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Deliverable D4.1: Roadside ITS Station Specification

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Contents

1 Scope

This document describes the elaborated architecture of C-V2X enabled Roadside Units in the field of Cooperative Intelligent Transport Systems (C-ITS). This document describes both, the generic design concepts (blueprint character) and the specific demonstrator implementations.

2 References

[1] ConVeX Project Deliverable D1.1, “Use Cases, Requirements, Performance Evaluation Criteria”

[2] ConVeX Project Deliverable D2.2, “Final ConVeX System Architecture Description”

[3] ConVeX Project Deliverable D6.1, “Report on Lab and First Field Trials”

[4] ConVeX Project Deliverable D7.1, “Report on Final Field Tests and Evaluation”

[5] C-ITS Platform, Final report, January 2016, https://ec.europa.eu/transport/sites/transport/files/themes/its/doc/c-its-platform-final-report-january-2016.pdf

[6] ETSI TS 102 637-3: "ITS Vehicular Communications; Basic Set of Applications; Specification of DENM"

[7] "MQTT 3.1.1 specification". OASIS. December 10, 2015, available at https://www.oasis-open.org/standards#mqttv3.1.1

[8] https://www.bast.de/BASt_2017/DE/Verkehrstechnik/Fachthemen/v2-verkehrszaehlung/Aktuell/zaehl_aktuell_node.html?cms_map=1&cms_filter=true&cms_jahr=Jawe2018&cms_land=9&cms_strTyp=A&cms_str=&cms_dtvKfz=&cms_dtvSv=

[9] https://www.qualcomm.com/products/qualcomm-9150-c-v2x-chipset

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[11] https://www.osgi.org/

3 Definitions and Abbreviations

3.1 Definitions

Roadside Unit (RSU): An entity supporting V2I Service that can transmit to, and receive from a UE using V2I application. RSU is implemented in an eNB or a stationary UE.

Uu transport: Transmission of V2X data from a source UE (e.g., a vehicle) to a destination UE (e.g., another vehicle, road infrastructure, a pedestrian, etc.) via the eNB over the conventional Uu interface (uplink and downlink).

V2I Service: A type of V2X Service, where one party is a UE and the other party is an RSU both using V2I application.

V2N Service: A type of V2X Service, where one party is a UE and the other party is a serving entity, both using V2N applications and communicating with each other via cellular network (e.g. LTE or 5G) .

V2P Service: A type of V2X Service, where both parties of the communication are UEs using V2P application. For this service the vehicle-side UE is a V-ITS-S, the pedestrian-side (respectively VRU-side) UE is a P-ITS-S.

V2V Service: A type of V2X Service, where both parties of the communication are UEs using V2V application. For this service both vehicle-side UEs represent V-ITS-S.

3.2 Abbreviations

3GPP	3rd Generation Partnership Project
5G	5th Generation
5GAA	5G Automotive Association
5G-PPP	5G Private Public Partnership
A9	Motorway A9
ACC	Adaptive Cruise Control
API	Application Programming Interface
AWS	Amazon Web Services
CACC	Corporative Adaptive Cruise Control
CAM	Cooperative Awareness Message
CAN	Controller Area Network
CCARD	Connected Car Application Reference Design
C-ITS	Cooperative Intelligent Transport Systems
C-ITS-S	Central ITS Station
C-V2X	Cellular Vehicle to Everything
C-V2X DP	C-V2X Development Platform
CV2XBox	Cellular V2X Communication Module
CVRIA	Connected Vehicle Reference Implementation Architecture
DENM	Decentralized Environmental Notification Message
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved UMTS Terrestrial Radio Access

EU	European Union
FCD	Floating Car Data
GLOSA	Green Light Optimal Speed Advisory
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HW	Hardware
ICS	ITS Central Station
IoT	Internet of Things
IRS	ITS Roadside station
ITS	Intelligent Transport System
IVI	In-Vehicle Information
IVIM	In-Vehicle Information Message
IVS	In-Vehicle Signage
KPI	Key Performance Indicators
LOS	Line Of Sight
LTE	Long Term Evolution
MAPEM	Map Standard Extended Message
MEC	Mobile Edge Computing
MQTT	MQ Telemetry Transport
OBU	Onboard Unit
OEM	Original Equipment Manufacturer
OSGi	Open Services Gateway initiative (now OSGi Alliance)
PC5	ProSe Communication reference point 5
PoE	Power over Ethernet
ProSe	Proximity-based Services
PVD	Probe Vehicle Data as in discussion in CEN/ISO a message to allow vehicles to issue collected data to other vehicles or infrastructure
P-ITS-S	Personal ITS Station
PKI	Public Key Infrastructure
PVD	Probe Vehicle Data
R-ITS-S	Roadside Intelligent Transport System Station
RV	Remote Vehicle
RSU	Roadside Unit
RWW	Roadworks Warning
SPaT/MAP	Signal Phase and Time / Map Standard
SPATEM	Signal Phase and Time Extended Message
SRM	Signal Request Message
SSM	Signal Status Message
SUMO	Simulation of Urban Mobility
SW	Software
SWD	Shockwave Damping
TCC	Traffic Control Center
TJW	Traffic jam ahead warning

UE	User Equipment
USB	Universal Serial Bus
V2C	Vehicle to Cloud
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2P	Vehicle to Pedestrian
V2V	Vehicle to Vehicle
V2X	Vehicle to Everything
V-ITS-S	Vehicular Intelligent Transport System Station
VMS	Variable Message Sign
VRU	Vulnerable Road User
WAN	Wide Area Network
WLAN	Wireless Local Area Network

4 Roadside ITS Station Architecture

4.1 Introduction

In the overall architecture of Intelligent Transport Systems (ITS) [2, 4], the Roadside ITS Station (R-ITS-S) represents the entity which provides

1) direct communications with vehicles via vehicle-to-infrastructure (V2I) radio transmission,
2) a communication interface towards central ITS infrastructure equipment such as a Traffic Management or Traffic Control Center (TCC) for exchange of traffic management data.

This is illustrated in Figure 4-1. A frequently synonymously used term for Roadside ITS Station is the more shorthand expression Roadside Unit (RSU). Sometimes also the term ITS Roadside Station (IRS) is used.

More details of the RSU communication endpoints are described in the following subsection.

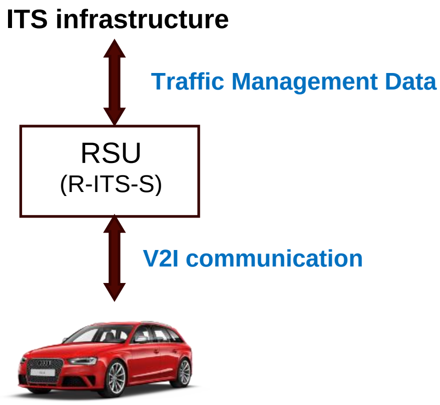

Figure 4-1: Communication functions of the Roadside Unit (RSU)

4.2 Embedding C-V2X RSUs into existing infrastructure

RSUs must be embedded into the context of the typical architecture found in Intelligent Transport Systems (ITS) which may differ somewhat in different countries or regional markets (e.g. in Europe, US, China).

The principal architecture of the existing highway transport management system in Germany is depicted in Figure 4-2 (see also Deliverable D2.2 [2]). A key element of the architecture is the Traffic Control Center (TCC) which is hierarchically divided into a high-level coordination and visualization centre (Verkehrsrechenzentrale VRZ) and local area control centers which execute operations on a dedicated stretch of road (*Unterzentrale* UZ). These TCCs are connected with outstations (in German: *Streckenstation* (SST)), which are installed at the roadside. Each outstation can serve one or more different types of field equipment such as dynamic traffic information signs, variable speed limit signs, induction loops, traffic surveillance cameras, or other devices as exemplary shown in Figure 4-2.

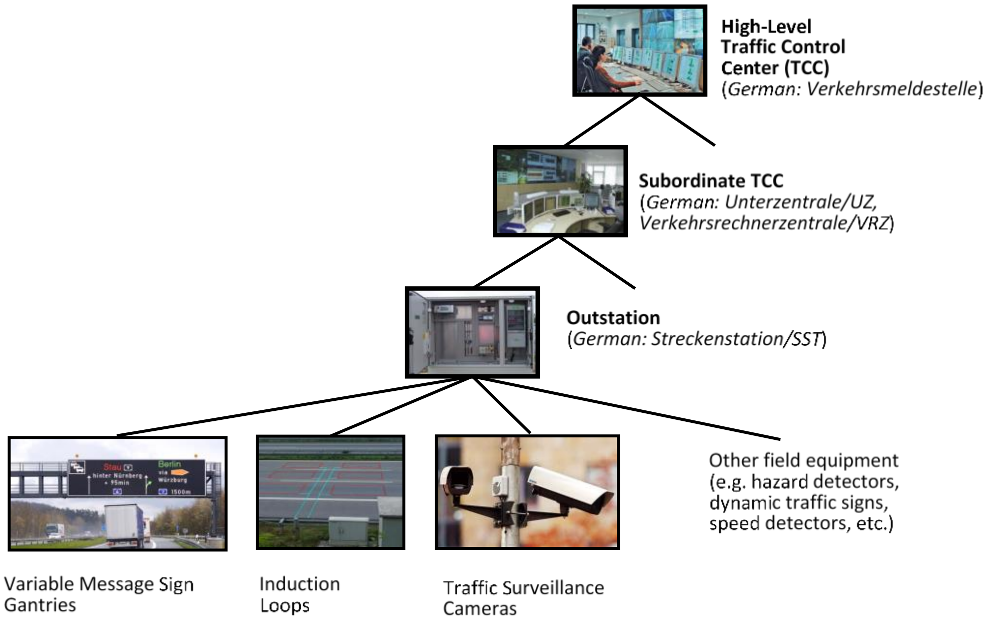

Figure 4-2: Architecture of today's highway traffic management systems in Germany

Integration of C-V2X RSUs into the legacy infrastructure yields to the C-ITS architecture depicted in Figure 4-3. The RSUs are physically installed like any already existing field equipment and possibly co-located, e.g. installed directly at traffic sign gantries in order to access to existing facilities such as power supply and telecommunication resources required to connect the RSUs with the central equipment. Logically the RSU is connected with a Central ITS Station (C-ITS-S) which will be typically collocated with subordinate or high-level TCC facilities. For management of C-V2X security procedures, each RSU requires connectivity with Public Key Infrastructure (PKI) Services (see deliverable D2.2 [2] for more details on PKI services).

As also illustrated in Figure 4-3, an RSU may also be installed on mobile facilities, such as a roadworks safety warning trailer. In such scenarios it is clear that the communication with central ITS equipment (C-ITS-S, PKI, TCC) is required to employ mobile radio technology. Stationary RSUs, however, may either reuse any existing wired telecommunication resources, or alternatively mobile communications, i.e. 3G, 4G or upcoming 5G mobile systems.

The RSUs designed by ConVeX employ exclusively mobile communications, i.e. connectivity via the 4G/5G A9 test network, or alternatively via any available commercial 3G/4G mobile network.

In the downlink direction, an RSU receives data from the C-ITS-S and forwards it via PC5 to the vehicles in its communication range represented in form of DENM and In-Vehicle Information Messages (IVIM).

In the uplink direction, the RSU receives via PC5 Probe Vehicle Data (PVD) represented as Cooperative Awareness Messages (CAM) from the vehicles which, after pre-processing, are forwarded to the C-ITS-S for utilization in control algorithms for ITS traffic management services (e.g. in-vehicle speed recommendations, Shock Wave Damping (SWD)).

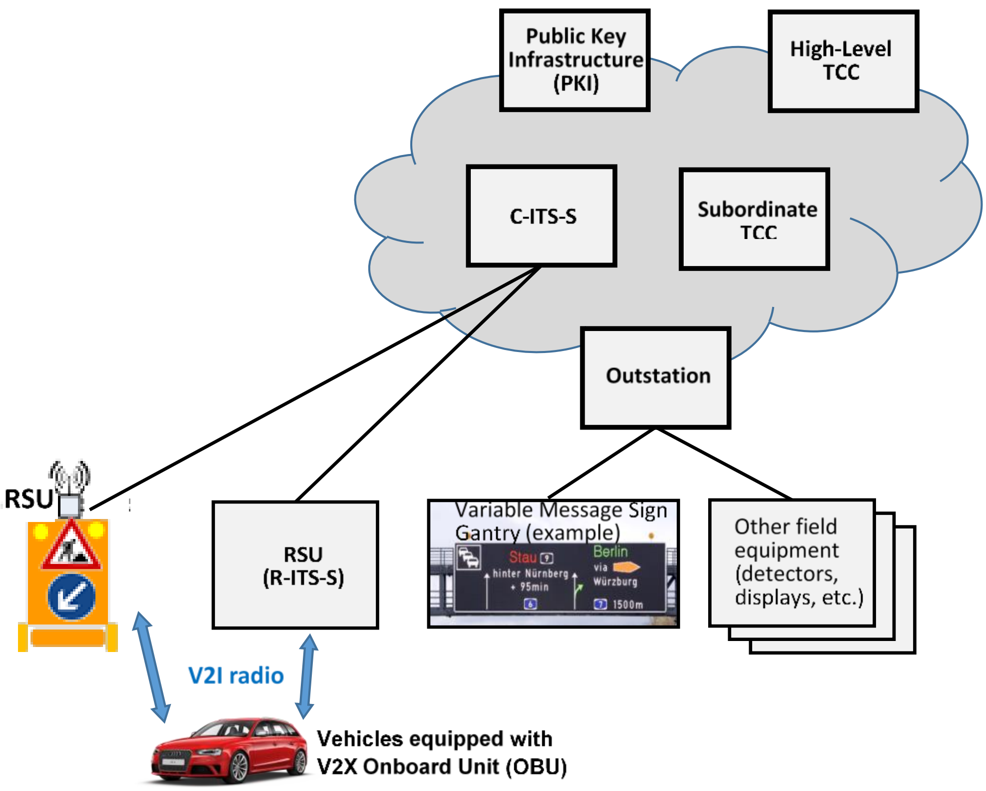

Figure 4-3: C-ITS architecture with integrated C-V2X RSUs

The RSUs designed by the ConVeX project are placed in temporary outdoor environment, i.e. not permanently installed at a fixed location. For the investigated use cases, the RSU does not require an interface to stationary gantries, but is representing an amount of virtual gantries containing cross-section measurement and cross-section display units.

The RSU is responsible for decoding and encoding of C-ITS messages sent and received over the PC5-based C-V2X link and for preprocessing of information received in the uplink direction. Furthermore, the RSU handles the communication with the C-ITS-S and is responsible for appropriate processing of traffic management and security information.

It has not been in the work scope of ConVeX to implement communication with real existing central ITS equipment. Instead, the C-ITS-S/TCC functionality has only been emulated by using a personal computer connected to the internet which is accessible remotely from the RSUs in the field. We denote this setup as Virtual TCC.

4.3 Design of RSUs used by ConVeX

4.3.1 Use of C-V2X Development Platform

In the ConVeX project, design of both, vehicular and roadside infrastructure C-V2X units, i.e. OBUs and RSUs, are based on the same communication platform.

Figure 4-4 shows its functional components (see also Deliverable D2.2 [2]. It is composed of two hardware boards,

1) C-V2X Development Platform (C-V2X DP) shown on the right side,
2) Communication Module (CCARD - Connected Car Application Reference Design) shown on the left side.

The CCARD provides connectivity to 3G/4G mobile networks.

When used in an OBU, it provides the Uu-based V2N communication link. When used in an RSU, it provides the communication link to central ITS equipment as depicted in Figures 4-1 and 4-3.

In addition to this wide area modem functionality, the CCARD board also offers functionality and computing power for network-based telematics services. These functions however are not exploited in the ConVeX project. In ConVeX, all C-ITS use case related functions are served by the C-V2X DP.

When building an OBU or RSU with a CCARD and a C-V2X DP, the two boards would be connected with each other via an Ethernet hub. Each board would require its own power supply. The CCARD would be connected with an antenna suitable for Uu-based communications in the 3G/4G bands (700 to 2600 MHz). The C-V2X DP needs to be connected to 5.9 GHz antennas and a GPS antenna.

In in OBU, the C-V2X DP also serves for connectivity towards the vehicle CAN bus system and the HMI. This is omitted inside of an RSU. If required for any specific RSU use case, connectivity between the RSU and any field devices (e.g. sensors and/or detectors) these could be established via WLAN, wired Ethernet or USB.

Since only the modem functionality of the CCARD is required in an OBU or RSU, the CCARD can actually be replaced by an ordinary mobile phone, or, in a vehicle, by any in-car integrated cellular communication device. In such a setup, a simple way of connecting the wide area modem with the C-V2X DP is by setting up WLAN connectivity (i.e. by means of a WiFi hotspot) between these two modules.

The C-V2X Development Platform consists of the Application Processor (AP) module and the C-V2X Module and peripheral components. These two modules are linked and communicate via an Ethernet connection. The C-V2X DP furthermore provides external connectivity via Ethernet, CAN and USB.

When applied in an RSU, the C-V2X DP provides the following functions:

- A high-performance programmable application processor platform which hosts all required software systems, including
  - Linux-based operating system
  - ITS communication protocol stack used for V2I
  - Use case specific ITS applications
  - Applications for communication with central ITS equipment (C-ITS-S, PKI)
  - Application Programming Interfaces (APIs) supporting programmer-friendly interoperation between the various software modules
- PC5-based V2I communication module in the 5.9 GHz band
- GNSS module for position location and GPS-based time synchronization
- Interfaces to wide area modem (Ethernet or WiFi-based)
- Interface to field sensors or detectors (Ethernet, WiFi or USB)
- Hardware Security Module (HSM) for safe handling of security functions

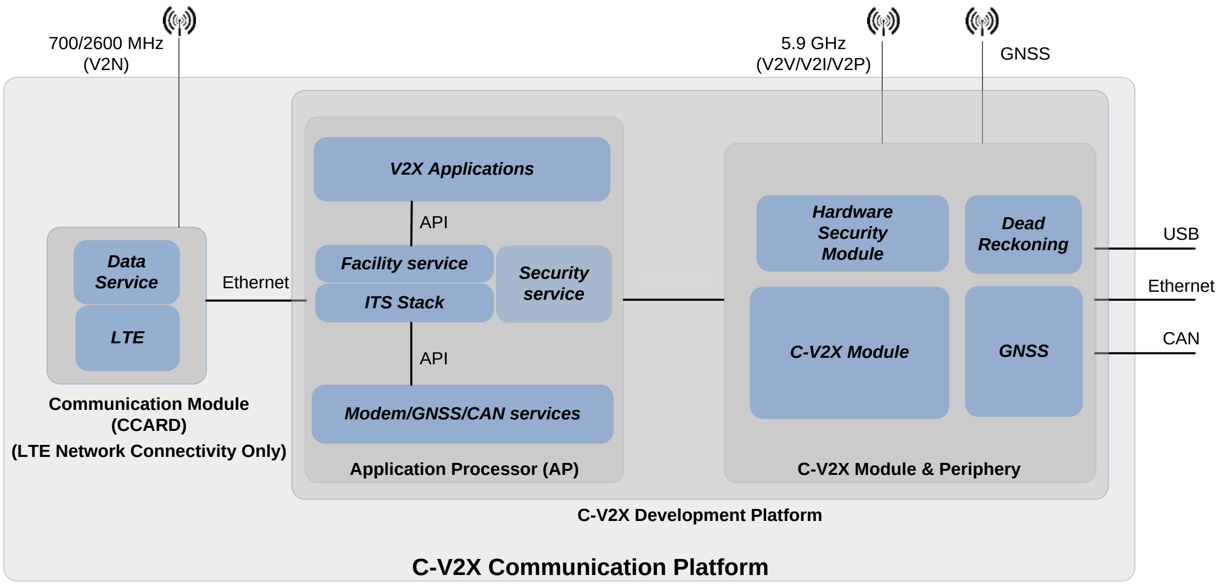

Figure 4-4: C-V2X Communication Platform

4.3.2 RSU Functions, Interfaces and Software Architecture

To enable existing ITS infrastructure with C-V2X communication capability, the RSU must support special functions and various interfaces.

Each supported use case requires a dedicated application software module which represents the actual implementation of the use case inside of the RSU. Such application software module typically receives information from the C-ITS-S/TCC or from an existing Roadside Controller (e.g. traffic light controller, variable message signs controller, road-sign controller). This information is formatted into standardized messages (DENM, IVI, SPATEM, MAPEM, SRM, SSM) which are sent via PC5-based V2I communication to the surrounding vehicles. Vice versa, the use case specific application software modules evaluate any standard messages (CAM, DENM) received from vehicles and trigger functions in a relevant local Roadside Controller or in the Traffic Control Center.

Typical domain specific RSU functions are:

- Sending current traffic light information as SPAT/MAP message (SPATEM/MAPEM), Signal Request Message (SRM) and Signal Status Message (SSM)
- Indication of a specific road sign image code in a IVI message
- Sending warning messages as DENM
- Receiving CAMs from vehicles to evaluate traffic flow/speed/waiting times in order to trigger traffic control actions
- Receiving DENMs and transforming warnings into actions such as alerting road authorities or activating traffic sign reactions for hazard warning

Supported RSU interfaces are the following:

- Interface to existing Roadside Controllers. This interface is specific to the type of roadside controller. In most markets this interface is not standardized and must be integrated in a vendor-specific way.

- Interface to a TCC. Different markets/nations and market domains (urban, inter-urban) have their own (national) standards for such integration. Typically, the national standards require extensions to support C-ITS functionalities. One example for city traffic control systems is the OCIT version 3 specification in Germany.
- Interface to the mobile network (3G/4G/5G). Towards 5G the presence of a Mobile Edge Computing (MEC) instance is a feature, which can achieve high availability and low latency functionality e.g. to support message exchange beyond the direct physical device-to-device communication realized by PC5.
- Interface for PC5-based direct communication. In C-ITS, standard messages are used to communicate between infrastructure and vehicles. Only by using standard C-ITS messages it can be ensured, that all vehicle brands and all different national infrastructure have a common basis to achieve inter-operable use cases.

The interfaces of the RSU employed in the ConVeX project and its project-specific software architecture is illustrated in Figure 4-5.

Figure 4-5 also includes a ConVeX project specific interface between the (virtual) TCC and the SUMO-based traffic simulation system. This interface actually emulates communication of the TCC with other RSUs and carries information relevant for support of the Shockwave Damping (SWD) use case.

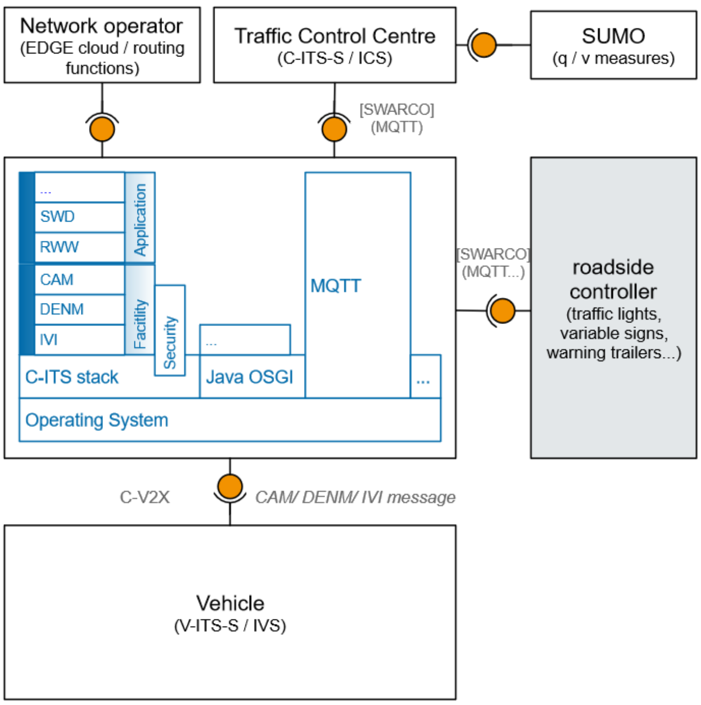

Figure 4-5: RSU-internal Software Architecture and Interfaces

The application processor of the C-V2X DP hosts the software modules depicted in Figure 4-5. Depending on the actual use case, the Application modules compose information sent with the ETSI standard compliant ITS messages and/or process information which is received. A description of the various layers of the ITS message handling stack can be found in Deliverable D2.2 [2].

Communication between the Virtual TCC and RSU is based on the MQTT protocol where the TCC acts as message broker and the RSU as a client [2]. This function is required for the IVI use case.

For communication between the RSU and a Roadside Controller also MQTT could be used, where the MQTT broker is hosted by the RSU. However, this feature is not required for the demonstrated use cases.

In contrast to the OBU implementation, in the RSU, Application and the Facility sublayers of the ITS message stack [2] have been implemented as modular JAVA OSGi [11] bundles which interfaces with the third-party GeoNetworking Layer, supplied by SAVARI Inc.. The Facility Layer encodes sent ITS messages and decodes received ITS messages:

- DENM sent in the Roadworks Warning use case
- IVI messages sent in the IVI (Speed Recommendation for shockwave damping) use case
- CAMs received and used for CAM aggregation in order to evaluate vehicle movements for the shockwave damping use case demonstration.

Further the elements in the architecture comprise the following functions:

- SPAT/MAP message sending to provide current traffic light signaling, traffic light forecast
- CAM evaluation for emergency and public transport priority prioritization on intersections
- Linkage to the EU/national PKI system for secure, verified communication.

4.3.3 Communication between Virtual TCC and RSU

The RSU generally must ensure permanent connectivity with a TCC. To accomplish this feature, an Application process is running on the RSU which retrieves relevant information originating in the TCC, for instance a recommended vehicle speed setting applicable to the geographical region served by that RSU. A change of such information then needs to trigger transmission of a respective ITS message. For example, in case of the speed recommendation use case, a respective IVI message needs to be generated and transmitted by the RSU. This requires inter-process communication between the various Application software modules, i.e. between the TCC-communication software application and the IVI application.

In the transmission direction from RSU towards the TCC, any relevant information received from vehicles may be processed and forwarded to the TCC. For instance, warning information received in DENMs from a vehicle could be forwarded to the TCC for further evaluation. Also, information received in CAMs could be preprocessed in the RSU and forwarded to the TCC in order to steer traffic flow control functions.

Especially processing of CAMs, however, potentially requires a very large processing power which may overload the RSU’s Application processor. Some of the required processing power can be swapped out into the cloud, especially if edge computing capability is available.

As described in Section 4.2, the RSUs in ConVeX are connected via LTE to the internet cloud. Therefore, when RSUs are connected via the Ericsson A9 test network, it is possible to exploit the available Mobile Edge Computing (MEC) resources (see Section 5.2.2.2 in Deliverable 7.1 [4]). Conceptually, this means that processing functions of local geographical scope are moved from the TCC to the edge of the cloud in order to reduce message transport latency and network load.

Note that network selection and access is controlled by information stored on the SIM card used in the WAN modem (i.e. CCARD or equivalent module used by the RSU). Access to the A9 test network requires the use of special SIM cards issued by Ericsson.

As described in Deliverable D2.1, the C-V2X DP furthermore permanently runs an application process which reports logging data to a central measurement server. In ConVeX, the measurement server is realized as an Amazon Web Services (AWS) - Cloud Computing Service. This function also allows remote monitoring of the RSU operations.

4.4 RSU Physical Assembly

4.4.1 Design concept and requirement profile

In ConVeX, a prototype RSU was designed which is built around the pre-commercial C-V2X DP supplied by Qualcomm. Therefore, the RSU itself does not represent a commercial design.

However, most of the following important design goals and requirements of a future commercial RSU have already been met:

- Ability to integrate into legacy ITS infrastructure
- Ability to integrate physically with other roadside field equipment (e.g. typical roadside cabinets
- Connectivity to a variety of different peripheral devices such as roadside controllers by using generic Ethernet communication
- Suitability to provide extended processing power (e.g. additional application processor board)
- Power over Ethernet (PoE) as power supply system to save use of multiple power adapters
- Future-proof provision of WAN connectivity via 3G/4G/5G mobile network. Wired WAN connectivity possible via Ethernet adapter)
- Flexible use of antennas, allowing both options, antennas mounted directly to the device cabinet or remote from the device

A future commercial C-V2X module will likely provide integrated 4G/5G V2N WAN and PC5-based connectivity such that a separate V2N modem module will not be needed.

Figure 4-6 shows the generic architecture of a C-ITS Roadside Equipment. It consists of two main building blocks, denoted here as C-V2X Roadside Unit and Roadside Controller. In addition, the architecture includes an Ethernet-based communication system with PoE-based power distribution.

The roadside equipment shown in Figure 4-6 may be integrated typically into a single cabinet, or, alternatively split between two cabinets, a C-V2X RSU Cabinet and a Roadside Controller Cabinet. When split cabinets are used, the Ethernet system may be integrated with either of these.

The Roadside Equipment as shown in the shaded area of Figure 4-6 is typically referred to as Roadside Unit (RSU). In ConVeX, however, we also denote the C-V2X Roadside Unit function shown in Figure 4-6 in shorthand notation simply as RSU.

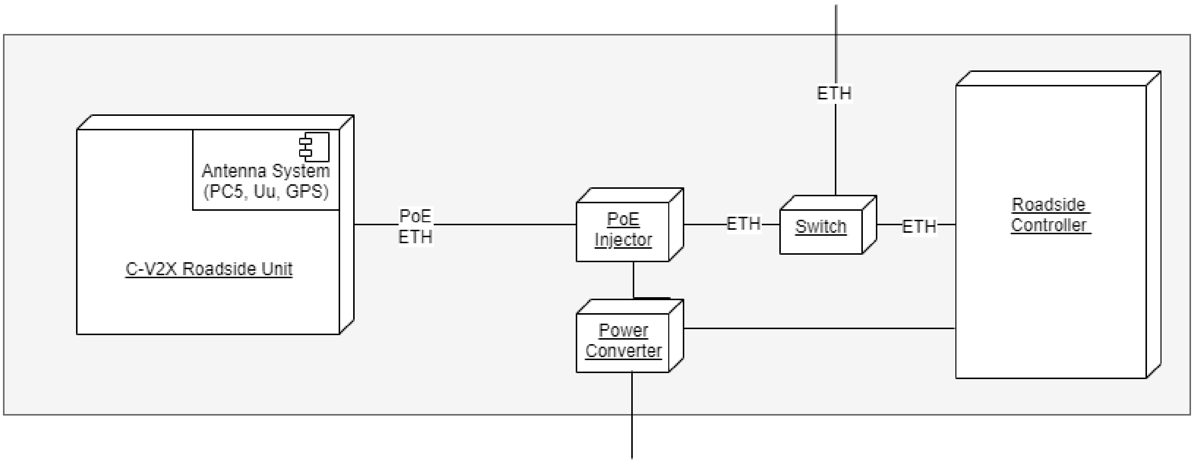

Figure 4-6: Generic Architecture of C-ITS Roadside Equipment

4.4.2 RSU variants employed in field tests and demonstrations

4.4.2.1 Introduction

For the field tests and use case demonstrations, two exemplary C-V2X RSU variants have been employed:

1) Stand-alone C-V2X RSU mounted in a dedicated cabinet.
2) C-V2X RSU integrated with Roadside Controller equipment. For this implementation option, a roadworks warning trailer has been used.

These two RSU variants are further described in the subsections below. Note that the physical design of the RSU, i.e. whether it is integrated in stand-alone fashion or placed together with other ITS field equipment has no impact on the radio performance of the RSU. Radio performance however can be affected by the characteristics of the antennas used and their physical placement (antenna height and radiative orientation relative to the street environment).

4.4.2.2 Stand-alone RSU

The RSU implemented as a stand-alone system integrates all required functionality into a single cabinet. Figure 4-7 shows views of the cabinet with closed and opened door.

The cabinet includes the C-V2X DP, an LTE modem with integrated antenna and integrated Ethernet hub, power sockets and power adapters. Uninterruptable power supply of 220 V is provided from an external battery. A 5.9 GHz antenna for PC5 communication and a GPS antenna are mounted on top of the cabinet.

Figure 4-7: RSU cabinet with closed and opened door

The described stand-alone RSU has for instance been employed for demonstration and performance evaluation of the IVI use case at the A9 (see Section 6.1.6 of Deliverable D7.1 [4]).

Figure 4-8 shows the installation of the RSU cabinet on the A9 highway bridge during the demonstration event in October 2019. The RSU cabinet is mounted to a pole and connected to battery (UPS) at the bottom of the pole. An Ethernet cable connection leads into the vehicle where a test supervisor can monitor the correct function of the RSU on a Laptop computer during test and demonstration.

Figure 4-8: RSU setup for IVI use case demonstration at A9

4.4.2.3 RSU on Roadworks Warning Trailer

In this setup, the RSU components are installed in an installation box of the roadworks warning trailer, together with other required controller equipment. The trailer has integrated 220 V power supply. The required antennas are installed on top of the screen which displays the actual roadworks warning information.

Figure 4-9 shows the RWW trailer as employed at the cross-border ITS demonstration event in Schengen/Luxemburg in April 2019.

Figure 4-8: Roadworks warning trailer with integrated RSU as employed for demonstration in Schengen

5 Considered RSU Use Cases

5.1 Introduction

For a comprehensive description of the Use Cases investigated and selected by ConVeX for implementation and demonstration refer to Deliverable D1.1 [1].

A more detailed description and performance analysis of the RSU use cases is given also in Deliverable D7.1 [4].

5.2 In-Vehicle Information (IVI)

In-Vehicle Information (IVI) is an Infrastructure-to-Vehicle (I2V) Use Case where C-V2X technology is used to transfer road sign information (e.g. displayed speed limits, warning sign content) in electronic form to vehicles employing In-Vehicle Information messages (IVIM).

Figure 5-1: Indication of a recommended speed on the vehicle dashboard in IVI use case

5.3 Roadworks Warning (RWW)

Roadworks Warning (RWW) is a well-defined safety use case defined for Cooperative Intelligent Transport Systems (C-ITS). For the RWW use case implementation as considered by ConVeX, it is assumed that a conventional roadworks trailer is equipped with a C-V2X RSU. The warning trailer is parked at the roadside in a safety distance ahead of a road construction site and displays a warning sign and speed limit to approaching vehicles, as shown in Figure 5-2.

Figure 5-2: Example of Roadworks Warning trailer

The RSU generates a DENM warning message compliant with specifications in ETSI EN 302 637-3 [6] and sends it via PC5-based V2I communication to vehicles in its communication range. The OBU of the vehicles receiving the RWW DENM, displays an audio-visual warning to the vehicle driver as illustrated in Figure 5-3.

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Figure 5-3: Roadworks Warning indication on the vehicle dashboard

5.4 Shock-Wave Damping (SWD)

The IVI Use Case described above provides a basis for many other applications. One of it is the "Speed recommendation for Shockwave damping (SWD)" Use Case. The SWD Use Case has been invented to achieve a more homogenous traffic flow and specifically to provide electronic speed recommendations for vehicles in the in-flow towards a traffic jam and its dangerous shock waves.

IVI is used to provide a "recommended speed". The target is an automated car-function which regulates the speed. Using C-V2X on PC5 to transfer IVI messages, cars (and drivers) can receive timely triggers to slow down, before a shock wave is built up. This prevents strong and sudden breaks, contributes to safety and avoids further loss of traffic flow. Apart from using the RSU to disseminate the speed recommendations, it can also be used as a powerful detector of speed information from all the cars in the vicinity, simply utilizing the information inside the CAMs received (assuming these cars will be equipped with C-V2X in the future). The RSUs would feedback aggregated speed information back to the traffic center, where sophisticated algorithms would analyze the data, detect changes in the traffic flow, and calculate the speed recommendations to avoid the shock waves.

Within the ConVeX project, parts of this future looking use case were implemented and also investigated with simulations using the SUMO traffic simulator. The simulation concept and results are presented in detail in Deliverable 7.1 [4].

6 RSU Deployment aspects

6.1 Considerations on RSU deployment

When considering the extension of existing ITS infrastructure with C-V2X RSUs, one of the most important question is, where these RSUs would need to be rolled out and how many of them would be required.

Clearly, the answer to these questions depends primarily on the following aspects:

1) Which particular ITS use cases are to be served by each specific RSU?
2) What are the size and shape of the geographical area where the RSU-based ITS service(s) shall become available?
3) What are the achievable PC5 and Uu radio coverage area around an installed RSU?
4) In case mobile network connectivity to ITS infrastructure is employed rather than wired connectivity, does the available mobile network at the considered RSU location support the required level of QoS?
5) Cost, operational cost, resilience and failure probability of roadside infrastructure equipment.

For instance, an RSU solely dedicated to serve the RWW use case would need to be deployed just individually ahead of a road works site. At most one RSU at either side of the construction might be required. If the road construction length is short compared to the PC5 radio coverage range of the RSU, a single RSU might even be sufficient.

For provision of a Time-To-Green service at a traffic light, a single RSU might cover the traffic of all directions at a street intersection.

To realize a Green Light Optimal Speed Advisory service longer stretches of a road towards a traffic light would need to be covered such that depending on the RSUs coverage range, multiple RSUs may need to be deployed along a road. Here also the allowed maximum vehicle speed impacts the size of the area that would need to be covered to achieve the desired traffic flow control.

For the In-Vehicle Information (IVI) use case in a highway scenario, ideally blanket coverage of a potentially several kilometers long section is required. This would also apply to the shockwave damping and avoidance use case as it is essentially based on the IVI service.

Our PC5 radio range measurement results (see Deliverable D7.1 [4]) have shown that under line of sight (LOS) conditions, the communication range amounts to at least 1.5 km. LOS condition between vehicles and an RSU can be achieved more easily when the RSU antenna can be placed at an elevated position, for instance when it would be installed at a gantry which is crossing a highway. A single RSU can serve both driving directions of a multi-lane road.

Based on these results, we believe that PC5-based blanket coverage on a highway can realistically be achieved by installing RSUs at an average distance of around 3 kilometers. Dependent on morphology or in cases of sharp curves, a denser deployment might be needed.

As an illustrative example we may consider the extreme traffic jam prone section of the A9 highway between Nuremberg-Feucht and Munich-Schwabing of 150 km length. It will likely be enough to deploy between 50 to 100 C-V2X RSUs on that A9 section to achieve full blanket coverage and consequently enable all types of use cases which rely on RSU services, including shock-wave avoidance and traffic flow optimization. It is also worth noting, that depending on the use case blanket coverage might not be needed, since many of them work with messages that include the actual validity location. With that, one could “pre-load” the passing car in the coverage of the RSU, which would display the respective warning or speed limit etc. at the desired location further down in the direction of travel.

The value of such services for the road users (traffic carried 90.000 to 140.000 vehicles per day [8]) will be huge at an affordable cost of enhanced ITS infrastructure.

6.2 Business aspects of ITS Infrastructure deployment

This section addresses essential business aspects of ITS infrastructure evolution which have been observed in the course of the ConVeX project.

ITS infrastructure operators, service categories and service providers

Where deployed today, ITS systems in Germany and Europe are currently operated by state-owned road authorities. Integration of C-V2X RSUs as discussed in the section above, however, addresses only one aspect of the upcoming C-ITS infrastructure evolution.

When C-V2X RSUs are integrated into existing ITS infrastructure, it is natural to assume that the added equipment will be operated and maintained by the road authorities as well.

In future however, there will be a large variety of diverse ITS services, including,

- Distribution of road safety–critical information (hazardous location notification),
- Distribution of information enabling traffic flow control, improved traffic efficiency, emission reduction,

- Information sharing for support of autonomous driving,
- Enhanced navigation,
- Road assistance and vehicle maintenance,
- Vehicle tracking/insurance related,
- Comfort for drivers and entertainment for other passengers.

C-ITS services can be differentiated and categorized into services which require or do not require V2I communication between vehicles and RSUs (see Deliverable D1.1 [1]. Services relying on V2I communication can be enhanced by parallel V2N communication for range extension (see Deliverables D1.1 [1] and D7.1 [4]). These services, however, require new functionality in the network cloud (servers) and at the network edge (MEC). The question arises who will operate the equipment and how service provisioning cost can be compensated.

Clearly, only a limited category of future C-ITS services can be provided and maintained by road authorities. Naturally, pure V2N-based ITS services which do not require any interaction with the existing ITS infrastructure could be offered by greenfield service providers.

Depending on service category, there will be different ITS service providers such as e.g. auto manufacturers, insurance companies, roadside/breakdown assistance providers, which potentially will have to interact with operators of roadside infrastructure systems.

Services such as mobile entertainment, mobile social networking will likely not require interaction across different service providers.

The road users likely will have to deal with multiple service subscriptions to a number of different service providers.

Key business requirement: Use of global communication standards

For successful introduction of C-ITS services in Europe and elsewhere, a number of critical technical as well as business requirements must be met.

Besides important technical requirements such as very low transmission latency and high availability and reliability of communication links, an important requirement from business perspective is that future ITS is based on global standards of communication technology. The definition and agreement of the industry of a worldwide standard was the key to global success of mobile communications in the past decades.

An important result of the ConVeX project work is that emerging 3GPP-standardized 4G/5G mobile technology, combined with IP-based communication and introduction of advanced standardized IoT technologies on the Middleware and Application layers (including e.g. MQTT used in ConVeX) is well suited to comply with these requirements. ITS message encoding complying with existing standards defined by ETSI and SAE can be used on the Application layer. Essentially, these are the technologies that have been considered and trialed in the ConVeX project.

Cost of future ITS services

PC5-based direct radio communication in the 5.9 GHz ITS frequency band with transmission mode 4 does not require maintenance and control by a radio network operator and does not create any cost for radio spectrum usage. However, the available radio resource is limited and therefore cannot serve all conceivable services. Hence, it is necessary to regulate the type of services permitted in a given radio spectrum. Road-safety relevant ITS services are best suited for the 5.9 GHz band.

V2N communication creates costs for the serviced user: (i) by the mobile network operator, (ii) potentially in addition by infrastructure service provider (e.g. MEC operator).

B2B business models and commercial ecosystems need to be established to address potentially required real-time communication and business interactions between different cloud services providers, and whether or not road users will have to contribute to cost recovery.

Additional requirements from road safety perspective

There are a number of technical challenges which are very important from a business perspective and which need to be addressed and resolved.

Even when focusing on the important category of hazard notification services only, it would be desirable and important that a future C-ITS system enables the following features:

- Ability to include all type of traffic participants, i.e. must be suitable to also include Vulnerable Road Users (VRU) such as cyclists and pedestrians which are likely subject to limited battery power.
- Possibility to retrofit older vehicles with C-V2X technology
- Capability to build-up ITS services on a unified and consistent service model, where the end user can easily subscribe to services and ITS messages published by service providers.
- Ability to adapt communication range flexibly and efficient in terms of radio resource consumption.

Vulnerable Road Users could participate in the C-ITS scenario by enhancing commercial smart phones with C-V2X technology. Commercial chipsets supporting C-V2X and 4G mobile communications are already available [9]. Chipsets suitable for C-V2X enabled 5G smartphones are under development and will become available in 2020 [10]. It remains to be seen, however, if C-V2X enabled phones will be marketed by handset manufacturers any time soon.

C-V2X enabled smart phones could also represent a viable solution to enable cost-efficient retrofitting of vehicles which are not yet upgraded with C-V2X at serial-production stage. The car driver could benefit from many safety-critical ITS functions even when the C-V2X device would not be connected to the vehicular CAN bus system. Retrofitted CAN connectivity should however also become feasible using wireless technologies such as WLAN or Bluetooth.

C-V2X in smart phones requires easy management of ITS services by the end users and service providers, e.g. to enable and disable services automatically dependent on user location and environmental conditions, in order to save battery power and to enable efficient use of the radio resources available for ITS services.