

Legend	digital twin of physical attribute C-ITS			
		Sensing & Perception		
Physical attribute (equivalent)	**Digital attribute (equivalent)**	**Ego localisation**	**Environmental awareness (object classification & incident detection)**	**E**
Lanes dedicated to automated vehicles	**Element in HD map / C-ITS message (MAP)**			
Sight distance restriction (curvature, hilly road, bridges,	**Element in HD map / C-ITS message (MAP)**			
Horizontal Traffic Signs, Lane markings (for human, video and lidar sensors), Special road markings for road works	**Element in HD map / C-ITS message (MAP), incl. number and type of lane (e.g. bus, taxi, cyclist, etc)**	lateral positioning	good lane detection improved lane keeping	Vis wea
Street lighting	Element in HD map			Su

Figure 4: Attributes of the PI and DI from the CCAM SP Final Report

2.3 Digital and Communications Infrastructure Support and Scales of Levels

The Digital and Communications Infrastructure (DCI) has been defined in the previous sections. It was defined as a set of inter-related components in the infrastructure that help in the realization of automated driving.

Beyond a simple definition, the DCI needs to be characterized. A useful way of characterization is to consider the DCI along a scale of values. When comparing DCIs deployed at sites it is advantageous to be able to compare DCI at one site with the DCI at another site. That comparison can be realized if common scales of values are agreed. In this document we propose to advance towards a common scale for DCI, but we do not give a definitive answer defining such a scale.

Generally speaking, over the course of recent years several scales of automation levels for automated driving have been developed. The currently known scales of automation are:

- SAE Levels (the most pertinent to vehicle automation)
- ISAD Levels (the most pertinent to infrastructure support of vehicle automation)
- SAE Classes of cooperation (the most pertinent to communications)
- ENSEMBLE Platooning levels (relevant to the particular use-case of platooning)

2.3.1 SAE Levels

In the widely known “SAE scale” of automated driving levels [J3016] developed by the Society of Automotive Engineers (SAE International), Level 5 corresponds to the highest autonomy (a best level) and Level 1 corresponds to no autonomy at all.

Widely known for its L1..L5 levels, the **SAE scale of automated driving levels** is defined in document SAE J3016. This document has been released for free access in year 2021, even if in previous versions it was a paid document. In this scale, Level 5 corresponds to the most autonomy (a best level) and Level 1 corresponds to no autonomy at all.

These levels do not consider communication systems; it is assumed that, in essence, the involvement of a communication system reduces the autonomy, since it renders the vehicle dependent on the other end of the communication (the other car, or the control centre), whereas presumably a purely autonomous vehicles only depends on itself. However, the use of a communication system changes the perspective of autonomy: on the one hand the data a vehicle might obtain via communication has the potential to significantly improve its view of the world (e.g. data from HD maps can be communicated by radio, when the camera cannot see because of fog); this perspective of the use of a communication system might go as far as completely replacing the use of traditional sensors for driving automation; for example, instead of *seeing* an obstacle an autonomous vehicle might learn its presence from a server in the Internet. It is assumed that the presence of an object of significance, be it a vehicle or otherwise, was uploaded previously to that server in the Internet either by the object itself, or by another object having sensed it (seen it with a camera or other means of detection).

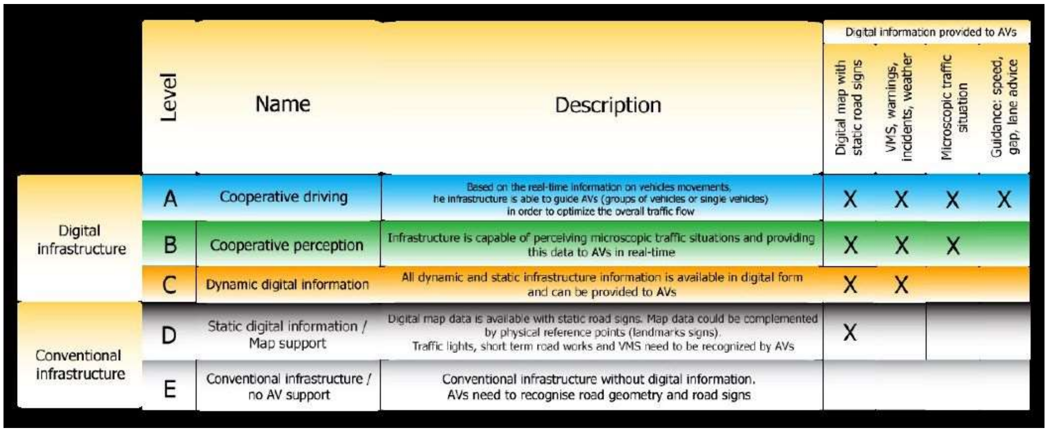
As an initial step, this use of a communication system for obstacle detection instead of the use of cameras was demonstrated in a simpler setting. A demonstrator of convoys of cheap autonomous vehicles that have no cameras has been realized in the frame of the project AUTOPILOT. The vehicles in the convoy do not have any cameras or lidars installed. Each vehicle is aware of its own position, immediate trajectory, acceleration and speed by relying on a combination of GNSS data from an on-board GNSS receiver and odometer. Further, each vehicle continuously communicates to one another (not through a server in the Internet); they communicate their respective position and other parameters such as their immediate planned trajectory, speed, acceleration. Based on these data, each vehicle is able to adapt its speed and trajectory depending on the others, and advance synchronously, in a convoy. These vehicles do not need to 'see' each other with cameras and they drive autonomously, and the convoy is autonomous.

Other uses of the communication system for autonomous vehicle was demonstrated in the project, such as communication between the vehicle and the traffic lights, through the Internet. Whereas many existing autonomous vehicles use cameras to detect the colour of the traffic lights, here again the demonstrator in AUTOPILOT used a communication system between the vehicle, a server in the Internet and the Traffic Lights Controller (TLC) to help the AV's onboard AD process in efficiently crossing a TLC-controlled intersection.

Based on this demonstrator of project AUTOPILOT, the AUTOPILOT deliverable D1.2 titled 'Use-cases' proposes new levels; these levels are dubbed L1-C, up to L5-C. They signify that the respective level of automation is achieved exclusively using a data communication system, as opposed of using cameras or radars and lidars.

2.3.2 ISAD Levels

Whereas the SAE Levels permit to qualify vehicles (e.g. this particular automobile is 'Level 5', meaning it is fully autonomous), a more relevant scale for digital infrastructure is the **ISAD scale of levels** (ISAD stands for Infrastructure Support for Autonomous Driving) which were mainly developed for highways. This scale, or rather a categorisation, has been defined in the project INFRAMIX (see URL https://www.inframix.eu/ accessed on October 26th, 2021; an EU H2020 project). It defines Levels from A to E, where Level A corresponds to most support for automated driving offered from the infrastructure (best) and Level E corresponds to no Autonomous Vehicle support at all. For example, a certain infrastructure might be qualified as Level A to mean it offers full support to AVs. The levels are described briefly in the following figure:



	Level	Name	Description	Digital information provided to AVs: Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Digital infrastructure	A	Cooperative driving	Based on the real-time information on vehicles movements, he infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow	X	X	X	X
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time	X	X	X	
	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs	X	X		
Conventional infrastructure	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs	X			
	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs				

Figure 5: ISAD levels, categorisation (from INFRAMIX project)

The ISAD Levels are defined mainly for large highway situations. Some of the characteristics considered (e.g. digital maps, guidance speed, microscopic traffic situations) apply to smaller deployments such as urban areas. That constitutes both an advantage and an inconvenient. The advantage is that the ISAD Levels can be applied to sites in SHOW project, and the question of matching a site to an ISAD Level can be answered. The inconvenient is that many sites are reluctant in defining themselves on a certain ISAD Level. That inconvenient is addressed later.

In the following table we present the situation of DCI of sites in SHOW on ISAD Levels:

Table 1: Situation of DCI of sites in SHOW on ISAD Levels

Site name	ISAD Level
Tampere	C
Trikala	Currently at D and progressing towards C
Thessaloniki	
Madrid Carabanchel	D
Madrid Villaverde	D
Rouen Madrillet	D, progressing towards C
Rouen city-centre	D, progressing towards C
Lindhölmen	
Linköping	D, but not aware of any official classification
Graz	D

Site name	ISAD Level
Salzburg	C and B partially, meaning that the some parts of the digital infrastructure are not available for the full test site but specifically at some sections, e.g. cooperative perception will be available for one intersection on the test track.
Aachen	
Karlsruhe	C
Turin	D progressing towards C
Belle Idée	
Brussels	E, clearly
Carinthia Pörtschach	E
Carinthia Klagenfurt	D or C (plan under discussion)
Brno	D. Because of inclusion of a digital map with static traffic signs.
JRC Ispra	

It is recommended that each site progresses towards the higher ISAD level ‘A’ when considered appropriate.

2.3.3 SAE Classes of cooperation (from SAE)

The SAE Cooperation Classes for DDT: In order to address the lack of use of communication systems in SAE Levels, the SAE recently proposed the use of M2M communication systems between entities towards the realization of a DDT (Dynamic Driving Task). The introductory sections stipulate that:

> *Cooperative driving automation (CDA) aims to improve the safety and flow of traffic and/or facilitate road operations by supporting the movement of multiple vehicles in proximity to one another. This is accomplished, for example, by sharing information that can be used to influence (directly or indirectly) DDT performance by one or more nearby road users.*

The following ‘classes’ of CDA cooperation are defined:

- Class A “Status-sharing cooperation”
- Class B “Intent-sharing cooperation”
- Class C “Agreement-seeking cooperation”
- Class D “Prescriptive cooperation”

The relationship between classes and levels is illustrated in the following figure:

	SAE Driving Automation Levels					
	No Automation	Driving Automation System		Automated Driving System (ADS)		
	Level 0 *No Driving Automation (human does all driving)*	**Level 1** *Driver Assistance (longitudinal OR lateral vehicle motion control)*	**Level 2** *Partial Driving Automation (longitudinal AND lateral vehicle motion control)*	**Level 3** *Conditional Driving Automation*	**Level 4** *High Driving Automation*	**Level 5** *Full Driving Automation*
CDA Cooperation Classes						
No cooperative automation	(e.g., Signage, TCD)	Relies on driver to complete the DDT and to supervise feature performance in real-time		Relies on ADS to perform complete DDT under defined conditions (fallback condition performance varies between levels)		
Class A: Status-sharing *Here I am and what I see*	(e.g., Brake Lights, Traffic Signal)	Limited cooperation: Human is driving and must supervise CDA features (and may intervene at any time), and sensing capabilities may be limited compared to C-ADS		C-ADS has full authority to decide actions Improved C-ADS situational awareness beyond on-board sensing capabilities and increased awareness of C-ADS state by surrounding road users and road operators		
Class B: Intent-sharing *This is what I plan to do*	(e.g., Turn Signal, Merge)	Limited cooperation (only longitudinal OR lateral intent that may be overridden by human)	Limited cooperation (both longitudinal AND lateral intent that may be overridden by human)	C-ADS has full authority to decide actions Improved C-ADS situational awareness through increased prediction reliability, and increased awareness of C-ADS plans by surrounding road users and road operators		
Class C: Agreement-seeking *Let's do this together*	(e.g., Hand Signals, Merge)	N/A	N/A	C-ADS has full authority to decide actions Improved ability of C-ADS and transportation system to attain mutual goals by accepting or suggesting actions in coordination with surrounding road users and road operators		
Class D: Prescriptive *I will do as directed*	(e.g., Hand Signals, Lane Assignment by Officials)	N/A	N/A	C-ADS has full authority to decide actions, except for very specific circumstances in which it is designed to accept and adhere to a prescriptive communication		

Figure 6: Relationship between classes and SAE levels (from J3216)

A new set of **Platooning Automation Levels** are defined in project ENSEMBLE, see deliverable D2.2 of project ENSEMBLE, titled "V1 Platooning use-cases, scenario definition and Platooning Levels", dated 13 May 2020. Despite being dedicated almost entirely to vehicle systems, and more specifically to trucks, and not to automobiles, these levels have a direct relationship to infrastructure: an RSU can be used to delimit 'regions' of applicability of platoon; a vehicle entering such a region detects by the presence of CAM messages emitted by the RSU present in that region. A platoon is considered to be an 'interconnected' system, and potentially uses V2X messaging between trucks. By 'V2X' messaging it is understood the ETSI ITS messages such as 'CAM' that are exchanged in V2V or V2I manners. This interconnection aspect is used as a reason to back the need to define these new levels, as the SAE Levels are not considering connectivity.

The platooning levels are denominated as follows:

- Platooning Level A
- Platooning Level B
- Platooning Level C

Some of the characteristics of these platooning levels are illustrated in the following figure:

	Platooning level A	*Platooning level B*	*Platooning level C*
Longitudinal automation	Leading truck: manual or advanced assist system (e.g. ACC) Following & trailing vehicle: Autonomous longitudinal control (CACC, CAEB, Cxxx, …)	*Leading truck: manual or advanced assist system (e.g. ACC)* *Following & trailing vehicle: Autonomous longitudinal control (CACC, CAEB, Cxxx, …)*	*Leading truck: manual or advanced assist system (e.g. ACC)* *Following & trailing vehicle: Autonomous longitudinal control (CACC, CAEB, Cxxx, …)*
Lateral automation	Driver	*In lane + lane*	*Full automation from*

	Optionally: in lane by system (standalone vehicle)	*changes (coordinated)*	*A to B*
Operation area	Triggered by driver in dedicated areas (e.g. highway)	*Dedicated areas (e.g. highway)*	*Dedicated areas (e.g. highway + parking areas)*
Fault tolerance	Longitudinal degradation functionality	*Longitudinal & lateral degradation functionality*	*Longitudinal & lateral degradation functionality*
Platoon engaging	Only from behind (by single truck & existing platoon)	*From behind (by single truck & existing platoon) and from the front by single truck*	*From behind (by single truck & existing platoon), from the front by single truck and merging of single trucks in existing platoon*
System & environment monitoring	System itself + Driver (environment)	*System itself*	*System itself*
Fallback of the DDT (dynamic driving task)	Driver; as long it is safe and the driver can react in time	*System (for x seconds)*	*System*
Safe state	Fail-safe (driver in control after reaction time of the driver)	*Stopped in ego lane or rightmost lane*	*Stopped in safe stop area (e.g. fuel station)*
Timegap (Steady state @ 80 kph)	>0.8s	*>0.5s*	*>0.3s*
Maximum number of trucks	7 (maximum for simulations & verifications)	*No principle technical limitation as for now*	*No principle technical limitation as for now*
Platoon formation (orchestrated) possible	Yes	*Yes*	*Yes*

Figure 7: Illustration of platooning levels from project ENSEMBLE, D2.2

Recently, the Platooning Automation levels are also suggested in the C2C-CC (Car to Car Communications Consortium) roadmap of future technologies deployment. The C2C-CC roadmaps are well known previously for the concepts of Day1, Day2 and Day3 deployment phases. The relationship between the ‘Day*x*’ and the Platooning levels are illustrated in the following figure:

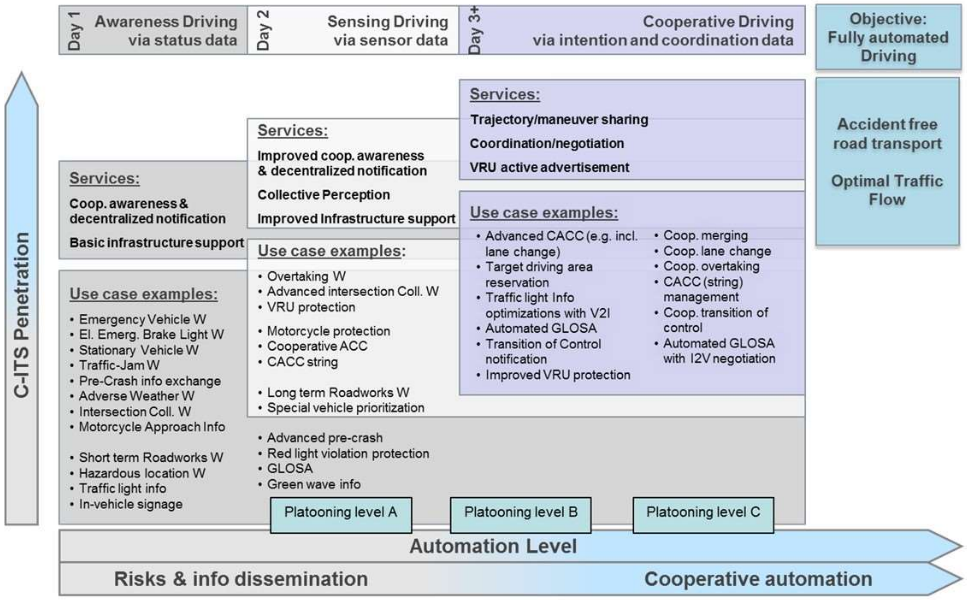


Figure 8: Relationship between platooning levels and Dayx concepts of C2C-CC (see presentation titled "CAR 2 CAR Communication Consortium presentation to ITU - Collaboration on ITS Communication Standards", September 2021)

SHOW Relevance

Having presented the four scales of levels related to automated driving it is now necessary to characterize the DCI at sites in project SHOW according to these scales. However, it is not possible during the current project timeframe to provide a full characterization. A few examples of questions are given below and are left as future work.

In this context, it is possible to formulate and try to answer a set of questions:

- Can ISAD Levels apply to urban environments where autonomous shuttles circulate?
- Which of the SHOW DCI features support for which platooning levels? At some sites the platooning use-cases are relevant, whereas at other sites the platooning use-cases are not relevant.
- How ISAD levels match DCI deployments at sites in SHOW? Is it possible to ask whether a particular site, is situated at a particular ISAD level? (e.g. is Madrid Carabanchel at ISAD Level A?) Whereas it is known that the ISAD scale was designed with highways in mind, and in SHOW the sites are mainly urban, many aspects related to DCI are present both on highways and on urban, such as the heterogeneous ITS-G5 and 5G communication systems. This leads to an additional question: might it be necessary to design a new scale of levels of DCI along the lines of highway, peri-urban, urban?
- Does a particular ISAD Level help with a particular SAE Level? Is a particular SAE Cooperation Class necessary in order to offer more help for that?

In order to answer these questions, it is possible to imagine a three-dimensional space of scales (see the figure below). Along each axis, a particular scale presented earlier would be situated. For example, the left hand diagram has the ISAD levels on the *y* scale, the SAE levels and the AUTOPILOT levels on the *x* scale and the Platooning levels on the *z* scale. Similarly, the right hand diagram has the ISAD Levels, SAE Cooperation Classes and Platooning Levels on *x, y,* and *z* scales respectively. The points in each of these two spaces (to be depicted later) would represent the DCI of a particular SHOW site.

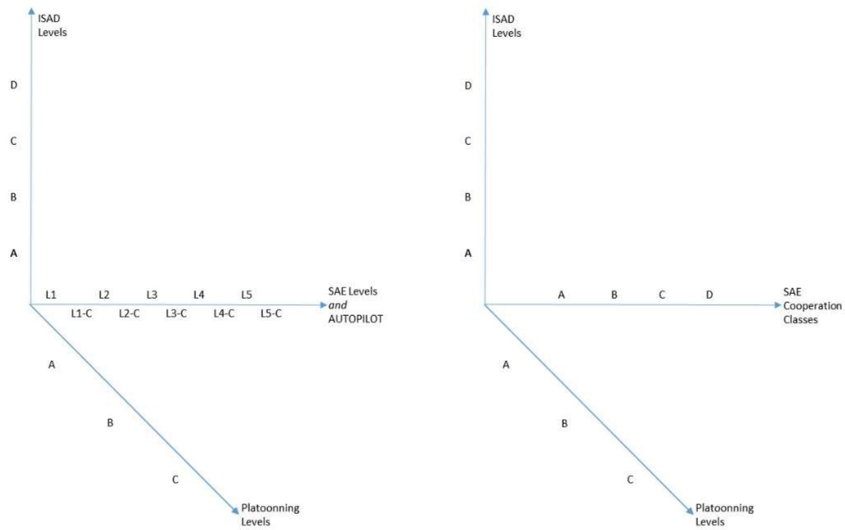


Figure 9: Preliminary tri-dimensional overview of automation levels and classes

2.4 ODD attributes from the MANTRA project and definition from via-AUTONOM, an Austrian project

A case can be made defending that the Digital and Communication Infrastructure is a predominant aspect of the landscape where the Autonomous Vehicles evolve. In SAE terms, that landscape is named an 'Operational Design Domain'. The ODD is defined in [J3016] to be:

> *Operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.*

Several examples of ODDs are given in [J3016]. One such example is the following: "a fully access-controlled freeways in low-speed traffic, under fair weather conditions and optimal road maintenance conditions (e.g., good lane markings and not under construction)".

As the descriptions of the examples of ODDs are still quite generic, it is necessary to rely on a more precise definition of ODDs. We present next a few such definitions by means of attributes. Their attributes such as communication, satellite positioning, HD maps and others relate to the DI concept.

The definitions of ODD are extracted from two relevant projects – MANTRA and via-AUTONOM – in an European Member State. Other projects on the same subject matter may exist.

2.4.1 Project: "MANTRA" (www.mantra-research.eu)

The CEDR project "MANTRA: Making full use of Automation for National Transport and Road Authorities – NRA Core Business" (www.mantra-research.eu), running from 2018 until 2020, aimed to answer the following questions [x][x stands for "Please refer to the following source: Aigner, W., Kulmala, R., & Ulrich, S. (2019). MANTRA: Making full use of Automation for National Transport and Road Authorities - NRA Core

Business. D2.1 Vehicle fleet penetrations and ODD coverage of NRA- relevant automation functions up to 2040.]:

- What are the influences of automation on the core business in relation to road safety, traffic efficiency, the environment, customer service, maintenance and construction processes?
- How will the current core business on operations & services, planning & building and ICT change in the future?

To respond to these questions, the Operational Design Domain (ODD) for the developed use cases (Highway autopilot including highway convoy (L4). Highly automated (freight) vehicles on open roads (L4), Commercial driverless vehicles (L4) as taxi services, Driverless maintenance and road works vehicles (L4)) was defined. As a basis, the ODD attributes listed in the Activity 4.3 of the European ITS Platform (EU-EIP) were reviewed and expanded. The results are shown in the table below. The table shows different attributes and also distinguishes whether they are physical or digital infrastructure. Communication is seen as part of digital infrastructure.

Table 2: Table of ODD attributes [Source: Ulrich, S., Kulmala, R., Appel, K., Aiger, W., Tenttinen, M. & Laitinen, J., (2020). MANTRA: Making full use of Automation for National Transport and Road Authorities - NRA Core Business. D4.2 Consequences of automation functions to infrastructure.]

ODD attribute	Physical / Digital infrastructure	Static / Dynamic
Road	Physical	Static
Speed range	Physical	Static
Shoulder or kerb	Physical	Static
Road markings	Physical	Static
Traffic signs	Physical	Static
Road furniture	Physical	Static
Traffic	-	Dynamic
Time	-	Dynamic
Weather conditions	-	Dynamic
HD map	Digital	Static
Satellite positioning	Digital	Static
Communication	Digital	Static
Information system	Digital	Static
Traffic management	Digital	Dynamic
Infrastructure maintenance	Physical/Digital	Dynamic
Fleet supervision	Digital	Dynamic
Digital twin of road network	Digital	Dynamic

Following this list of ODD attributes, sub-attributes were developed. The sub-attributes of digital infrastructure are shown in the following table. These reveal in more detail, which elements are meant.

Table 3: ODD related requirements for commercial driverless vehicles as taxi services as stated in the project MANTRA. [Source: Ulrich, S., Kulmala, R., Appel, K., Aiger, W., Tenttinen, M. & Laitinen, J., (2020). MANTRA: Making full use of Automation for National Transport and Road Authorities - NRA Core Business. D4.2 Consequences of automation functions to infrastructure.]

Digital infrastructure attributes		
Infrastructure attribute	**Sub-attributes**	**Comment**
Communication	Short-range V2I	Communication at hot spots and road sections
	Medium and long-range V2I	Communications over road networks and corridors
	Medium and long-range V2I with low latency and wide bandwidth	Communications facilitating remote supervision of vehicles
Satellite positioning	Land stations	Improving accuracy of positioning in challenging areas
	Positioning support in tunnels	GPS repeaters or other solutions to provide accurate positioning also in tunnels
HD map	Maps of road environment including landmarks for camera, radar, and ultrasound sensors	Accurate positioning of the vehicle in the transport system, road and lane
	Maps of road environment including landmarks for LIDAR sensors	Accurate positioning of the vehicle in the transport system, road and lane
Information system (digital layer of the HD map)	Real-time event, roadworks, incident & other disturbances	Providing extended horizon beyond sensor range
	Digital traffic rules and regulations	Proving permanent and temporary rules of operation
	Geofencing information	Informing of access to specific roads, networks, and areas and/or right of use of specific automated driving use case
	Availability of physical infrastructure	Real-time information of the availability and usability of the physical infrastructure required for ODD
Traffic performance status on road network	Traffic status on network	Provides the transport system real-time traffic status information to the HD map
	Real time digital twin of the network managed including traffic flows	Enables simulation, modelling and testing of different traffic management measures in order to

Digital infrastructure attributes		
Infrastructure attribute	**Sub-attributes**	**Comment**
		select optimal measure for vehicle flows including also CAVs
Traffic management	Road works management	Standardised markings and processes to maintain ODD
	Incident management	Standardised markings and processes to maintain ODD
	ODD management	Management of factors affecting the ODDs of vehicles using the roads
	Traffic management centre and processes	Adaptation of the centres and processes consider special requirements from automated vehicles and mixed fleets
Fleet supervision	Fleet monitoring and supervision centres	Remote monitoring and supervision of fleets, pervision centres likely necessary for shuttles, robotaxis, road- work trailers, maintenance vehicles

2.4.2 Project "Via-Autonom" (national Austrian project)

The Austrian project "via-AUTONOM" [Source: Mischinger, M., Nitsche, P., Piribauer, T., Schneider, P., Schwieger, K., & Wimmer, P. (2017). via-AUTONOM - Verkehrsinfrastruktur und Anforderungen für autonomen Straßenverkehr. Bericht B2.1. Dokumentation der Szenarien, Anforderungen und Maßnahmen] dealt with infrastructure requirements for implementing automated driving in Austria. Possible infrastructure measures were identified, which were divided into the categories built, built-digital and digital [Source: Mischinger, M., Nitsche, P., Piribauer, T., Schneider, P., Schwieger, K., & Wimmer, P. (2017). via-AUTONOM - Verkehrsinfrastruktur und Anforderungen für autonomen Straßenverkehr. Bericht B2.1. Dokumentation der Szenarien, Anforderungen und Maßnahmen]. The measures for urban areas include the following elements in the category digital:

- 5G connectivity
- Traffic sign registry
- GNSS correction data or pseudo-satellite information
- Real-time traffic information
- Information about planned events (e.g. demonstrations leading to road or lane closures)
- Data from construction site management systems
- Digital map of the immediate vicinity (e.g. detailed map of intersections)
- Dynamic, high-precision digital road maps
- "Hot Spot" map, showing where conflicts/accidents accumulate
- Train information (train radar)
- Data exchange about the current train volume/train schedule

Additionally, there are partly digital measures which are seen as both built and digital measures. These mixed measures and the relationship between digital and built (or physical) infrastructure are further described in the section titled "PI inside DI or DI inside PI".

2.5 Sub-categories of DI:

2.5.1 Inclusion relationship between PI and DI

As stated at the beginning of the section titled "Definition of Digital and Communication Infrastructure", DCI and PI have an inclusive relationship. In the SHOW deliverable D8.1 [Source: SHOW (2021): D8.1: Criteria catalogue and solutions to assess and improve physical road infrastructure. Deliverable of the Horizon-2020 SHOW project, Grant Agreement No. 875530], which deals with physical road infrastructure, it says:

> *"Physical infrastructure is hard to be separated strictly from digital infrastructure. On the one hand digital infrastructure often needs physical infrastructure e.g. to fix sensors, cameras etc. on PI assets. On the other hand, challenges with physical infrastructure and associated safety issues could be overcome with digital infrastructure".*

The possible infrastructure measures for urban areas identified within the Austrian project "via-AUTONOM" also show the strong connection between digital and physical infrastructure. Being categorized into "built", "digital" and mixed "built/digital" measures there were many built/digital measures, indicating that a lot of them consist of both digital and physical infrastructure components at once. The measures [Source: Mischinger, M., Nitsche, P., Piribauer, T., Schneider, P., Schwieger, K., & Wimmer, P. (2017). via-AUTONOM - Verkehrsinfrastruktur und Anforderungen für autonomen Straßenverkehr. Bericht B2.1. Dokumentation der Szenarien, Anforderungen und Maßnahmen] were as follows:

<u>Built:</u>

- Uniform infrastructure, standardization efforts
- Special road and lane markings (e.g. with metal splinters, retro-reflective)
- Rumble strips
- Delineators at construction sites
- Separation of Lane/Not lane (physical or visual)
- Traffic signs particular for automated vehicles

<u>Digital:</u>

- 5G connectivity
- Traffic sign registry
- GNSS correction data or pseudo-satellite information
- Real-time traffic information
- Information about planned events (e.g. demonstrations leading to road or lane closures)
- Data from construction site management systems
- Digital map of the immediate vicinity (e.g. detailed map of intersections)
- Dynamic, high-precision digital road maps
- "Hot spot" map (showing where conflicts/accidents accumulate)
- Train information (train radar)
- Data exchange about the current train volume/train schedule

<u>Built/Digital:</u>

- Intelligent traffic signs e.g. with sensors, beacons, transmitters or QR codes

- Intelligent infrastructure e.g. traffic lights with sensors, beacons, transmitters or QR codes
- Roadside units providing weather information, information on lane occupancy or travelled speeds
- Roadside units for the detection and trajectory recognition of road users (e.g. pedestrians, cyclists)
- Additional external video observation
- Tunnel guidance systems
- Georeferenced landmarks
- Galileo satellite navigation system
- UWB (Ultra Wide Band) based positioning system
- Infrastructure-based collision warning (I2V communication)
- C-ITS: intelligent intersections

Being aware of the inclusive relationship, a distinction between physical and digital infrastructure still is necessary, as physical and digital infrastructure are addressed in separate activities within the SHOW project. Within *SHOW (2021). D8.1: Criteria catalogue and solutions to assess and improve physical road infrastructure. Deliverable of the Horizon-2020 SHOW project, Grant Agreement No. 875530*, physical infrastructure components were considered as those parts that can be used without digital infrastructure. Examples were given, including the following:

- Road furniture as a physical element on the road, that could be used as a landmark within a digital dynamic map
- RSUs are considered as digital infrastructure, as they are useless without it. The existence of such an element can be acknowledged physically e.g. in limiting sight distances.
- Traffic lights are physical infrastructure when acknowledging their physical position and classic visual signals – any other form of communicating right of way is considered digital infrastructure.

From this definition, digital infrastructure includes their physical components as they are needed for the DI to function, but their representation as physical entities is physical infrastructure.

Also, there is the exception of digital dynamic maps or high-definition maps that are mostly considered to be digital infrastructure according to the definitions in the section titled “3.4 ODD attributes from MANTRA project. Definition from via Autonom, an Austrian project”. Within the SHOW project digital dynamic maps are discussed in D8.1 [*SHOW (2021). D8.1: Criteria catalogue and solutions to assess and improve physical road infrastructure. Deliverable of the Horizon-2020 SHOW project, Grant Agreement No. 875530*], as the maps present a copy of the real environment.

2.5.2 DCI Data component and the Digital Twin

As presented earlier, the DCI is defined as consisting of several components grouped in the following categories:

- the data-oriented physical entities (road-side units and base stations, sensors, cameras, antennas, other),
- the stored data,
- and the messages.

In the category of stored data, a particular example is that of a Digital Twin. A Digital Twin that represents a site will most certainly represent the DCI of that site. Next we briefly describe a digital twin at a particular site.

To support the development of automated and autonomous transport a digital twin was developed in Tampere, Hervanta suburb. The goal of the Hervanta Digital Twin project was to create high quality Digital Twin for the Tampere autonomous vehicle test site in Hervanta and facilitate 3rd party stakeholders with access to data. In collaboration with VTT, Business Tampere and the City of Tampere, Sitowise created a Digital Twin – a detailed, intelligent and reactive 3D model of the area. The broader goal was to pilot the uses of the Digital Twins in autonomous driving planning, testing and studies, with the focus on innovation, efficiency and quick iterations in conducting studies. A Digital Twin is an ideal tool to communicate project results and goals to the public and use for communication between stakeholders. The Digital Twin aims to improve safety and reduce costs of traditional testing methods in autonomous driving studies. In this work the real world geometry and infrastructure were modelled featuring dynamic weather and time simulation from local data and real time 5G mmWave propagation simulation tool. The geometry package in 'Unity' has been shared with 3rd party stakeholders. The project video can be found at the following URL: https://www.youtube.com/watch?v=G8Nj2-BmUtI (accessed on November 24th, 2021).

2.6 Distribution of DCI deployment in Europe

As presented earlier, the first category of components of the DCI is the data-oriented physical entities. The most visible part of these components is consisting of the Road-Side Units and of the cellular base stations.

In this section we describe the deployment of Road-Side Units and of cellular base stations in Europe. With respect to RSU deployment we also present briefly the situation of the RSU deployment at SHOW sites compared to the maps of RSUs in Europe that are constructed outside of this project.

2.6.1 Road-Side Units (RSU) deployment in Europe

The level of deployment of Cooperative Intelligent Transportation Systems (C-ITS[1]) in Europe can be evaluated - informally - by using several sources of information. The maps of deployed Road-Side Units (RSUs[2]) that emit CAM messages is a good indicator. Such maps can be obtained, for example, from the sources listed below. These sources are separate and, to the best of editor's knowledge, there is no attempt to combine these sources.

- **The Layer "C-ITS stations" in the TENtec Interactive Map viewer** (https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html). This information has been provided by members of the "C-Roads Platform"; the RSUs are those whose deployment has been co-funded by the CEF programme;they are under the responsibility of Member States (or road operators "supervised"by the Member States) who participate in the C-Roads Platform. This layer of the map can be consulted at the following URL: https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html (accessed on July 27th, 2021).
- **The 5 pilot sites of project SCOOP in France, called "SCOOP pilot sites"** (http://www.scoop.developpement-durable.gouv.fr/les-5-sites-pilotes-scoop-

[1] In this section we understand by C-ITS the technology at the 'traditional' 5.9GHz frequency band allocated in Europe at the time of writing, i.e. 5875MHz-5925MHz.

[2] An RSU might be connected to a cellular network as well, like 3G, 4G or 5G; an RSU might also work with a LTE-V2X or C-V2X technology, rather than ITS-G5; at that point it would rather be called a 'base station'. In this section we consider only the deployment of RSUs that are on C-ITS technology, or otherwise known as ITS-G5, or DSRC, or 802.11p more specifically.

a4.html retrieved on July 27th, 2021). This lists several areas on highways that have deployments of RSUs.

- **The information from the "C-ITS Deployment Group"** (See https://c-its-deployment-group.eu/activities/c-its-deployments/ (retrieved on July 27th,2021.) – a few success stories from Austria, Germany and the Netherlands. In the particular case of Austria, the road operator ASFINAG are deploying a production C-ITS system along 2200 kilometres with up to 525 RSUs[3].
- **The private mapping information maintained at the highway road operators**. For example, in France, the road operators Cofiroute and APRR have deployed several Road-Side Units ("Unité de Bord de Route",fr.) which are visible on the road although not yet publicly useable. To obtain the maps of these RSU deployments one would have to get in contact with the cited operators.
- The private mapping information maintained by the **City authorities in conjunction with RSU manufacturers**; for example, in France, several RSUs are deployed in the city of Versailles with manufacturer Lacroix. The maps of these RSUs are maintained at the manufacturer.
- The private RSUs deployed by **research centers** for local experimentation purposes, outdoors. (e.g. maps of RSU deployments maintained by the research center VEDECOM; these maps describe the RSUs deployed in places such as the City of Versailles, Paris-Saclay area, and others).
- The information from **administrators, deployers and manufacturers of connected Traffic Lights**, such as the organisation EPI78-92 in the Paris Region, France and manufacturer Aximum.

Table 4: SHOW RSU deployments vs. presence in known maps of RSU in Europe

	Site has RSUs with V2X at 5.9GHz?	**Are the site's RSUs mapped by the TENtec "C-ITS Layer"?**	**Are the site's RSUs mapped by the "SCOOP pilot sites"?**	**Are the site RSUs mapped by the "C-ITS Deployment Group"?**
Trikala	Yes, for V2I and V2P, for traffic lights.	No. But TENtec "Comprehensive/Core Network Roads" layer does contain the Karditsis route through Trikala, which is also a route in SHOW project.	No.	No.

[3] This ASFINAG C-ITS RSU deployment has been announced publicly in October of 2020; the announcements are visible at URLs such as https://www.itsinternational.com/its7/news/siemens-provides-c-its-austrian-highways and https://c-its-deployment-group.eu/activities/c-its-deployments/2020-10-09-asfinag-connects-roads-with-vehicles-on-a-large-scale-in-europe/ as of November 3rd, 2021.

	Site has RSUs with V2X at 5.9GHz?	Are the site's RSUs mapped by the TENtec "C-ITS Layer"?	Are the site's RSUs mapped by the "SCOOP pilot sites"?	Are the site RSUs mapped by the "C-ITS Deployment Group"?
Thessaloniki	Yes, RSUs to be installed at selected intersections, within SHOW project.	No. But TENtec "Comprehensive/Core Network Roads" layer does contain the E02 route through Thessaloniki, which is also a route in SHOW project.	No.	No.
Tampere Satellite Site	Yes, there are three RSUs at intersections in Hervanta at Hermia.	No.	No.	No.
Madrid Carabanchel	Yes, one RSU at bus depot.	No. But TENtec "Comprehensive/Core Network Roads" layer does contain the M-40 routes passing nearby (approx.. 1km distance).	No.	No.
Madrid Villaverde	Yes, on traffic lights.	No. But TENtec "Comprehensive/Core Network Roads" layer does contain Avenue de Andalucía; this avenue is crossed by the route to be used in SHOW.	No.	No.

2.6.2 Cellular network deployments related to DCI

In the previous section, several sources of information, and a comparison table, were provided. They describe the deployment of ITS-G5 technology with 'Road-Side Units' along roads in Europe. However, ITS-G5 is not the only technology for wireless communications dedicated to, or that can be used for, vehicles. The cellular network deployments (e.g. 2G..5G, or 'mobile communications') can also be used to connect vehicles to the Internet. One high-level difference between ITS-G5 deployments and cellular network deployments is that the former is targeting specifically the vehicles, whereas the latter connects vehicles as any other kinds of entities. Simply put, the

RSUs are targeting vehicles specifically, whereas vehicles represent a ‘vertical’ market users for cellular networks; in cellular networks other such ‘verticals’ are used: agriculture users, smart city users, health domain users and more; moreover, the cellular communication technologies are widely deployed for humans using smartphones, in general. That is a key difference between ITS-G5 and cellular networks.

For ITS-G5 RSUs several maps of deployment are provided in the preceding section.

For **cellular network deployments** (mobile networks such as 2G..5G) one must consider the maps of deployments of coverage, and of ‘base stations’ that are maintained by several actors. Depending on the country and domain, the following actors maintain actively maps of deployments of base stations. These maps were used in the descriptions of the DCI at Sites in this document.

- Crowd sourced maps generated and maintained by end users. These include sites such as cellmapper (www.cellmapper.net, consulted in September of year 2021). This mapping service contains data provided by individual users, in a similar distributed and self-controlled manner as when contributing to Wikipedia, for example. A smartphone application is used by the end user to upload data about the current signal strength and geographical position. Aggregating this kind of information from multiple users leads to relatively comprehensive, even if at times imprecise, maps of coverage of cellular networks. These maps include roads, so that cars obviously might take advantage of them.
- Maps of cellular networks maintained by cellular network operators. For example, in France, the operator Orange maintains maps of coverage of various technologies, such as 3G to 5G. These maps are available at the following URL, consulted on September 16th, 2021. https://reseaux.orange.fr/cartes-de-couverture/mobile-3g-4g-5g .

  Another example is, in Austria, there is the network operator A1. A1 provides such maps that are used in this document. The URL is https://www.a1.net/hilfe-support/netzabdeckung/frontend/main.html (accessed on September 16th, 2021).

  These maps are relatively precise and often very well maintained and updated. However, the maps of a certain operator only contain the coverage of that particular operator – so in an area where a particular operator is absent, coverage might still be there (from another operator) for an automobile to use, but the respective map would not show it. This leads to the exhaustive work of considering all operators when analyzing maps, as a particular connected automobile, even if it holds a SIM card from particular operator, might connect to any other cellular network in that area if the operator of the SIM is present in that area.

- Aggregating map information from several operators: Providers such as nperf (e.g., URL https://cdn.nperf.com/fr/map/5g) aggregate the coverage information from different sources. The information of coverage is obtained from several operators but also from end users (crowd sourcing) and from persons who maintain servers. Contrary to maps generated from uploading smartphone information with brief connections, with nperf there are continuously active tests ongoing about bandwidth and latency, with dedicated servers.
- Maps maintained by the regulators of the telecommunications in particular countries: these maps typically display more fundamental data, such as the precise coordinates of the base-stations together with their antenna angles

(azimuth and elevation). Additionally, they might provide measurements of signal strength performed by regular smartphones or with professional equipment by qualified personnel. They represent authoritative information, and the information is well maintained. In France for example, the regulator's maps are available at cartoradio, whose URL is https://www.cartoradio.fr/index.html#/ (accessed on September 16th, 2021).

2.7 Spectrum allocation for DCI

Radio spectrum is an important natural resource[4] on which the good functioning of DCI depends. The DCI for automobiles is mainly concerned about two classes of radio frequency spectrum: the cellular network spectrum and the ITS-G5 spectrum. The allocations of spectrum are subject to several levels of regulation: country-level, EU-level and international-level regulations.

Currently, there are disruptive changes in the spectrum allocation that happen worldwide. In particular the changes are being pursued in USA and in China. For the sake of brevity we describe the nature changes of spectrum allocation in Europe and in USA.

Such dramatic changes in spectrum allocation might impact the existing deployments in various ways. For example the DCI deployments at sites in SHOW might need to consider new strategies of deployment to abide to new regulations.

The currently established radio frequency spectrum allocation in Europe can be considered in two main parts:

- A part that covers bands at around 5.9GHz for ITS-G5.
- A part that covers bands at around 1.9GHz, 2.3GHz, 3.5GHz and 27GHz for 2G to 5G.

There are more bands existing (e.g. unlicensed spectrum for Bluetooth or WiFi, or licensed spectrum for PMR Personal Mobile Radio), but these are not considered in this section as they are not/rarely used within automated mobility.

Generally speaking, the 5.9GHz bands are 'unlicensed' whereas the 2G..5G bands are 'licensed'. The access technologies (e.g., the modulation techniques at PHY layer, or the access control at MAC layer) are very different between those parts. An 'unlicensed' band (5.9GHz) can be considered more free, in the sense that in order to use it, a 'license' from authoritative regulators does not have to be obtained. However, in these bands one must limit the power of the emissions to certain thresholds (e.g. 33dBm in Europe) and avoid certain well defined geographically areas (e.g. certain military campuses, or areas of certain mobile equipment from law enforcement). At the 2G..5G bands, an operator must first obtain a license from the regulator, or an end user must get a well identified and typically paid long-term subscription-based approval from an operator (who obtained a license from a regulator). The allowed power limits are higher than with ITS-G5: it is possible to emit at 1 Watt or 2 Watt (for a base station), compared to 500 milli-Watt (e.g. 33dBm) for ITS-G5. This leads to differences in several kilometers of range between an RSU and a base station (a base station covers much more). The licenses are relatively expensive and are distributed during an auction process from a regulator to about 3 to 5 operators in a country. This 2G..5G

[4] Spectrum is a natural resource like water, air, etc. The use of spectrum is shared among the public.

situation is very different from the ITS-G5 situation with respect of how revenues are generated.

The spectrum allocation for DCI is constantly being challenged and updated, depending on the evolution of the local European market and, indirectly, on the evolution of the ITS market in other countries, which produce and use the same kind of technology. Both parts of spectrum are evolving: the ITS-G5 part of spectrum and the 2G-5G part.

Current developments in the allocation of ITS spectrum:

- The ITS spectrum[5] allocation in Europe is being updated to interact with **railway** communications in the upper part of the spectrum, in a range from 5915 MHz to 5935 MHz. The interpretation is the following: 5 875-5 935 MHz is for ITS (notice an extension of the upper limit of typical ITS from 5925 to 5935), 5 925-5 935 MHz is for urban rail ITS; road ITS has priority in 5875-5915 and rail ITS has priority in 5915-5935; road ITS in 5915-5925 is only for I2V (Infrastructure to Vehicle). By way of elimination, the 5925-5935 is *only* for urban rail ITS.

  This road-rail spectrum decision is described in Article 3 of the document titled "COMMISSION IMPLEMENTING DECISION (EU) 2020/1426 of 7 October 2020 on the harmonised use of radio spectrum in the 5 875-5 935 MHz frequency band for safety-related applications of intelligent transport systems (ITS) and repealing Decision 2008/671/EC (notified under document C(2020) 6773)" which was consulted on October 28th, 2021 at the URL https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1602230223168&uri=CELEX:32020D1426

- Also, this ITS spectrum band (5875-5925MHz) is seeing suggestions of inclusion of uses of **LTE-V2X** technologies. The LTE-V2X technology is a cellular network kind of technology; the typical spectrum allocated for cellular kinds of technologies resides normally outside the 5875-5925MHz range. The suggestion of allocating parts of ITS spectrum to LTE-V2X (named 'C-V2X') is from 5GAA (). The position paper suggests a deployment band for 'C-V2X' at 5.9GHz in Europe. The 'C-V2X' technology is understood as being LTE PC5 interface mode 4 'sidelink'. 'C-V2X' is a cellular technology that is understood by many to not need assistance from the infrastructure, even though some C-V2X module manufacturers make 'V2I' claims for their C-V2X modules.

  The 5GAA proposal is to allocate the space 5905-5925 MHz in Europe to LTE-V2X (or 'C-V2X') for 'Day-1 safety related use-cases'.

  This 5GAA proposal represents a significant change to the current allocation in Europe. The current allocation of the 5905-5925 MHz space is for ITS in Europe (ITS-G5, 802.11p). If the 5GAA proposal takes effect then the respective space should be liberated by the current users.

  A similar proposal of taking bands of spectrum typically used for ITS (5875-5925MHz for 802.11p, DSRC) away and giving them to C-V2X is being proposed and currently implemented in the USA, by the FCC. However, the current plan in USA is different than the plan proposed by 5GAA in Europe. For one, the FCC plan is already ongoing towards enforcement, with a deployment plan, whereas the 5GAA plan is still in an early proposal phase; for

[5] The ITS spectrum is typically understood to be from 5875 MHz to 5925 MHz in Europe.

example, the FCC plan is that by the end of 2022 certain bands of spectrum should be freed by current users. A second difference, is that the FCC plan considers distributing parts of the ITS spectrum not only to C-V2X but also to new WiFi technologies, such as WiFi 6, WiFi 6E WiFi 7 and more. Third, the part that is proposed by FCC to be taken away from ITS and given to C-V2X is 5895-5905MHz rather than the 5905-5915 MHz part proposed by 5GAA.

- This more recent ITS band obtained from consideration of the urban rail ITS interactions (5875 up to 5935MHz instead of up to 5925MHz, as of year 2020, see the first bullet item) is considered as an important factor in current processes of decision of allocation of spectrum for WiFi 6E in Europe. The WiFi technology is important, because both the ITS-G5 technology (DSRC, 802.11p) and WiFi are part of the generic 802.11 standards; for example, 802.11p is an old variant of 802.11 operated in OCB mode; more recent IEEE proposals work on 802.11bd which represents an operation of 802.11ac in OCB mode; 802.11bd would offer a higher bandwidth than 802.11p for vehicles). Recently (October 2021) new smartphone devices are announced for deployment in Europe. They use WiFi 6E in a frequency range touching on the ITS spectrum. In order to make sure the two bands stay well separated (the WiFi 6E band and the ITS band) the Commission issued a Decision of harmonized spectrum at 5945-6425 MHz (see the document titled "COMMISSION IMPLEMENTING DECISION (EU) 2021/1067 of 17 June 2021 on the harmonised use of radio spectrum in the 5 945-6 425 MHz frequency band for the implementation of wireless access systems including radio local area networks (WAS/RLANs) (notified under document C(2021) 4240)", accessible at URL https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32021D1067&from=FR accessed on October 28th, 2021.)

  In this decision, an analysis of currently allocated ITS spectrum for road and rail is cited and guarantees of separation between WiFi 6E and ITS are given.

Current developments in the allocation of cellular technology spectrum: the 2G..5G allocation of spectrum is considering:

- extensions below the 1GHz limit (e.g. at around 750Mhz) for long roads. The lower the frequency, the better the signal is carried on longer distances across relief, which is typically the case of vehicles on roads.
- it also considers extensions in the 26 Ghz band (24,25 – 27,5 GHz) for beyond 5G future networks (e.g. 5G+), and at the 60 Ghz and even further in the THz domain for potential developments of 6G.

The current and future spectrum allocation of radio frequencies for DCI (ITS, cellular) will constitute guidance and will impact the future of deployment of DCI for autonomous shuttles.

3 DCI Components

In an earlier section the DCI (Digital and Communications Infrastructure) was described as a set of components, which can be split up into two categories:

- Data-oriented physical entities: RSUs and base stations, sensors, cameras, antennae, as well as traffic lights controller, variable (-length) message signs, GNSS augmentation RTK stations, proximity and detection sensors.
- Stored data and messages: e.g., real-time weather data of the road, traffic situation data.

The operational infrastructure, which can also be considered to be a component of DCI, is described in the section titled "Definition of DI from CCAM SP WG3".

Among the data-oriented physical entities, the RSUs and base stations are probably the most important for CCAM. A particular organisation also considers the term 'Roadside ITS Station' with a specific meaning relating RSUs and base stations.

In the following paragraphs a brief description of RSUs and base stations is provided from a generic point of view. The specific deployments of RSUs and base stations as used at SHOW sites are described in subsequent sections.

Among the stored data components, some of the most illustrative components are the platforms, the control rooms (or control centers) and backend systems. For example:

- SHOW Data Management Platform. This platform is described in deliverable D5.1. The data from all vehicles in SHOW is saved and edited in this platform. The data in this platform can be visualized in the SHOW Dashboard. The data can be utilized for new services including services that rely on Autonomous Driving.
- Control rooms: the DCI at Rouen in France includes a control room for real-time monitoring and sending instructions to the vehicles and human operators. See the section 'DCI in Rouen'.
    - In some of the control rooms data is situated on information systems. This data is used to configure the deployed Road-side Units, in a remote manner. Typically the RSUs must be configured with data of more static nature (e.g. advertising a local fixed Point of Interest), or of more dynamic nature (e.g. advertising an ongoing accident, need to slow down).
- Light data on ephemeral lightweight and highly dynamic 'configurators'. Many of the deployed RSUs include a capability of being configured remotely. This offers the advantage of eliminating a need for a human operator to go to the RSU placement to configure it – they can be configured from anywhere in the Internet. However, many RSUs are not configured from a control centre or from a backend system. Additionally, some of the RSUs are operating more in a *standalone* manner: it means they can continue working even if they are not connected to the Internet.

  Additionally, some RSUs are not connected to a backend centre or control rooms. For these RSUs, the configuration still happens remotely, but the 'configurator' is not fixed in a control room or in a backend server. The 'configurator' might be a laptop of a human operator which holds the data to be configured in a very ephemeral manner (maybe from a USB dongle); once the 'configurator' computer has configured the RSUs, the configurator deletes the local data; on another day maybe another 'configurator' computer connected on other parts of the Internet will configure the RSUs.

- There are other examples of stored data components at other DCI at other sites.

3.1 Road-Side Units

A **Road-Side Unit** is typically a gateway with wireless connectivity. The designation 'RSU' is principally related to its capability of offering or using the ITS-G5 kind of wireless connectivity at 5.9GHz. However, depending on manufacturer's features and on the purpose of deployment, an RSU might use, in addition, several other kinds of wired and wireless connectivity, such as 4G/5G and Ethernet. An RSU that uses both ITS-G5 and 4G/5G could be considered also as a 'Roadside ITS Station'.

Among the deployed RSUs some have IP (Internet Protocol) capabilities. The RSUs deployed within the SHOW project are described in the section titled "Digital and Communication Infrastructure in Support of Automated Shuttles at Sites"; for each site, there is a sub-section that describes the respective ITS-G5 deployment, if present. The IP capabilities in a RSU serve different purposes:

- Offer a remote management and configuration capability for the RSU. This allows an operator, or a software module, situated far away from the RSU deployment site to control its operation. This includes but is not limited to configuring various parameters of the CAM messages advertised by this RSU, the dynamic triggering of warning messages (DENM) to be announced to the road and the configuration of system-specific parameters such as time. The remote management and configuration capability is happening on the 4G/5G interface of the RSU. The protocols used to realize this capability are SNMP RFC 1157 and HTTPS RFC 7231.
- Offer Internet connectivity to vehicles connected to the ITS-G5 interface of the RSU. This allows one or several vehicles to connect to the Internet via their onboard ITS-G5 interfaces, and not via their onboard 4G/5G interfaces. An RSU offering Internet connectivity to vehicles via ITS-G5 uses the standard "Basic Support for IPv6 Networks Operating Outside the Context of a Basic Service Set over IEEE Std 802.11", RFC 8691, December 2019.

Connecting to the Internet via an ITS-G5 interface offers several advantages compared to 4G/5G, including a higher bandwidth and lower latency (within the same generation, the 802.11 technology will always[6] offer a higher bandwidth than the respective cellular technology: in year 2005 the 802.11p bandwidth was 16mbit/s while the 3G technology was at 1mbit/s; in year 2021 the 802.11bd bandwidth is expected at 1.5gbit/s while 5G is expected at 1gbit/s; see the figure below titled "Evolution of wired and wireless communication"). However, the range of coverage as permitted by the allowed power levels is lower for ITS-G5, hence the naming 'short range' compared to a 'longer range' of 5G. To extend the 'range' of ITS-G5 the protocol IP is used: it allows indefinite extension beyond the radio range (to the size of the internet itself) by means of IP hop-by-hop forwarding of datagrams. The IP hop-by-hop forwarding, or IP routing, is described in several scientific publications.

The following figure illustrates a topology using a RSU connected to the Internet which offers Internet access to the vehicles nearby. In this figure, the arrows represent wireless antennas. The antenna of the vehicle is connected to the antenna of the RSU,

[6] This statement is derived from an analysis of recent developments. It is true that as time advances the difference between bandwidths of 802.11 and cellular technology seem to minimize, at the same time it is also true that since their inception (decades) the difference has always been present (802.11 offers more bandwidth than cellular).

forming an IPv6 subnet. The RSU is connected to the Internet with a wired line. Overall, the Vehicle is connected to the Internet via the RSU.

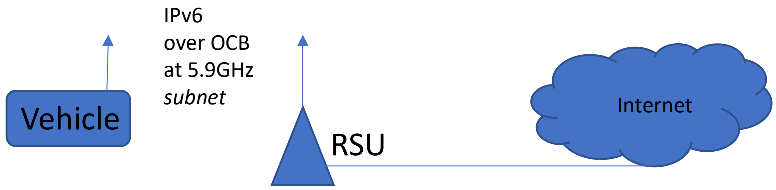


Figure 10: Illustration of an RSU offering Internet connectivity to a Vehicle using RFC 8691

This kind of deployment of RSU to offer Internet access to the Vehicle is almost similar to deployments of RSUs that don't offer Internet access to Vehicles, even though these RSUs are connected to the Internet. These non-Internet-offering RSUs do not use RFC 8691. Their main goal is to advertise CAM messages on their ITS-G5 interfaces; the connection between these RSUs and the Internet is mainly dedicated to configuring parameters on the RSUs remotely (the contents of the CAM or of DENM message).

A more common RSU deployment (the most RSUs deployed, actually) is an RSU that has no link to Internet at all. It is operated as standalone equipment, does not offer Internet access to vehicles and can not be configured remotely. It does advertise CAM messages, or PoIs or POTI, to vehicles, but not DENM.

The use of RSUs to offer Internet connectivity is realized experimentally in a few places in Europe, even though they are not used in this project.

In the following sections several descriptions of DCI at sites of SHOW are provided; in these sections several kinds of Road-Side Units from various manufacturers will be illustrated. These RSUs are used for:

- Advertising CAM and DENM messages. Advertise PoI information.
- Advertise time and position information, such as location corrections, to vehicles.
- In other deployments (outside of SHOW) they are used for signalising entering and leaving to and from dedicated purpose-specific areas such as platooning areas, or others. They are also used for establishing more secure connections with IPv6, in project SYNCOPARK in Germany. Also in other deployments they are used for offering Internet connectivity, and for signalling road works (mobile RSUs).

3.2 Bandwidth constants in the evolution of WiFi, cellular and Ethernet

Finally, for clarification, we come back to a statement about bandwidth evolution of various technologies. Very often in the current state of deployment of networking technologies for vehicles a competition is invoked about two different technologies: 5G-V2x (also sometimes referred to as C-V2X) and ITS-G5. The persons in charge of making such deployment are facing questions about which of those two technologies should be deployed.

In order to make educated answers with respect to that dichotomy (in short 5G-G5 dichotomy) several factors should be considered such costs, frequency regulation and relevant KPIs (bandwidth, latency, distance range).

From a bandwidth[7] standpoint, it is advantageous to consider the evolution of these technologies, identify constants and propose qualified forecasts.

We illustrate in the following table the evolution of bandwidth for different communication technologies (Ethernet, WiFi, 5G..6G) as noticed in the past. This table also mentions a forecast of 6G to be 10 Gbit/s in year 2025. The reason of this number (10gbit/s) stems for the noticed evolution of bandwidth of cellular systems in the past years. In year 2015 the bandwidth on cellular was 100mbit/s so in 2020 1Gbit/s. The term '6G' designates the generation after 5G; but it might be that a new 5G+ technology might be the same as early 6G prototypes. In the table, the bracket numbers refer to documents pointed by the next figure.

Table 5: Evolution of bandwidth of wired and wireless technologies in the recent past (source: CEA in SHOW)

	100 Mbit/s	1 Gbit/s	10 Gbit/s	100 Gbit/s	1 Tbit/s
Year Ethernet	1995 [6]	1999[1]	2006 [7]	2010 [8]	2020 [9]
Year WiFi	2009 [11]	2013 [12]	2021 [2]		
Year 4G/5G/6G	2015 [5]	2020	2025 [14]		

This simple table permits a quick interpretation of the past and allows for a brief forecast in the near future: 10gbit/s will be permitted by 6G in 2025. It is also possible that in that same year 2025 a WiFi technology might reach higher-than-10gbit/s (maybe 100 gbit/s). Thus, in year 2025 still – as of today in year 2021 – the higher bandwidth and lower latency are offered by WiFi-kind of technologies, and not by cellular.

The evolution of cellular systems prior to 4G was the following is analysed in two perspective. In the first perspective, a yearly plan lists the years of announcements of standards from 3GPP. In the second perspective, the deployment announcements are listed.

The announcements of standard documents from 3GPP is the following (the 3GPP body specified 3G, and not 2G which was specified by ETSI):

- 3G UMTS 1999-02-12 (SMG-#28).
- 4G Release 8 2008-12-11 (SA#42).
- 5G Release 15 2019-03-22 (SA#83).

This list was published on the 6GIP email list of IETF, visible at the following URL: https://mailarchive.ietf.org/arch/msg/6gip/7l3MZnCowpcWhYw4R-e-9xR7d_0/ (accessed on December 30th, 2021).

This list expresses the following separation between generations: 9 years, 11 years. It can be qualified as an apparent deceleration in separation between generations.

[7] Bandwidth and latency are two distinct KPIs of communication systems, even though there are tight interrelations noticed in practice. For example, higher bandwidth almost always means lower latency (4G has higher bandwidth *and* lower latency than 3G).

Thus, based on this data a forecast can be made: 13 years between 5G and 6G. This means that 6G might be specified in year 2032.

Another perspective of analysis of time between generations is that of dates of deployment. The deployment phases of various generations varies a lot between countries and operators. Only an approximate analysis can be performed. We propose the following analysis:

- The term 1G (first generation) was never actually used during its deployment. The term 1G appeared only when the term 2G appeared, to situate 2G in contrast to it: 1G was analogue and 2G was digital; moreover, it was a comparison of an European technology being better than a technology developed and deployed mostly in USA. By comparison, where the Internet was an American success further replicated in Europe, the GSM (2G) was an European success later replicated in USA with 3G handheld phones that were compatible both in Europe and in USA.
- The 2G networks appeared in 1991 (a first deployment by operator Radiolinja in Finland),
- Fourteen years later, it was followed by 3G starting in 2005 (a first deployment by operator '3' – Tre – in Italy).
- Since then, the evolution has accelerated with 4G 10 years later and then further accelerated with 5G at 6 years later, approximately.

By this observation of an acceleration of deployment of cellular technology, it can be forecast that 6G first trials might appear 5 years after 5G (2025?) and then 7G at 4 years after (2029?).

However, performing forecasts is not easy. Looking at more details of the recent evolution, there are several things that need to be noticed in order better qualify the details:

- The physical (PHY) layers of both wireless technologies – cellular and wifi – seem to converge to certain variants of OFDM. In this way, the ways to pack, or encode, more bits, are the same. Thus, in theory the bandwidths might be the same in the future.
- The allocation of spectrum bands to various technologies is directly impacting the availability of higher bandwidth: more spectrum implies more bandwidth. The spectrum allocation is an administrative operation, and not technological. It is possible that if there is thrust for more allocation of spectrum for cellular technologies than for WiFi, then the WiFi-kind of technologies will offer lower bandwidth.
- Deciding on dates of the past is difficult in itself: a certain technology is announced in a prototype form in a certain year, then demonstrated publicly maybe a year later, then standardized and then available for the large public in yet another year. If the past dates are imprecise, so the future dates might be imprecise as well.
- Wired technologies for Ethernet are divided in two main classes: optical and copper. This distinction is further complicated by hybrids like copper-transmission with optical-interconnect. In this way, it is difficult to use a single year to date the first demonstrator of an Ethernet at a particular gigabit per second bandwidth.
- Despite a constant cadenced evolution of cellular systems (a roughly 8-year period is noticed between generations 3G, 4G, etc.) the Ethernet technologies seem to be slowing in recent years.
- The quantum communication interconnects add a new dimension in the near future. Their theoretical ability of instantaneous communication, or even of the

counterintuitive receive-before-send conclusion of some theories, have a strong impact of the definition of the bandwidth term in itself.

- Contrary to our suggestion of a constant of higher bandwidth for WiFi than for 5G, it was noticed by other authors that that constant might no longer hold true as of these days. This was described in Ian Fogg, VP Analysis, The State of Wifi vs Mobile Network Experience as 5G Arrives, Nov. 2018, URL: https://www.opensignal.com/sites/opensignal-com/files/data/reports/global/data-2018-11/state_of_wifi_vs_mobile_opensignal_201811.pdf
- A reader should note that the forecasts made in this paragraph about bandwidth, represent the opinion of one particular author of this document, and does not represent an agreed opinion of the entire project. One particular reviewer expresses that some of the forecasts made in this section cannot hold, and has provided persuasive reasoning for that expression.

Having presented all these warnings, let us introduce a more detail analysis of the past, together with a longer term perspective on the evolution of bandwidth. The following figure presents it:

	bandwidth							
	100mbit/s	1Gbit/s	10Gbit/s	100Gbit/s	1Tbit/s	10Tbit/s	100Tbit/s	1Petabit/s
Year Ethernet	1995[6]	1999[1]	2006[7]	2010[8]	*2020[9]*	*2030[10]*	*2042[10]*	*2055[10] or 2026[15]*
Year WiFi	2009[11]	2013[12]	2021[2]	*2035[3]*	*2055[3]*	*2080[3]*	*2110[3]*	*2145[3]*
Year 4G	2015[5]							
Year 5G		2020	*2025[13]*					
Year 6G			*2025[14]*	*2035*				
Year 7G				*2035[4]*	*2040[4]*			

[1]: 802.3ab Ethernet 1gb/s on unshielded twisted pair ratified in 1999.
[2]: 802.11ax in year 2021, demos at CES 2018 with 11Gbit/s.
[3]: WiFi can offer higher than 10Gbit/s only if more spectrum is allocated than today (year 2021).
The evolution of spectrum allocation for WiFi has too been a constant in the past (width of channel, number of channels).
The forecast of years is based on a supposed growing periodicity of 5 years, 10 years, 15 years and so on (today is year 2021).
[4]: as of today (year 2021) one can only speculate about what bandwidth 7G might support and when.
These forecasts are logically derived from the history of 4G and 5G.
[5]: first deployments of 4G at 50mbit/s in year 2010 in France, and at 150Mbit/s in year 2016 in France.
[6]: 802.3u Fast Ethernet at 100mbit/s in 1995.
[7]: 802.3aq 10gbit/s on fiber.
[8]: 802.3ba 100gbit/s on fiber.
[9]: Terabit Ethernet expected in year 2020.
[10]: an approximate numeric forecast based on the sequence of earlier years: 1995, 1999, 2006, 2010, 2020.
Also, the public draft of the Partnership SNS states in 2021 that
"Terabit-per-second (Tbps) links are expected to become a reality within the next five years."
[11]: 802.11n
[12]: 802.11ac
[13]: Forecast based on the evolution of bandwidth of 4G to 5G. This is 5G+.
[14]: in 2025 the deployed 5G+ will reach same bandwidth as early 6G prototypes.
: designates a time constant cut through. For example, the rightmost red dotted line cuts through the year 2035.
This cut means that in year 2035 the deployed 6G+, the initial 7G prototypes, the WiFi and the Ethernet will be at 100Gbit/s, 1Tbit/s and 10Tbit/s, approximately.
[15]: the HE Cluster 4 "HORIZON-CL4-2022-DIGITAL-EMERGING-01-39" calls for projects starting in year 2022, for a typical duration of 3 to 4 years that target 10 terabit/s for optoelectronic and 1 petabit/s for optical fibre (not sure whether this applies to portable devices).
Also, the public draft of Partnership SNS states in 2021 that "the development of fundamental technologies able to reach rates of 10 Terabit/s optoelectronic Interfaces and multi-Petabit/s for optical fibre systems."

Figure 11: Comparison of bandwidth growth for wired and wireless links for mobile computers: origins, constants and forecasts. Source: CEA in SHOW

In this figure we list on the columns the bandwidth numbers; each column is named by a number that is one order of magnitude larger than the preceding. In the row names we list Ethernet (independent of optical or copper), WiFi and cellular technologies

4G..7G. The rows contain approximate years of specification or deployment. For each year we cite between brackets a number. That number is below the figure and points to a proof of why we have proposed that year.

The red dashed curves express the ‘constants’: a cut through of a same year across technology. Following such a constant it is possible to see, for example that in year 2020 5G is at 1Gbit/s, WiFi at 10gbit/s and Ethernet at 1Tbit/s.

The years most towards right (e.g. 2042, 2055), and the highest bandwidths (e.g. 100Tbit/s and 1petabit/s) are expected but these numbers are the least precise. The bandwidth 10 petabit/s has been deliberately left out from the table but it is also possible that it might arrive before the mentioned years.

The important is the constant: up to now, and presumably in the near future, this constant will hold: the best WiFi-kind of systems provides more bandwidth and lower latency than the best cellular system at a given point in time.

3.3 Base Stations

A base station is a telecommunications equipment used principally to offer 4G/5G connectivity to the general public and also to vehicles. This connectivity is principally a connectivity to the Internet at large, even though it might offer services that are specific to the immediate operator, or voice, SMS, time and location services. The Internet connectivity and the operator-specific services are all based on IP. The voice (e.g. permanent redirection of calls, simultaneous calls, and similar) and SMS services (e.g. notifications, re-transmissions), and time and location are principally a link-layer specific service that does not use IP. These specific non-IP services are not dedicated to vehicles, even though some cars do use SMS for vehicle specific operation such as unlocking the doors in a carsharing service.

A base station that is dedicated entirely to ITS, could be considered to be a Roadside ITS Station. A Roadside ITS Station might, in addition to cellular technology, offer ITS-G5 technology.

The deployment of base stations varies extensively from country to country, from region type to other type (e.g. city, rural, highway, mountain and others), from frequency to frequency (e.g. 1.9GHz vs 2.5GHz) and from generation to generation (2G..5G). With respect to IP, it can be considered that the 2G-only deployments are little or not at all used by the vehicles to connect to the Internet, whereas the 5G deployments are used mostly to connect to the Internet. In terms of numbers of vehicles, it can be assumed, that most vehicles connected to the Internet today in Europe are on 2.5G (on GPRS, considering the deployed cars with running eCall and live traffic features onboard) with a strong tendency to move to 3G.

4 Digital and Communication Infrastructure in Support of Automated Shuttles at SHOW Test Sites

In the following sections several descriptions of various components of DCI at sites of SHOW are provided.

There are two kinds of sites: Mega sites and Satellite sites. The smaller sites in SHOW sites are the Satellite sites.

In these sections several kinds of Road-Side Units deployment from various manufacturers will be illustrated. These RSUs are used for:

- Advertising CAM and DENM messages.
- Advertise time and position information, such as location corrections, to vehicles.
- In other deployments (outside of SHOW) they are used for signalising entering and leaving to and from dedicated purpose-specific areas such as platooning areas, or others. Also in other deployments they are used for offering Internet connectivity, and for signalling road works (mobile RSUs).
- The stored data, visualization at control centers and HD maps are also presented at certain sites.

Also, descriptions of placement of base stations or the radio coverage identified along roads are often included.

The goal of this section is to describe in more detail the DCI that is already deployed and trialled at pilot sites.

4.1 DCI at Trikala, Greece

4.1.1 Pilot Description

The almost 6,7km long route for the automated shuttles runs between the city center and the intercity bus station covering also specific points of interest of the citizens such as Hospital, Milk Factory, major suburbs and villages.

In summary, the ODD related requirements for the specific route include:

- support for mixed traffic with passenger and heavy vehicles on the lanes,
- support for signalized intersections, roundabouts, adjacent bicycle and pedestrian routes and street side parking and pedestrian crossings.
- support for seamless operation of the autonomous vehicles which requires adequate 4G/5G network coverage along the entire length of the route, high data throughput for video data transmission and low latency to support video streaming service, VoIP and exchange of data between the Remote Control Center and the vehicle. Full base station (BS) coverage is also provided for the entire route of the vehicle, ensuring minimum handover when moving from a BS to a neighbouring BS.

4.1.2 Digital and Communication Infrastructure

The **Trikala Fleet Management Platform (TFMP)** is depicted below and includes apart from the main cloud data management system responsible for SHOW data collection and KPIs computation, the interface to a cloud **Traffic Management Center**

(TMC) and Traffic Light Signalling Monitoring, Control and Management (TLMC). In the lower layer, the following actors are involved:

- CAVs nodes (shuttles and cargo vehicle)
- Pedestrian nodes (V2X enabled smart devices)
- Smart city nodes (traffic lights controllers, road sensors for traffic monitoring)

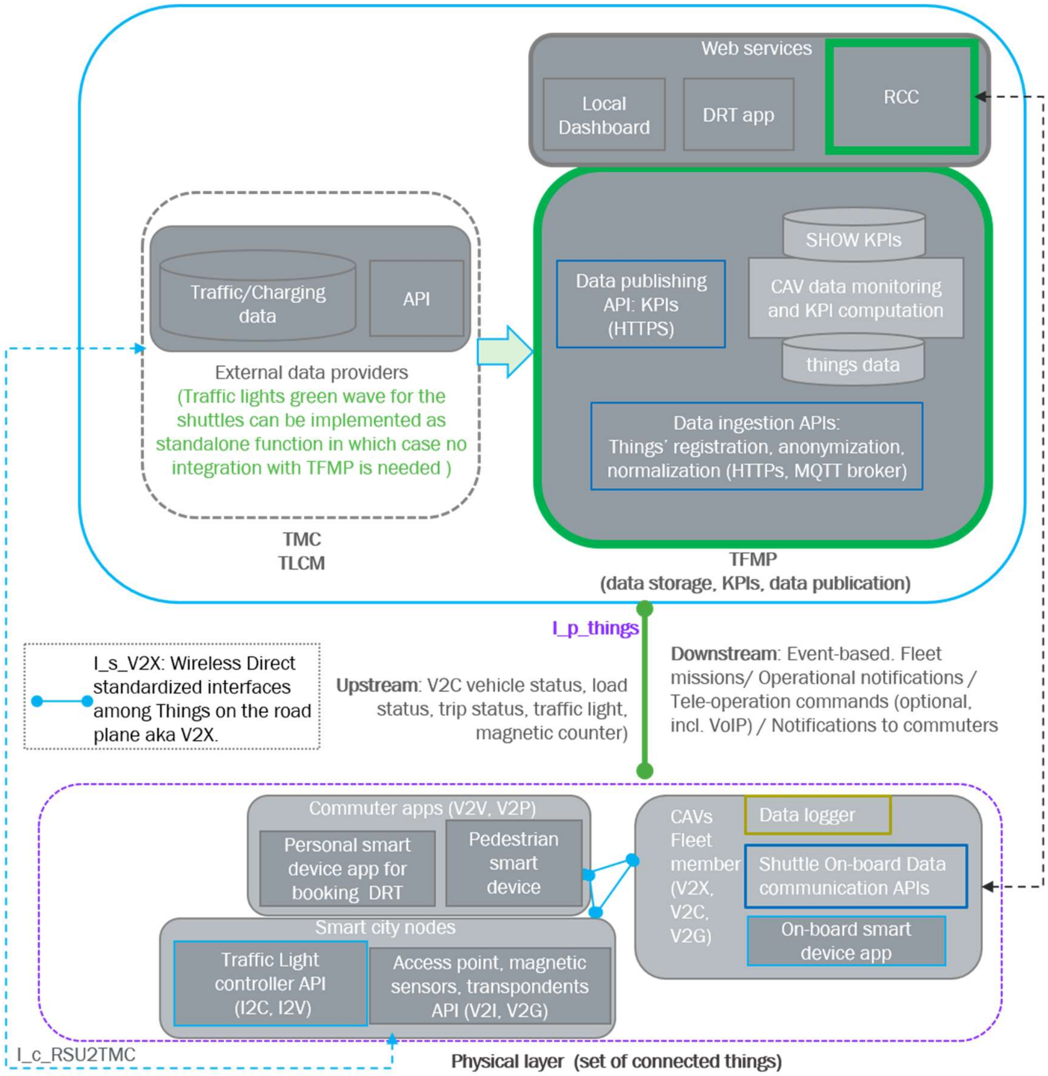


Figure 12: Trikala FMP architecture diagram (final architecture to be provided in D4.3)

The shuttles serving the specific route at Trikala are capable of independent navigation and locomotion in an urban environment, within real traffic conditions in mixed traffic. The autonomous vehicles actual driving is executed mostly without human intervention. Human intervention is mandatory from the Greek Legislation to be executed remotely in order to go over limited number of unforeseen, escalated, or difficult driving conditions. In addition, physical human intervention is expected in case of an impending accident, daily maintenance like charging, and other similar limited number of events that stop the actual service and cannot be fulfilled remotely.

Trikala Remote Control Center

Respecting the current Greek legislation, at Trikala satellite site a **Remote Control Center (RCC)** has been developed, where a live feed of cameras mounted on the vehicle is provided using 5G/4G network communication. In more detail, 5 cameras, one looking in front, one on each side mirror, one looking at the back of the vehicle and one on the vehicle ceiling showing the vehicle interior, will provide a live feed. In addition, an emergency phone line is provided inside the vehicle (VoIP). The RCC will be also equipped with i) an emergency button giving the ability to smooth breaking and immobilization of the vehicle and ii) remote execution of overtaking maneuvers (optionally only if safety conditions allow it).

The RCC's operation is depicted in Figure 13.

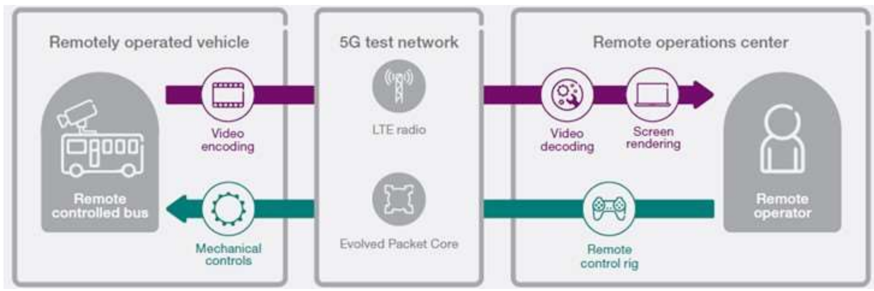


Figure 13: Remote Control Center operation

As aforementioned, the other fundamental and central components of the Trikala city's digital infrastructure are the TLMC, operated via the TMC and the TFMP, operated via the RCC. These two central components are used for:

- Dynamic and real-time adjustment of the Traffic Lights Signalling program based on current traffic conditions
- Real time remote monitoring of the Traffic Light Signalling system.

Connectivity and remote operation functionalities and capabilities

Data transmission

The types of data transmitted from the vehicle to the RCC via the network are:

A. Raw data that will come from the telematics device and will include GPS coordinates of the bus position, speed, direction, odometer & events of interest for the vehicles on a digital map (e.g. start, stop, engine start-up, peripheral status if the corresponding information is received from the vehicles, etc.) which are sent by the vehicle via TCP/IP to a central server at the RCC, within a certain period of a few seconds. For this type of data, the GPRS service is considered sufficient for transmission.

B. VoIP communication through a network telephone device.

C. Video data from the 5 cameras placed on the vehicle in order provide to the RCC a complete view mainly of the external but also of the internal environment of the vehicle, as according to the regulation.

Latency

In the case of 5G network coverage, in addition to the more than enough available bandwidth for video transmission, a minimum latency is provided, in order to ensure the seamless communication between the RCC and the vehicle. For example, during tests the time counting starts from the moment the operator notices an unexpected obstacle in the route and reacts, by sending an activation command e.g. braking, then the command reaches the vehicle via the 5G network and ends when the vehicle starts to slow down until its immobilisation was observed. The time was around 185 ms.

The most important contribution to this duration was the response time of the electromechanical peripherals (servo driven mechanics, measurement & control sensors), then the delay in video processing (here possibly to reduce the time delay to be used in UDP or RTP transmission) and then Network delay (RTT, round-trip time). Network RTT was below 50 ms (theoretically it ranges between 20 and 60 ms). However, in some areas with probably more reduced coverage, RTT exceeded the above size. The uplink throughput was measured at 10-20 Mbps. In 5G the RTT is expected to be even smaller at 4 msec, and the upload data throughput at 1 Gbps.

Vehicles' monitoring and data storage

An essential device in the RCC is the DVR (digital video recorder) which is a specialized computer designed to manage analogue and digital video signals, digitize the analogue, compress and store them in the hard disk and transfer them via video output to a monitor screen or via internet to the appropriate destination with DDNS services (Dynamic DNS, Domain Name System). The DVR has the ability to present cameras simultaneously on a screen and set the recording to specific days and hours or even to only when it detects movement from the cameras. It also provides HDMI output (High-Definition Multimedia Interface) for monitor and VGA connection (Video Graphics Adapter). The cameras installed in the vehicle send the image data to the control centre via the network and, using the IVMS 4200 software, they are stored and kept for a period of 2 weeks. At the same time, the front camera and the internal one have the possibility of storing the recording locally on memory cards that are installed inside them. This data will be kept for a few days.

The network architecture for video data transmission from the vehicle to the remote-control centre is shown in the following figure:

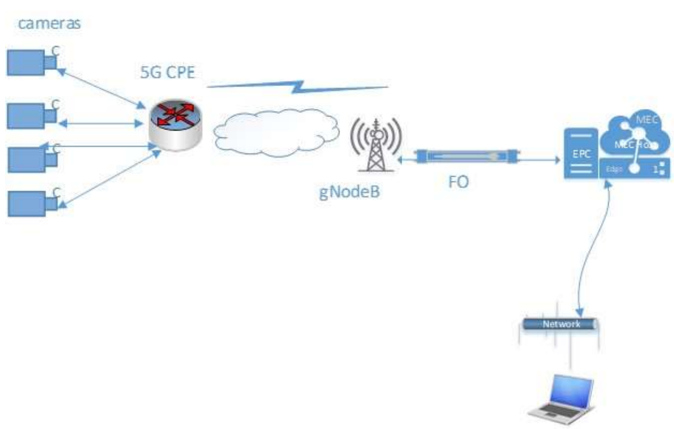


Figure 14: Video Transmission.

Trikala Traffic Light Control and Management

The **TLCM** will be hosted in the Cloud and will have the possibility in a nutshell of:

i. two-way communication with all traffic light controllers installed along the route,
ii. send commands to traffic light controllers to implement a specific traffic signalling program,
iii. to receive current data of the traffic signalling programs
iv. to receive current traffic data from the Traffic Management System,
v. monitor the operation of signalized junctions,
vi. to carry out diagnostic functions on field equipment,
vii. store in the database
viii. provide a user-friendly interface with authorized access, and

ix. be able to receive data for the bus priority system from the Fleet Management System.

As regards bus priority, the system includes the operation and control of the traffic lights of crossroads as well as the installation of wireless connection of the vehicles with the traffic lights, so that every time an emergency vehicle has to reach a specific destination, the controller gives priority with green wave on the roads from which it passes and interrupts (in red) all the others.

For automated vehicles to pass through traffic light junctions, traffic lights must light red on all lanes of other vehicles colliding with the automated vehicle lane and green on the automated vehicle lane. Each automated vehicle is equipped with a device that takes its position via GPS and recognizes the approach to the junction, via the wireless two-way connection with the device located at the traffic light (controller), sends request to be allowed to cross the junction. The traffic light controller communicates with the automated vehicle and manages the requests, instructs the traffic light controller to make the appropriate adjustments to the traffic light and after receiving the confirmation sends back to the automated vehicle the transit order. If for any reason a transit order is not sent or received from the device of the automated vehicle, it does not cross the junction. When the vehicle passes the junction and after a time delay which is adjusted according to the topography of the junction, the traffic lights return to normal operation. The traffic light remains in normal operation until the next automated vehicle approaches.

Trikala Fleet Management Platform

The **TFMP** provides the remote operator with comprehensive real-time monitoring of bus position as well as events, traffic and route-related reports with the cooperation of the TMC. Specifically, the remote operator can monitor in real time the current geographical location of a bus on a digital map and receive information about its position, speed, direction, and other statuses of the bus, such as starting, stopping, speed, low battery, door opening. Also, the remote operator will be able to create itinerary reports with the above data for specific periods of his choice, so that it is possible also to monitor and assess the movement of the fleet in the past.

The **TFMP** consists of three subsystems:

1. The Vehicle Fleet Service which is the main system responsible for pumping GPS data from the manufacturer's external subsystem (GPS Device Service that undertakes the communication with the devices) through API (Application Programming Interface), their processing and the synthesis of the generated information based on business logic, its storage in the System Database and finally the dissemination of information and communication with the applications used by remote operators.
2. The Fleet Vehicle Client Application (installed on the operator’s computers (PCs), which offers the overall supervision of the application and constitutes the user interface with the system.
3. The Vehicle Fleet Database, in which all the necessary data for the operation of the above two applications are stored.

Interaction with VRUs (Vehicle and Infrastructure)

VRU related infrastructure

In Trikala pilot site one RSU will be installed in one signalized intersection to monitor the pedestrian crossing area in order to detect possible dangerous situations (Figure 16). The RSU device will be placed on a traffic light pole, or in a suitable location with clear view to the zebra crossing. This device integrates many communication technologies and it has the following capabilities:

- G5 radio
- PC5 side link
- 5G/LTE/4G/3G
- WiFi/BLE
- Gigabit Ethernet
- GNSS with RTK base station
- Optical Camera,
- RF mmWave RADAR
- ETSI C-ITS full V2X software stack

Additionally, in Trikala site a special prototype handheld device that has been designed and developed by CERTH/HIT will be used to increase the interaction between VRUs and AVs. This device uses G5 direct communications with vehicles and infrastructure in order to exchange awareness and notification messages with other connected actors. It evaluates dangerous situations by itself and it uses audio and visual warning alerts via HMI when a risky situation is predicted (Figure 15).

More details on interaction with VRUs can be found in Deliverable D7.3.

Figure 15: VRU interactions with V2X and handheld device

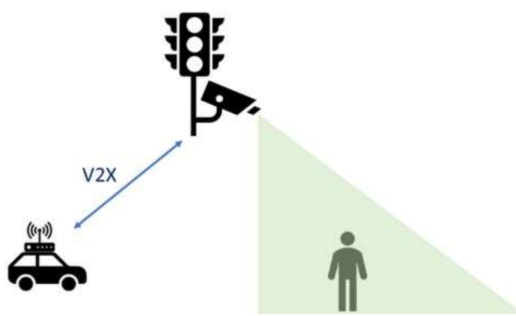


Figure 16: VRU interactions with V2X and camera

4.1.3 Infrastructure Equipment specifications for traffic management related activities

Traffic controllers

Traffic controllers are going to be deployed within the Trikala site route in major crossings. The controllers will meet the requirements of the Technical Regulation "For the Determination of National Requirements for traffic light and pedestrian traffic controllers" (Decision DMEO / o / 1925 / g / 254, Government Gazette 1321 / 23.5. 2014, issue B!).

Router

The 4G (router) technology (ethernet to gateway) for mobile networks will allow the traffic controller to be connected to the Light Signaling Center via the internet. The router will have at least one digital input and one digital output, with the possibility of remote management via SMS messages from default mobile phones (e.g., the contractor and the competent service body) so that an immediate warning in case of failure can be executed as well as telematics control on the controller.

The dedicated router should have the following technical characteristics:

- Web management
- Firewall
- Secure access via VPN
- 2 Ethernet ports
- Transmission speed 10/100 Mbps
- Supported protocols: TCP/IP, UDP/IP, FTP, HTTP(S)
- Antenna: SMA antenna socket
- SIM slot
- 1 digital input and 1 digital output
- Possibility of remote management via SMS
- Operating voltage range: 10V DC - 30V DC
- Power consumption: <10 W
- Operating temperature range: -20°C to + 70°C

Equipment for enabling *magnetic* type vehicle detection (optional, might be included at a later stage of the project)

Wireless vehicles' detection sensors of magnetic type

The principle of operation of magnetic type vehicle detectors is based on detecting the presence and / or passage of vehicles, by measuring the change in the earth's magnetic field caused by the presence above their sensors of the metal mass of vehicles. The magnetic type sensor has a function similar to induction loop detectors and is used to detect the presence and / or passage of vehicles in a traffic lane. The sensor detection zone extends in a circle, about 2 meters in diameter.

Wireless access point (Access Point)

The wireless interface module is mounted on a mast near the traffic controller at a height of approximately 6 meters and communicates wirelessly with the local magnetic sensors and / or their transponders. The output and transmission of the signals from the interface to the inputs of the traffic controller is achieved through building units (boards) that have a relay with the necessary contacts or by another suitable method compatible with the respective traffic controller, such as e.g., via TCP / IP communication protocol.

Wireless transponders for magnetic vehicle detection sensors

The transponder is used for the restoration of communication in case one or more magnetic sensors are planned to be placed at the point of intersection outside the scope of the corresponding interface unit and will have built-in batteries for its autonomous operation. The data transmission frequency, the communication protocol and its other technical characteristics will be suitable and compatible for its communication both with the interface unit and with the corresponding magnetic sensors.

4.2 DCI at Thessaloniki, Greece

4.2.1 Pilot Description

The Thessaloniki pilot site, which will execute two use cases within the SHOW project, namely 1. Shared mobility services using connected and automated vehicles and 2. Integration of CAVs into traffic management, is comprised of extended parts of the metropolitan road network as depicted in the following figure:

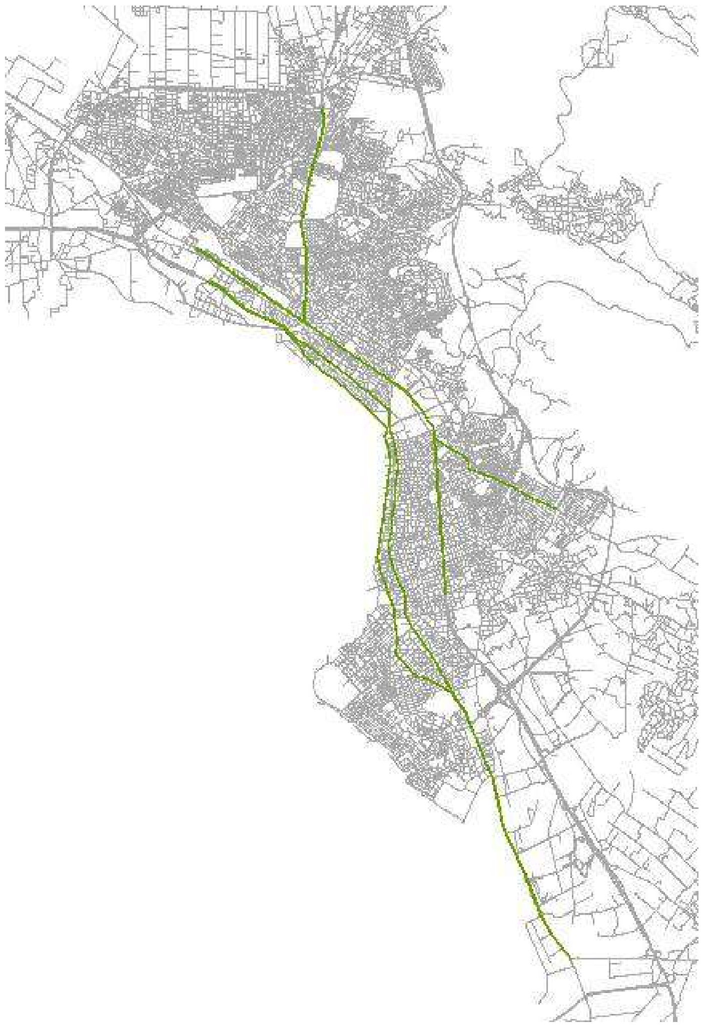


Figure 17: Thessaloniki pilot site in SHOW

4.2.2 Digital and Communications Infrastructure

The above shown part of the road network is already provided with LTE C-ITS services, including the following standard messages: CAM, MAP, SPAT, DENM and IVI. A C-Roads compatible geo-messaging platform is used for the broadcasting of the C-ITS messages Furthermore, ITS G5 Roadside Units are currently being installed at selected intersections. The broadcasting of the C-ITS messages is coordinated through a C-ITS enabled dynamic traffic management module.

Furthermore, there are approximately 45 Bluetooth detectors installed at major intersections of the metropolitan area, data from which is used for real-time travel time estimation.

The open data portal of CERTH-HIT, the National Access Point, as well as standard interfaces with existing traffic management systems serve as real-time data feeds for operational purposes.

Concerning traffic management, an ongoing project (to be finalized by Q4 2021) is integrating the existing traffic management centres under a common and integrated environment, which also supports the deployment of dynamic traffic management scenarios with the use of C-ITS services for connected and automated vehicles.

4.3 DCI at Tampere Satellite Site, Finland

4.3.1 Pilot Description

The test area of Tampere Satellite Site (the smaller SHOW sites are called satellite sites) is depicted in the map in the figure below. It is roughly the same as the Tampere test communication environment area called “L1” communications network that has been built by Nokia to enable future smart city services. This private network supports pilot operations in the area and consists of eight Nokia Flexi Zone Micro Outdoor, LTE-A base stations as shown in the 3rd figure below titled “Nokia Flexi Zone Micro Outdoor, LTE-A base station locations”. One of the key objectives in the area is to guarantee a sufficient band for automated vehicles even if commercial networks are too crowded.

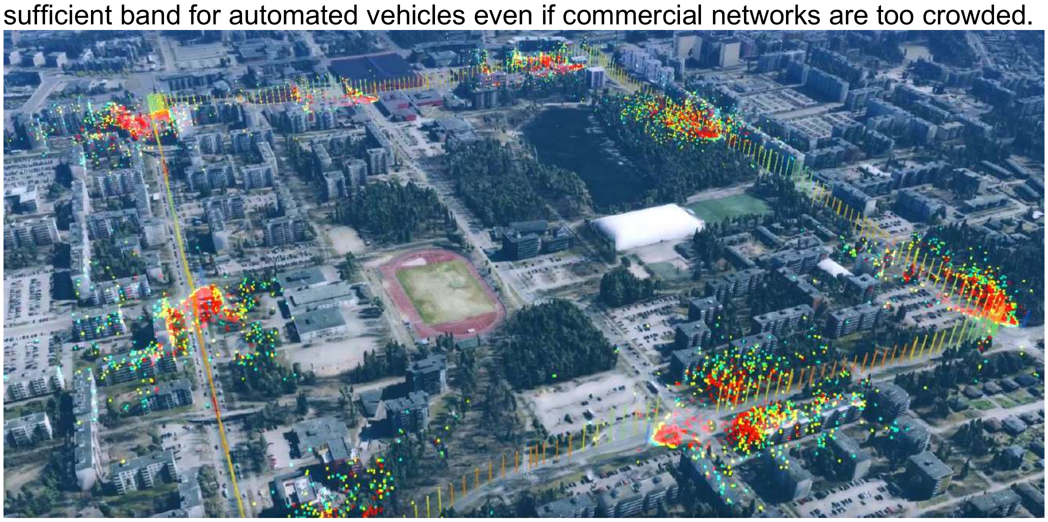


Figure 18: The points are showing coverage of the test network (source: Sitowise Oy)

The following two figures tabulate the specifications of the communication components in use and show the eight eMBB base stations, installed on light poles, mapped to the L1 area.

Figure 19: Nokia Flexi Zone Micro Outdoor specifications (source: Nokia)

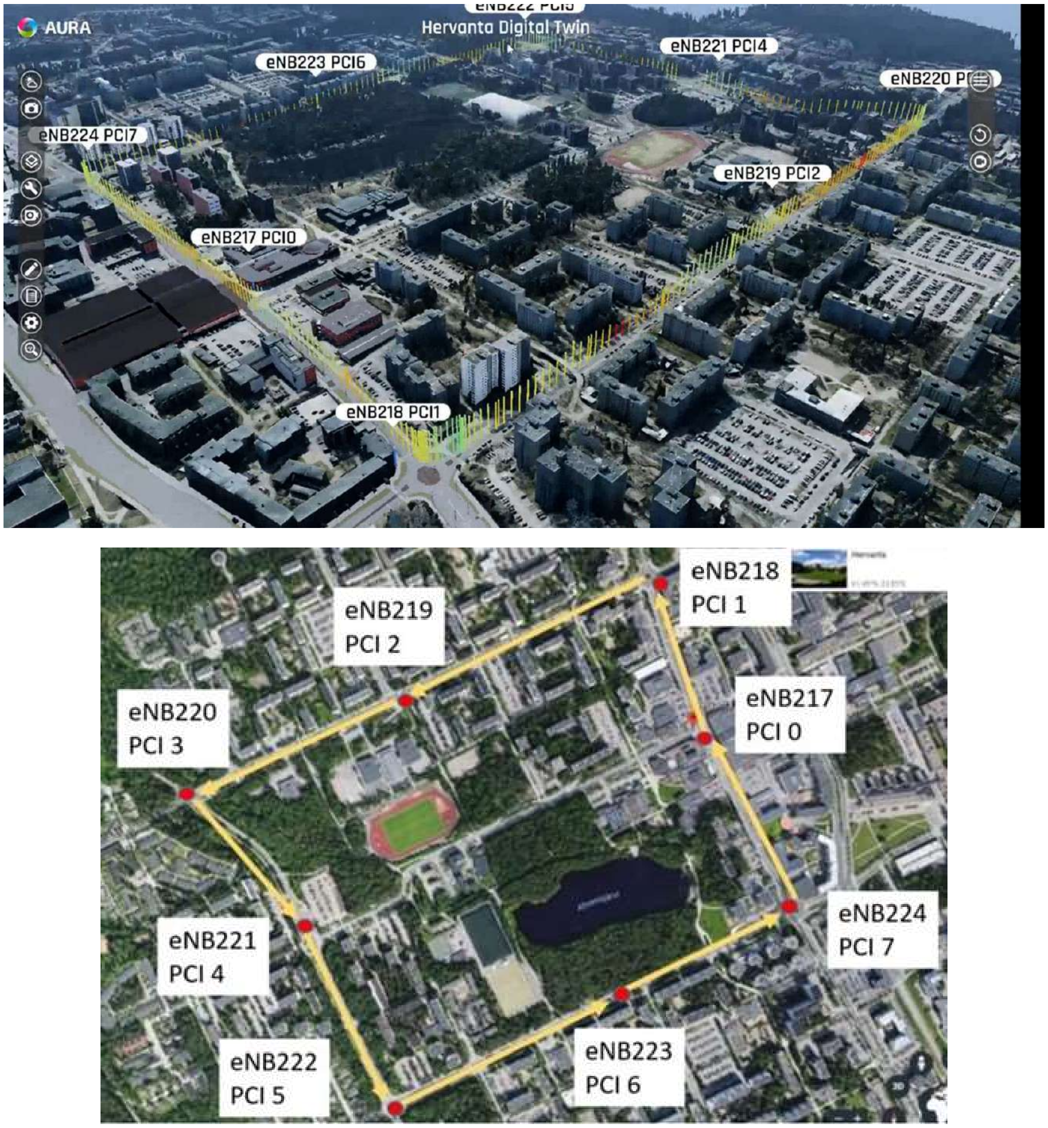


Figure 20: Nokia Flexi Zone Micro Outdoor, LTE-A base station locations (sources: Sitowise and Tampere testbed respectively)

4.3.2 ITS G5 / IEEE 802.11p devices

There are three hybrid V2X road side units in the area to support ITS G5 operations. The devices used are PEEK/Dynniq RSU Wifi-11p Mk2 G5 routers. The next figure, titled “PEEK…”, presents locations of the devices in the area and the table in the figure below, titled “PEEK…specifications”, lists their main specifications.

Table 6: PEEK - Dynniq RSU Wifi-11p Mk2 specifications. (Source: Dynniq)

Communication (internal antenna)
G5 modem interface
- Transmit power: +23 dBm max.
- Receive sensitivity: -97 dBm
GNSS receiver (internal antenna)
3G modem interface (internal antenna)
100 Mb Ethernet
IEEE 802.11p
ETSI ES 202 663

Figure 21: PEEK - Dynniq Wifi-11p Mk2 V2X RSU locations in the test site

RSU n3 is capable of sending lane specific GLOSA messages over the air from the traffic light controller of intersection TRE906 (next to ‘n3’ in the above figure). Traffic light controller TRE906 is accessible also from the infrastructure side.

4.3.3 Traffic light data using MQTT protocol

Mattersoft Oy provides MQTT protocol topic streams for the intersection TRE906 as well as for several other locations. The available topics and different traffic lights are: TRE906/A, TRE906/B, TRE906/C, TRE906/, TRE906/D, TRE906/E, TRE906/F, TRE906/G, TRE906/_H, TRE906/_J and TRE906/_K. The figure below presents the lane configuration at the intersection:

Figure 22: Intersection TRE906 lane configuration (source: City of Tampere)

The MQTT topics' naming follows the lane naming convention, e.g. topic TRE906/B publishes the state of the traffic light for lane B (ingress lane B from right). The update frequency for all topics is 1 Hz.

The format for all topics is:

{"id":"B","state":1,"ttg":7200,"rgt":-1,"timestamp":"2021-02-09T11:27:09+02:00"}

The table below clarifies the used MQTT message format:

Table 7: Traffic light message description

variable	Description	Notes
id	topic name	
state		
ttg	predicted time-to-green in milliseconds[8]	if ttg > 0 remaining time until green appears
rtg	predicted remaining-green-time in milliseconds	if rtg > 0 remaining time until green disappears
timestamp	timestamp for when data was received from proxy	

[8] Sometimes ttg or rtg gets values 999900. At that time TTG is set to 999900 seconds if state is amber or red, and predicted value is -1. RGT is set to 999900 seconds if state is red, amber or green and predicted value is -1.

The test area includes two intersections with a newly installed tram traffic light. These tram traffic lights (see the figure below) are right before roundabouts and they are to provide priority for trams as well as safety for other road users.

Figure 23: Tram traffic lights at Tampere (source: VTT)

Work is ongoing to access the status of the tram traffic lights over internet. The alternative of detecting traffic light status using vehicle systems would not be straightforward, as the traffic light type is new to most popular neural networks for the purpose.

4.3.4 RTK correction services

The following relative correction services for satellite positioning are available in the Tampere area:

- Tampereen Infra Oy provides free of charge RTK correction service for the Tampere downtown area.
- National Land Survey of Finland, RTK is available for research purposes only
- Hexagon HxGN SmartNet.

The test vehicles in SHOW will use map matching based positioning supported with RTK GPS from Tampeeren Infra Oy. In addition, a landmark-based positioning setup has been considered for supporting automated driving scenarios.

4.3.5 LTE-A commercial network

The commercial mobile network coverage in the area is depicted in the following figure. It presents the main cell tower locations, eNB IDs and approximate signal strength.

Figure 24: Commercial Elisa 4G-LTE mobile network coverage in Tampere Satellite Site area (©Cellmapper) (source: Elisa Oyi)

4.3.6 Roadside monitoring station development

VTT is developing a small, camera and radar/lidar-based roadside monitoring system to detect the presence of vehicles and pedestrians in a specified area. The area can be an intersection with visual obstructions, where a pedestrian or vehicle could appear suddenly. The goal is to support vehicle detection systems and further improve safety. Alternatively, the same system could be used to count passengers waiting at bus stops. The detection software is close to complete, but the final hardware setup and installation on the test route are pending. The figure below shows an example of the used sensor data fusion, where a neural network-based detection of objects is combined with (here lidar) distance measurements.

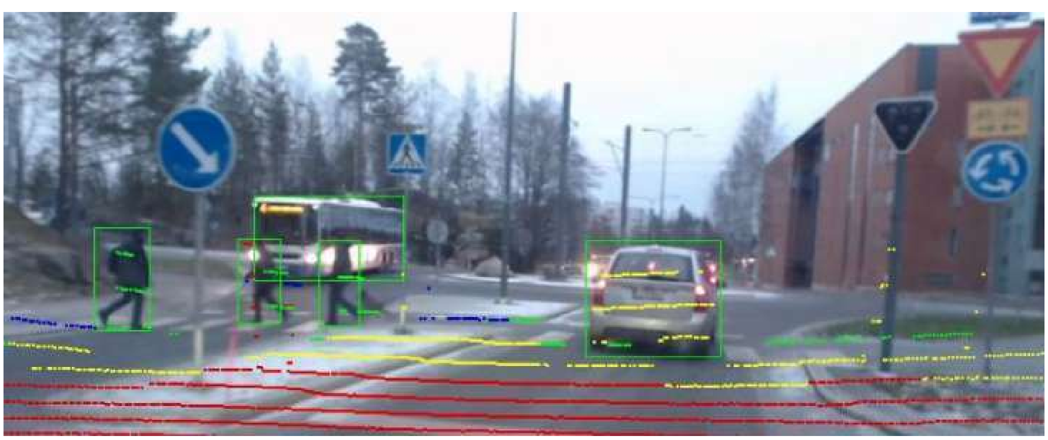


Figure 25: VTT's sensor data fusion for detection of road users (source: VTT)

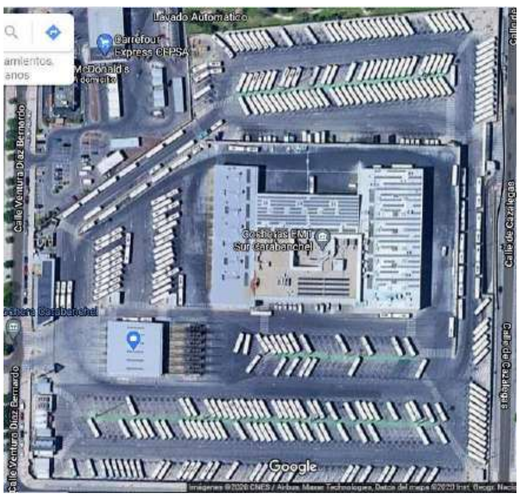
4.4 DCI at Madrid, Spain

The Madrid pilot will be carried out to enhance and provide a safety, sustainable and integrated mobility, through the deployment of an automated bus fleet that will follow complex trajectories, helped by the intelligent equipment placed on the road.

The DCI will be deployed in two sites:

1. Carabanchel semi-controlled environment, where EMT depot is located. EMT is Madrid's PTO (Public Transport Operator).
2. Villaverde open urban environment, with a route of 800 meters between the Villaverde Bajo-Cruce interchange and "La Nave" innovation centre.

The first one is in Carabanchel, within a semi-controlled environment, inside the public bus depots of the EMT, the company in charge of the management of urban public bus transport in Madrid capital city. The second, in Villaverde, within an open environment, with a route of 800 meters between the Villaverde Bajo-Cruce interchange and "La Nave" innovation centre.



Madrid Mega Pilot Site – Carabanchel bus depot.	Madrid Mega Pilot Site - Villaverde round itinerary.

Figure 26: Carabanchel and Villaverde test areas (Source: Prepared by the authors on the basis of Google MAPS data.)

Figure 27: Madrid Mega Pilot test areas (Source: Prepared by the authors on the basis of Google MAPS data.)

4.4.1 DCI at Madrid Carabanchel test site

The Carabanchel site is a semi-controlled environment, being EMT bus depot. The environment consists of a multitude of parking spots for the buses, as well as transit, entrance and exit areas, where Madrid PT (Public Transport) fleet management activities are performed, such as parking, charging, washing and maintenance.

Figure 28: Madrid Mega pilot site - Carabanchel scenario

4.4.1.1 Connectivity

In order to cover the SHOW use cases foreseen in UCs 1.7, 1.8, 3.3 and 3.5 at Madrid Carabanchel scenario, the following element enabling V2V is foreseen: 4th generation of Commsignia's vehicular connectivity system, which offers superior performance coupled with V2X Software stack. The unit provides low cost and easy aftermarket integration, offering built-in Tamper-proof Hardware Security Module, CAN, and high range V2V radio.

Madrid Mega pilot's UC 1.8 (Platooning for higher speed connectors in people transport) at Carabanchel considers two Renault Twizy (homogeneous topology), which communicate via the Commsignia[9] ITS-OB4 devices, following the ETSI-G5 standard (figure below). Specifically, CAM messages are used, changing the ego-vehicle speed field (of the leader) with its reference speed. The approach is based on Tecnalia's CACC controller, which uses the speed reference of the vehicle leader as reference. The maximum speed of the platoon is 25 km/h.

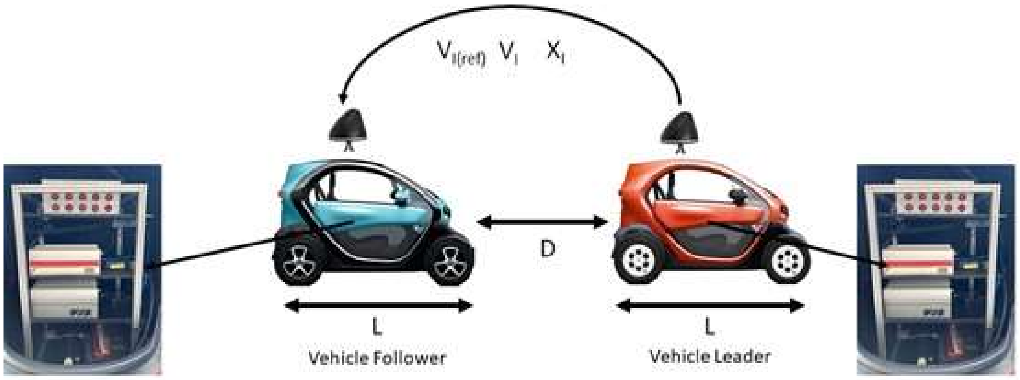


Figure 29: Madrid Mega pilot site – SHOW UC1.8 Platoon – homogenous vehicle topology

Figure 30: Madrid Mega pilot site – SHOW UC1.8 Platoon – homogenous vehicle topology preparation phase at EMT

4.4.1.2 Infrastructure equipment (RSU)

There will be 1 hybrid V2X road side unit (RSU) in the area. This device is a MK5 RSU from Cohda wireless which specification are showed in the following table:

Table 8: Madrid Carabanchel's RSU specifications

MK5 RSU Specs

[9] https://www.commsignia.com/products/obu/ consulted on July 26th, 2021.

Text standard conformance	IEEE 802.11 – 2012 IEEE 1609 – 2016 ETSI ES 202 663 SAE J2735 – 2016 CE and FCC Compliant
Bandwidth	10 MHz
Data Rates	3 - 27 Mbps
Operating System	Linux 4.1.15
Antenna Diversity	CDD Transmit Diversity MRC Receive Diversity
Receiver Sensitivity	-99 dBm @ 3Mbps
Environmental Operating Ranges	-40ºC to +85ºC
Frequency band	5.9 GHz
Max Tx Power	+ 22 dBm (ETSI Mask C)
GNSS	2.5 m Best-In-Class Accuracy
Mobility and Multipath Tolerance	Dopper Spread: 800 km/hr Delay Spread: 1500ns
Dimensions	240 x 165 x 67 mm
Power Supply	POE Regular

Table 9: Madrid Mega pilot site - Carabanchel scenario RSU installation

The RSU can provide information to bus fleets through the data received from the C-ITS Hub, which gathers pertinent information about traffic. It is a C-ITS platform for real-time control and operation of connected cooperative and automated mobility that includes:

- Adoption of the European CCAM strategy
- CCAM management for all levels of EDCs
- Integrated mobility management with connected and automated vehicles
- Technology-agnostic management of connected and automated vehicles

4.4.1.3 C-ITS Hub

The C-ITS Hub has been developed under the Horus Platform developed by Indra, which is a comprehensive, multi-modal platform delivering unified, real-time operation of infrastructures and fully automated incident response. The main characteristics are:

- Highly flexible and easily customisable to adapt perfectly to customer needs and generate real efficiencies in daily operations
- Horus goes even further: customer autonomy in upgrades, with tools that enable customers to manage their growth independently
- High availability and integration of DRP (Disaster Recovery Plan) mechanisms: minimises risks and offers greater stability, security and performance
- Risk reduction through optimal emergency response
- Unifying incident response plans across legacy, current systems and connected or autonomous cars.

Figure 31: Madrid Mega pilot site - Horus Platform

The C-ITS Hub integrates information from various sources (public traffic operator authorities, road operators, weather experts, etc.) for managing the C-ITS services that can be customized and scaled according to the volume of information received and the deployment environment. The following information will be integrated:

- Number of vehicles and average traffic speed, traffic interruptions, traffic conditions
- Crashes, animals/persons on the road, obstacle on the road, slippery road surface, road works, slow or stopped vehicle, road or lane closures, delays, weather information
- Safety alerts, dangerous slowdowns
- Weather conditions

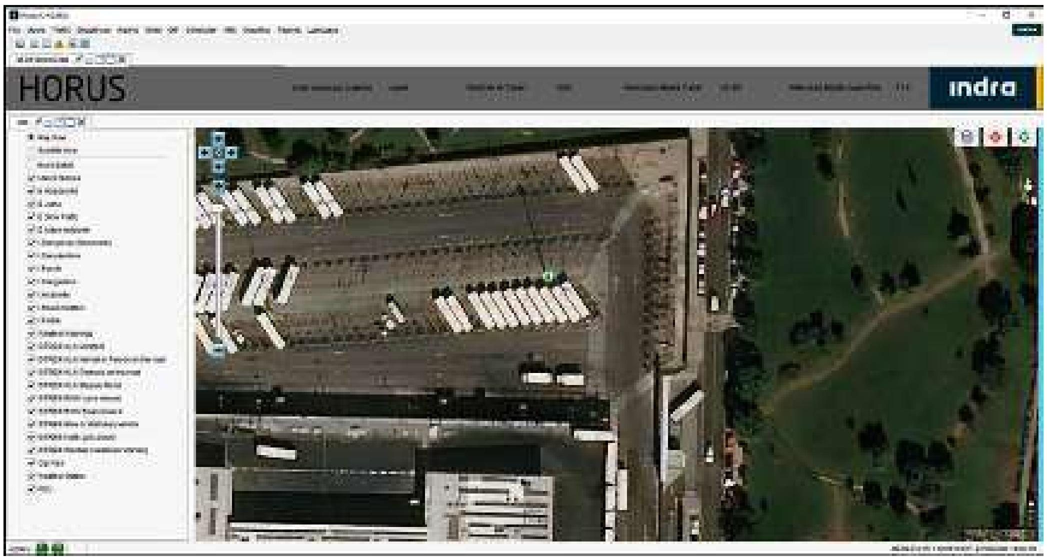


Figure 32: Madrid Mega pilot site – C-ITS Hub Platform to deploy in Carabanchel scenario

4.4.2 DCI at Villaverde Madrid test site

The scenario foreseen in Villaverde extends along a route of about 800 meters, between the innovation center La Nave (bottom left of the following picture) and the multimodal station of Villaverde Bajo Cruce (top of the picture). It is an urban environment open to mixed traffic, with several intersections and roundabouts.

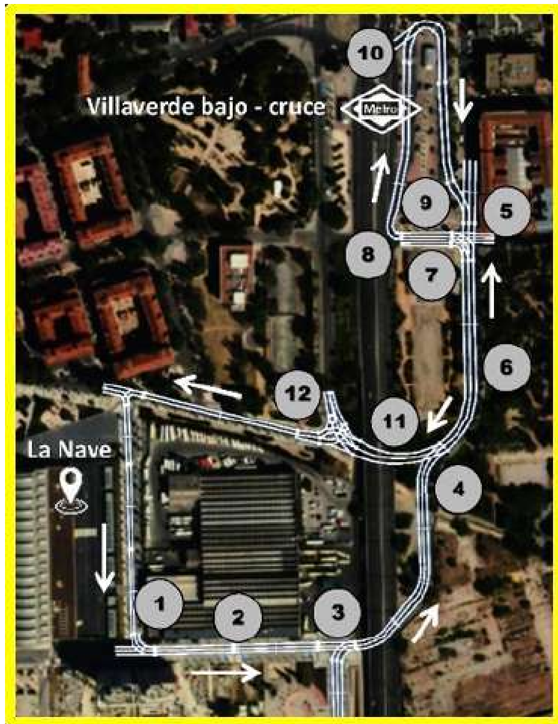


Figure 33: Madrid Mega pilot – Villaverde scenario (Source: Prepared by the authors on the basis of Google MAPS data.)

4.4.2.1 Road-side Units

Throughout the test site, different intersections equipped with RSU are located along the vehicles' route in order to offer digital services to vehicles. V2I cooperative communication is used by the AVs in order to obtain the information of the traffic lights (TL). Based on this TL data AVs generate a speed profile which allows them to pass through the TL without the need to stop at the intersection Specifically, services "Road and Lane Topology" (RLT) and "Traffic Light Manoeuvre" (TLM) are used (refer to sections titled "Traffic Light Manoeuvre (TLM) services " and "Road and Lane Topology (RLT) service" respectively):

- With the first service, RLT, the location of each traffic light is obtained through the MAP messages.
- Whereas using the second service, TLM, all the information concerning each traffic light itself is obtained (actual time, duration of each light state, current state, among others). These are obtained using SPaT messages. Based on the traffic lights' locations, the current states and the actual time, a speed profile is calculated to cross the intersections.

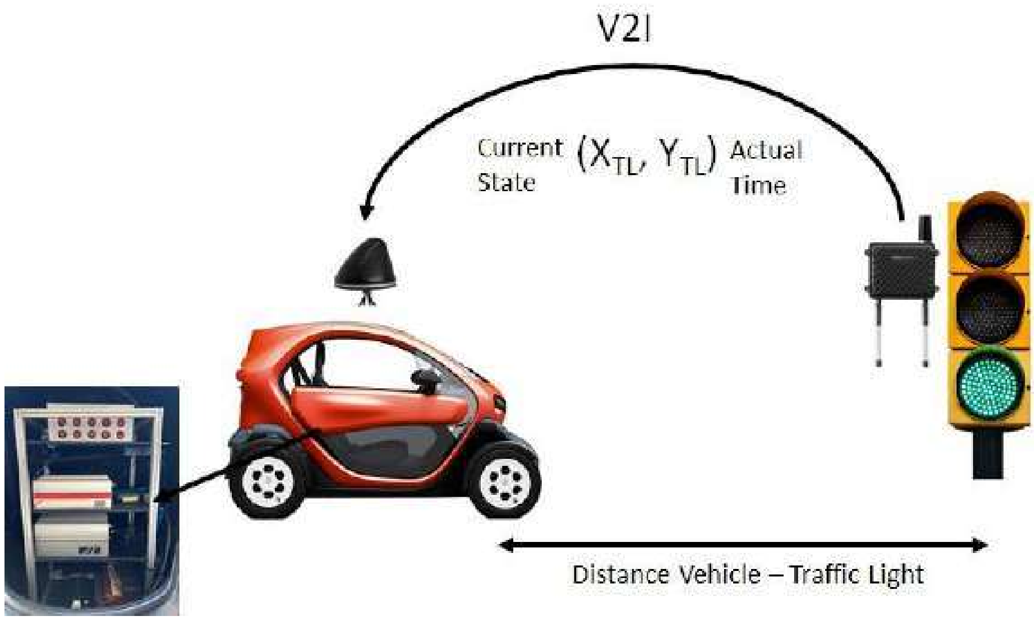


Figure 34: Madrid Mega pilot – V2I cooperative communication configuration

During the installation of the V2X equipment, some communication tests were carried out between RSUs and OBUs, so that the services generated from the C-ITS Control Centre were received. The following image on the right shows the OBU interface where a DENM message with the service "Heavy Rain" is represented, as a preliminary example.

Figure 35: Madrid Mega pilot – AV and RSU preliminary preparation phase (V2I testing and readiness)

The Villaverde test site deploys a hybrid communication system, with 4G as telephony communication and ITS-G5 short-range communications through the RSU that will be installed. The RSU is a hybrid MK5 from Cohda Wireless whose specifications are illustrated in the Carabanchel section.

4.4.2.2 C-ITS Platform

This device provides information to bus vehicles about traffic, through the data integer in the C-ITS Hub. The C-ITS Hub deployed at Madrid Villaverde site is the same as the defined in Madrid Carabanchel site (see DCI at Carabanchel scenario).

In addition, in the Madrid Villaverde scenario, information related to the traffic light cycle will be collected, directly or through a platform or cloud service, so that this information can be sent to the buses through the RSU, and facilitate the circulation of the automated bus in the traffic light intersections present in the route.

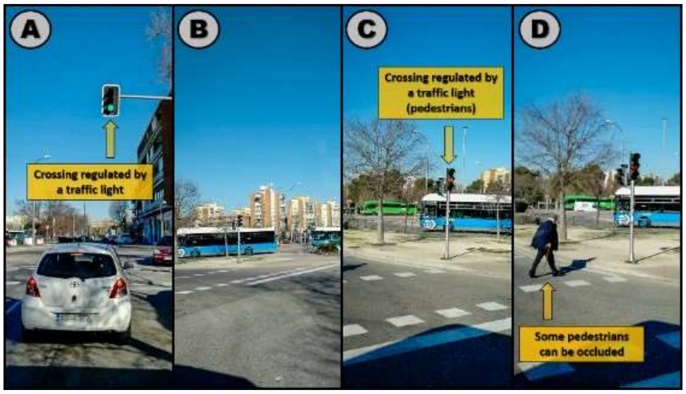


Figure 36: Madrid Mega pilot site - Traffic light intersection in Villaverde scenario

It will be necessary to regulate both intersections in order to allow automated fleets to drive through them assuring safety, by following the traffic light's priority or by setting its phase duration (figure above).

4.5 DCI at Rouen, France

Under the SHOW project, Transdev is not addressing directly the topic of digital and physical infrastructure because all the development has been done in other projects. But in this document, we only give an overview.

In the following figure we are describing the Autonomous Transport Systems with the elements composing our systems.

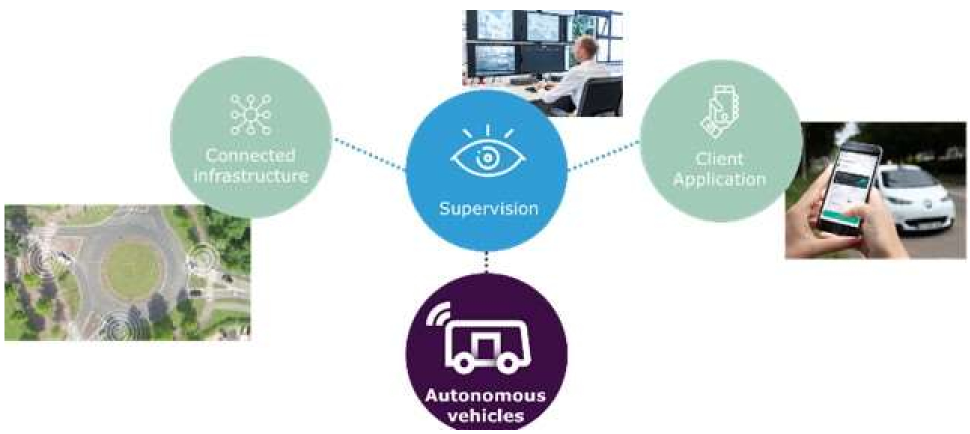


Figure 37: Transdev Autonomous Transport Systems

In Rouen the digital infrastructure includes:

- Secure telecommunication networks / Private 4G+/5G Network
- ITS G5 networks
- On-Board Unit (OBU), Road-side Unit (RSU)
- Connected traffic lights / Traffic Light Controller (TLC),
- Extended perception (with lidars, connected cameras)
- A public transport operational control centre for a multi-brand fleet (located in the same room with the Public Transport Control Centre in Rouen)
- A user app for on-demand service

Figure 38: Rouen – Physical and Digital Infrastructure

4.5.1 DCI at Rouen Madrillet area

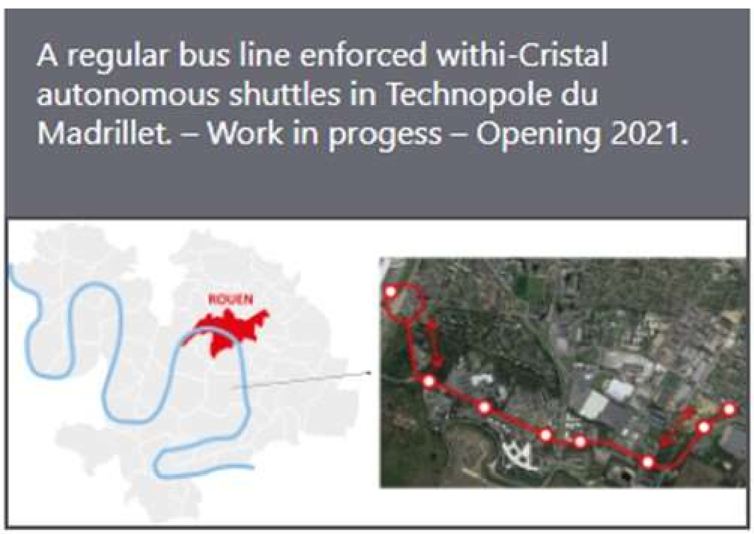


Figure 39: Rouen - bus line service with automated shuttle

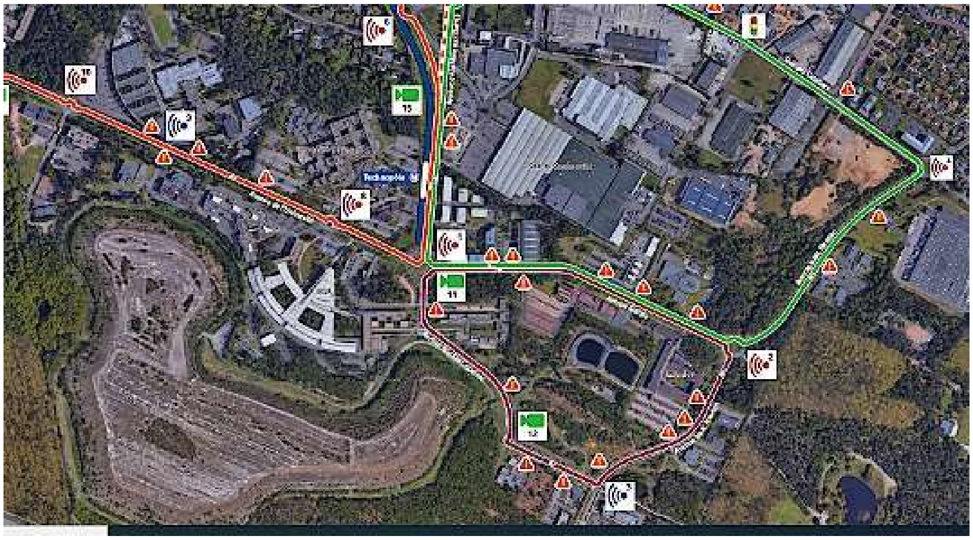


Figure 40: Rouen - digital infrastructure sites - Only the L#27bis (red trajectory) will be experimented during #SHOW_Project

The V2X infrastructure that will be used are 8 V2X sites are located along L27bis, 2 of them being linked with traffic lights controllers. Even if in SHOW only the connected infrastructure installed along the red trajectory (bus line 27) will be used, all historical V2X sites are maintained.

Figure 41: Rouen - Site 1 – Extended perception by lidar

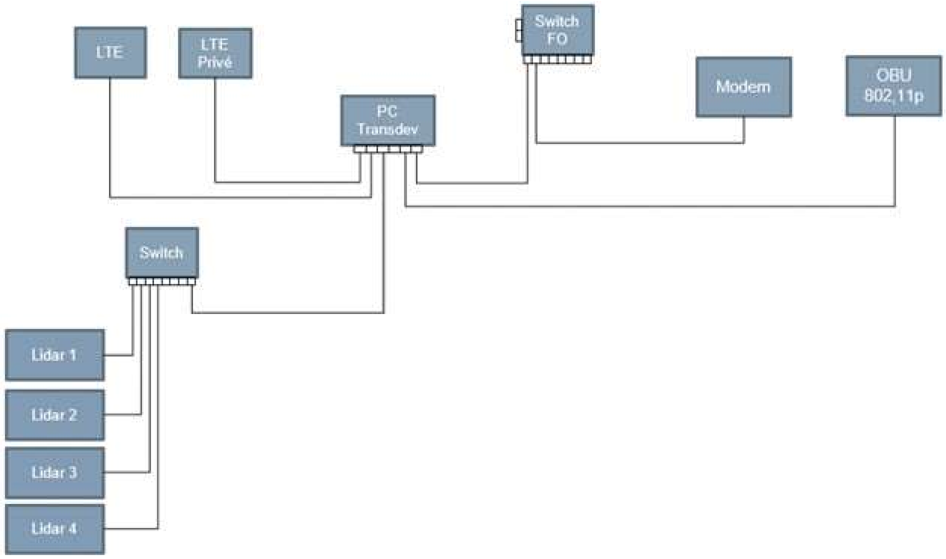


Figure 42: Rouen - Site 1 - HW / IT connectivity

Figure 43: Rouen - Site 1 - Various configuration for perception infrastructure with lidar type 1

Figure 44: Rouen – Site 1 - Various configuration for perception infrastructure with lidar type 2

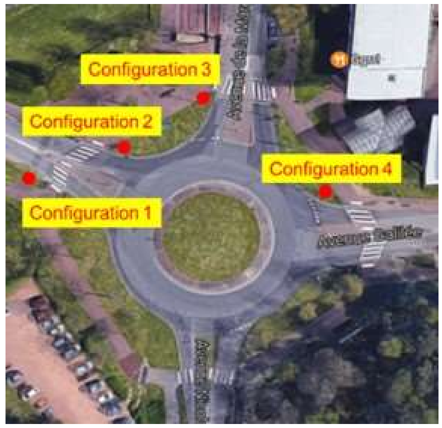


Figure 45: Rouen – Site 1 - Various configuration for perception infrastructure with camera

Figure 46: Rouen - Site 13 - Extended perception by camera

Figure 47: Rouen - 2G / 3G / 4G / 5G - network coverage in the Rouen Madrillet area - antennas and directions of emission (info from cartoradio.fr)

4.5.2 DCI at Rouen city-centre area

In the city centre area, the idea is to realise the same level of experimentation with a minimum of added infrastructure, i.e. use the existing 3G/4G network connectivity.

At this moment only connected traffic light are under study to be added.

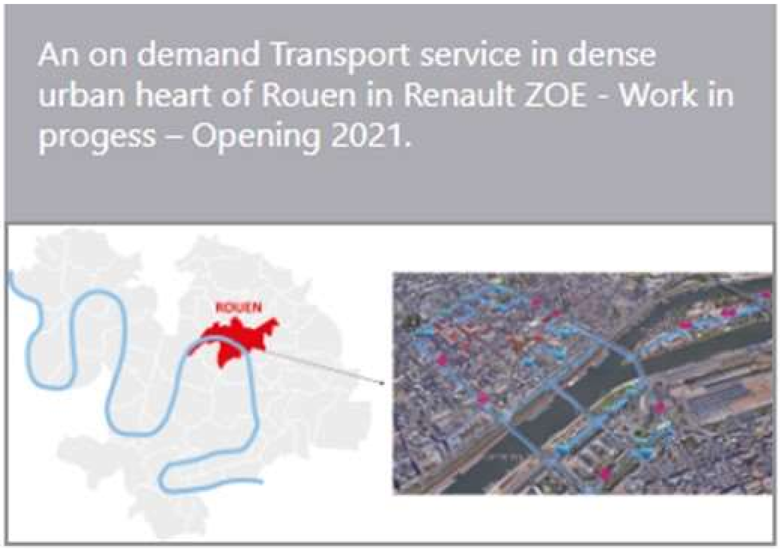


Figure 48: Rouen – Robo-taxi service (this complex network of trajectories are going beyond the SHOW project, and might be subject to changes)

Figure 49: Rouen - 2G / 3G / 4G / 5G - network coverage in the Rouen city centre - antennas and directions of emission

4.5.3 DCI at Rouen: Fleet Supervision Centre

In the Transdev ATS, all automated vehicles are continuously connected to the Fleet Supervision Centre for operational purposes, but the vehicle is dealing with the safety related function without being necessary connected to the supervision.

In Rouen we distinguish different systems located in the same Control Room.

Please note that this is the Control Room for Public Transport and for functions under the control of a Public Transport Operator.

Figure 50: Rouen - Control Room for Public Transport

The main goal of this Control Room is to ensure a high quality of the public transport services for passengers by:

- Real-time monitoring of network status
- Management of operational hazards/incidents
- Sending instructions to drivers/vehicles

In the left part of the photo shown above you can distinguish 2 separate work posts (red, yellow) dedicated to the Autonomous Transport System (L4 SAE) and the other 3 work posts dedicated to the “traditional” public transport: buses, BRT (L2 SAE), metro/tramway, intervention team…

4.6 DCI at Lindholmen in Gothenburg, Sweden

4.6.1 5G infrastructure used by shuttles

The radio- and mobile network at Lindholmen site in Gothenburg (see the figure below) consisted of three 5G mid-band (3760 – 3800 MHz) radio units and a 5G vEPC (virtual Evolved Packet Core). Two of the radio units were temporarily installed on a roof top in the centre of the shuttle route (next figure below, titled “Radio unit installed on roof top at Lindholmen/Gothenburg site”), and one radio unit was located at Ericsson’s premises at Lindholmen/Gothenburg. The remote radio units were connected to 5G EPC via microwave backhaul (Mini-Link). The 5G vEPC was located in data center in Ericsson premises at Lindholmen.

Figure 51: Route of the shuttle at Lindholmen/Gothenburg with position of the new radio site

Figure 52: Radio unit installed on roof top at Lindholmen/Gothenburg site

At the shuttle, a 5G modem/router (E-Lins H900 / Quectel RM900Q module) was installed together with a Raspberry Pi 4 equipped with Adafruit GPS HAT. 5G vehicle antennas were mounted on the roof of the Navya shuttle (the following two figures), and GPS antenna was mounted inside the vehicle at a flat surface by the wind screen.

Figure 53: Navya shuttle type used at site Lindholmen/Gothenburg with GPS antenna

Figure 54: 5G vehicle antennas on the roof of the Navya shuttles

At the Raspberry Pi, a number of Python3 scripts are running:

- GPS locations extracted from GPS HAT and published on a “location” MQTT topic as well as stored in local Influxdb database
- Radio information extracted from modem, using AT commands, and stored in local Influxdb database
    - MCC, MNC, PCI, RSRP, RSRQ, SINR, CQI and RSSI
- Network latency measurements in form of average round-trip time of 5 x ping tests, packet drops and standard deviation which is stored in local Influxdb database
- Local environmental measurements:
    - CPU temperature
    - CPU usage (%)
    - Used memory / free memory

The latest data sets stored in Influxdb database were sent to a MQTT broker in a separate “network” MQTT topic.

The backend systems consist of Ericsson Innovation Cloud (EIC) and a Network Supervision dashboard. These backend systems subscribed to the MQTT topics and presented the location data and network data in different Graphical User Interfaces (GUIs).

Network Supervision dashboard was used at Network Operations Center at Lindholmen to monitor radio characteristics and mobility, and this was a read-only presentation dashboard (see the following figure).

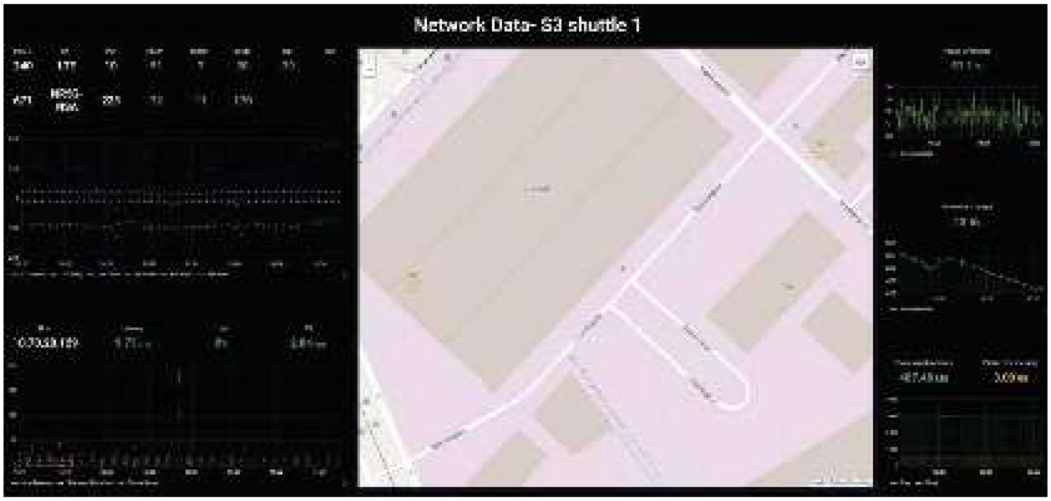


Figure 55: Network Supervision dashboard at Network Operations Center at Lindholmen/Gothenburg site

4.6.2 Geofences and VRU detection

Ericsson Innovation Cloud, besides visualizing location of the vehicle, and network information at the particular location, it also contains logic to trigger actions based on location / heading of reporting objects. The objects included in SHOW project were the autonomous shuttles (marked with vehicle icons) and a Vulnerable Road User (VRU) sensor (marked with vest icon in the middle of the next figure).

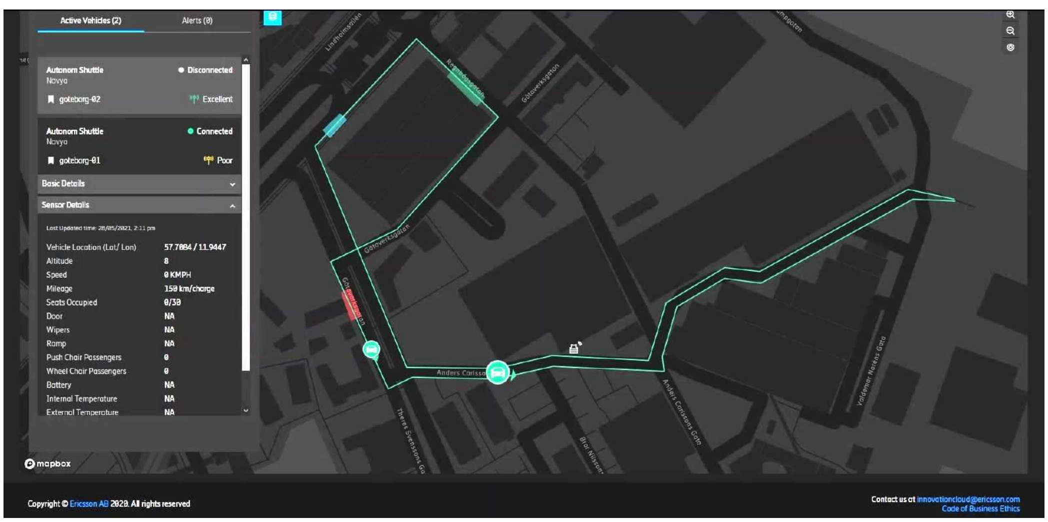


Figure 56: Ericsson Innovation Cloud making it possible to visualize location/heading of objects such as shuttles and Vulnerable Road Users (marked with vest icon in middle)

To trigger events, the logic in Ericsson Innovation Cloud supports two different kinds of geofences:

- Static geofences (like green, blue and red areas in the map above) are coordinate-based and can represent areas were certain rules applies, as example reduced speed, no-entry, emission-free zone etc. Static geofence can be applied around, for example, construction work areas, accident area, etc.

In the SHOW project, notifications are sent over MQTT protocol to both vehicle and VRU sensor when entering and leaving a static geofence. In vehicle, and in Ericsson Innovation Cloud, in the form of messages and at VRU sensor the notification is transformed to audiovisual notifications (LED lights in front and back on safety vest as well as audio in earphones). See the following two figures.

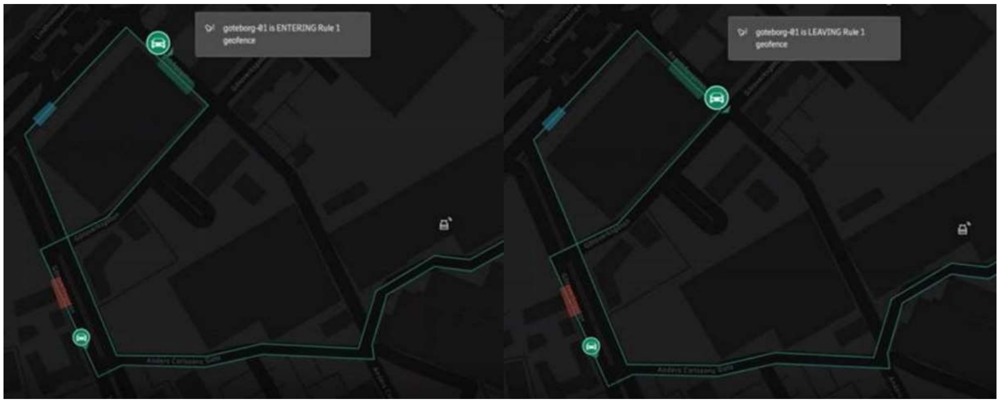


Figure 57: Static geofences for Lindholmen/Gothenburg site

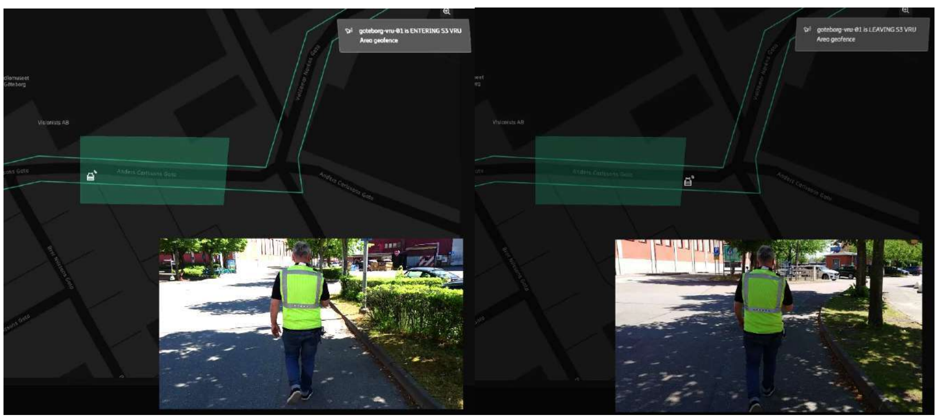


Figure 58: VRU area geofences at Lindholmen/Gothenburg site

- Dynamic geofences are created around objects, instead of static coordinates, and follow the object as is moves. In SHOW project, dynamic geofences were created in front of vehicles (in shape of polygon) and around Vulnerable Road User sensors (circular). The areas of the dynamic geofences are configurable.

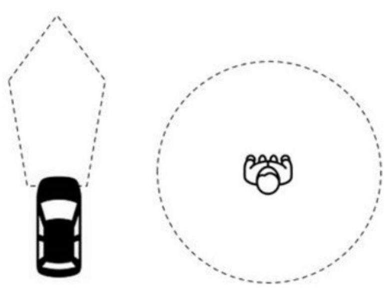


Figure 59: Dynamic geofences

Once a vehicle- and a VRU geofence overlap, notifications are sent to respective connected sensor (notification messages + audio-visual at VRU sensor) as well as in Ericsson Innovation Cloud (see the following figure).

Figure 60: Vehicle-VRU geofence overlap trigger notification messages and audio-visual messages at VRU sensor and in Ericsson Innovation Cloud

4.7 DCI at Linköping (Sweden)

There are two autonomous shuttles in operation at the Linköping pilot site from two different suppliers – one from Navya and another one from EasyMile. Both shuttles follow the same fixed circular route encompassing campus Valla of Linköping University shown in the figure below. The length of the route is approximately 2 km. The route contains several small intersections and consists of eight stops with an additional stop nearby serving as a garage/parking. Around half of the route follows the road around the campus (speed limit 30 km/h) which accommodates regular traffic with cars, public transport buses and delivery vehicles. The other half of the route is encompassing the main campus passage with many pedestrians and cyclists. Both shuttles use pre-recorded maps of the environment. Additional LIDAR panels were installed around the road as, at some places, the buildings are too far away for proper LIDAR positioning. A second route, reaching a small neighbourhood near campus Valla, is expected to open in August 2021. Both vehicles are communicating their data to the respective suppliers' cloud-based platforms via 4G connections.

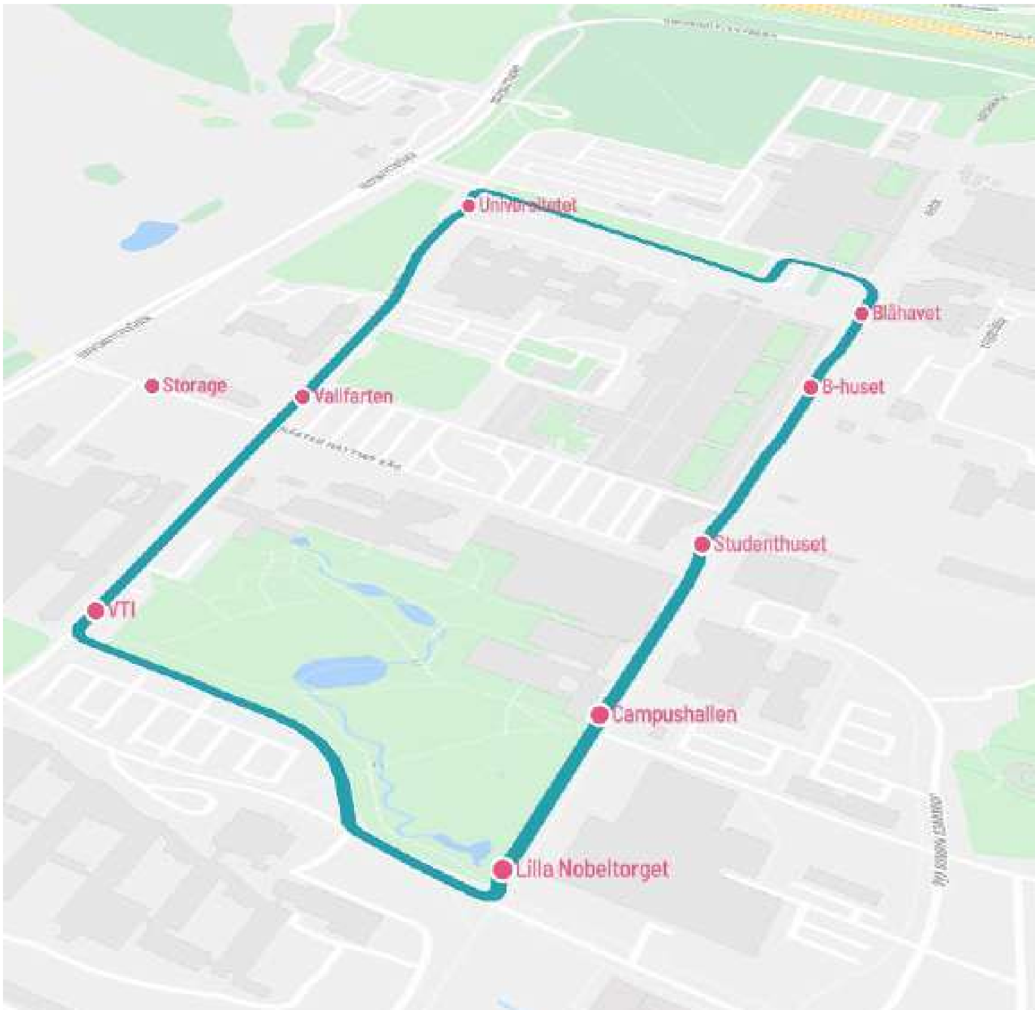


Figure 61: The route at the Linköping site with 8 stops along the route.

4.7.1 Data collection and presentation

The data, communicated by the vehicles, are retrieved from the suppliers' cloud services using HTTP REST API calls (for the static data) and WebSocket (for the dynamic data). This is achieved by several data acquisition flows developed in Apache NiFi, shown in the following figure, which retrieve the data from the public APIs and store them in a local MySQL database. Two types of data can be distinguished:

- Static data retrieved once per day from the HTTPS REST API vehicles' suppliers' endpoints. The static data focuses on the description of the site with the location of the stations and their coordinates as well as preconfigured routes and lines. Additionally, some information about the vehicle equipment is also provided.
- Dynamic (near real-time) data pushed once or twice per second via WebSocket Secure. The dynamic data can also be separated into several categories:
  - Vehicle identifier and a timestamp of the message.
  - Current vehicle location and heading – including GPS coordinates and GNSS correction if available as well as hit ratio (proportion of the radar hits that match the pre-recorded map).
  - Current state/values of the vehicle's sensors and actuators –

        ▪ Vehicle control - speed, acceleration, mileage, and steering data as well as connection status (connected/disconnected).
        ▪ Signal lights and wipers.
        ▪ Passenger access and accessibility equipment (door and ramp) as well as number of passenger and payload.
        ▪ Battery status and state (i.e. charging).
        ▪ Internal, external, engine and battery temperatures.
    - Mode of operation – autonomous or manual navigation, operating on a predefined route (with or without stopping at each stop) or on-demand service, in-use status - transporting passengers or in stand-by before/after the current trip.
    - Next stops and waiting times as well as progression to the next stop.
    - Events – describing unexpected situations and the location of the vehicle at the time of event.

Additionally, an application for passenger counting is under development to allow for analysing the flow of passengers between the different parts of the route.

Collected dynamic data is transmitted via MQTT to the SHOW Dashboard and will be transmitted to the SHOW Data Mobility Platform when it is deployed. Additionally, an HTTP server is being setup to communicate the static site data to the SHOW Dashboard. SHOW Dashboard is a service designed to visualize (near) real-time operations of vehicles in the SHOW project as well as KPIs. SHOW Data Mobility Platform is the central SHOW data collection and management platform which will provide the data visualized in the SHOW dashboard. All the data will be communicated only to the SHOW Data Mobility Platform which will then provide the data for the SHOW dashboard.

A local dashboard is under development using Combitech's SAFE platform where various KPIs will be visualized. A near real-time location service, using OpenStreetMap, showing the current vehicle position has been implemented and is available at https://elin.linkoping-ri.se/ (see the next figure; the goal of the next figure is only to provide a high level view of the data collection flows) (the URL was accessed on November 5th, 2021). Location data displayed by the location service are also available in textual format https://elin.linkoping-ri.se/getpos (the URL was accessed on November 5th, 2021).

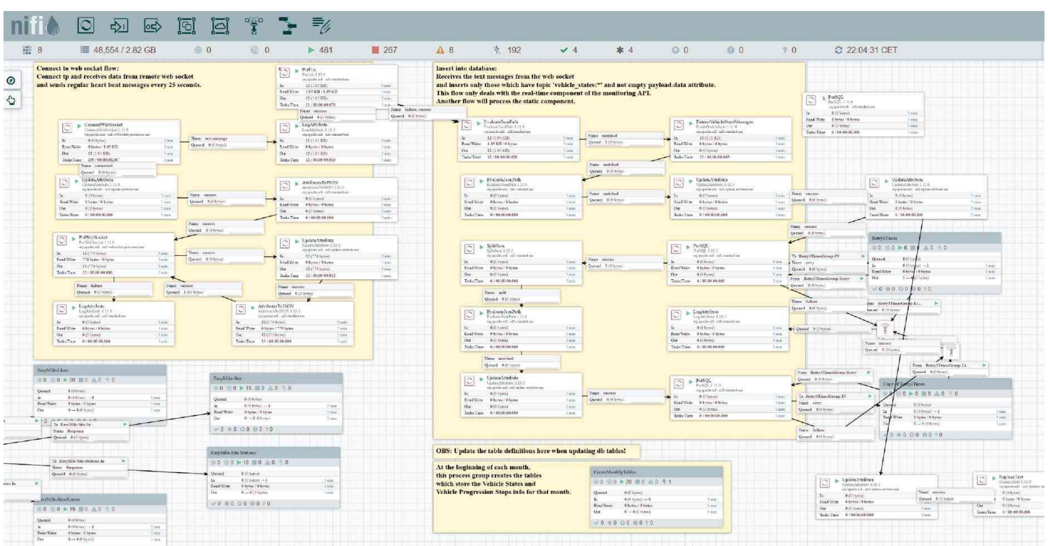


Figure 62: An example data collection flow implemented in Apache NiFi.

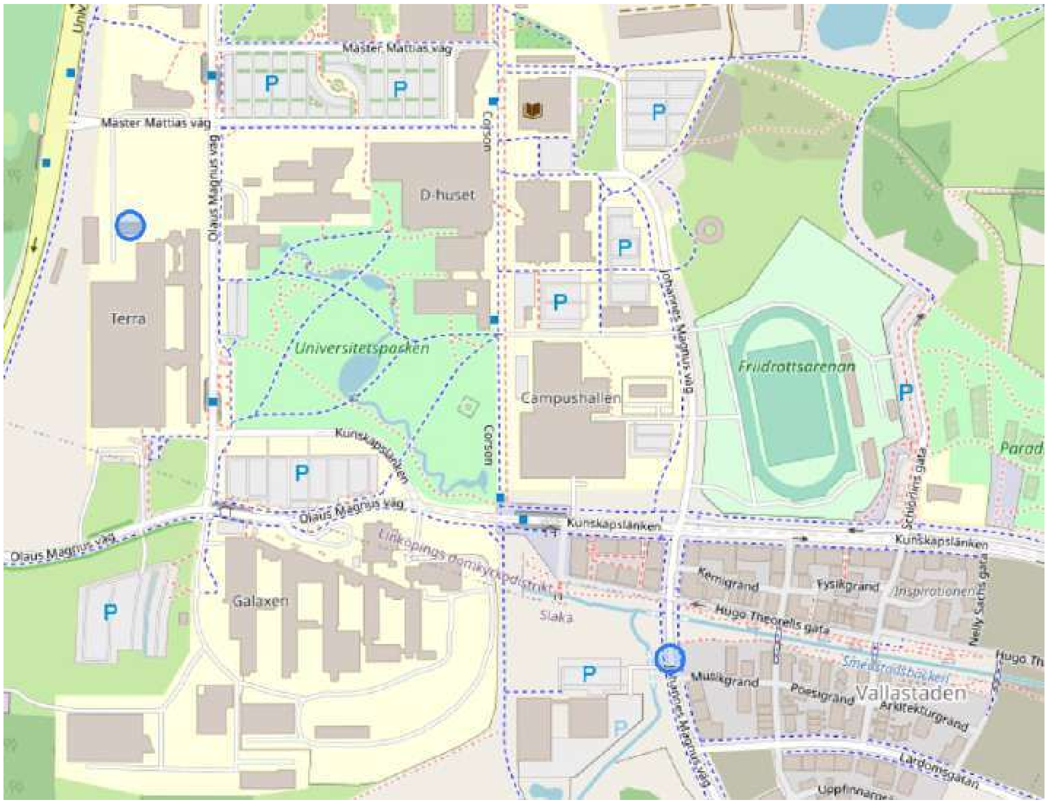


Figure 63: A screenshot from the near real-time location service available at a particular URL (https://elin.linkoping-ri.se/)

4.8 DCI at Graz, Austria

The pilot site of Graz is located at the local transport hub of the district Puntigam of the city of Graz ("Nahverkehrsknoten Puntigam") and will cover the following use-cases (as defined in SHOW deliverable D1.2):

- UC1.2: Automated passengers/cargo mobility in Cities under complex traffic & environmental conditions
- UC1.3: Interfacing non automated vehicles and travellers
- UC3.4: Automated services at bus stops

(Editor's note: for other DCI at Sites sections, their respective relevance to particular use-cases of SHOW are mentioned in the Annex 'Super Spreadsheet'; for example the Italy, Turin site lists the use cases for Turin to be '1.2, 1.3, 1.5, 1.7 and 1.10')

The local transport hub of Puntigam consists of bus-stops and a tramway reversal point, which leads to a high bus and passenger traffic. Therefore, digital infrastructure shall be applied to support the automated shuttle.

The digital infrastructure will monitor the bus and passenger traffic in order to:

- detect non-automated vehicles as well as vulnerable road users (VRU);
- warn the automated shuttle about detected objects, by using ITS-G5 connectivity.

The following figure illustrates the local transport hub of Puntigam.

Figure 64: Local transport hub of Puntigam (Graz); Source: Google Earth

4.8.1 Detection of non-automated vehicles & VRUs

The detection of non-automated vehicles and VRUs will be realized by a local installation of a smart camera system. The YUNEX Traffic “awareAI” smart camera system uses artificial intelligence to detect and track vehicles as well as pedestrians in flexible detection zones, which will be configured based on the given local transport hub.

The awareAI System is an all-in-one smart camera solution for reliable traffic detection. The key functionalities for the pilot site in Graz will be the detection, classification and tracking of road users, such as pedestrians and busses. The camera solution determines speed, position and the movement direction of road users within defined zones, in order to detect road users and trigger alerts.

The following figure illustrates an exemplary of a monitored crosswalk, including its defined detection zones as well as detected objects.

All detection tasks will be performed within the local processing unit of the camera system, guaranteeing the highest level of data protection as only fully anonymized information is processed by the connected Road Side Unit.

The awareAI camera system will be directly connected to the local installed ITS-G5 road side unit (see the following section titled “ITS-G5 infrastructure”). Detected objects of the awareAI will be processed to ITS-G5 messages, to inform the automated shuttle of VRUs or other vehicles.

4.8.2 ITS-G5 infrastructure

The V2X infrastructure at the pilot site of Graz will be realized by a YUNEX Traffic SITRAFFIC® ESCoS Road Side Unit. The RSU, as illustrated in the following figure, will be installed at the local transport hub and will act as the roadside infrastructure for the wireless ITS-G5 communication.

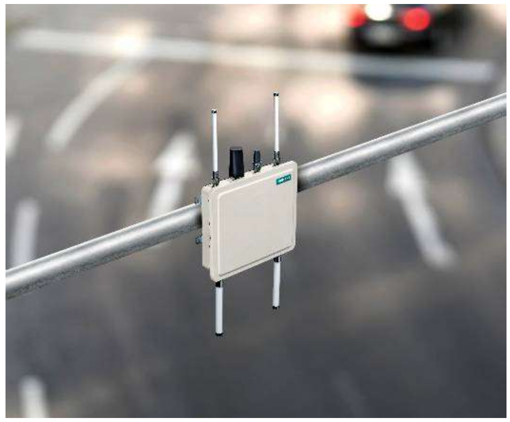


Figure 65: Illustration of the YUNEX Traffic SITRAFFIC® ESCoS RSU

The RSU works as both a transmitter and a receiver, enabling bi-directional communication. The RSU operates in the 5.9 GHz frequency band, which is reserved for traffic applications.

4.8.2.1 Standalone operation of RSUs

The RSU will operate in a standalone mode. This means the RSU will get locally connected to the awareAI smart camera system and does not need to get connected to a backed system for a message management. The direct connection to the awareAI system enables the transmission of detected objects from the smart camera system to the RSU, in order to send out corresponding ITS-G5 messages. The systems need to get configured first, but after the configuration time the systems will work completely in a "standalone" mode. The Road Side Unit / camera system are directly accessible via VPN over Internet for service activities, if needed.

The RSU supports state of the art C-ITS message types, as illustrated in the technical data of the RSU (see figure X). Further, the next generation "Collective Perception Message" (CPM) will be investigated in the course of the SHOW project.

The technical data of the RSU is illustrated in the following figure:

Table 10: Technical data of the YUNEX Traffic SITRAFFIC RSU[10]

• **IEEE 802.11p 5.9 GHz Dual-Radio (ITS-G5 / DSRC-C-V2x on request)**
• **Receiver sensitivity: -97 dBm (802.11p)**
• **Max. output power: 23 dBm (mask C)**
• **Hardware security module for secure signing and storage of private keys**
• **2.4 GHz WIFI/BT hotspot for travel-time applications and remote maintenance**
• **LTE for fast back-end connection**
• **Browser-based webGUI for remote diagnosis and configuration**
• **Range of up to 2500m (free field, line of sight)**
• **Supports ITS-G5 and WAVE in line with the latest standards**

[10] The YUNEX Traffic SITRAFFIC ESCoS RSUs are described at the following URL https://www.yunextraffic.com/global/en/portfolio/traffic-management/connected-mobility-solutions/vehicle2x-communication (this URL has been accessed too on November 3rd, 2021)

Message types ITS-G5	• CAM • DENM • SPATEM • MAPEM • IVIM • SSEM • SRM
CPU / memory	• 800 MHz Dual-Core CPU for edge computing • 1 GB Ram
Interfaces	• 2x ITS-G5 / DSRC • 2x RJ45 10/100 Mbit Ethernet • 1x 802.11 b/g/n WIFI & Bluetooth 4.0 • 1x GNSS wit position accuracy of 2.0m • 1x R5232 • 1x LTE Cat4
Mechanical features	• 1x Dimensions: 27 x 31 x 8cm (WxHxD) • Weight: 4.1 kg • Installation: on mast or wall • Material: cast aluminium, anodized
Ambient conditions	• Operation temperature -40°C to +74°C • Protection class: IP67/NEMA 6P
Power supply	• 48 V PoE+ (802.3at) • Typically 12 W

4.9 DCI at Salzburg, Austria

4.9.1 Pilot Description

Within the pilot site Salzburg the implementation of two scenarios (scenario 1 and scenario 2) on two different but connected routes is planned. With these scenarios, the pilot site in Salzburg will be able to realise and evaluate UCs: 1.2, 1.3, 1.5, 1.6 and 3.1 as described in detail in Deliverable 1.2 titled “SHOW Use-Cases” and Deliverable 9.2 titled “Pilot experimental plans, KPIs definition & impact assessment framework for pre-demo evaluation.”

- Scenario 1: (UCs 1.2, 1.3, 1.6, 3.1): Testing automated demand responsive transport (DRT) on the first/last milein the municipality of Koppl for connecting a peri-urban area to a city centre via an intermodal mobility hub. The length of the autonomous shuttle route is approximately 1.4 km one-way. It is a slightly curved asphalt road with a maximum of 8 percent incline (equivalent to 65 m height difference). The whole route has driving lanes for both directions. Including start and terminus stops and serves four bus stops in each direction.
- Scenario 2 (UC 1.5): Testing of a C-ITS enabled bus corridor, connecting an intermodal mobility hub to the city centre at high efficiency. The length of the route is approximately 7.9 km one-way, the maximum speed limit is 80 km/h. It is a partly curvy asphalt road with separate driving lanes bridging nearly 300 meters height difference between Koppl and the city of Salzburg. There are eleven bus stops in each direction on this route.

The next figure visualises the test routes for scenario 1 and 2 in the pilot site Salzburg.

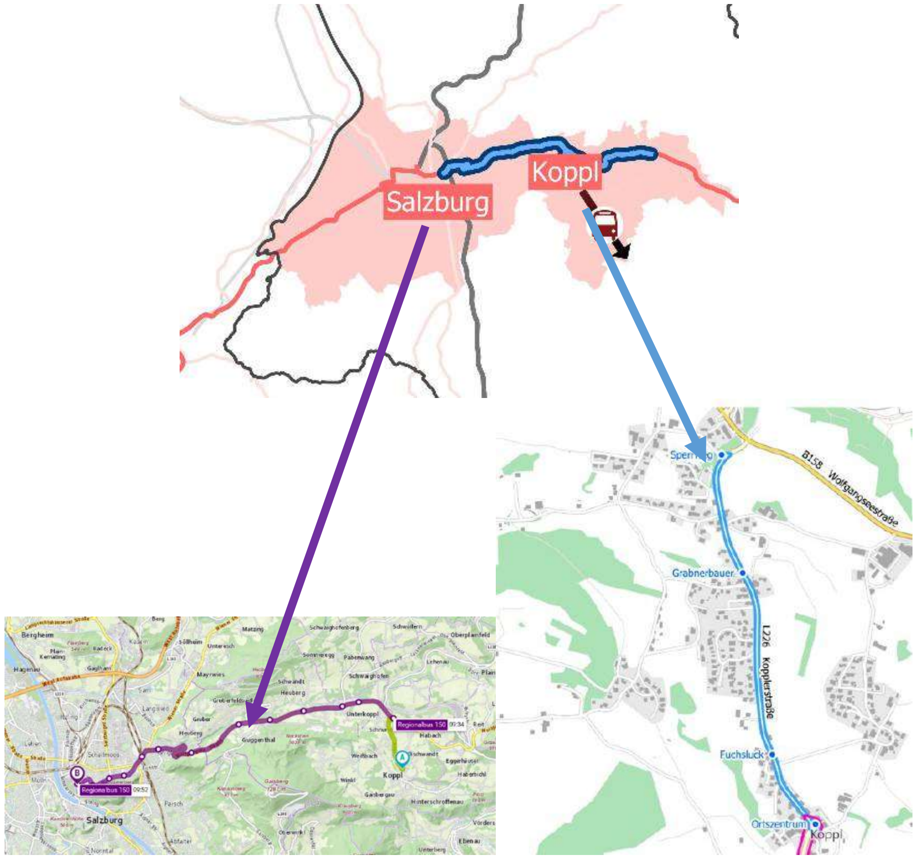


Figure 66: Test routes in the pilot site Salzburg (Source: own figure); on the bottom left side is depicted the test route Koppl – Salzburg for C-ITS scenario (scenario 2); on the bottom right side is depicted Test route in Koppl for DRT-scenario (scenario 1)

4.9.2 V2X Infrastructure

The pilot site Salzburg is equipped with V2X RSUs from Kapsch TrafficCom AG for ITS-G5 communication with the CAVs. The following figure shows the data sheet of the Kapsch RSU (RIS-9160).

Technical features

ITS protocol standards
- IEEE 802.11p™/IEEE 802.11™
- SAE J2735 2016
- ETSI ITS-G5 standard set
- IEEE WAVE 2016 standard set

5.9GHz radio characteristics
- IEEE 802.11p™ radio
- Freq. band: 5.850 – 5.925 GHz
- 10 MHz channel spacing
- Output power: max. 20 dBm
- Sensitivity: typ. -92 dBm @ 6 Mbps
- Antenna 1 (or 2, 2nd radio chann.).

Power supply
- PoE 802.3at-2009
- < 14 W (basic configuration) max. < 25 W

Enclosure
IP67, IEC 60529

Positioning and time (pps)
Multi GNSS (GPS, GLONASS, Galileo, BDS)

External interfaces (incl. options)
- 2 x 5.9 GHz Antenna 50 Ohm, N female
- 1 x GBit Ethernet (1 x PoE feed-in)
- 1 x GPS, N female
- 3 x Auxiliary, N female (e.g. LTE)*
- 3 x GPIO* in, 3 x GPIO* out
- 2 x LED, 3-col.(power, status) +2 x*

* Option

Security
- ECC
- Hardware Security Module

Environmental conditions
- Operation: -40 °C to +74 °C
- Storage: -40 °C to +85 °C
- Protection: NEMA Type 4X, IP67

MTBF
> 100.000 hours

Mechanical
- Aluminium die-cast
- Dimension: 290 x 200 x 78 mm (wo installation bracket)
- Weight: 3 kg

General conformity
FCC, CE

Configuration options
- Cellular modem module (3G/LTE)
- WiFi module
- BT module
- 3 x GPIO in, 3 x GPIO out
- 24 V / 48 V DC

- **Computer platform**
- 1,33 GHz, 64 Bit, dual-core
- x86 CPU Architecture, 1 GB RAM ECC
- 4 GB Flash
- SD-Card Slot
- SSD Slot

OMNIAIR™ CERTIFIED

C-ROADS

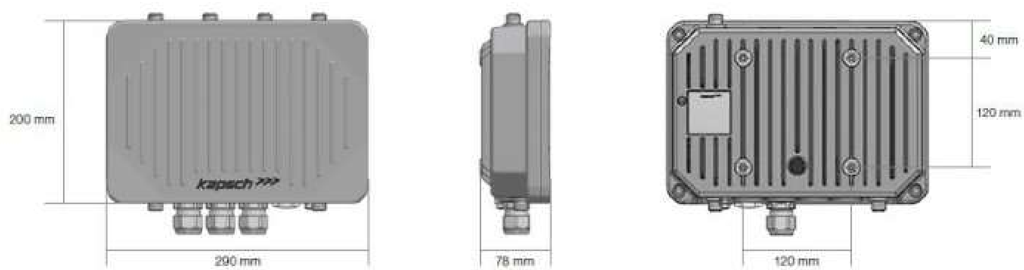


Figure 67: Data sheet of Kapsch RSU: RIS-9160 (Source: Kapsch TrafficCom)

V2X RSU Installations

Currently, there are five V2X RSUs installed on the road between the main road B158 and the centre of Koppl (scenario 1). The locations of the RSUs are shown in the following figure:

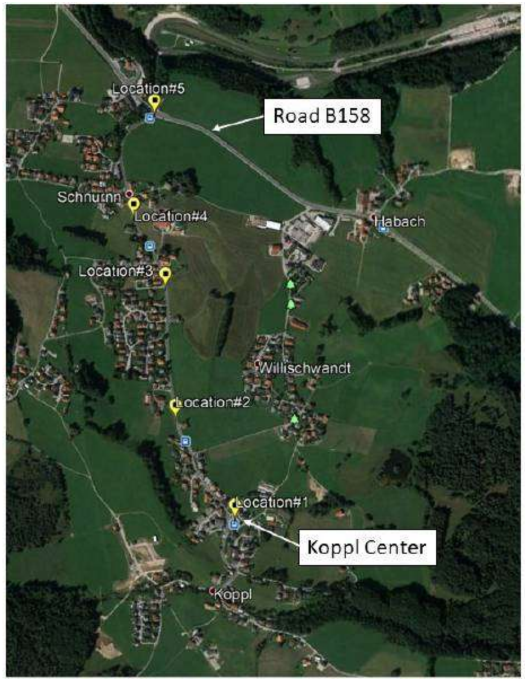


Figure 68: Salzburg Pilot Site: Locations of RSUs in Koppl (Source: https://www.google.at/maps adapted by Kapsch TrafficCom).

The RSUs are mounted on street light poles and connected to a permanent power supply available at the street lights. On the top side the RSUs are equipped with a GNSS antenna and two LTE antennas. For ITS-G5 communication with the vehicles there is a 5.9GHz antenna connected at the bottom side of the RSU. The following figure shows a picture of one of the installed V2X RSUs on a street light in Koppl.

Figure 69: Kapsch TrafficCom RSU installed in Koppl (pilot site Salzburg): Location#5 (Source: Kapsch TrafficCom).

For the SHOW project a further installation of a V2X RSU is planned on the main road B158 between Koppl and Salzburg city (scenario 2). This planned installation shall be connected to a traffic light, in order to transmit traffic light signal information to the CAVs and to receive prioritisation requests from the CAVs.

4.9.2.1 V2X Communication and Basic Services

The RSUs are communicating at 5.9GHz via ITS-G5 with the vehicles. Further they are connected with an internal LTE module to the cellular network.

ITS-G5 Communication

The installed RSUs in Koppl are currently supporting the following ETSI ITS-G5 message formats

- RSU Transmission
  - CAM
  - DENM
  - IVIM
- RSU Reception
  - CAM
  - DENM

Further it is planned to test the GNSS correction service via the RSU. The RSU will generate GNSS correction data based on the received GNSS signal, map this to the standardised ETSI ITS-G5 message (RTCMEM) and broadcast it to the vehicles. The vehicles can then improve the accuracy of their own position, based on their GNSS signal reception, with this correction data.

- Transmission
  - RTCMEM

For the SHOW project another service is planned to be implemented for the new RSU location in conjunction with a traffic light controller. It is planned to broadcast the signal phase and timing of a traffic light to a public transportation vehicle and give prioritisation to designated public transportation vehicles at this traffic light.

- RSU Transmission
  - SPATEM/MAPEM
  - SSEM
- RSU Reception
  - SREM

Backhaul communication

The RSUs are connected via the LTE network to the FlowMotion-Platform[11] from Salzburg Research (SRFG). This FlowMotion-Platform is acting as a Central-ITS-Station with two main functionalities:

- Receiving, processing, logging and visualisation of probe vehicle data (PVD)
- Monitoring the RSUs

For the PVD service the RSUs are forwarding the received CAM and DENM messages from the vehicles to the FlowMotion-Platform. In case of monitoring, the RSUs are sending status information to the FlowMotion-Platform in a proprietary format. The following figure shows a screenshot of the monitoring system for the RSUs:

[11] The software-as-a-service (SaaS) FlowMotion is a software developed by Salzburg Research since year 2012 for the efficient processing and analysis of large amounts of network-related motion data in near real-time and also of historical data sets.

Figure 70: Monitoring of RSUs with the FlowMotion-Platform (Source: own figure)

For the traffic light service it is planned that the FlowMotion-Platform is forwarding SPATEM/MAPEM information from a centralised traffic light controller system to the RSUs. Further the FlowMotion-Platform shall be the connection point for traffic light prioritisation between CAVs / RSUs and the central traffic light controller system.

Another functionality of the LTE connectivity of the RSUs is to give remote maintenance possibility to Kapsch TrafficCom.

4.9.3 Services

4.9.3.1 Mobile communication

4G/LTE is available along the test routes (LTE-capable base station provided by “A1 Telekom Austria AG” is located right next to the test route in the center of Koppl). LTE designated areas are those areas in which data services are possible in the downlink at up to 150 Mbit/s or 300 Mbit/s and in the uplink at up to 50 Mbit/s outdoors. The 4G/LTE network is not designed for time-critical, highly reliable communication. The following figure shows the mobile network coverage for the pilot site Salzburg:

Figure 71: Mobile network coverage for the demonstration sites in Salzburg (Source: https://www.a1.net/hilfe-support/netzabdeckung/frontend/main.html; accessed on November 8th, 2021)

4.9.3.2 GNSS RTK

High-resolution and reliable positioning of vehicles is an essential prerequisite for automated driving. As a rule, a combination of different positioning systems (GNSS RTK, LIDAR, video, inertial measurement system, odometer metrology) is used in an automated vehicle to ensure the most reliable, continuous positioning possible. The combination of different positioning systems should balance out the advantages and weaknesses of the individual systems.

In general, two options for GNSS RTK positioning at the pilot site Salzburg exist:

- the correction data can be obtained over the cellular network (4G) using the Ntrip[12] protocol from an internet-based correction data service (e. g. Hexagon NxGN SmartNet[13]).
- testing the GNSS correction service via the RSU as described in the earlier section titled “V2X Infrastructure” within the section titled “DCI at Salzburg”.

At the time of writing this section (November 2021), the decision of the supplier for the vehicles is still open and subject to a public procurement. Hence, no detailed information about the use of GNSS RTK at the site can be given. This information will be delivered once the supplier of the vehicles is chosen.

4.9.3.3 HD Map

In the Digibus® Austria project[14], the Austrian flagship project for automated driving in public transport, one of the main research goals was to specify and optimize the process for generating a HD map for automated passenger shuttles. This process is described in detail in the Deliverable 8.1 of the project SHOW, deliverable titled “Criteria catalogue and solutions to assess and improve physical road infrastructure.”

[12] https://igs.bkg.bund.de/ntrip/about
[13] https://hxgnsmartnet.com/de-AT
[14] https://www.digibus.at

The following figure shows parts of the HD map generated in Digibus® Austria, which is available for the demonstration at the pilot site Salzburg within the SHOW project. The HD map consists of an HD lane model, a HD lane connectivity model (which makes it fully routable) and an HD centreline (white dotted lines) for each lanelet (a lane object). These centrelines are automatically generated during import. In order to generate the drive path, the HD route from the start bus stop to the destination bus stop is calculated. The drive path consists of all centrelines of all connected lanelets which have to be traversed along the route.

Figure 72: 2 kilometres long HD map of the SHOW test track in Koppl represented in the Lanelet2 format, visualized with Graphium Viewer

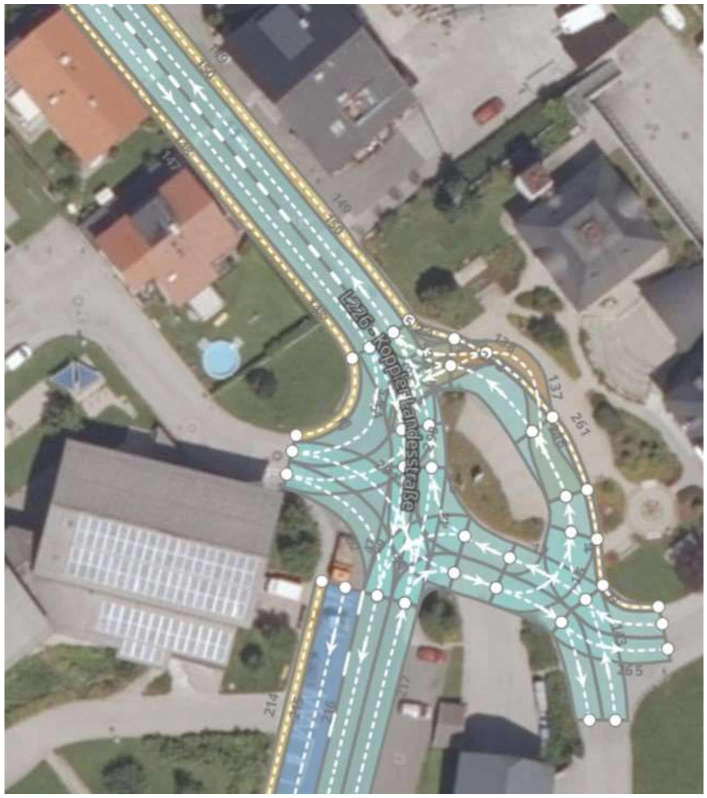


Figure 73: HD map extent around Koppl village center. Color codes: turquoise: roads; yellow: sidewalks and walkways; brown: bus lane or bus stop; blue: parking area; dotted white lines: centerlines.

4.10 DCI at Carinthia, Austria

4.10.1 Pilot Description

The Carinthian site is replacing the site of Vienna within the Austrian Mega Site.

The specific test cases are built around three of the original use cases, in addition one test case with focus on safe Covid-19 transportation will be demonstrated. The test cases are as follows:

- UC1.1: Automated passenger/cargo mobility in cities under normal traffic & environmental conditions (including semi-automated DRT)
- UC1.2: Automated passenger/cargo mobility in cities under complex traffic & environmental conditions (including semi-automated DRT)
- UC1.6: Mixed traffic flows
- UC2.1: Automated mixed spatial mobility (mixed mobility of cargo/passenger at the same time)
- UC3.6: Covid-19 safe DRT

There are two demo sites in Carinthia, one is in Pörtschach at the Lake Wörthersee and one is in the city of Klagenfurt.

Pörtschach: The demo site of Pörtschach is a site with a length of 2.7 km and 8 bus stops. Pörtschach is situated directly at the Lake Wörthersee and therefore a typical Austrian tourist area. The route is connecting the train station with the lake, hotels, shops and the town centre.

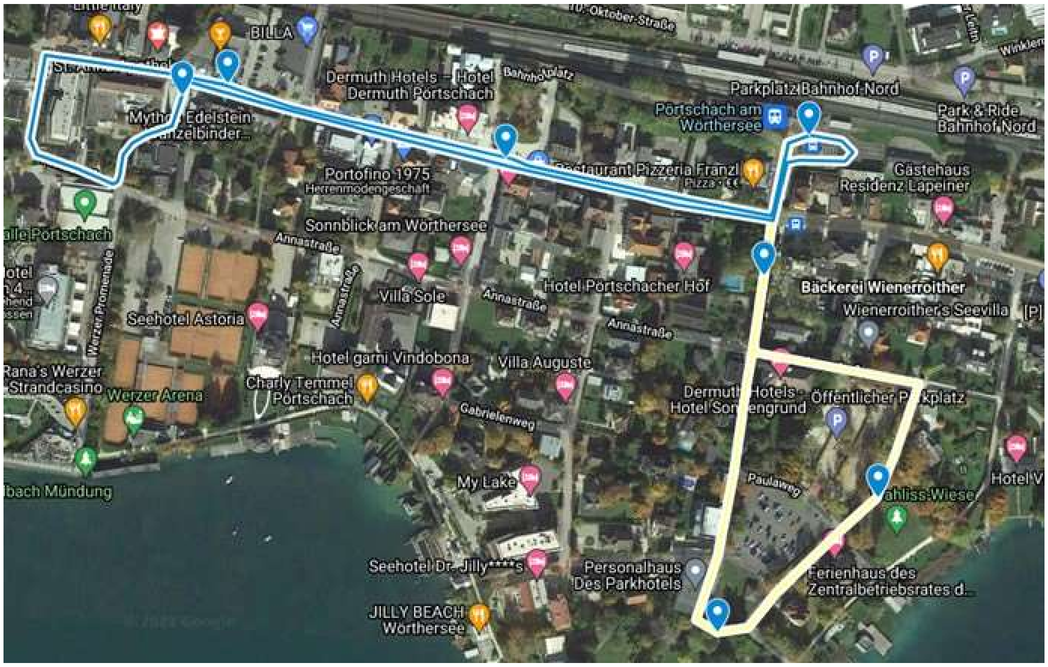


Figure 74: Carinthia demo site: Route options in Pörtschach

At the demo site Pörtschach we are not using any C-ITS infrastructure yet. Since this is the smaller demo site in Carinthia, it's also not planned for the future. The current state of the art is 4G/LTE for data communications. The GNSS base station for satellite communications previously required to increase position accuracy could be omitted in the pre-demo that has just ended.

For autonomous driving, the exact positioning of the vehicle is a fundamental basic requirement. We are using a Navya autonomous shuttle at this demo site. The positioning is carried out as usual via GNSS and RTK, together with Lidar sensors, Odometry and IMU.

The GNSS RTK positioning used at the pilot site in Carinthia for data correction is Ntrip (Networked Transport of RTCM via Internet Protocol) from the service provider Eposa (https://www.eposa.at/). This service was already implemented and tested on the Navya Shuttle on the demo site in Pörtschach and was working fine since 01.09.2021.

Klagenfurt: This is the larger site in Carinthia with a complex traffic situation. The route will include traffic lights, a roundabout and different traffic barriers. There are three different route options, which will be implemented as level 1-3, the final route length will be 4.4 km. The route will connect the train station with a living area, restaurants, shops, the university and a business and science park.

Figure 75: Carinthia demo site: Routing options Klagenfurt

At the demo site in Klagenfurt it is planned to use C-ITS, RSU, a warning system for VRUs and for the subsequent traffic. Since we joined the SHOW project on a later basis this demo site is still in a planning stage, and we can’t give any technical descriptions at this point. For the next update all technical details will be included.

4.11 DCI at Aachen, Germany

4.11.1 LTE-V2X Sidelink

Vehicles will be equipped with LTE-V2X Sidelink OBUs of type Cohda Wireless MK6C[15] enabling V2V communication in the 5.9 GHz band. The communication will be used to support automated driving manoeuvres at bus stops with an optimization algorithm for the longitudinal vehicle motion for a group of vehicles to minimize the collective energy consumption (see the project SHOW deliverable document D1.2 “Use Cases”).

[15] This URL was accessed on October 1st, 2021. https://www.cohdawireless.com/solutions/hardware/mk6c-evk/

4.11.2 5G-Industry Campus Europe

The 5G-Industry Campus Europe[16] (5G-ICE) is a DCI deployed at the Melaten Campus of RWTH Aachen University. It is intended to validate 5G in production, but the outdoor network can also be used to deliver communication services to vehicles used within the SHOW project. A figure shows the four outdoor sites of the network, each with one or two radio sectors (*the figure needs to be drawn, or it needs permission from Ericsson author*). The 5G network operates in the frequency range 3.7 to 3.8 GHz and is accompanied by a 4G anchor network operating at 2.4 GHz. It is therefore currently a non-standalone (NSA) 5G deployment.

The network is used to deliver the same service as done through direct V2V communication; this direct V2V communication is described in the previous section title “LTE-V2X Sidelink”. For that purpose, an edge-hosted message broker is used to relay messages in the network. This is sometimes called “V2N2V”.

4.11.3 3GPP GNSS-RTK

3GPP has extended its Location Services set of specifications to include a standardized way to distribute GNSS correction signals; this is described in the documents 3GPP, “TS 37.355 v16.0.0 LTE Positioning Protocol (LPP),” 2020 and 3GPP, “TS 36.355 v15.0.0 Evolved Universal Terrestrial Radio Access (E-UTRA); LTE Positioning Protocol (LPP),” 2018. This allows broadcasting of information relevant in a certain area through base station sites in that area. Besides broadcasting, also unicast dissemination is possible and will be enabled in the Aachen site.

4.12 DCI at Karlsruhe, Germany

The test site Karlsruhe was set up to demonstrate a variety of the SHOW Use-Cases (UC1.1, UC1.2, UC1.6, UC1.7, UC1.9, UC2.1, UC2.2). Since different Use-Cases come with different requirements regarding the test site, it consists of two sub-sites as visualized in the figure below. The left part of the figure shows the sub-site “Campus-Ost”, which is located on a restricted area belonging to the Karlsruhe Institute of Technology (KIT). The right image shows a map of the subsite “Weiherfeld-Dammerstock”, which is located in the suburb of Karlsruhe of the same name, of Karlsruhe, and will be used to perform tests and demonstrations on public roads.

As the distinct Use-Cases also have different requirements on one or more autonomous vehicles (AVs), a fleet consisting of two modified EasyMile EZ10 Gen2 shuttles and an autonomous car, based on an Audi Q5, is utilized.

[16] This URL was accessed on October 1st, 2021. https://5g-industry-campus.com/infrastructure/

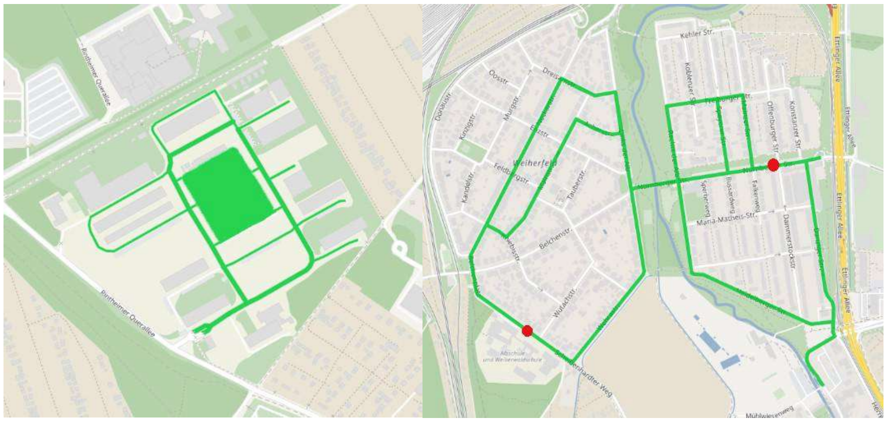


Figure 76: Test test site Karlsruhe. RSU positions are marked in red (Lambing, et al., 2021)

4.12.1 Road-Side Units

Two intersections in the subsite "Weiherfeld-Dammerstock" are equipped with intelligent roadside infrastructure including roadside units (RSUs) as part of the "Test Area Autonomous Driving Baden-Württemberg", which in turn are connected to the traffic light controller of pedestrian crossings via Ethernet and communicate with the AVs (Autonomous Vehicles) using ITS-G5 (IEEE 802.11p). The technical data of the installed RSUs are listed in the following table:

Table 11: Technical data of the RSUs installed in the subsite "Weiherfeld-Dammerstock"

Specification	Sitraffic RSU	WaveBee Road
WIFI standard	IEEE 802.11p	IEEE 802.11p
Supported ITS-G5 message types	CAM, DENM, SPATEM, MAPEM, IVIM, SSEM, SREM	CAM, DENM, SPATEM, MAPEM, IVI, CPM, SSEM, SREM
Supported DSRC messages types	BSM, TIM, SPAT, MAP, SRM, SSM; PSM, RTCM	BSM, WSA, AMP, SPAT, TIM, EVA, NMEA, PSM, RTCM, SRM, SSM, CSR, ICA, PDM, PVD
Receiver sensitivity	-97 dBm (802.11p)	-96 dBm
Max. Output Power	23 dBm (mask C)	+33 dBm

Furthermore, an operation centre is connected via WAN. The system overview is visualized in the following figure:

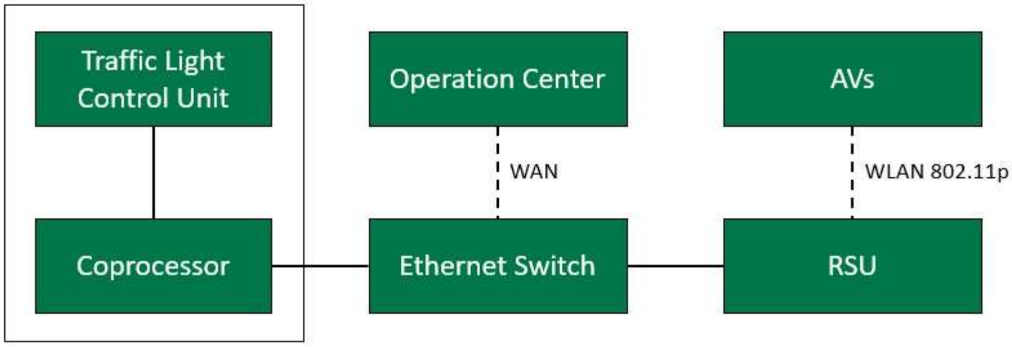


Figure 77: Intelligent Infrastructure system overview

4.12.2 Communication Systems

This system architecture enables the AVs to utilize three types of communication.

1. The roadside infrastructure can be used to support the HAD functions directly by providing additional information that otherwise must have been sensed by the perception system or that cannot be sensed in general (e.g. intersections are often occluded) thus complete information cannot be gathered by a single measurement. To increase vehicle safety, the RSUs are used to broadcast signal phases (SPaT) and road geometry and topological quantities (MAP). Warnings regarding accidents or construction sites, are communicated via Decentralized Environmental Notification Messages (DENM).
2. The AVs can receive information from and about other (intelligent) vehicles via Collective Perception Messages (CPM) and Cooperative Awareness Messages (CAM).
3. The connection between the RSUs and the AVs is utilized to aggregate all available information from the intelligent roadside infrastructure and the AVs in the operation centre, which will be used to evaluate possibilities for future fleet management. This also includes second order information, such as received signal strength indications (RSSI).

Besides, remote supervision potentials for tele-operation or tele-guidance will also be evaluated. To achieve this, the communication between the operation centre and the AVs is designed to be bidirectional.

Figure 78: Visualization of aggregated information in the operation center (Lambing, et al., 2021)

The preceding figure shows how the aggregated information can be visualized (in an exemplary part of the Test Area Autonomous Driving Baden-Württemberg). Aside from data about the AV, such as current position or speed, the health status of the intelligent infrastructure is also visualized making it possible to detect errors such as loss of connection from remote.

4.13 DCI at Turin, Italy

The Turin Satellite Site is depicted in the following figure. The objective of the pilot is to integrate a Demand Responsive Transport (DRT) Service into the existing Turin Traffic Management Centre.

Two vehicles (one autonomous shuttle and one retrofitted tele-operated car) will provide flexible public transport services in the City of Health and Science area to special categories (e.g., people with chronical diseases, elderly, etc.)

A booking service will be provided, and an intelligent system will calculate the optimal timetables and routes of the vehicles to pick up the target users (i.e., employees of the hospital / patients) at the pick-up points located at some local public transport stops along the route, bring them to the hospital and return them back when desired.

A Priority service at traffic lights for the DRT vehicles will also be implemented.

Figure 79: Turin pilot area[17]

4.13.1 Smart Traffic Lights

The city of Turin has a Traffic Operations Centre (TOC), created and managed by the organisation 5T, which allows real-time monitoring and supervision of traffic in all the city area. The traffic management system of the city consists of:

- Traffic sensors,
- Smart Traffic Light Systems, with 51 centralised traffic lights, 39 with public transport priority and 7 existing traffic lights with Traffic Light Assistant-enabled service,
- Variable Message Signs.

On the identified path (see the figure below), two centralized intersections will provide priority to the automated shuttle (highlighted in red), while two others will be equipped to provide the Traffic Light Assistant service (in orange)[18].

[17] The blue line represents the route of the Turin pilot, where the shuttle and tele-operated vehicle will operate in fully automated mode. The yellow and purple lines instead represent the routes to reach the deposit, where the vehicles will operate in manual mode only.
[18] Still to be confirmed, depending on the final approval of the path by the municipality.

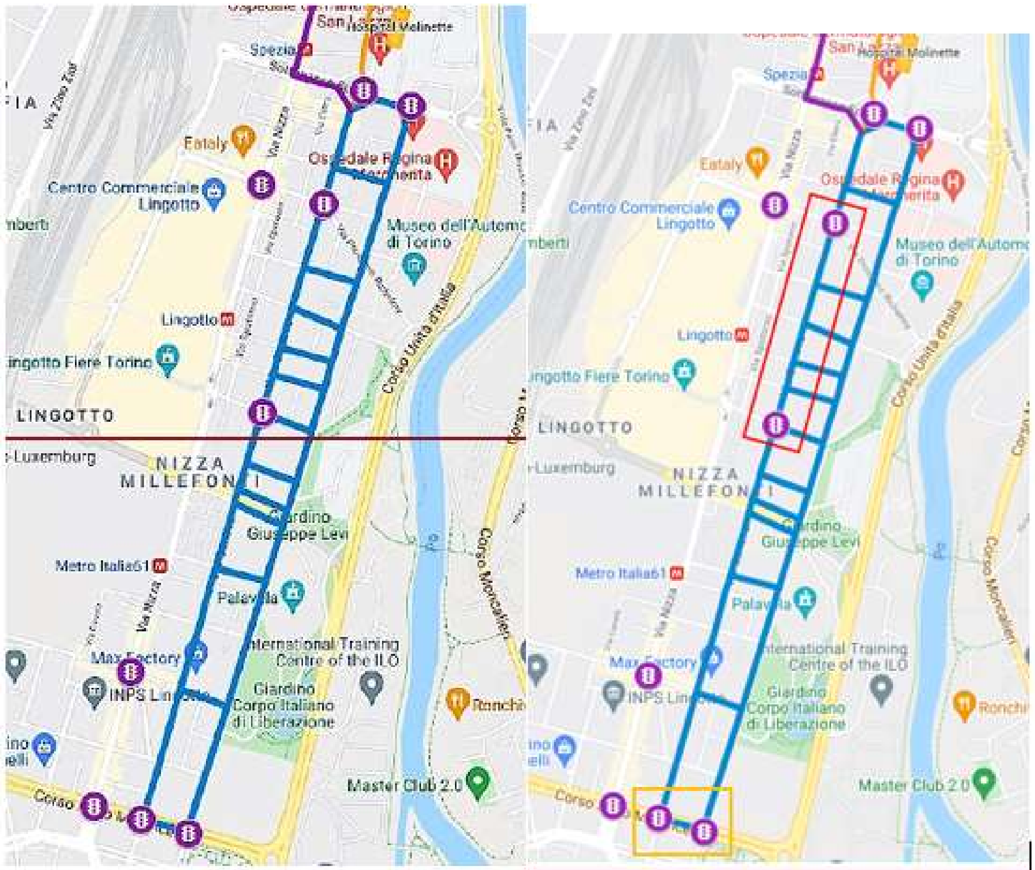


Figure 80: Position of the connected intersections

4.13.2 Communication technologies

WiFi, 3G and 4G is fully available in the City of Torino.

4.13.2.1 Roadside Units: ITS G5 / IEEE 802.11p devices

LINKS will provide the Roadside Unit (RSU) of the pilot. This is a hybrid ITS router supporting both ETSI ITS G5 and LTE/5G connectivity. The RSU implements the main day 1 and day 1.5 services[19] in a reliable and secure way.

Messages can be sent and received using an API, available for the main programming languages. The OS is based on Linux and is optimized for the C-ITS world.

The RSU supports cameras and/or LiDARs, which are used to gather information from the surroundings exploiting AI algorithms.

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[19] A comprehensive list of the Day 1 and Day 1.5 C-ITS services has been laid down in "COM (2016) 766 final". This pdf document is titled "COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS; A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility". It is authored and issued by the European Commission in Brussels, on November 30th, 2016. It has been accessed on the web also on October 5th, 2021, at the following URL: https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v5.pdf

Figure 81: Rendering of LINKS RSU, Source: LINKS Foundation

The LINKS RSU implements a full C-ITS stacks and supports the main ETSI TC ITS features, including:

- Geonetworking: ETSI EN 302 636-4-1 V1.4.1 (2020-01)
- CAM: ETSI EN 302 637-2 V1.4.1 (2019-04)
- DENM: ETSI EN 302 637-3 V1.3.1 (2019-04)
- SPAT/MAP: SAE J2735:2020 and ETSI TS 103 301 V2.1.1 (2021-03) and ETSI TS 102 894-2 V1.3.1 (2018-08)

All the messages are secured according to the following standards:

- ETSI TS 102 731 V1.1.1 (2010-09),
- ETSI TS 103 097 V1.4.1 (2020-10),
- ETSI TS 102 940 V1.3.1 (2018-04),
- ETSI TS 102 941 V1.4.1 (2021-01),
- ETSI TS 102 942 V1.1.1 (2012-06).

Currently, the OS is powered by a Linux UBUNTU 18.04 with a 4.9.140-tegra kernel.

Table 12: Turin pilot site RSU general specifications

General specification	
Component	**Description**
Processor	8-core ARM v8.2 64-bit CPU, 6MB L2 + 4MB L3
GPU	512-Core Volta GPU with Tensor cores
Memory	8GB 256-bit LPDDR4x - 85GB/s
Storage	32GB eMMC 5.1
Radio	• G5 (802.11p) • WiFi/BT • LTE and 5G connectivity
GNSS	Based on UBlox F9P with RTK (GPS, GLONASS, Galileo, BeiDou) bands L1 and L2
Camera	The RSU can support different types of IP cameras connected via Ethernet.
LiDAR	The RSU can support different types of LiDAR connected via Ethernet

The RSU will be installed closed to the intersections providing the traffic light priority service (see the figure above which depicts a map titled “Position of the connected intersections”).

4.13.2.2 5G Network

The initial development plan for 5G foresaw first implementations in two central areas of the city in early 2019. During 2019, the city coverage has been progressively extended, favouring the areas of greatest interest from the point of view of innovative services. The status of the city coverage, in the area of the SHOW pilot, is depicted in the following figure. On the left column is shown the Vodafone Mobile Network coverage and on the right hand is shown the TIM network coverage.

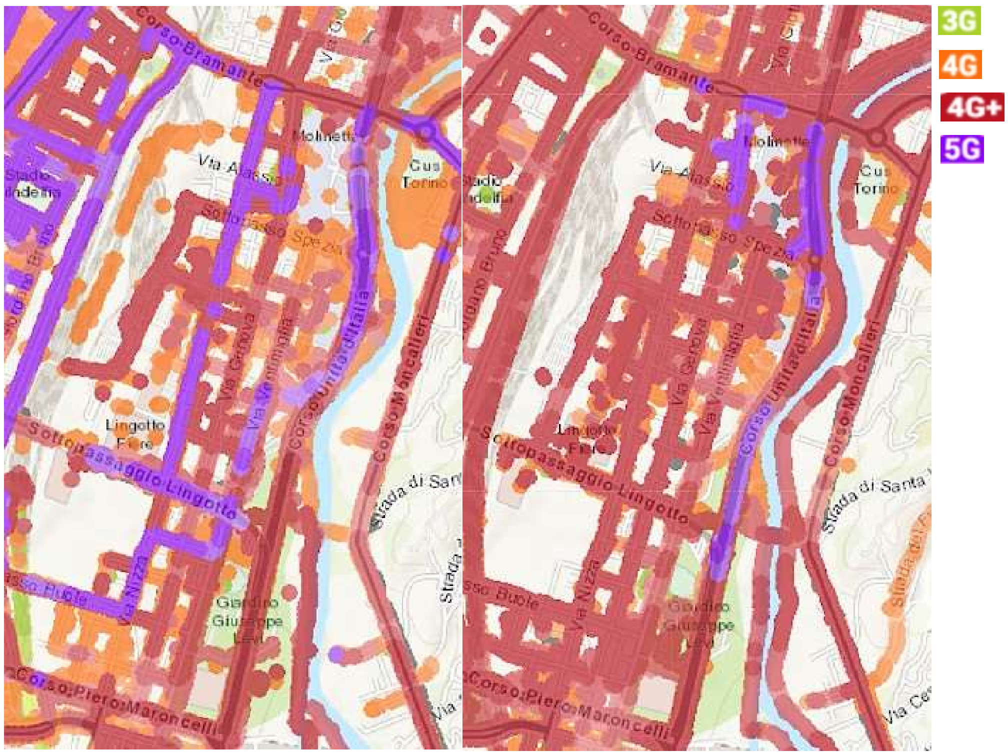

Figure 82: Network Coverage - Turin (Vodafone Mobile, TIM) [Source: nPerf]

4.13.3 GNSS

The localisation of the automated shuttle, provided by NAVYA, depends on two main technologies: LIDAR and GNSS localisation RTK.

The GNSS localisation requires GNSS corrections to work properly and get enough precision (< 4cm). The GNSS corrections are provided either by a NAVYA GNSS base station or by a NTRIP network. The former can provide corrections to the shuttle using both cellular network and radio, whereas the NTRIP network only provides corrections using cellular network.

4.13.4 RSU with Camera for VRU detection

As part of the SHOW project, the installation of a camera (Wisenet X series (XNO-8080R)[20]) is foreseen to realize the use case related to Vulnerable Road Users (VRU). The camera will be directly connected to the RSU where an AI algorithm will detect

[20] https://www.hanwha-security.eu/business-security-products/xno-8080r/ accessed on May 21st, 2021.

pedestrians and send back warnings to the vehicles via ETSI ITS G5 or towards the control centre in the case of tele-operated driving.

4.14 DCI at Geneva Belle Idée, Switzerland

The Belle-Idée site implements a deployment of Fully Automated Mini-buses in on-demand, door-to-door services. As of February 2021, the Transports Publics Génevois (TPG), has rolled out the first on-demand, (quasi) door-to-door, fully automated public transportation service in open roads, deploying three NAVYA shuttles in the 38 hectares Belle-Idée site, covering more than 10 km of all routes in the domain. Passengers can reserve shared rides using a mobile app, while the fleet management and orchestration system assigns the optimal shuttle to serve a specific ride, sending the right mission orders directly to the right vehicle at the right time.

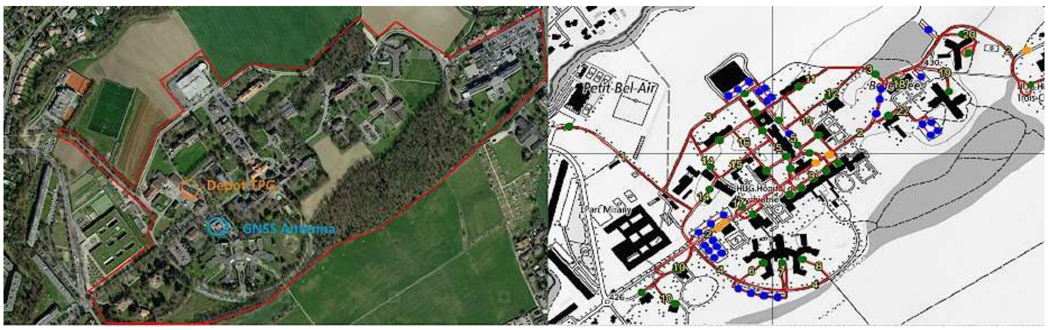

Figure 83: The Belle-Idée and routes network

4.14.1 3G..5G coverage

The Belle-Idee test sote provides a 4G coverage with sufficient bandwidth for normal communications and control, but not enough for high quality video transmissions. The 5G coverage is available, but depending on the operator, it can only work with specific mobile phone models. Some shadow areas with reduced bandwidth have been observed next to some buildings, but this does not create a problem to the operation of the vehicles.

5G is not used by the services, but it is used for the live demos with video streaming.

4.14.2 GNSS

Although a GNSS service is provided by the canton of Geneva, we choose not to use it and we have installed our own GNSS antenna in the domain. The reason for not using the state-provided GNSS service is that there is no information on service quality (uptime). The state provided service was more oriented towards non-critical applications (building construction).

The installed GNSS antenna is supported by a secondary correction information channel, sent via the 4G network.

4.14.3 Inductive charging

An inductive charging platform in the depot was installed in view of a fully start to end automation of the vehicles. However the installation of the inductive charger on the vehicles requires a new homologation of the vehicle, which can only be done at Bern, Switzerland (with a high costs to transfer the vehicle to Bern, and leaving the service without vehicle to operate for 2-3 weeks). For this reason the installation is postponed, and we will re-consider in the future.

4.14.4 Passenger counting

We are experimenting with a video based passenger counting system. The system requires the installation of a camera and of local “services PC” able to locally count faces (and thus preserve fully the passenger privacy).

4.15 DCI at Brussels, Belgium

The Brussels Satellite Site is depicted in the figure below.

The chosen site has been already tested in 2020 in a first phase of a project (called “season 1”). By that time, the green part of the way on the picture has been tested (setup phase) with two shuttles. The test has come to an end due to Covid-19 pandemic, the hospital being closed to visitors for a long period of time. The second phase of the project (called “season 2”) has also been delayed for the same reason.

One of the key objectives of the second phase consisted in getting out of the hospital site, to establish a connection with the nearby metro station through public roads. The main challenge is to equip a cross road intersection with traffic lights (RSU) communicating with the OBU of the shuttles but also with the tramways and emergency vehicles.

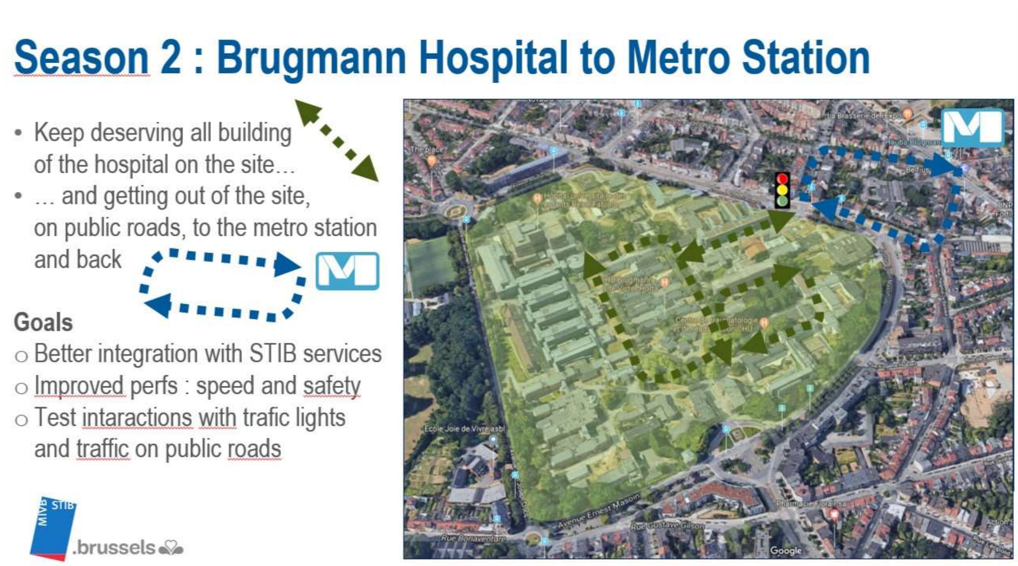

Figure 84: "Season 2" of a project of deployment at Brussels

The next figure shows one of the possible configuration that could be implemented for the communication between the traffic lights and the shuttles and other vehicles. So far, the supplier of the shuttles has not yet been chosen. The supplier for the road sign unit and the traffic lights is also still unknown and will later be chosen through a public tender procedure.

Figure 85: One possible configuration for communications at Brussels

4.16 DCI at Brno, Czechia

Brno Satellite Site is dedicated to passenger use cases and deploys a fleet of three automated vehicles, two shuttles and one robotaxi. Initially, there will be two main areas where these vehicles will be operating. The first area is a city centre, whereas the second one is an area around a technology park and university.

This demo site does not utilize any V2X components. The reason for that is an unwillingness of road authorities to make any modifications of the current road infrastructure. As such, our approach is to develop automated vehicles as self-sufficient without any dependency on external scaffolding in the form of intelligent infrastructure.

4.16.1 LTE Coverage and Tele-operation

One of the main use cases of our location is teleoperation in the form of remote driving, remote supervision, and remote fleet management. This is being done from the remote-control station (see the figure below).

Figure 86: A remote-control station used for teleoperation (remote driving, supervision, and management)

For teleoperation, a 4G network is utilized. This network is provided by two independent mobile carriers (T-Mobile and Vodafone). The whole city area is 230 km2, T-Mobile covers 99,1 % of that with 4G, whereas Vodafone 99 %. There is also an initial 5G coverage, in this case T-Mobile covers 37,1 % of the city, Vodafone 82,9 %. Both automated vehicles deployment areas are fully covered by 4G and partially covered by 5G. During our initial measurements, latency did not exceed 50 ms. The figure below shows the precise network coverage for each carrier.

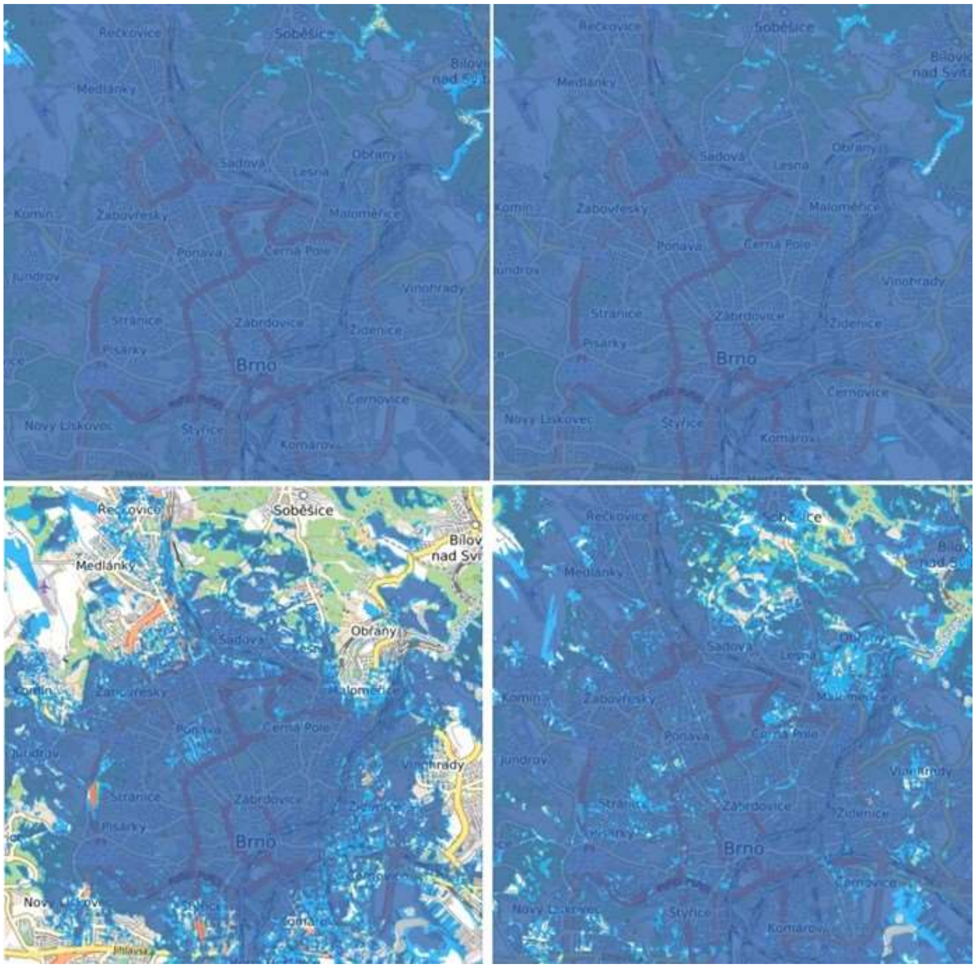

Figure 87: Maps of LTE coverage in Brno, upper left: T-Mobile 4G, upper right: Vodafone 4G, bottom left: T-Mobile 5G, bottom right: Vodafone 5G. [Source: national Telecommunication Office in Czechia, https://digi.ctu.cz/pokryti/pokryti/pokryti/pokryti/ accessed on December 17th, 2021].

4.16.2 GNSS

Each of the three vehicles are equipped with GNSS receivers and RTK units to allow precise localization. Initial measurements showed accuracy at a centimetre level.

4.16.3 HD Maps

A crucial piece of DCI at Brno Satellite Site are HD maps. These maps were created throughout previous months, and they function as the main navigation tool. All three vehicles have these HD maps installed and follow the trajectory. A LiDAR point cloud of the city centre can be seen in the figure below.

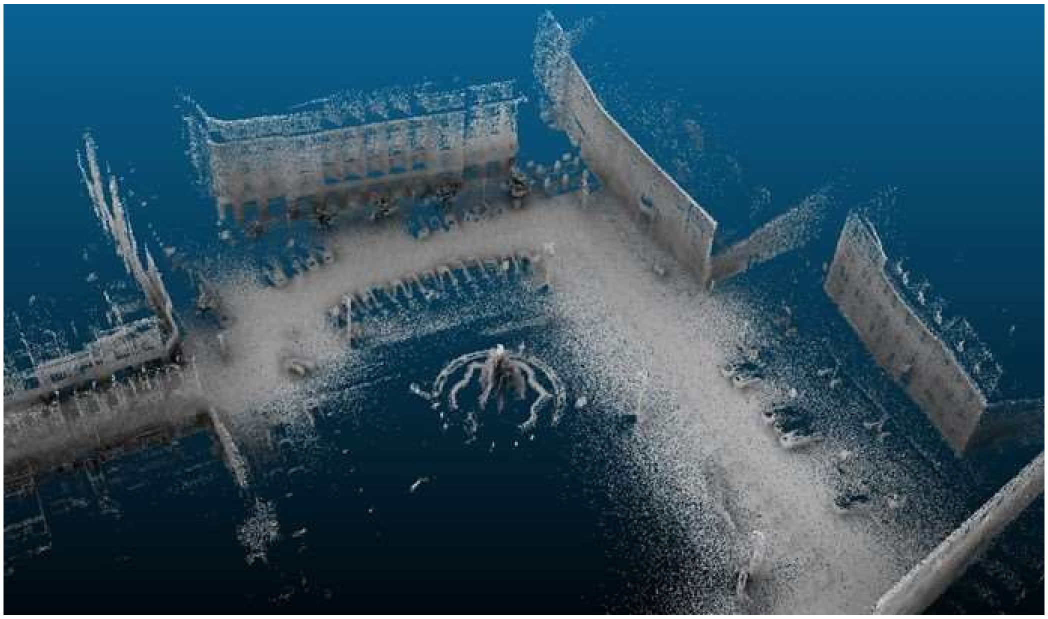

Figure 88: LiDAR point cloud of the city centre that has been used for our HD maps

4.17 DCI at Brainport, Netherlands

The Brainport demonstration site is aimed for supporting public transport on bus lanes in Eindhoven (230,000 inhabitants) with automated driving. Eindhoven is the 5th largest city in the Netherlands, with a clear strategic interest in mobility innovations. The figure below shows the scope of the Brainport and Eindhoven.

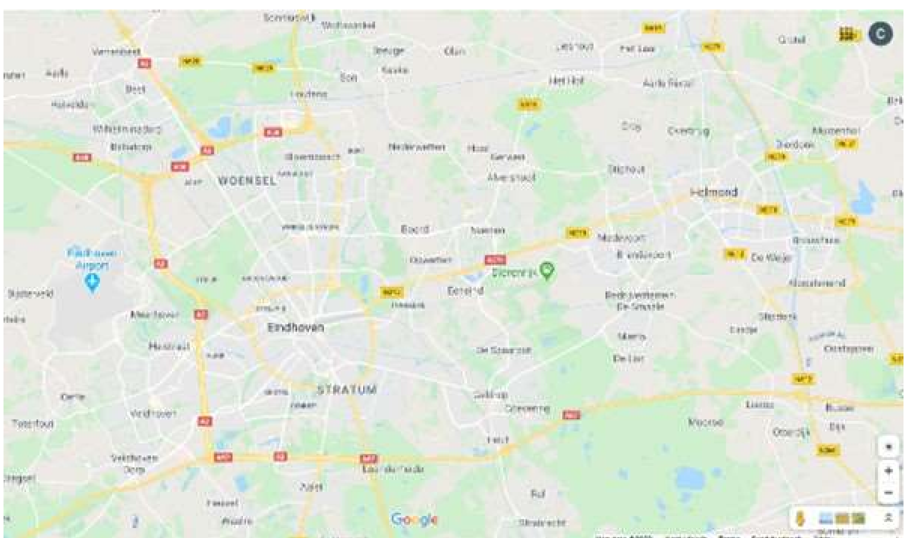

Figure 89: The Site Brainport, Eindhoven

The Netherlands has been represented in the C-ITS platform by various organizations (including TNO), that have had direct access to the standards that have been developed. As a result, the deployment of C-ITS systems and services is executed at a national level, with Brainport as a frontrunner region. The presence of C-ITS equipped intersections in the Brainport has been the enabler for developing technology for crossing intersections with automated driving at normal operational speeds of buses.

4.17.1 C-ITS Services

To increase vehicle safety, road side units (RSU's) are used to exchange traffic light controller Signal Phase and Timing messages (SPaT) as well as road geometry and topological quantities (MAP). Based on these messages, a Green Light Optimised Speed Advice (GLOSA) service is available around Brainport area.

Based on Decentralized Environmental Notification Messages (DENM), Signal Violation Warning services are available. Finally, the area also supports Emergency Vehicle Warning and Green Priority Services.

In relation to the control functionality developed it is relevant to mention that there are some prototype implementations of a Collaborative Perception Service to notify about the presence of vulnerable road users. The setup has been developed in the EU C-Mobile project.

The vehicles are equipped with a communication platform supporting ITS-G5, C-V2x and 4G/5G. In the current setup ITS-G5 is used for V2I intersection services (GLOSA and Signal Violation Warning), as well as for V2V vehicle functions (Cooperative Automated Cruise Control).

4.17.2 C-ITS Infrastructure

Within the Brainport site, both cellular (5G) and ITS-G5 communication technologies are deployed in order to provide road users with C-ITS services.

4.17.2.1 Roadside Units: ITS G5 / IEEE 802.11p devices

RSU's are connected to the traffic light controller (TLC) to acquire Signal Phase and Timing (SPaT) information. GLOSA, Signal Violation Warning and Green Priority services run on the RSUs and use the information from the TLC to encode MAP/SPaT and DENM information. For the Signal Violation Warning the CAM messages of the vehicles are used to evaluate if a vehicle is (about to) violate the red light. There is also an interface to accept the CAM messages from the TMC level for the service Cooperative Traffic Light for Vulnerable Road Users.

4.17.2.2 5G Network

The figure below depicts the current 5G network coverage in the Brainport region. Currently the majority of the site has coverage, and, as the 5G rollout is an ongoing process in the Netherlands, the coverage is expected to expand even further.

Figure 90: 5G coverage Brainport site, source: https://www.kpn.com/netwerk/dekkingskaart.htm (accessed on December 14th, 2021)

4.17.3 RSU with Camera for VRU detection

A prototype installation is available in order to provide safety monitoring of the traffic at the intersection considering different road users. For improving the efficiency of traffic it is required to obtain information of traffic beyond the range of sensors.

4.18 Other sites in SHOW

Copenhagen: the site is currently under exploration. The partner DTU orally reported early in the activity, a description at a place named **Ballerup**. DTU reported in the super spreadsheet (see annex “Super Spreadsheet”) that smart Traffic Lights are used in Ballerup (see column ‘Traffic Lights, smart’).

JRC Ispra: the DCI at JRC in Ispra is reported in D11.1 “Validation” of project SHOW; see the section 3.3.2 “Communication infrastructure” of D11.1. The JRC site is a validation site where vehicles can go to test use cases before the demo period in their original test site.

5 Cameras used for Traffic Monitoring

The goal of this section is to describe sensors for Traffic Monitoring. The 'sensors' are something else than RSUs; an electromagnetic detection loop, an RFID tag, a LIDAR are sensors. The length of this section is 3 pages.

5.1 Mobility Observation Box (MOB) – for overall safety evaluation

Figure 91: Mobility Observation Box. [Source: AIT Austrian Institute of Technology GmbH (2021): Mobility Observation Box. Measure objectively and improve road safety. https://www.ait.ac.at/en/solutions/traffic-safety/safe/mobility-observation-box?no_cache=1]

The "Mobility observation box" developed by AIT is an additional sensor for traffic monitoring and safety evaluation. It observes the traffic on a road section with a length up to 50 m via camera during a defined time span in order to get information on how the road section is used and to objectively evaluate traffic safety through conflict detection and gathering traffic volumes for all different road users. Conflict analysis is crucial for a comprehensive road safety evaluation as there are far more conflicts than crashes. Detecting the conflicts and taking measures to prevent them, leads to much higher road safety than focussing only on crashes.

The mobility observation box can be used before implementing automated vehicles (here the usual time span for monitoring is one week) or while testing. All road users are recorded and later categorized into cars, trucks, bicyclists, pedestrians and e-scooter-drivers. Trajectories are calculated, including the speeds, which allows conflict detection. The behaviour of each traffic participant is monitored individually and the interactions between the road users can be analysed objectively. For this objective analysis different parameters, among them time to collision, post-encroachment time, gaps between vehicles, braking and accelerating manoeuvres, are calculated.

Implementing the mobility observation box before automated vehicles are used helps answering whether a road section is safe to use for AVs through:

- Knowing the number of VRUs.
- Knowing the driven speeds, which might differ from the given speed limits.

- Knowing the trajectories.
- Problems with infrastructure and hazardous road user behaviour can be detected.
- Conflicts already happening without automated vehicles can be detected.

Implementing the mobility observation box while testing autonomous vehicles helps evaluating safety and also detecting conflicts at specific road sections:

- Knowing when the AV stops and being able to detect why.
- Interactions between VRUs and AVs are recorded.
- Knowing if there are any conflicts between the AV and other road users. This information might be available through driving dynamics, but the mobility observation box provides video recordings and another view angle.

Beyond these usages, data generated by the mobility observation box can be used as an input for automated mobility simulations. This enriches the simulations as site-specific real-world situations are included, which makes it comparable to real-world operation.

5.2 Monitoring cameras – for monitoring tram lines

In Tampere, there will be 27 spots/sites with 79 monitoring cameras along the new tramline that will be launched and fully opened for public in August 2021. Two of these spots/sites with 7 cameras are situated close/alongside the SHOW automated feeder transport pilot route. These settings are described in the figure below:

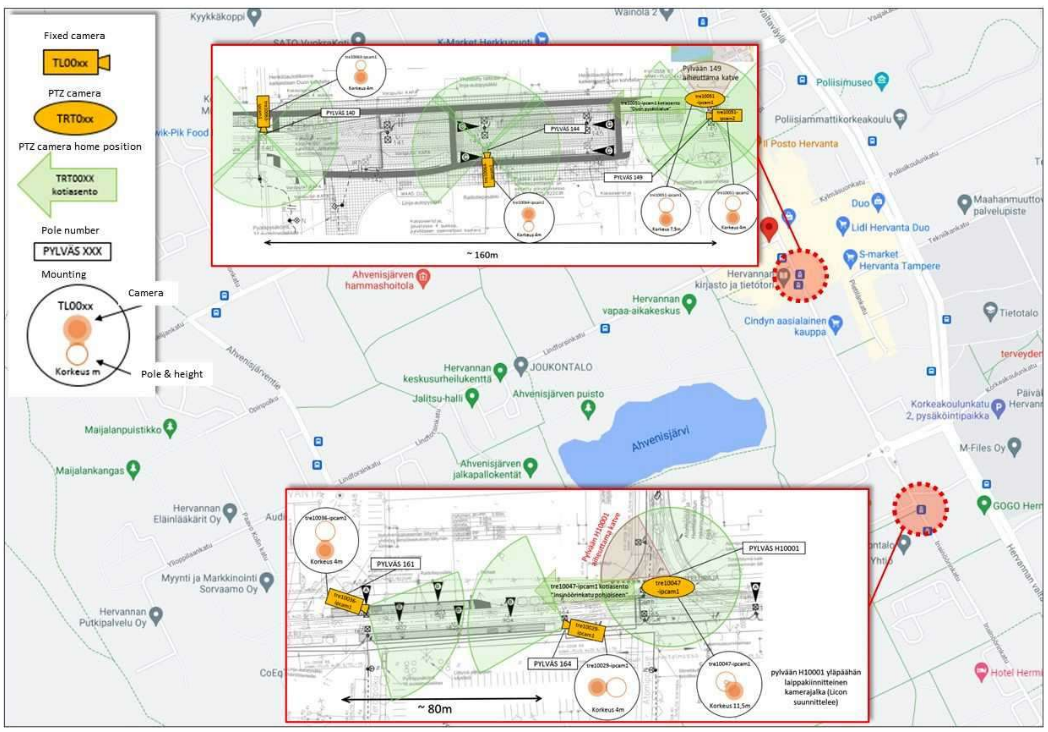

Figure 92: Tram monitoring cameras in Hervanta suburb.

The cameras are coming from several main manufacturers and thus there are several models and types being used. However, because of data protection issues, there is a suggestion from the authority side, that the names of vendors and cameras are not publicly announced.

In practice, they are all Full HD cameras with 4K resolution. They are either fixed or PTZ (pan tilt zoom) cameras. The height of the camera poles to be used in Hervanta pilot area varies from 4 meters to 11,5 meters. The cameras will be used to monitor the tram and its environment. Thus also the automated vehicles, when moving in the tram corridor in Tampere/Hervanta, will be monitored by these fixed and PTZ cameras.

5.3 Smart camera system with deep learning capabilities – for live VRU protection

The YUNEX Traffic awareAI system is part of the infrastructure realisation at the demo site in Graz (refer to section titled “DCI at Graz”), which monitors and detects vulnerable road users at a local transport hub. This smart camera system is equipped with deep learning capabilities focussing on detection, classification and tracking of road users, including pedestrians, bikes, cars, trucks and busses.

The smart camera system performs all detection tasks within a local processing unit, to guarantee the highest level of data protection as only fully anonymized information is processed by external systems. Further, the awareAI system supports advanced setups by incorporating multiple cameras.

Typical mounting positions are poles, gantries or building facades. Mounting heights are typically between 4 m and 7 m from ground, depending on the application. In special cases, mounting heights are possible between 2 m and 9 m. Pedestrians can typically be detected within a range of 3–25 m from the camera mounting position, vehicles within 3–40 m.

The awareAI system enables features for different applications, such as:

- Traffic monitoring, including counting and travel time measurement in urban areas
- Pedestrian crossing monitoring
- Measuring parking space occupancy
- Vehicle tracking

The object detection and classification are key features of the smart camera, which enable the identification of object types. The awareAI system supports a set of eight different object types, which can be detected and classified based on the integrated deep learning engine. The following object classes can be identified:

- Pedestrian
- Bicycle
- Motorbike
- Car (including vans)
- Truck
- Bus
- Tram
- Train

For specific applications, individual detection zone can be configured. These zones enable that all detected objects are referenced to the respective zone. Only objects within the boundaries of a detection zone are detected and included in the data transmission. Typical applications are pedestrian crossings, parking applications or further generic tracking areas. The next figure illustrates an example of a detection zone at a pedestrian crossing and highlights its individual configuration possibilities, including the consideration of specific crossing-angles for pedestrians.

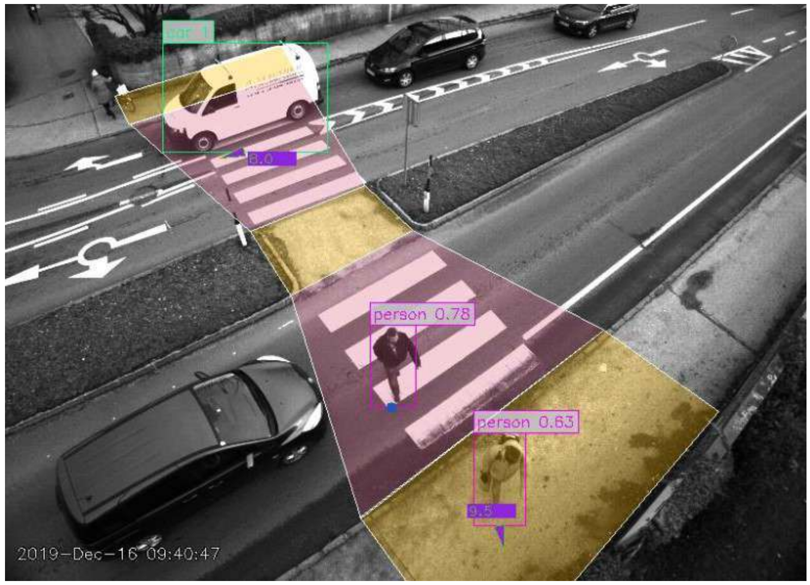

Figure 93: Example of a detection zone of the awareAI smart camera system

Further, smart camera systems enable functionalities to determine movement directions and speed data of detected objects, which can be used for applications such as crossing time prediction.

A major key feature of smart camera systems, such as the awareAI system, is the provision of detected objects as anonymized information to further system components. This enables the combination of the smart camera system with digital communication technologies, to achieve a cooperative safety and traffic efficiency between road users and roadside infrastructure.

The awareAI system provides for each object a set of information, including:

- Object ID
- Object class
- Location in image / Bounding box
- (optional) Geolocation (WGS84)
- (optional) Movement direction
- (optional) Speed
- (optional) Detection Zone

The demo-site in Graz makes use of this, by linking the awareAI system with a C-ITS Road-Side Unit to process detected objects to C-ITS messages, which will get transmitted to nearby ITS-stations via ITS-G5.

Therefore, the standardized Day1 C-ITS service “Decentralized Environmental Notification” (according to ETSI EN 103 301 and ETSI EN 302 637-3), can be applied to inform about dangerous situations.

A more precise C-ITS service will be available in the future, known as Day2 C-ITS “Collective Perception”- service (according to ETSI TS 103 324, which is currently in standardization-process). The Collective Perception service will address the transmission of detected road users or obstacles in real-time, including its position, its dynamics and further attributes. Therefore, the CP-service will require the integration of local perception infrastructure sensors, such as the awareAI System, which detects and provides objects to sending ITS-stations.

6 Analysis and recommendations on Internet access and use

In this section we provide an analysis together with recommendations on how to access and the Internet for realization of CCAM.

In the analysis, the use of a basic communications system (be it IP protocols at network layer for Internet, or not, like CAM messaging without a network layer) is compared to the use of 'bouncing signal' systems (radars, camera, sonars, lidars). These two systems can be used independently, or together, for realization of AD. Several advantages of the use of Internet in the realization of AD are presented.

A further motivation for deployment of Internet for automated vehicles is given. This motivation stems from a recommendation of using IP-based RSUs that are well adapted in places where cellular systems cannot be used. For example, in places where deployed base stations do not reach certain small areas, an RSU could be deployed to offer Internet access. Measurements of wireless coverage are given in support of such deployment.

6.1 Recommendation on the use of IP protocols in networks of vehicles

The importance of Internet connectivity for CCAM (Connected Cooperative Automated Mobility) is often overlooked. When thinking of automated mobility, there are so many other technologies and sensors (radars, lidars, cameras, sonars, infrared and thermal camers) that the Internet itself does not immediately come to mind as a key enabling technology.

Principally, in the current widespread belief it is assumed that Internet is 'everywhere' already – including in the vehicles – as most people are used to *having* Internet in their pockets on their smartphones. The 3G/4G and now 5G deployments cover significant spaces of the daily activities of numerous Europeans. Hence the presence of the Internet in the vehicles – be them automated or not – is inherited directly: one can browse the web or listen to music in a car already. In addition to this generic use of the Internet, several sites in SHOW have DCIs that use the Internet. For example:

- Trikala: the control center uses the Internet to record videos monitoring the vehicles. The buses are linked to the control center via the Internet.
- Tampere: work is ongoing to access the traffic lights of tramways over the Internet.
- Salzburg: the NTRIP-related position corrections are communicated over the Internet.

However, the use of the Internet is, at a first sight, *not* the key aspect in rendering an automobile *autonomous* – the key technologies for automating the driving depend on other local, read 'non-Internet', technologies such as radars, cameras, lidars and algorithmics in fast computing loops of sensing and actuation. These are also called 'bouncing signal' technologies, since their inner workings rely on a radio signal being emitted, bounced and the time being measured precisely at reception. This is the PHY layer in the well-known ISO OSI stack of layers of communication systems.

An additional, but still 'non-Internet', aspect that can also be used for realization of AD is represented by the typical V2X messaging (CAM, DENM); these messages are dedicated to automobiles and could be used to guide the autonomy: e.g. an AV might receive a DENM warning of approaching an accident scene and better instruct the autonomy process to slowly break in advance. However, V2X messages are application layer messages that do not use a network layer (e.g., IP); this results in a lack of scalability for deployment of traditional V2X messages for AD.

Given the wide availability of (1) Internet via 3G..5G, (2) bouncing signal technologies and (3) network layer-less V2X messaging, the immediate question can be formulated to ask whether a potentially more straightforward use of Internet could be better at realizing the AD process?

For (1), the Internet of 3G..5G helps the AD process in an indirect manner. There are the computers realizing the AD process: the remote software update is accessing the Internet, the HD maps are downloaded from the Internet, etc. This use of the Internet, albeit indirect, is of utmost importance to the realization of AD. Without an almost continuous process of remote software update the 'brains' of the AV is not capable of adapting to the very various situations of the environment where it evolves.

For (2), the use of Internet based communication technologies (TCP/IP family of protocols) can completely replace the use of bouncing signal technologies in the realization of automation. An AV connected to the Internet might learn the weather status on the road from a server in the Internet, rather than using an infrared ray (bouncing signal) to check for fog; it might learn the position of other vehicles by querying another server in the Internet, rather than using a camera or sonar (also bouncing signal technology). The data available in the Internet might be much more rich than the data that can be sensed with bouncing signal technologies.

For (3), the V2X messages can be transported on a network layer (rather than currently without network layer) to offer further scalability to larger sizes of networks, coverage areas and, generally, a longer 'reach'. This network layer can be the IP network layer. The use of the IP network layer can be advantageous when compared to other network layers. The advantage of IP relies on its compatibility to the Internet at large: an IP-based network of vehicles using V2X on IP messages can easily interoperate with IP-based RSUs connected to the Internet and to all other platforms connected to the Internet.

In the following paragraphs we give a few more details of these advantages.

We start by taking a perspective from the standpoint of the Internet on 3G..5G and how it is useful for AVs.

An expert in Internet technologies might note that Internet is not only about 3G..6G or just about browsing the web. The Internet overall covers a much wider set of link layer technologies including Ethernet, satellite and more; these technologies have the ability to bring in significant, if not disruptive, improvements to the way CCAM is considered, deployed, used or monetized. If Internet technologies are allowed to flourish in the CCAM ecosystem then new applications of very different kinds will only improve: new applications using Internet range from new forms of combining the existing MaaS models to better responsive digital twin experiences with Internet of Senses.

In order to realize the promise of these new applications the first aspect to be considered is how to cheaply connect all the vehicles to the Internet, in a same manner that all computers are connected to the Internet. Only when all vehicles are connected reliably to the Internet can new applications appear. Towards that goal, the use of a common 'glue' – the IP protocol – is of paramount importance. The widespread of use of IP in vehicular networks allows universal and permanent reachability: any car can connect to any other car, be it nearby or on another side of the Earth.

The use of 'IP protocol' should happen, principally, *in lieu* of existing protocols that are proposed at the network layer, even though those other protocols might continue to run simultaneously. For example, a Road-Side Unit must offer principally IP access over ITS-G5, even if on that channel the CAM messages might still be advertised (CAM messages are not run on IP, typically). A brief description of a Road-Side Unit offering Internet access is provided in an earlier section titled “Examples of Components in the DCI”.

In addition to deploying Road-Side Units which provide principally Internet access (rather than simply advertising CAM, DENM or POTI messages) there is a need of Internet-based protocols for inter-connecting vehicles in a vehicle-to-vehicle manner. These protocols are to be employed principally when RSUs, or base stations for that matter, are not present nearby, or are not visible to the cars. An example of vehicle-to-vehicle topology is illustrated in the following figure:

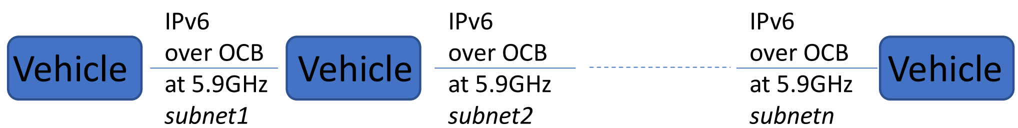

Figure 94: Illustration of a vehicle-to-vehicle topology using IP protocols, RFC 8691

The topology of vehicles illustrated above uses the ITS-G5 communication medium (a link layer based on the IEEE 802.11p link layer); the use of IP on this medium offers the advantage of scaling the set of vehicles to a very large number. Even if the radio range between two vehicles is limited to the range of the use of a single channel at 5.9GHz (a few hundred meters), the use of IP allows to scale up to very numerous vehicles by employing datagram hop-by-hop forwarding. This forwarding is not possible with the use of solely ITS-G5 technology made of the IEEE 802.11p link layer.

6.2 Example and motivation of deployment of Internet for vehicles with an 802.11-based RSU

As stated in the section titled “Digital and Communication Infrastructure in Support of Automated Shuttles at Sites”, the digital infrastructure offers many possibilities for increasing HAD “Highly Automated Driving” functions and fleet management. Assuming that AVs use intelligent infrastructure, the question arises, whether intelligent infrastructure could also be used for providing internet access to vehicles and the passengers. This would especially come in handy when LTE is not available or might get distorted, e.g. in tunnels.

The figure below shows the measurement of the RSSI of 802.11p based communication between a WaveBee Road as specified in the table titled “Technical data of the RSUs installed in the subsite “Weiherfeld-Dammerstock”” and a commercially available V2X-device placed in an autonomous shuttle. As expected, RSSI decreases with increasing distance to the autonomous vehicle. The maximum distance the device was able to communicate with the RSU is about 300 m. Assumming that intelligent infrastructure will get used in a significant amount of intersections, providing AVs with internet over infrastructure could be an alternative for using LTE, at least in urban areas. In more rural areas ensuring signal coverage using intelligent infrastructure could be uneconomical because less synergies with existing infrastructure can be used. As a result, hybrid communication concepts, which are able to communicate via intelligent infrastructure and LTE or 5G might be of interest for the future. Note that the RSU utilized for this experiment is not capable of serving as an actual internet access point. Since the quality of the wifi connection is the communication bottleneck in the scenario described above the results should be transferable.

Figure 95: The RSSI of ITS-G5 based communication. Low signal strength is depicted in yellow, high signal strength is depicted in red, the position of the RSU is marked in blue (Lambing, et al., 2021).

7 Traffic lights control and cooperative intersection

This chapter describes the digital enhancement of traffic lights in a cooperative environment. This comprises the digital mapping of the traditional traffic light signals, digital enhancements to achieve a cooperative communication as well as an overview of different available protocols for the communication with traffic light controllers.

The “Traffic lights control and cooperative intersection” chapter includes:

- An overview of the standards and technical specifications, which are the baseline to achieve a standardized digital communication between the infrastructure and traffic participants.
- The illustration of specified infrastructure services and corresponding message profiles to realize a communication interoperability between all entities.
- The description of digital traffic light services, which:
    - Enable the digital provision of information from the infrastructure to the traffic participants (e.g., Signal Phase and Timing)
    - Enable a bidirectional communication between the infrastructure and the traffic participants to achieve prioritization (e.g., Emergency vehicle approaching).

Furthermore, this chapter includes a summary of available protocols for communications with traffic light controllers. This includes a table distributing protocols per country, and a recommendation for evolution of these protocols.

The traffic light control will be used in the SHOW project for various applications such as traffic light manoeuvring and traffic light priority. These services will be implemented, for example, at the satellite site in Turin and in the Joint Research Center of Ispra. Further information regarding the uses and applications of these services can be found in deliverable D8.3.

7.1 Infrastructure ITS services and message profiles

The transmission of information between the infrastructure and traffic participants (or vice-versa) requires the application of a standardized C-ITS communication to achieve interoperability.

To achieve this, the technical specification “ETSI TS 103 301” (current version: 2.1.1; status June 2021) of the European Telecommunication Standardization Institute (ETSI) has been developed. ETSI TS 103 301 defines infrastructure-related services and specifies protocols and communication requirements for the communication between the infrastructure and traffic participants.

The specification defines services to construct, manage and process ITS messages in order to achieve a communication interoperability between infrastructure services (e.g. Roadside ITS-Station[21]) and vehicle services (e.g. Vehicle ITS-Station). It thereby refers to the Facility Layer of ITS-stations.

[21] A ‘Roadside ITS Station’ could be an RSU, but not necessarily. this is a general term used to address all roadside ITS sub-systems. A Roadside ITS Station could also employ mobile communication.

The technical specification supports, among others, services for traffic light control and cooperative intersections, which meet the SHOWs infrastructure requirements. Following traffic light related services are part of the ETSI TS 103 301:

- Traffic Light Manoeuvre service
- Road and Lane Topology service
- Traffic Light Control service

These services support the management of standardized message types to enable a C-ITS communication interoperability. The standard describes common protocol requirements, such as security requirements for the messages as well as an encoding scheme for the messages. Further, it defines the encapsulation of the message payload, based on ETSI TS 102 894-2. This includes the protocol version of the ITS payload, the ID of the message and the stationID identifier of the message.

The following table illustrates the infrastructure services of the ETSI TS 103 301 standard and describes the required message standard:

Table 13: Infrastructure services defined by ETSI TS 103 301

Infrastructure ITS service	Message Type
Traffic Light Manoeuvre	Signal Phase and Timing (SPAT-EM)
Road and Lane Topology	MAPEM
Traffic Light Control	Signal Request Message (SREM) Signal Status Message (SSEM)

The following sections describe each infrastructure service, which meet the requirements of a traffic light control and cooperative intersection in the SHOW EU-project.

7.1.1 Traffic Light Manoeuvre (TLM) service

The "Traffic Light Manoeuvre" service defines the dissemination of the status of the traffic light controller and traffic lights. It provides in real-time the information of the signal phase and timing of a traffic light, including the operational state of the traffic light controller, the current signal state, the residual time of the state before chaining to the next state, as well as allowed manoeuvres. It can further include information about green way advisory and status-information about the public transport prioritization.

ETSI TS 103 301 specifies the TLM service based on the "Signal Phase and Timing"-Message (SPATEM). This includes the header of the SPATEM, according to the data dictionary ETSI TS 102 894-2, as well as the data elements of the SPATEM payload, according to ISO/TS 19091. Its transport protocol port number is defined as 2004, according ETSI TS 103 248.

7.1.2 Road and Lane Topology (RLT) service

The "Road and Lane Topology" service defines the dissemination of the digital topologic map, which describes the topology of a cooperative intersection (or any other infrastructure area). The topology includes the description of lanes for all relevant traffic participants (e.g. vehicles, public transportation, bicycles or pedestrian crossings) and its allowed manoeuvres within this area. The digital topological map describes this information based on approaches by having an “ingressing” as well as an “egressing” lane and a corresponding “conflict area”.

While the ingressing lanes describe the direction towards the conflict area, the egressing lanes describe the direction away from the “conflict area”. Each ingressing lane is connected to one or more egressing lanes and so defines the allowed manoeuvres in the intersection. These connections integrates the information of the related signal groups, which link the topology information to the corresponding SPATEM, based on the TLM service.

The next figure illustrates this topology organization, including ingressing lanes (marked in red), corresponding egressing lanes (marked in blue) and its resulting conflict area (shown in the middle as dark blue connections).

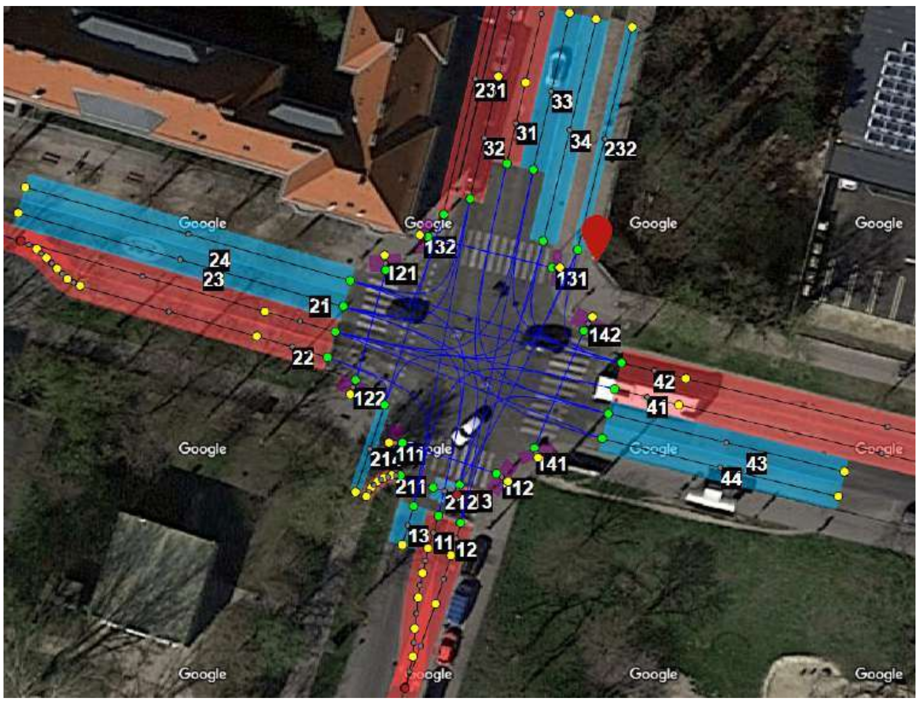

Figure 96: Illustration of a "Road and Lane Topology" service

ETSI TS 103 301 specifies the RLT service based on the MAPEM message. This includes the header of the MAPEM, according to the data dictionary ETSI TS 102 894-2, as well as the data elements of the MAPEM payload, according to ISO/TS 19091. Its transport protocol port number is defined as 2003, according ETSI TS 103 248.

7.1.3 Traffic Light Control (TLC) service

The Traffic Light Control service defines the process to execute a cooperative prioritization (i.e. establish, or give a priority to a selection among choices) at signalized intersections. The service supports the local prioritization of public transport or public emergency vehicles to cross a signalized traffic area safe and as fast as possible. The service is specified by the application of two message types, the “Signal Request” message (SREM) and the “Signal Status” message (SSEM).

The SREM is used by vehicles to request a traffic light signal priority or an extension of the signal phase. The message shall be sent out on demand or automatically, based on the vehicle’s localization or based on received SPATEM (see also TLM service)

A receiving traffic C-ITS infrastructure (e.g. Roadside ITS station) needs to forward this to the traffic controller or Traffic Control Centre, in order to decide about the request. In response, the “Signal Status” message (SSEM) gets sent out by the infrastructure unit as feedback to the signal request, to transmit the status of the request (e.g. granted, cancelled).

ETSI TS 103 301 specifies the TLC service based on the Signal Request message (SREM) and the Signal Status message (SSEM). This includes the header of the SREM and SSEM, according to the data dictionary ETSI TS 102 894-2, as well as the data elements of the SREM and SSEM payload, according to ISO/TS 19091. Its transport protocol port number is defined as 2007 for the SREM and 2008 for the SSEM, according ETSI TS 103-248.

7.1.4 C-ROADS Message Profiles

The C-Roads Platform is a joint initiative of European Member States and road operators for testing and implementing C-ITS services in light of cross-border harmonisation and interoperability. Through the C-Roads Platform, authorities and road operators join together to harmonise the deployment activities of cooperative intelligent transport systems (C-ITS) across Europe. The goal is to achieve the deployment of interoperable cross-border C-ITS services for road users. This is described in a document in the file named “C_Roads_WG2_TF3_MessageProfiles_R2.0.0“; this file can be requested electronically from the following URL https://www.c-roads.eu/platform/documents.html This URL has been accessed also on November 5th, 2021. However, on that date the file could not be accessed at that URL. For access, it is best ask someone from the C-ROADS project.

The C-Roads Platform covers, among others, the topic of light control and cooperative intersection services by providing a common functionality for signalized intersections. The Signalized Intersection functionality includes 5 use-cases in the current available C-roads specification (v1.8, status June 2021)

1. Signal Phase and Timing Information
2. Green Light Optimal Speed Advisory
3. Imminent Signal Violation Warning
4. Traffic Light Prioritisation
5. Emergency Vehicle Priority

Based on these use-cases, message profiles have been developed and specified by the C-Roads Platform. These profiles are defined in the “C-Roads C-ITS Message Profiles” specification and refines and (de-)selects possibilities that the underlying ETSI TS 103 301 standard (see chapter Infrastructure ITS service) provide, to guarantee a harmonized communication approach for interoperable C-ITS cross-border services.

The use case descriptions in the following two sections (titled “V2X Information of traffic light status” and “V2X Traffic Light prioritisation”) are based on the C-Roads specifications and are adapted to CAV scenarios.

7.2 V2X Information of traffic light status

Description of the use cases:

1. Signal Phase and Timing Information (SI-SPTI)

Within this use case, Connected and Automated Vehicles (CAV) approaching and passing signalised intersections receive information on the phase(s) of the traffic lights.

More specifically, the I2V-enabled signalised intersection transmits in real-time the current phase state and predicted timing of the traffic lights and road topology for the intersection ahead.

This information allows CAVs to adapt their behaviour when approaching a signalised intersection, minimising sudden stops, deceleration, or accelerations. Vehicles can adapt their speed when knowing the time left until the next phase of the upcoming traffic light, or engine can be switched off when stopped at a red phase. These features can improve safety, traffic efficiency, sustainability and driving comfort.

Three possible scenarios can be foreseen:

1.1. Vehicle approaches a green traffic light:

The infrastructure transmits periodically and in real time the current green phase state and timing of upcoming phase changes of the traffic lights. The CAV approaching the intersection, aware of its own location, velocity, and speed limit receives the messages and extracts the relevant time to red information and uses that information to determine its speed towards the intersection.

1.2. Vehicle approaches a red traffic light:

The infrastructure transmits periodically and in real time the current red phase state and timing of upcoming phase changes of the traffic lights. The CAV approaching the intersection, aware of its own location, velocity, and speed limit receives the messages and extracts the relevant time to green information and uses that information to determine its trajectory towards the intersection.

1.3. Vehicle stopped at red traffic light:

The infrastructure transmits periodically and in real time the current red phase state and timing of upcoming phase changes of the traffic lights. The CAV extracts the relevant time to green information.

2. Green Light Optimal Speed Advisory (SI-GLOSA)

Within this use case, Connected and Automated Vehicles (CAV) receive speed advice information from a single or a sequence of signalised intersections. This information allows CAVs to adapt their approach speed and to pass one or more signal-controlled intersections more safely and in an energy efficient manner, minimizing stops, acceleration, and deceleration.

Traffic conditions, e.g., queues or traffic jams, can affect the validity of speed advisory information and therefore they need to be considered.

Two possible scenarios can be foreseen:

2.1. The vehicle calculates speed advice:

The infrastructure transmits periodically and in real time the current phase state and timing of upcoming phase changes of the traffic lights. The CAV approaching the intersection, aware of its own location and velocity, receives the messages and calculates the optimal speed advice for approaching the intersection, taking into consideration legal speed limits.

2.2. The infrastructure calculates speed advice:

The infrastructure, knowing the position and velocity of the CAV, calculates and transmits in real time advisory speed information for one or more signal-controlled intersections, taking into account legal speed limits. The CAV approaching the intersection receives the messages and extracts the optimal speed advice for approaching the intersection.

3. Imminent Signal Violation Warning (SI-ISVW)

Within this use case, Connected and Automated Vehicles (CAV) approaching traffic light controlled intersections receive imminent signal violation warnings.

This information shall reduce the likelihood and severity of collisions and injuries at signalized intersections by warning the driver that there is a potential violation of a red intersection signal.

This use case requires lower latencies, compared to the previous two, due to its time critical nature.

Benefit for CAVs (Connected Automated Vehicles)

- CAVs have increased awareness on traffic lights statuses, with information on predicted phase changes. This can help to:
    - Increase energy efficiency due to smoother driving,
    - Improve traffic flows,
    - Improve driving efficiency, reducing stops and emissions,
    - Improve traffic safety, also due to reduced red-light violation and lower risk of collision when passing the intersection.

7.3 V2X Traffic light prioritisation

Description of the use cases

1. Traffic Light Prioritisation (SI-TLP)

This use case is especially considered to give priority to designated Connected and Automated Vehicles (CAV), e.g. public transportation, over individual vehicles at cooperative signalised intersections for assuring on time transportation schedule and/or minimize emissions.

Within this use case, CAVs approaching a cooperative signalized intersection transmit a prioritisation request to the prioritisation system of the traffic light controller (either local or central). The prioritisation system processes the request and either accepts (e.g. the vehicle is behind schedule and/or eligible to get priority) or rejects (e.g. other priorities are granted) it then gives feedback to the CAV. If the request is accepted, e.g. "red phases" may be shortened and "green phases" extended, thus the CAV gets a green light with minimum delay at the stop line. After the CAV has successfully driven through the intersection, the traffic light controller switches back to normal operation.

2. Emergency Vehicle Priority (SI-EVP)

Using Connected and Automated Vehicles (CAV) as emergency vehicles is maybe a scenario that is more in the future. Nevertheless, there is a use case defined that provides a clear and safe way for the emergency vehicle through a cooperative signalized intersection.

Traffic light prioritisation for emergency vehicles can be distinctly different from normal traffic light prioritisation. Depending on intersection geometry, lanes other than those that the emergency intends to use may be cleared, offering the emergency vehicle an easier approach to and passage through the intersection. Moreover, drivers of other vehicles are often not aware that they can pass through a red light if an emergency vehicle (with sirens and light bar enabled) is approaching and there is no other way to clear a path. This results in drivers blocking the path of the emergency vehicle until the light turns green.

Within this use case the connected and automated emergency vehicle approaching the intersection, sends periodically and in real time its current position and operational state. The cooperative signalised intersection receives the prioritisation request and checks its validity. Dependent on the position, the heading and the distance to the intersection the traffic light phases are controlled in a way that, at first, conflicting traffic streams are stopped, then under regard of minimum inter green times, all or selected lanes of the ingress approach of the emergency vehicle get a green light and are cleared. Based on the prioritisation status information, the emergency vehicle passes the intersection using the cleared lane(s). After detecting that the emergency vehicle has successfully passed the intersection, the intersection control switches back to normal operation (i.e. starting with green for conflicting lanes with high traffic).

Benefits for CAVs

- The designated CAVs drive through an intersection without stopping at "red light" or waiting for "green" light and can pass the signalized intersection with minimum delay. This can contribute to:
    - Reduced emissions from designated CAVs
    - Improved punctuality due to reduced disturbance on branch lines
    - Increased attractiveness of public transport due to improved comfort
    - Improved efficiency of CAV operations (e.g. same service quality with less vehicles or higher frequency with equivalent fleet)
    - Improved choice of suppliers for fleet operators or public authorities due to standardised V2X solution for designated vehicle prioritisation systems
- Prioritisation of connected and automated emergency vehicles at intersections can contribute to:
    - Shorter travel time for emergency vehicles
    - Less collision risk at the intersection
    - Increased flexibility to alter the priority lane/signal and use different routes
    - Convoy of automated shuttles are un-separated during passing through a prioritized intersection.

7.4 Protocols for communication with Traffic Lights Controllers

In this section we provide a list of communication protocols dedicated to traffic lights controllers. The list is provided for several purposes:

1. Each protocol is different from the others. Each protocol is used in one or a few member states. For example DIASER is used in France and IVERA in the Netherlands. In France there are several manufacturers of traffic lights controllers (about 8) and all implement DIASER, but none implements any other protocol such as IVERA. The situation is probably similar in the Netherlands where DIASER is not used at all.

   This illustrates a larger point of view: the market of traffic lights controller equipment is fragmented in countries with manufacturers holding what appear to be *monopolies* of deployment in areas.

2. This aspect of protocols has a profound impact on deployment. If a certain automated shuttle is deployed in two distinct countries then it will have to carry implementations of two distinct protocols in order to

communicate to traffic lights of each country. This is a negative aspect of software named 'bloatware'. Ideally, a single communication protocol should exist to communicate with the traffic lights controller.

3. A unique communication protocol is that offered by ETSI SPAT-EM. It is implemented in all countries, almost in a similar way. However, the details of implementations involve *conversion* from SPAT-EM and the respective country protocol. For example, a SPAT-EM on a traffic lights in Netherlands will convert to IVERA, and in France it will convert to DIASER. But the two IVERA and DIASER protocols are not eliminated, simply another protocol is added together with conversions; the conversion software also adds up to bloatware. Whereas this direction eliminates bloatware in the autonomous shuttle, it enhances bloatware on the traffic lights controllers. An ideal solution, is that of replacing DIASER and IVERA with another protocol (be it SPAT-EM, or another new one, to be developped). A characteristic of this ideal solution could be to reuse the common aspects of DIASER and IVERA: one of the common aspects is their ability to be carried on IP datagrams (Internet Protocol).

Country	**Protocol used for communication with Traffic Lights Controllers**
France	DIASER
The Netherlands	IVERA, V-Log, TLEX
Finland	TLEX
Germany	OCIT
The Czech Republic	OCIT
Spain	Tipo V
Certain Scandinavian Countries	RSMP
Italy	Provided by manufacturer named "3G Signaletica"

ISO PRESTO 22951: a protocol to communicate with traffic lights controller, to obtain priority for special vehicles. It is standardized at international level (ISO) and not at ETSI.

SPAT/SSM/SRM: protocols used by future traffic lights controllers; specified by SAE in J2735. The 2009 version is freely available, whereas the 2016 (non retro-compatible) is paying 100 USD, approximate. SPAT is Signal Phase and Timing, whereas SRM is Signal Request Message. They are further reused at ETSI specifications.

SPAT-EM: an European version of SPAT, specified by ETSI, which encapsulates SPAT. Free access, but SPAT still paying (free encapsulated paying).

DIASER: a protocol used to communicate to Traffic Lights controllers. Used in France. Specified by AFNOR. Works on hardware platforms from Lacroix (model Traffy) and Aximum (model Maestro), and probably others. Works on serial and on UDP/IP. DIASER is known to work on RS232, TCP and UDP. Seen on IPv4; not known on IPv6. SEA is a traffic lights controller manufacturer in France that produces some, implements DIASER too. There are about 10 manufacturers in France (Aximum of Colas, Fareco of Fayat, Lacroix, SEA, others?), all doing DIASER. In France, in addition to DIASER there is also LCR protocol for Traffic Lights.

API WIM 7101: a proprietary API interface used by organisation NEAVIA of organisation Lacroix in France; it is used to provide access to data of traffic lights controllers.

IVERA: the IVERA protocol is used in the Netherlands to provide a manufacturer-independent communication method between traffic control installations and a control centre. The protocol is also suitable for communicating with parking management signs and ramp meters (traffic lights) that regulate traffic entering freeways.

V-Log: the V-Log protocol is a similar protocol to IVERA emerging from the Netherlands, but with a focus on logging data from traffic control installations. It's an open standard and free from license fees.

TLEX: Traffic Light EXchange platform (TLEX) is a protocol mentioned in countries Netherlands and Finland; it is mentioned together with the acronyms iVRI and IVERA.

Traffic Light EXchange (TLEX) platform was first introduced in the Netherlands as part of their effort to connect to all intelligent traffic light controllers and create a national coverage. The TLEX generally connects different roadside equipment and information brokers, authorities. The platform uses ETSI standards for communication such as SPAT and MAP messages, but also proprietary protocols. It enables defining traffic light priorities for specific groups without additional installations. The system is used also in other European countries. (https://monotch.com/solution/tlex-i2v/)

The manufacturers are SWARCO, Dynniq, Siemens.

MQTT: The generic MQTT protocol has been used at the Tampere Satellite Site to retrieve traffic light status data over Internet. The proprietary messages provide traffic light statuses and remaining-time-green & time-to-green. The detailed implementation has been described in section titled “Traffic light data using MQTT protocol” within the section titled “DCI at Tampere Satellite Site”.

OCIT: Open interfaces for connections between central and distributed components (https://www.ocit.org/en/ocit/interfaces/). Protocol family used at least in Germany and in the Czech Republic. The OCIT protocols may be used for communication with Traffic Lights Controllers, with some implementations from Siemens and from Cross. Not known whether OCIT works on IP, and on IPv6.

RSMP: Roadside message protocol originating from Scandinavian countries (https://rsmp-nordic.org/uk-about-the-protocol/). Its specifications are maintained on GitHub (there is also a document titled “CEN/TC 278/WG 17 N 207”).

Tipo V: The 'Tipo V' (read 'type V', like in ‘Valencia’, not the number five) is a protocol used in Spain to communicate to traffic lights controllers. The spec number is UNE 135401-5 IN. It is standardised by Spanish organisation AENOR. ETRA, at least, implements it.

NTCIP: In the USA a protocol to communicate with Traffic Lights Controllers. It is on the web at https://www.ntcip.org/document-numbers-and-status/. It has Internet specifically (it has profile for it, dated 2001). Further, it may be implemented by Thales, a French company.

UTMC: In UK there is UTMC protocol for traffic management.

In other countries in Europe the situation is the following:

- Italy:
  - City of Livorno:

        - 3G Segnaletica: an organisation in Italy that provides hardware for controllers for traffic lights. Also has models carried in 'mobile' traffic lights. It provides a Raspberry Pi to access the traffic lights data. The Raspberry Pi uses an API to access the controller status. That API uses HTTP. (source: oral communication by member from Links Foundation).
    - City of Rome: it is not clear which communication protocols are being used to communicate to the traffic lights controllers. (source: slide titled 'ITS Systems Deployment' of a presentation during an ERTICO workshop on the occasion of meeting Dubai RTA in 16 December 2021):
        - Omnia/Utopia systems of company SWARCO Mizar,
        - Tmacs system of company Semaforica,
        - Sigma+ system of Leonardo.
- Romania:
    - City of Timisoara:
        - Some deployment from company Aximum (ex-Sagem) with protocol DIASER (source: oral presentation by Aximum, year approx. 2019)
    - Cities of Cluj and Bucharest:
        - Some potential deployment from SWARCO. It is not clear which protocol is being used (source: https://www.swarco.com/de/stories/bukarest-cluj-rumaenien accessed on December 17th, 2021).

8 GNSS RTK with V2X communication via ITS-G5, LTE and L-band

This chapter explains the GNSS RTK service especially for vehicles. GNSS RTK can improve the accuracy of a pure GNSS service by introducing a reference station that calculates correction signals and deliver them to the GNSS receiver in the vehicle. The chapter is structured as following:

- The section “Overview” gives a short overview about GNSS RTK and their usage via the V2X communication system.
- The section “Improvement of vehicle positioning via ITS-G5 GNSS RTK” explains the expected advantages when using GNSS RTK via the V2X communication system ITS-G5.
- The Section “ETSI standardisation of GNSS RTK via ITS-G5” gives an overview about the most important standardisation in ETSI for the ITS-G5 communication case.
- The section “High-Precision Localisation with redundant GNSS Correction Signals and Galileo High Accuracy (HA) Service” explains the usage of RTK GNSS with redundant GNSS Correction Signals and Galileo HA Service.

8.1 Overview

The current state of the art, in order to transmit RTK-correction signals is via mobile communication systems (3G/4G) or with a proprietary UHF (Ultra High Frequency) radio communication systems. As protocol the internet-based NTRIP (Networked Transport of RTCM via Internet Protocol) is used, in order to transmit the correction data, via an internet-based connection from the base station to the rover. The correction data/message itself is called RTCM (Radio Technical Commission for Maritime Service).

Another possibility to transmit the RTCM messages is the usage of the V2X communication system. The V2X communication system ITS-G5 offers the possibility to transmit traffic relevant information between vehicles (V2V) or between the infrastructure and vehicles (V2I), combined in the acronym V2X. Transmitting the GNSS correction data with the RTCM message via ITS-G5 is quite a new ITS-G5 service that is implemented and tested in only a few projects. The V2X Roadside Unit (RSU) is acting as the RTK base station and since it is placed on a stationary location it can generate the GNSS RTK correction data. The V2X RSU is transmitting the RTCM signal via ITS-G5 to the V2X Onboard Units (OBU) installed in vehicles. Based on the received GNSS signals from the satellites together with the GNSS correction data from the V2X RSU the OBU can improve the accuracy of its own position. The next figure presents the GNSS-RTK provision via ITS-G5.

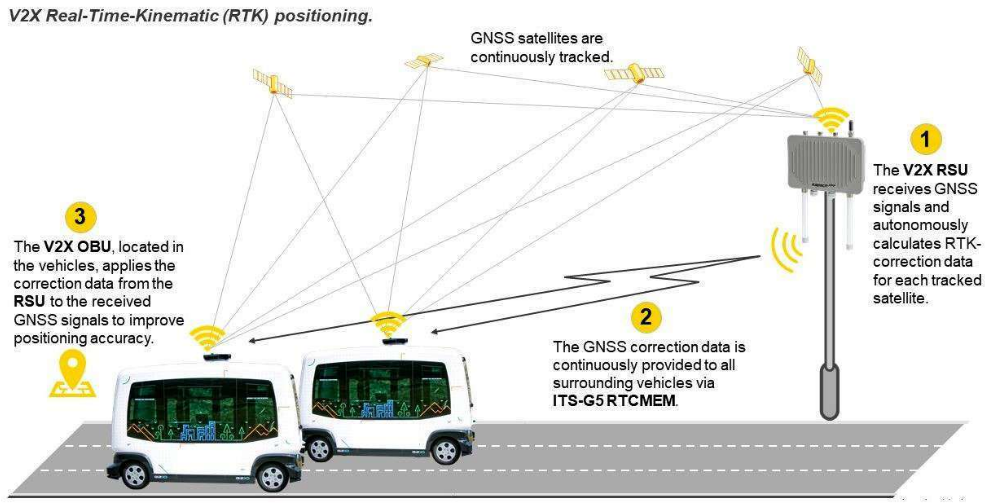

Figure 97: GNSS-RTK via V2X communication: ITS-G5

8.2 Improvement of vehicle positioning via ITS-G5 GNSS RTK

By using ITS-G5 for the transmission of RTCM messages from the base station to the rover, the following advantages are expected:

- If the vehicle is already equipped with an ITS-G5 OBU, there is no other hardware (other radio technologies modules) required, in order to receive the RTCM correction messages.
- Since the RSUs are placed above or next to the road, the distance between the base station (where the correction data is generated) and the rover is quite short. With this short distance the achievable positioning accuracy will be improved.
- The short range communication system ITS-G5 is designed, in order to achieve short latency in the transmission. With this, the reliability of the data transmission compared to internet-based systems will be improved.
- In comparison to web-based RTK services the ITS-G5-based RTK service is free of charge.

8.3 ETSI standardisation of GNSS RTK via ITS-G5

The ITS-G5 RTK correction data transmission is realised with the GNSS Positioning Correction (GPC) service defined in ETSI TS 102 301. The GPC service is using the ITS-G5 message format RTCMEM (RTCM Extended Message) for transmission of the RTCM correction message, defined in ETSI EN 302 890-2. The different correction information is split to several RTCM-types, e.g. the information about the stationary RSU (base station) is given in the RTCM-type 1005. The following table gives an overview about the most important RTCM-types.

Table 14: RTCM-types from ETSI EN 302 890-2

RTCM message type	Required periodicity for GPC service	Comments
RTCM3.2 - 1005	1 Hz	Contains R-ITS-S station coordinates

RTCM message type	Required periodicity for GPC service	Comments
RTCM3.2 - 1077	1 Hz	GPS MSM7 auxiliary operation information, up to 904 bytes length
RTCM3.2 - 1087	1 Hz	GLONASS MSM7 auxiliary operation information, up to 904 bytes length
RTCM3.2 - 1097	1 Hz	GALILEO MSM7 auxiliary operation information, up to 904 bytes length

8.3.1 High-Precision Localisation with redundant GNSS Correction Signals and Galileo High Accuracy (HA) Service

For autonomous shuttles the 100% availability of the exact actual position is one of the key preconditions. To ensure this, the GNSS correction data have to be always available for the localization system inside the vehicle.

The GNSS correction data – packed in a protocol according to norm ETSI EN 302 890.2 – are needed for the Precise Point Positioning (PPP) method. The PPP optimised and/or enhanced the GNSS position based on the received satellite data from the 4 different GNSS systems (Galileo[22], GPS, GLONASS and Beidou). Providing the PPP method as a service is established in almost all European Member states. The service is free of charge e.g. in some federal states of Germany and also in few other European Member states. The name of the service is SAPOS (Satellite-Positioning Service).

With SAPOS and under open sky conditions a reliable accuracy within centimetres can be achieved. In order to use this service for automated vehicles, it is necessary to test the reliability under urban conditions. This is planned inside the SHOW project for the years 2022 and 2023.

To ensure the GNSS correction data availability, the data must be provided ideally from different sources and ideally via different communication channels. With this needed redundancy, GNSS correction data always exists, even in case of downtime of the GNSS correction service or of the communication channel.

In January 2021 a new GNSS correction service was launched from a company named SAPCORDA GmbH. The SAPCORDA data are available:

a) with a European-wide unique NTRIP internet access point (needs always a LTE network);
b) via the L-Band channel from the Inmarsat satellite (works without LTE network).

Both solutions were investigated and successfully proven in a passenger car and will be deployed in year 2022 to some of the SHOW shuttles in the test sites.

[22] With the system from this provider, it is possible to use *only* Galileo, even though using the entire set of Galileo, GPS, Glonass and Beidou – where available – will certainly increase the overall efficiency of the system. See the Appendix titled “Example of use of Galileo-only” describing the use of Galileo-only with this system, and the use of all systems.

Another important positioning service for SHOW is the Galileo High Accuracy Service (HAS) with an accuracy within 20cm. Announced to be available in year 2024, service level 1 (SL1) will provide a global coverage and service level 2 (SL2) a regional coverage over the European Coverage Area (ECA). The source of this information (from October 8th, 2021) is at the following URL https://www.gsc-europa.eu/galileo/services/galileo-high-accuracy-service-has (accessed on December 13th, 2021).

As soon as HAS is in action inside the HAS pilot phase (planned for year 2023), GNSS equipment (HW and SW) will be adapted and deployed to some of the SHOW shuttles to gain experience/trust of the quality and the accuracy of the new European Galileo HAS service in urban conditions.

The advantage of Galileo HA is the secured/ensured integrity and availability. With Galileo HA the problem of GNSS jamming and spoofing attacks will be solved.

The above described three new solutions ("low cost but high performance and quality" RTK-system, L-Band data satellite, Galileo HA Service) are planned to be installed and to be put into operation at the following sites in SHOW:

- Karlsruhe,
- Gothenburg/Lindholmen,
- Trikala,
- and Geneva.

Further sites are in discussions. The solutions are retrofitted systems and are easily to be put into the robot shuttles. Therefore, a shift to other or more sites is possible in a short time frame. Discussion for this will happen in the first quarter of 2022.

One of the pre-conditions for the sites to use some of the first new GNSS use case is availability of a good 5G cellular. However, GNSS with L-band is also possible without 5G cellular. The explanation is the following:

- For showing the "low cost but high performance and quality" solution-1, there is a need of 5G, but no need of L-Band satellite communication.
- For showing the "low cost but high performance and quality" solution-2, there is a need of L-Band satellite communication, but no 5G network.
- Both solutions are desired to be integrated, shown and evaluated.

9 Conclusions

In this document we described the solutions for Digital and Communications Infrastructure in the SHOW project. This was achieved by 3 means:

1. Definition of the DCI
2. Description of DCI at sites
3. Description of a selected set of technologies: sensors for traffic management, Internet access and use and GNSS technologies for automated driving.

The key takeaways are the following:

- Most DCI deployments include both ITS-G5 and 5G.
- GNSS features are present only at some sites.
- Features of sensors and traffic management are present only at some sites.
- The use of Internet in vehicles is currently mostly via 4G/5G and the use of Internet on ITS-G5 is still in an infancy stage.
- The description of a DCI in a common way that is agreed at all sites and that can make it comparable is very difficult to achieve. To improve that, we propose the development of a new scale of values of characterization of the DCI.

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Super Spreadsheet

The *super spreadsheet* was a tool used during the execution of the activity, according to the Methodology agreed at the beginning of the activity. This tool is a unique table developed in the Excel software package. The table contains DCI data about all sites in the project SHOW.

Because the table is relatively large, it has been split in 5 parts in order to be printed in this document. The whole table is made of the entire set of all the 5 parts:

- Part 1: is the table on the next page. On the rows are listed the names of sites. For example, on the first row is the country Netherlands in the city Brainport. On the columns there are the names of features that are relevant for DCI. For example: 5G coverage, V2X features on 5G, and so on. When a 'x' is present at the intersection between the site name and the DCI feature, it means that feature is present at that site, otherwise it is absent. For example, at the first row, in Brainport there is '3G..4G coverage'; this means that the mobile telecommunications system of generation 3, 3.5 (HSUPA, HSDPA) and 4 are available at the Brainport site. It also means that at the third row (Greece, Thessaloniki) there is no 3G..4G coverage, because there is no 'x' in the respective cell.

  Some cells contain explanatory text, rather than simply crosses 'x'. It is because the person who filled in the table was unable to respond precisely yes or no, but was fully able to provide details about the answer. For example, the person Brainport was unable to tell yes/no 5G is present in Brainport, but was able to explain that 5G will be used in Brainport during the 'Automotive Week' event. That explanatory text is not visible entirely in the table, but is available separately in the Excel sheet.

  Part 1 finishes with site Salzburg in Austria.

- Part 2 is the table on the next page. It lists sites from Salzburg in Austria to Brussels in Belgium.
- Parts 3, 4 and 5: instead of describing presence or absence of DCI features, the parts 3, 4 and 5 describe Gaps, Challenges, Needs and the use-cases that are relevant at that site.

Country	City or suburb	5G coverage	3G..4G coverage	V2X features on 5G, C-V2X	LoraWAN, NB-IoT	ITS-G5 RSU, V2I, V2P	Which ITS-G5 messages are provided? (CAM, DENM, SPAT, MAP, etc.)	WiFi Access Points	Proximity sensors (Bluetooth, RFID, electromagnetic loops)	Traffic Control Center, remote or local	GNSS and/or GNSS roadside enhancements, (Galileo, GPS, RTK)	Traffic Lights, smart	Cameras and lidars on roadside	Data about environment (digital twin, HD maps)	Other use of satellite infrastructure: (1) satcom bidir infra (Galileo return path, Starlink-like Breton announced	inductive charging infra	photoelectric charging infra	passenger counting infra	V2V without infrastructure	Digital displays, vertical information boards (e.g. at bus stop, show itinerary, education	Mobility information box (Austria, AIT)	Shuttle communicates with garage doors to order opening
The Netherlands	Brainport	5G is there on the automotive campus, to be used during the Automotive	x	V2V with infra		x	DENM, CAM, SPAT, MAP, SSM, SRM					x										
Greece	Trikala	ow or soon. It ha	x			x			x	x		x								x		
	Thessaloniki	x				x	CAM, SPAT, MAP, DENM, IVI	x	x	x	x	x		x	x							
Finland	Tampere Satellite Site	has 5G	x	V2V with infra	x (LoRaWan available, but not used in SHOW)	x	DENM, SPAT				x, RTK	x	x mobile-RSU camera	x								
The Czech Repu	Brno	s 5G for remote su	x V2V w/ infra											x								
Spain	Carabanchel		x			x	DENM, CAM															
	Villaverde		x			x	DENM, CAM, SPAT, MAP					x										
France	Rouen City-centre	5G covered with 4 operators	x				CAM, DENM, SPAT			x	x	TBV		x					TBV			
	Rouen Madrillet	5G covered with 4 operators	x			x	CAM, DENM, SPAT			x	x	x	x	x					TBV			
Sweden	Lindholmen of city Göteborg	5G connection is almost ready	x	x	NB-IoT				x	x	x			x								
	Linköping	5G is available in the area	x							x												
Austria	Graz		x			ITS-G5 RSU (can be managed/monitored remotely);	CAM, DENM, IVIM, CPM (under development);					x	x (AI-based detection camera; connected to RSU); at	x								
	Salzburg		3G, 4G			ITS-G5 RSU (can be managed/monitored remotely); V2Infrastructure	CAM, DENM, IVIM; RTCM, RTCMEM (PoTi Service: GNSS correction signal to vehicle - under development)	one public WIFI access belonging to the municipality			x			HD map								

Country	City or suburb	5G coverage	3G..4G coverage	V2X features on 5G, C-V2X	LoraWAN, NB-IoT	ITS-G5 RSU, V2I, V2P	Which ITS-G5 messages are provided? (CAM, DENM, SPAT, MAP, etc.)	WiFi Access Points	Proximity sensors (Bluetooth, RFID, electromagnetic loops)	Traffic Control Center, remote or local	GNSS and/or GNSS roadside enhancements, (Galileo, GPS, RTK)	Traffic Lights, smart	Cameras and lidars on roadside	Data about environment (digital twin, HD maps)	Other use of satellite infrastructure: (1) satcom bidir infra (Galileo return path, Starlink-like Breton announced	inductive charging infra	photoelectric charging infra	passenger counting infra	V2V without infrastructure	Digital displays, vertical information boards (e.g. at bus stop, show itinerary, education	Mobility information box (Austria, AIT)	Shuttle communicates with garage doors to order opening
Austria	Salzburg		3G, 4G			ITS-G5 RSU (can be managed/monitored remotely); V2Infrastructure	CAM, DENM, IVIM; RTCM, RTCMEM (PoTi Service: GNSS correction signal to vehicle - under development)	one public WIFI access belonging to the municipality			x			HD map								
	Carinthia		x			ITS-G5 RSU (can be managed/monitored remotely);	CAM, DENM, IVIM, SPATEM/MAPEM, CPM (under development);						x (AI- based detection camera; connected to RSU)									
Germany	Aachen					V2V without Infra																
	Karlsruhe	x	x			x	CAM, MAP, SPAT, DENM				x	x										
	Braunschweig					for platoon																
Denmark	Copenhagen											x										
Italy	Turin	partial 5G coverage	x			ITS-G5 RSU	CAM, SPAT, MAP, DENM, SSEM, SREM (under discussion)			x	x, for NAVYA shuttle	x	x					x, with Bestmile driver app				
Switzerland	Belle Idée	yes, is there.	x		x (LoRA is there)					x	x	x				x		x				x
Belgium	Brussels		x	V2X		V2I, ITS RSU	No idea yet		RFID could be but not sure yet. To be confirmed later.	x (but to be confirmed)	x (but to be confirmed)	x										

Country	Gaps	Challenges	Needs	Use case relevant
The Netherlands, Brainport	N.A.	Initial set-up (Pre-demo) will be with retrofitted traffic light. Setting up direct interaction with existing infrastructure and controlling predefined test cases with existing infrastructure is the current challenge	N.A.	N.A.
Greece, Trikala	Vehicles are not yet arrived to Trikala so testing for the 5G connecivity of the vehicle with the remote control center has not completed yet. Smart traffic lights still under procurement. Check latency issues (if applicable) after testing the connection with the remote control center.	Smooth operation of the vehicles in the mixed traffic environement without dedicated lane and communication with the control center for emergency breaking and immobilization. Connection with the TMC and procurement of the necessary equipement. VRUs interaction with the whole system.	Procure equipement for the implementation of Green Wave and connection with the TMC. Testing the 5G communication of the vehicles with the remote control center when the vehicles arrive at the city.	As regards the DCI all things are under development and for no specific use case a problem is reported. Just a lot of work remains for UC1.3 and UC1.5 as the equipement is under procurement and architecture elements need to be defined thoroughly.
Greece, Thessaloniki				1. Shared mobility services using connected and automated vehicles. 2. Integration of CAVs into traffic management
Finland, Tampere				
The Czech Republic, Brno	Counting will be done manually by the crew in the beginning. Later probably automated, not clear yet.			
Spain, Carabanchel				
Spain, Villaverde			Connection to TMC Madrid for traffic lights priorization	

Spain, Villaverde			Connection to TMC Madrid for traffic lights priorization	
France, Rouen City-centre	Gaps to achieve a robust system. After 2 years, some of the infrstrucure is considered obsolete by the providers Still a lot of R&D need to be done in parallel with the production cost optimisation	The challenges is to find a business model (high cost of installation and maintenance)		
France, Rouen Madrillet	Gaps to achieve a robust system. After 2 years, some of the infrstrucure is considered obsolete by the providers Still a lot of R&D need to be done in parallel with the production cost optimisation	The challenges is to find a business model (high cost of installation and maintenance)		
Sweden, Lindholmen				
Sweden, LinkĶoping				
Austria, Graz	no DCI (ITS-G5) implementation yet;	CPM still in standardization progress;	use-case will be applied as a "stand-alon" use-case (no further connection (e.g. internet / TMC or central system) for the use-case is required)	collective perception at a local transport hub (monitoring VRUs), use case 1.3.
Austria, Salzburg	automated and reliable passenger counter		connection to TMC Salzburg for traffic light prioritization	1.2, 1.3, 1.6 (Columns C, F, G, K, N); 1.5 (Columns C, F, G, K); 3.1 (Columns C, F, K, N)
Austria, Carinthia	no DCI (ITS-G5) implementation yet;	CPM still in standardization progress;	tbd	this test-site is currently in planning-progress (since it just joined SHOW); it will most likely cover a collective perception (VRU) and Traffic Light use-case
Germany, Aachen				
Germany, Karlsruhe				
Germany, Braunschweig				
Denmark, Copenhagen				
Italy, Turin		Vehicles do not support V2X technology		1.2, 1.3, 1.5, 1.7, 1.10
Switzerland, Belle Idée	Vehicles do not support V2X technology			
Belgium, Brussels	We don't know yet the shuttle that we will select for the test. Will be known by the end of august 2021. Thus some gaps could still be unidentified. Already known ones are : - automated and reliable passenger counter - RSU ans OBU for communication with traffic lights on a crossroad that is curently not equipped with traffic lights - A way to impeach cars from geting parked on the trajectory of the shuttle. Could be road marking or any other infra solution to be determined.	The 2 main challenges are : - On the public road, to equip a cross road intersection (today with no equipment) with complex traffic lights (cars, bikes, tramways and pedestrian) that communicate with the shuttle - On the private site of the Hospital, avoid as much as possible cars beeing parked on the way of the shuttle while no fines are possible on a private site.	- automated and reliable passenger counter - Feedback about existing 'C-ITS' infrastructures (RSU ansd OBU) - A good way to interface the available API of the shuttle provider with our own systems and with SHOW system to share collected data's and real time information. - A good idea to avoid cars from geting parked on the traject of the shuttle (road marking, fake fines tickets, any other idea is welcome)	?

Example of use of Galileo-only

Question “*Positioning with Galileo only possible?”*

1. **Galileo only**:
   - Conditions
     - Date: 28.07.2021, 12:00 a.m.
     - Location: City of Hildesheim (Germany)
     - Visibility to sky: **Open Sky**
   - Result

     Receivable Galileo Satellites: 10

     Used for positioning: 8 (signal wise the strongest Galileo Satellites)

     Received Galileo Satellites IDs: E1, E7, E8, E12, E13, E18, E24, E26, E31, E33
   - Received Galileo Position NMEA-Message

     *$GAGGA,101041.00,5210.03118,N,00952.43165,E,1,08,0.95,98.6,M,46.3,M,,*7C*

1

2. **In comparison using all 4 main GNSS systems (GPS, Glonass, Beidou, Galileo)**:
   - Conditions
     - Date: 28.07.2021, 12:00 a.m.
     - Location: City of Hildesheim (Germany)
     - Visibility to sky: **Open Sky**
   - Result**:**

     33 **Satellites in total receivable**

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