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Deliverable D1.1: Use Cases, Requirements, Performance Evaluation Criteria

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Revision history

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1.0	30 June 2017	First Release
1.1	05 October 2017	Editorial updates and corrections

Contents

1 Scope

The objective of this document is to describe V2X use cases, requirements and performance evaluation criteria. The use case definitions include a short description of the stakeholders/roles and what is accomplished by the use case. Traffic scenarios that should be targeted with the use cases are defined such as the deployment environment, and vehicle characteristics (density, speed, lanes).

Based on the selected use cases and traffic scenarios, the set of requirements will be defined that are to be used and satisfied by the implementation technology. This includes requirements on:

- Communication links / protocols
- Intra-car-connectivity (sensors / actors),
- Applications (messaging, processing, HMI)
- General features to be supported by the selected use cases

Additionally, this document describes the test measurements and logs that are to be collected along with the collection methodology.

The evaluation criteria applied to the results of the use case trials and the data collected during drive tests will be defined. Qualitative evaluation criteria will be used to determine whether requirements and targeted features of the selected use cases have been satisfied. Quantitative evaluation criteria will be used to determine selected performance metrics such as effective range of safety messages or effective latency of warning signals etc..

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3 Definitions and Abbreviations

3.1 Definitions

Host Vehicle (HV): The vehicle whose driver is alerted or notified by a warning or notification indication by its In-Vehicle Information system (e.g. visually and/or acoustically), as a result of the reception and processing of CAM's and DENM's from surrounding other vehicles.

PC5 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 ProSe Direct Communication over the PC5 interface between the UEs (sidelink).

Remote vehicle (RV): The collection of all vehicles in a traffic scenario which surround a considered Host Vehicle. The Remote Vehicles broadcast their positions and vehicle information periodically and also create special DENM warning messages in case of safety-relevant events.

Road Side 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.

Vulnerable Road User (VRU): A road user, such as a pedestrian, a cyclist or a motorcyclist, bearing a greater risk of serious injury than vehicle occupants when involved in a traffic accident.

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
AEM	Availability Estimation Mechanism

API	Application Programming Interface
BSW	Blind Spot Warning
CACC	Corporative Adaptive Cruise Control
C2C-CC	CAR 2 CAR Communication Consortium
CAM	Cooperative Awareness Message
CAN	Controller Area Network
C-ITS	Cooperative Intelligent Transport Systems
C-V2X	Cellular Vehicle to Everything
CV2XBox	Cellular V2X Communication Module
CVRIA	Connected Vehicle Reference Implementation Architecture
DENM	Decentralized Environmental Notification Message
DTI	Distance to intersection
DVI	Driver Vehicle Interface
E2E	End-to-End
EEBL	Emergency Electronic Brake Light (use case)
ERTICO	European Road Transport Telematics Implementation Coordination
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved UMTS Terrestrial Radio Access
EU	European Union
FCD	Floating Car Data
FCW	Forward Collision Warning
FMI	Follow-Me Information
GLOSA	Green Light Optimal Speed Advisory
GNSS	Global Navigation Satellite System
HGV	Heavy Goods Vehicle
HMI	Human Machine Interface
HW	Hardware
ICS	ITS Central Station
IEEE	Institute of Electrical and Electronics Engineers
IMA	Intersection Movement Assist
ITS	Intelligent Transport System
IVI	In Vehicle Information
IRS	ITS Roadside station
IVS	In-Vehicle Signage
KPI	Key Performance Indicator
LCW	Lane Change Warning
LTA	Left Turn Assist
LTE	Long Term Evolution
MDM	Mobility Data Marketplace

OEM	Original Equipment Manufacturer
OLRV	Opposite Lane Remote Vehicle
PC5	ProSe Communication reference point 5
PER	Packet Error Ratio
ProSe	Proximity-based Services
PVD	Prove Vehicle Date
P-ITS-S	Personal ITS Station
R-ITS-S	Roadside Intelligent Transport System Station
RSSI	Received Signal Strength Indication
RV	Remote Vehicle
RSU	Road Side Unit
RTL	Reliable Transmission Link
RWW	Road Works Warning
SAE	Society of Automotive Engineers
SDK	Software Development Kit
SNR	Signal-to-Noise Ratio
SPaT/MAP	Signal Phase and Time / Map Standard
SW	Software
SWD	Shockwave Damping Service Deployment
TCC	Traffic Control Center
TGW	Traffic jam ahead warning
TTI	Time to intersection
TUKL	Technical University of Kaiserslautern
UE	User Equipment
URC	Ultra-Reliable Communication
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
WGS84	World Geodetic System 1984

4 General

4.1 System Assumptions

The test system will be deployed on A9 and optionally in the City of Rosenheim. In addition a simulation environment at TUKL for both, telecommunication and traffic, will support the project studies.

In the real test bed Ericsson will supply telecommunication infrastructure extensions while Qualcomm supplies communication hardware and software to the partners in order to equip vehicles and road-side-units with the communication technologies subject to the R&D work.

Together, simulation as well as implementation of V2V, V2I, V2N und V2P-Functions will be achieved.

4.2 Reference Point Definition

The C-V2X specifications in 3GPP release 14 include two complementary communication interfaces as illustrated in Figure 4.2-1 ConVeX High Level Network Architecture

Communication connections in the ConVeX system architecture can be classified in the following way: Direct communication such as vehicle-to-vehicle (V2V) is realized through PC5 (ProSe Communication reference point 5). The same holds true for vehicle-to-pedestrians (V2P) and vehicle-to-infrastructure (V2I).

In addition the LTE-Uu connection complements any communication in the non-direct links within the (wide area) network. This connection will also be used as backhaul-link between road-side-units (RSU) and its (traffic management) center, acting as transparent IP connection.

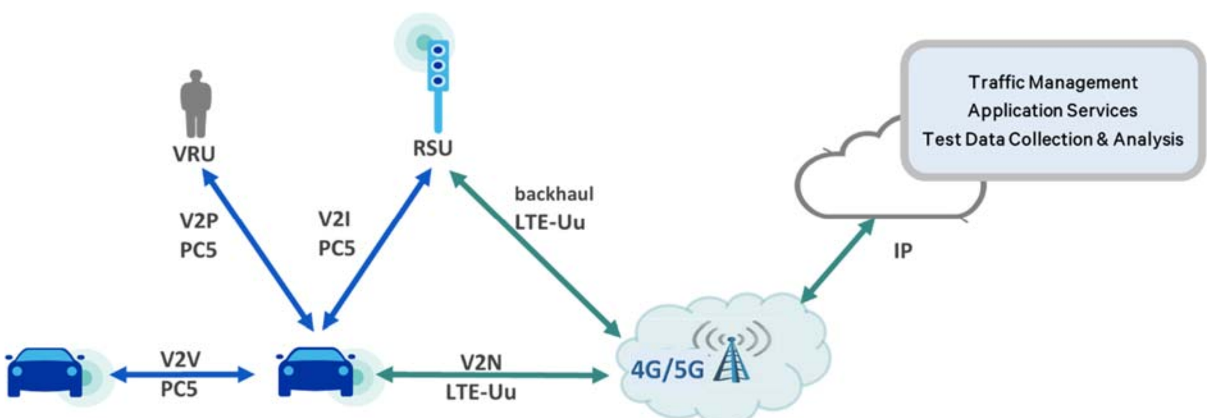

Figure 4.2-1 ConVeX High Level Network Architecture

4.3 Types of V2X

The vehicular communication referred to as Vehicle-to-Everything (V2X), contains following four different types:

- Vehicle-to-Vehicle (V2V) Communications

- Vehicle-to-Infrastructure (V2I) Communications
- Vehicle-to-Pedestrian (V2P) Communications
- Vehicle-to-Network (V2N)

Figure 4.2-1. illustrates these types of communications.

4.3.1 Vehicle-to-Vehicle (V2V)

V2V communication is realized with the means of LTE V2V Sidelink on PC5 interface enabling a direct vehicle to vehicle communication.

The LTE standard allows two different transmission modes on PC5: the so-called “in-coverage” mode, where an eNode B is scheduling the actual transmissions of the UE (Sidelink Transmission Mode 3), as well as the “out-of-coverage” mode where there is no eNode B scheduling involved, but an autonomous resource selection performed by the UEs (Sidelink Transmission Mode 4). The latter will be used for the trial and is also envisioned as the most relevant mode of operation for future real world usage.

As mentioned above, the same PC5 communication will be used for V2I and V2P.

The UE supporting V2V applications transmits application layer information (e.g. about its location, dynamics, and attributes as part of the V2V Service). The V2V payload must be flexible in order to accommodate different information contents.

V2V is predominantly broadcast-based.

Where a direct communication might not be possible e.g. due to the limited direct communication range, the V2V related application information exchange might be done using other V2X services alternatively, e.g. using additional infrastructure like RSU or application servers and the different underlying communication paths of V2I, V2N etc. potentially in a combined manner.

4.3.2 Vehicle-to-Infrastructure (V2I)

The V2I communication will also be implemented using LTE Sidelink Transmission Mode 4 on PC5, i.e. the RSU acts similar as a UE.

Note that the 3GPP standard also foresees a variant of a V2I communication via Uu link, then assuming the RSU to be part of an eNode B, but this setup is again not used within this trial as it is no probable option for a future real world implementation.

The UE supporting V2I applications transmits messages containing V2I application information to an RSU. The RSU and/or the locally relevant application server transmit messages containing V2I application information to one or more UEs supporting V2I applications.

A locally relevant application server serves a particular geographic area. There can be multiple application servers serving overlapping areas, providing the same or different applications.

4.3.3 Vehicle-to-Pedestrian (V2P)

V2P communication is very similar to V2V, also using PC5 LTE Sidelink Transmission Mode 4.

The UE supporting V2P applications transmits application layer information. Such information can be broadcast by a vehicle with UE supporting V2X Service (e.g., warning to pedestrian), and/or by a pedestrian with UE supporting V2X Service (e.g., warning to vehicle).

4.3.4 Vehicle to Network (V2N)

V2N is also introduced where one party is a UE and the other party is a serving entity, supporting both V2N applications and communicating with each other via cellular network (e.g. LTE or 5G). This means for the LTE case, the Uu interface will be used.

Network to Vehicle/UE communication can be multicast or unicast. The serving entities are usually connected to public internet, and possibly to the backends of several service providers.

4.4 C-V2X Communication Platform

The main new hardware component for the trial system is the C-V2X Communication Platform.

Figure 4.4-1 shows its main components - the Application Processor and the C-V2X Module.

The Application Processor modules carries the SDK-Layer with its SDK API and the ITS Stack and the V2X applications as well as the security layer – all typical V2X components.

C-V2X Module implements various communication technologies on its respective frequency bands for example V2V/V2I/V2P (5,9 GHZ) or V2N (700/2600 MHz). This module shall also carry important basis functions such as GNSS and the Hardware Security Module (HSM).

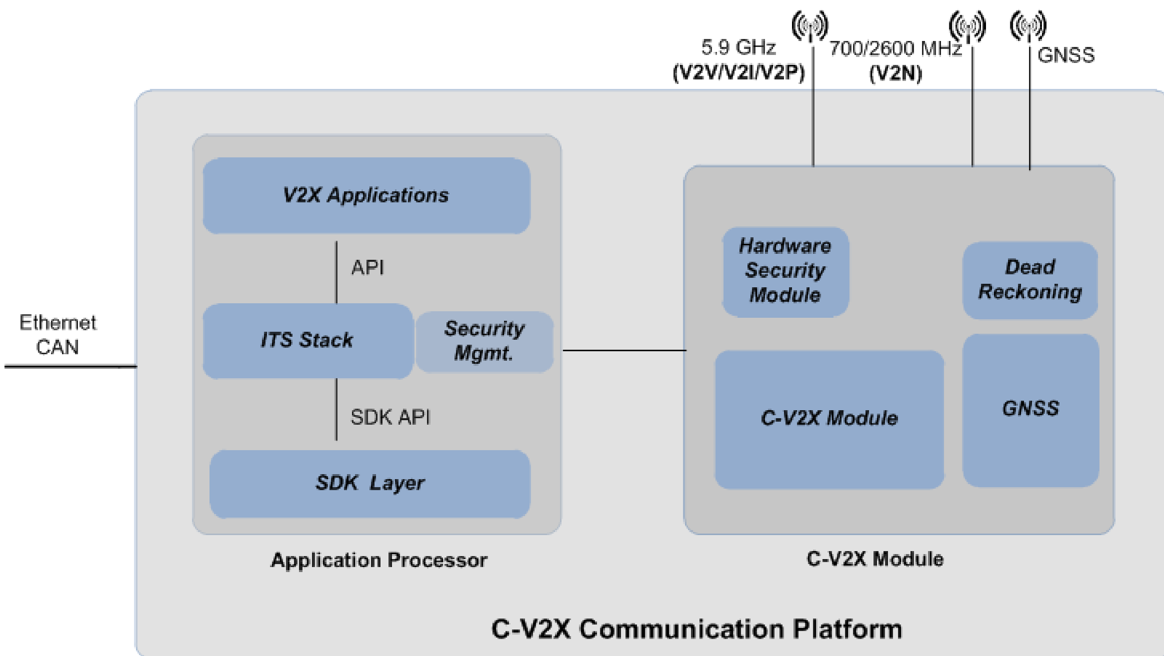

Figure 4.4-1 C-V2X Communication Platform

5 Categorization of Use Cases

Several V2X use cases have been put forward by various research projects which can be categorized in a large number of often overlapping ways. In this project, we adapt a categorization scheme that is most commonly used in many previous projects where the use cases are divided into three classes – Traffic Safety, Traffic Efficiency and Comfort/Entertainment applications.

This section is organized as follows. Section 5.1 presents the use cases proposed by various industry and standards organizations, government authorized strategic platforms, as well as various national and international projects. Section 5.2 presents the use cases considered as part of the current project ConVeX.

5.1 Use Cases – Review of the State of the Art

The following sections of this document list the use cases and applications which have been compiled by the following organizations, which are regarded as globally most influential:

- C-ITS Platform [1]
- EU FP7 funded project PRE-DRIVE C2X [2]
- ETSI defined Basic Set of Applications [3]
- 3GPP use cases described in TS 22.185 [6]
- SAE safety applications [11]
- Connected Vehicle Reference Implementation Architecture (CVRIA) Applications [9]

Note that the use cases derived by these organizations served as basis and starting point for the discussion of V2X use cases in the ConVeX project. A more detailed summary of all these use cases can be found in the referred documents and are therefore not reiterated in this document.

5.1.1 C-ITS Platform

The C-ITS Platform [1] defines a list of 'Day 1 services' and 'Day 1.5 services' which must be addressed to support a secure and safe deployment across Europe and have been identified and discussed within the C-ITS platform.

Day 1 services are expected to, and should be available in the short term, "because of their expected societal benefits and the maturity of technology (personal benefits, users' willingness to pay, business cases and market driven deployment strategies were not taken into account at this stage)" [1].

Day 1.5 services are "considered as mature and highly desired by the market, though, for which specifications or standards might not be completely ready" [1].

Table 5.1-1: Day 1 services defined by C-ITS Platform

#	Use Case	Type	Category
1	Emergency electronic brake light	V2V	Safety
2	Emergency vehicle approaching	V2V	Safety
3	Slow or stationary vehicle(s)	V2V	Safety
4	Traffic jam ahead warning	V2V	Safety
5	Hazardous location notification	V2I	Safety

6	Road works warning	V2I	Safety
7	Weather conditions	V2I	Safety
8	In-vehicle signage	V2I	Efficiency
9	In-vehicle speed limits	V2I	Efficiency
10	Probe vehicle data	V2I	Efficiency
11	Shockwave damping	V2I	Efficiency
12	GLOSA / Time To Green (TTG)	V2I	Efficiency
13	Signal violation/Intersection safety	V2I	Safety
14	Traffic signal priority request by designated vehicles	V2I	Efficiency

Table 5.1-2: Day 1.5 services defined by C-ITS Platform

#	Use Case	Type	Category
1	Off street parking information	V2N	Comfort
2	On street parking information and management	V2N	Comfort
3	Park & Ride information	V2N	Comfort
4	Information on AFV fueling & charging stations	V2N	Comfort
5	Traffic information and smart routing	V2N	Efficiency
6	Zone access control for urban areas	V2N	Efficiency
7	Loading zone management	V2N	Efficiency
8	Vulnerable road user protection (pedestrians and cyclists)	V2P	Safety
9	Cooperative collision risk warning	V2X	Safety
10	Motorcycle approaching indication	V2P	Safety
11	Wrong way driving	V2X	Safety

5.1.2 PRE-DRIVE C2X

The EU FP7 funded project PRE-DRIVE C2X [2] has been established mainly to prepare European Field Operational Tests (FOT). For this purpose, PRE-DRIVE C2X has been selecting sixteen use cases, which have to be priority assessed during European Field Operational Tests. Such selection is considered very relevant as it reflects intentions and decisions taken by the automobile industry, which is well represented in PRE-DRIVE C2X.

The 16 PRE-DRIVE C2X selected use cases are listed in Table 5.1-3.

Table 5.1-3: PRE-DRIVE C2X Use Cases

#	Use Case	Type	Category
1	Road Work Warning	V2I, V2V	Safety
2	Stop sign violation	V2I	Safety
3	Traffic jam ahead warning	V2I	Safety
4	Car breakdown warning	V2V, V2I	Safety
5	Slow vehicle warning	V2V	Safety
6	Approaching vehicle warning	V2V	Safety
7	In-vehicle signage	V2I	Efficiency
8	Regulators and contextual speed limits	V2I	Efficiency
9	Traffic info and recommended itinerary	V2I	Efficiency
10	Limited access warning	V2I	Efficiency

11	Decentralized floating car data	V2I	Efficiency
12	Greenlight optimal speed advisory	V2I	Efficiency
13	Vehicle software provisioning and update	V2N	Comfort
14	Fleet management	V2N	Comfort
15	Local electronic commerce	V2N	Comfort
16	Insurance and financial services	V2N	Comfort

5.1.3 ETSI defined Basic Set of Applications

The Basic Set of Applications (BSA) [3] has been structured and defined according to responses received from a questionnaire distributed and responded to by stakeholders active in ETSI and ISO ITS standards development and in EU ITS projects.

Table 5.1-4: ETSI Basic Set of Applications

#	Use Case	Type	Category
1	Emergency vehicle warning	V2I, V2V	Safety
2	Slow vehicle indication	V2V	Safety
3	Intersection collision warning	V2I, V2V	Safety
4	Motorcycle approaching indication	V2V, V2I	Safety
5	Emergency electronic brake lights	V2V	Safety
6	Wrong way driving warning	V2I	Safety
7	Stationary vehicle - accident	V2I, V2V	Safety
8	Stationary vehicle – vehicle problem	V2I, V2V	Safety
9	Traffic condition warning	V2I	Safety
10	Signal violation warning	V2I	Safety
11	Roadwork warning	V2I	Safety
12	Collision risk warning	V2I, V2V	Safety
13	Decentralized floating car data – Hazardous location	V2I	Safety
14	Decentralized floating car data - Precipitations	V2I	Safety
15	Decentralized floating car data – Road adhesion	V2I	Safety
16	Decentralized floating car data - Visibility	V2I	Safety
17	Decentralized floating car data - Wind	V2I	Safety
18	Regulatory/contextual speed limits notification	V2I	Efficiency
19	Traffic light optimal speed advisory	V2I	Efficiency
20	Traffic information and recommended itinerary	V2I	Efficiency
21	Enhanced route guidance and navigation	V2I	Efficiency
22	Limited access warning and detour notification	V2I	Efficiency
23	In-vehicle signage	V2I	Efficiency
24	Point of interest notification	V2I	Comfort
25	Automatic access control and parking management	V2I	Comfort
26	ITS local electronic commerce	V2I	Comfort
27	Media downloading	V2I	Comfort
28	Insurance and financial services	V2N	Comfort
29	Fleet management	V2N	Comfort
30	Loading zone management	V2N	Comfort
31	Vehicle software/data provisioning and update	V2N	Comfort
32	Vehicle and RSU data calibration	V2N	Comfort

5.1.4 3GPP Use Cases

Below is the example of the specific use cases that were used by 3GPP to derive service requirements for the V2X system (Release 14) were, as per 3GPP TS 22.885 [7].

Table 5.1-5: 3GPP V2X Use cases

1	Control loss warning	V2V, V2I	Safety
2	Emergency vehicle warning	V2V	Safety
3	Emergency stop	V2V	Safety
4	Cooperative adaptive cruise control	V2V	Efficiency
5	Queue warning	V2V	Efficiency
6	Road safety services	V2V	Safety
7	Automated parking system	V2I	Comfort
8	Wrong way driver warning	V2I	Safety
9	Pre-crash sensing warning	V2V	Safety
10	Traffic flow optimization	V2I, V2V	Comfort
11	Curve speed warnings	V2I	Safety
12	Vulnerable road user safety	V2I, V2V	Safety
13	Enhanced positioning	V2I	Safety

For the enhanced V2X work in 3GPP, additional, more challenging use cases are considered as a basis to derive service requirements (Release 15 and beyond), as per 3GPP TR 22.886 [27]. Some examples are shown in Table 5.1-6.

Table 5.1-6: 3GPP Enhanced V2X Use cases

#	Use Case	Type	Category
1	Vehicle platooning	V2V	Efficiency
2	Sensor and state map sharing	V2I, V2V	Efficiency
3	Remote driving of vehicles	V2N	Efficiency, Safety
4	Collective perception of the environment	V2V, V2I	Efficiency
5	Information sharing for full/automated driving/platooning	V2V, V2I	Efficiency
6	Dynamic ride sharing	V2N, V2I	Efficiency
7	Intersection safety information provisioning for urban driving	V2I	Safety

5.1.5 V2V Safety Applications related to Crash Scenarios

Table 5.1-7 derived by SAE illustrates the mapping between the crash-imminent scenarios and relevant safety applications [11].

Table 5.1-7: Basic Set of Applications

Crash Scenarios \ Safety Applications	EEBL	FCW	BSW/ LCW	IMA	LTA	CLW
Lead Vehicle Stopped		✓				
Control Loss without Prior Vehicle Action						✓
Vehicle(s) Turning at Non-Signalized Junctions				✓	✓	
Straight Crossing Paths at Non-Signalized Junctions				✓		
Lead Vehicle Decelerating	✓	✓				
Vehicle(s) Changing Lanes – Same Direction			✓			
Left Turn Across Path – Opposite Direction					✓	

5.1.6 Connected Vehicle Reference Implementation Architecture (CVRIA) Applications

The Connected Vehicle Reference Implementation Architecture is based on a set of Applications that have been defined by various connected vehicle programs. The source for the application descriptions ranges from Concepts of Operations (ConOps), Requirements Specifications, or existing Standards and Architectures. There are four types of Connected Vehicle Applications:

- Environmental,
- Mobility,
- Safety, and
- Support.

Each type is comprised of groups of applications [9].

Table 5.1-8: SAE defined Safety Applications related to Crash Scenarios

Type	Group	Application Name
Environmental	AERIS/ Sustainable Travel	Connected Eco-Driving
		Dynamic Eco-Routing
		Eco-Approach and Departure at Signalized Intersections
		Eco-Cooperative Adaptive Cruise Control
		Eco-Freight Signal Priority

Type	Group	Application Name
		Eco-Integrated Corridor Management Decision Support System
		Eco-Lanes Management
		Eco-Multimodal Real-Time Traveler Information
		Eco-Ramp Metering
		Eco-Smart Parking
		Eco-Speed Harmonization
		Eco-Traffic Signal Timing
		Eco-Transit Signal Priority
		Electric Charging Stations Management
		Low Emissions Zone Management
		Roadside Lighting
	Road Weather	Enhanced Maintenance Decision Support System
		Road Weather Information and Routing Support for Emergency Responders
		Road Weather Information for Freight Carriers
		Road Weather Information for Maintenance and Fleet Management Systems
		Road Weather Motorist Alert and Warning
		Variable Speed Limits for Weather-Responsive Traffic Management
Mobility	Border	Border Management Systems
	Commercial Vehicle Fleet Operations	Container Security
		Container/Chassis Operating Data
		Electronic Work Diaries
		Intelligent Access Program
		Intelligent Access Program - Mass Monitoring
	Commercial Vehicle Roadside Operations	Intelligent Speed Compliance
		Smart Roadside Initiative
	Electronic Payment	Electronic Toll Collection

Type	Group	Application Name
		Road Use Charging
	Freight Advanced Traveler Information Systems	Freight Drayage Optimization
		Freight-Specific Dynamic Travel Planning
	Planning and Performance Monitoring	Performance Monitoring and Planning
	Public Safety	Advanced Automatic Crash Notification Relay
		Emergency Communications and Evacuation
		Incident Scene Pre-Arrival Staging Guidance for Emergency Responders
		Incident Scene Work Zone Alerts for Drivers and Workers
	Traffic Network	Cooperative Adaptive Cruise Control
		Queue Warning
		Speed Harmonization
		Vehicle Data for Traffic Operations
	Traffic Signals	Emergency Vehicle Preemption
		Freight Signal Priority
		Intelligent Traffic Signal System
		Pedestrian Mobility
		Transit Signal Priority
	Transit	Dynamic Ridesharing
		Dynamic Transit Operations
		Integrated Multi-Modal Electronic Payment
		Intermittent Bus Lanes
		Route ID for the Visually Impaired
		Smart Park and Ride System
		Transit Connection Protection
		Transit Stop Request
	Traveler Information	Advanced Traveler Information Systems

Type	Group	Application Name
		Traveler Information- Smart Parking
Safety	Transit Safety	Transit Pedestrian Indication
		Transit Vehicle at Station/Stop Warnings
		Vehicle Turning Right in Front of a Transit Vehicle
	V2I Safety	Curve Speed Warning
		In-Vehicle Signage
		Oversize Vehicle Warning
		Pedestrian in Signalized Crosswalk Warning
		Railroad Crossing Violation Warning
		Red Light Violation Warning
		Reduced Speed Zone Warning / Lane Closure
		Restricted Lane Warnings
		Spot Weather Impact Warning
		Stop Sign Gap Assist
		Stop Sign Violation Warning
		Warnings about Hazards in a Work Zone
		Warnings about Upcoming Work Zone
	V2V Safety	Blind Spot Warning + Lane Change Warning
		Control Loss Warning
		Do Not Pass Warning
		Emergency Electronic Brake Light
		Emergency Vehicle Alert
		Forward Collision Warning
		Intersection Movement Assist
		Motorcycle Approaching Indication
		Pre-crash Actions
		Situational Awareness
		Slow Vehicle Warning

Type	Group	Application Name
		Stationary Vehicle Warning
		Tailgating Advisory
		Vehicle Emergency Response
Support	Core Services	Core Authorization
		Data Distribution
		Infrastructure Management
		Location and Time
		Map Management
		Object Registration and Discovery
		Privacy Protection
		System Monitoring
	Security	Security and Credentials Management

5.2 ConVeX Project Use Cases

A careful look into the use cases mentioned in the previous section resulted in the following observations:

1. The majority of the proposed use cases deal with traffic safety applications be means of exchanging warning messages via direct V2V links.
2. Traffic Efficiency can be leveraged by connected mobility applications (e.g., platooning, network coordinated autonomous driving) for which the detailed specifications and standards are still not ready
3. The rise in Comfort / Convenience applications is facilitated by the maturity and usefulness of first generation connected vehicle implementations.

The following project specific points are also relevant for the selection and evaluation of use cases:

1. The main objective of the project is to demonstrate the benefits of connected vehicle applications in a real test field. Hence, it is imperative to select those use cases that are highly mature and for which detailed specifications and standards exist.
2. It is important to consider heterogeneous link types – V2V, V2I, V2N and V2P since, ultimately, all these links are envisioned to be serviced by one unified access technology and if possible, by means of a modular hardware.

Based on the observations and the points outlined above, 12 use cases were proposed covering traffic safety (7), traffic efficiency (4), and comfort/convenience (1), and are listed in the table below. They are planned to be evaluated either in the trial system or by means of simulation studies or a combination of both.

Table 5.2-1: Categorization of ConVeX Use Cases

	Communication Link					
Use Case	**V2V**	**V2I**	**V2P**	**V2N**	**Category**	**Road Type**
FollowMe Information	X			Y	Comfort	Motorway, Urban, Rural
Cloud Based Sensor Sharing	Y	Y		X	Efficiency	Motorway, Urban, Rural
Blind Spot / Lane Change Warning	X		Y		Safety	Motorway, Rural
Do Not Pass Warning	X			Y	Safety	Rural
Emergency Electronic Brake Lights	X				Safety	Motorway, Urban, Rural
Intersection Movement Assist	X	Y			Safety	Urban
Left Turn Assist	X	Y			Safety	Urban, Rural
Vulnerable Road User Warning			X		Safety	Motorway, Urban, Rural
Shockwave Damping	X	X		Y	Efficiency	Motorway, Urban
In-Vehicle Information	Y	X		Y	Efficiency	Motorway, Urban, Rural
Road Works Warning	Y	X		Y	Safety	Motorway, Urban, Rural
Network Availability Prediction		Y		X	Efficiency	Motorway, Urban, Rural
Legend: **X:** applies **Y:** could be applied						

Further a series of subjective or qualitative ratings such as novelty, market relevance in short term, its complexity or risk in demonstration etc. have been considered in order to prioritize the use cases.

6 Performance Indicators

6.1 Introduction

This section defines the key parameters which characterize the performance of a V2X system. It differentiates between radio performance indicators, end-to-end performance indicators and position location performance indicators. The requirements on these performance indicators are typically use case specific and depend on traffic-scenario specific parameters such as, e.g., assumptions on vehicle speed and distance between vehicles. A summary of parameters related to traffic conditions is given in section 6.5.

Requirements on the most relevant KPIs are provided individually for each use case in the descriptions in Section 7.

6.2 Radio Performance Indicators

Radio performance needs to be differentiated depending on the type of radio technology and spectrum employed. Radio performance of V2N communication using V2N radio technology in, e.g., the 700 MHz or 2.6 GHz bands, and of V2V/V2I/V2P communication in the 5.9 GHz ITS band are independent of each other and therefore can be assessed separately.

Performance of V2V, V2I and V2P communication should be analyzed for one individual type of communication (e.g., for V2V only) as well as for mixed traffic scenarios when multiple types of communications are used simultaneously in a use case and where also additional users affect the load and thus the interference situation.

The Key Performance Indicators (KPI) are defined as follows (see [14]):

User Plane Latency

Time in milliseconds required to transmit a message from the radio transmitter to the radio receiver

Control Plane Latency

Time required for a transmitter to start user plane communication (transmission or reception), includes possibly time for random access and connection establishment.

Data Rate

Peak data rate and range of data rates achievable on a given radio link per user (applicable to different protocol layers (e.g. PHY, MAC, etc.)

Packet Reception Ratio

Peak data rate and range of data rates achievable on a given radio link per user

Packet Error Ratio

Ratio of data packets received in error or missed

Interruption Time

Time intervals where no communication is possible, e.g. due to handover procedures or loss of radio coverage

Range

Maximum distance between transmitter and receiver allowing communication with acceptable Data Rate, Packet Error Ratio and Latency.

6.3 End-to-End Performance Indicators

End-to-End performance indicators characterize the overall experience as perceived by an end-user of a service (see [14], [15]):

E2E latency

Different types of latency are relevant for different applications. E2E latency, or one trip time (OTT) latency, refers to the time it takes from when a data packet is sent from the transmitting end to when it is received at the receiving entity, e.g., internet server or other device. Another latency measure is the round trip time (RTT) latency which refers to the time from when a data packet is sent from the transmitting end until acknowledgements are received from the receiving entity. The measurement reference in both cases is the interface between Layer 2 and 3.

Experienced user throughput

Experienced user throughput refers to an instantaneous data rate between Layer 2 and Layer 3. Experienced user throughput is linked with availability and retainability.

Traffic volume density

Traffic volume density is defined as the aggregated number of correctly transferred bits received by all destination UEs from source radio points (DL traffic) or sent from all source UEs to destination radio points (UL traffic), over the active time of the network to the area size covered by the radio points belonging to the RAN(s) where UEs can be deployed. Thus, traffic volume density can have the following units: [Mbps/m^2] or [Gbps/km^2].

Reliability

Refers to the continuity in the time domain of correct service and is associated with a maximum latency requirement. More specifically, reliability accounts for the percentage of packets properly received within the given maximum E2E latency (OTT or RTT depending on the service). For its evaluation dynamic simulations are needed, and realistic traffic models are encouraged. Reliability is linked with availability and retainability.

Availability

The availability in percent is defined as the number of places (related to a predefined area unit or pixel size) where the Quality of Experience (QoE) level requested by the end-user is achieved divided by the total coverage area of a single radio cell or multi-cell area (equal to the total number of pixels) times 100.

Retainability

Retainability is defined as the percentage of time where transmissions meet the target experienced user throughput or reliability.

6.4 Position Location Performance Indicators

Accuracy of position location measurements is typically defined using the following criteria (see [23] and [24]):

Circular Error Probability (CEP):

The circular error probability is a well-accepted metric to describe the uncertainty of the latitude and longitude (horizontal plane) error between the measured and the true position (2-D error). CEP is defined as the radius of a circle centered on the true value that contains 50% of the actual GNSS measurements. The accuracy requirement is typically measured in meters or centimeters.

For example, a receiver with 10 meters CEP accuracy will be within ten meters of the true position 50% of the time. The circle of radius indicating the 95% probability is often referred to as R95 or CEP95, i.e. R95/CEP95 is the CEP with the radius of the 95% probability circle. If a CEP value is given without specifying the probability, CEP50 is assumed.

Spherical Error Probability (SEP):

SEP refers to the error on both horizontal and vertical planes (3-D error), i.e. including latitude, longitude and altitude.

For example, for a 50th percentile (SEP50), half the measured data points or positions would fall within a sphere of a given radius. If a SEP value is given without specifying the probability, SEP50 is assumed. As with CEP, the accuracy requirement is typically measured in meters or centimeters.

Localization Latency

Time elapsed from given GNSS timestamp until the calculated position estimate is available to an application

Confidence

The confidence by which the position is known to be within a given shape description, (expressed as a percentage) and is dependent on the amount of measurement samples collected for the calculation of a certain position estimate.

6.5 Road Traffic Related Performance Indicators

Sections 6.2 and 6.3 reflect only the radio performance for the vehicular networking applications. Since Vehicular networking aims to improve traffic safety and efficiency, application dependent metrics also need to be considered. In this section, we provide examples of such metrics for very specific applications.

6.5.1 Traffic Efficiency Applications

The aim of traffic efficiency applications is to increase the overall traffic efficiency in terms of road capacity, reduction of travel time emissions, etc.. ConVeX Use cases dealing with efficiency applications are the following:

1. Shockwave Damping (SWD)
2. In Vehicle Information (IVI)

The application specific metrics for these kinds of applications are as follows:

Travel Time

Travel time describes the time it takes for the vehicle to travel from origin to destination. Hence, it microscopically models the benefits an individual car can gain using, for example, a Traffic Information Service or e.g. ITS messages related to shockwave damping(see Section 7.9).

CO_2 Emissions

The emissions characterize the smoothness of a trip and can be used to describe the impact on the environment in general.

6.6 Conditions for Performance Analyses

This section describes the relevant physical conditions when obtaining performance measurements.

Velocity of vehicles

Speed and range of speed (measured in kilometers per hour) of the vehicles considered in a scenario, maximum speed depends on the geographic area.

Geographic Area

Following geographical scenarios are differentiated

- Urban [speed range 0 to 50 km/h]
- suburban [speed range 0 to 70 km/h]
- rural [speed range 0 to 100 km/h]
- highway [speed range 80 to 250 km/h]
  - assumptions on type of road, e.g.
    - 2 x 2 lanes
    - 2 x 3 lanes (as given in A9 test field)

Vehicle Distance and Density

Average distance between vehicles (measured in meters)

Vehicle density: number of vehicles per square km (taking into account parameters of the roads

V2X traffic load

Measured in dependence of radio technology:

V2N: radio network load per sector in percent

V2V/V2I/V2P: number of messages sent per second per vehicle, load of channel in percent

7 Use Case Descriptions

7.1 Follow-me information (FMI)

7.1.1 General Description

Follow-me information is a convenience feature for people travelling in groups of vehicles. The received information can be used to plan or optimize a route.

A potential following vehicle can subscribe to the location information of a leading vehicle which is providing the service. After an authentication at and an authorization of the leading vehicle the position information shall be transmitted.

The transmission of that position shall be handled via cellular and direct communication.

7.1.2 Objective

This use case will demonstrate that a following vehicle (RV) can be informed of the position of a leading vehicle (HV) via a direct link. The position of the HV is displayed in the HMI. The same functionality can be realized via a network link at larger distances between RV and HV.

If a vehicle enters the range of the direct link communication of a vehicle providing such an information, the communication shall switch to the direct link with a more accurate position and a higher, dynamic update rate.

Since the future world of connected cars, connected infrastructure and IoT will contain a lot of participants which are interested in specific information groups and are enabled to provide different types of data, a base service for positioning seems necessary. This use case bonds a positioning service, which can be used for future use cases, to an authentication.

The visualization for the user shall distinguish between a position service using direct transmission and a service instance which handles the position updates via the network.

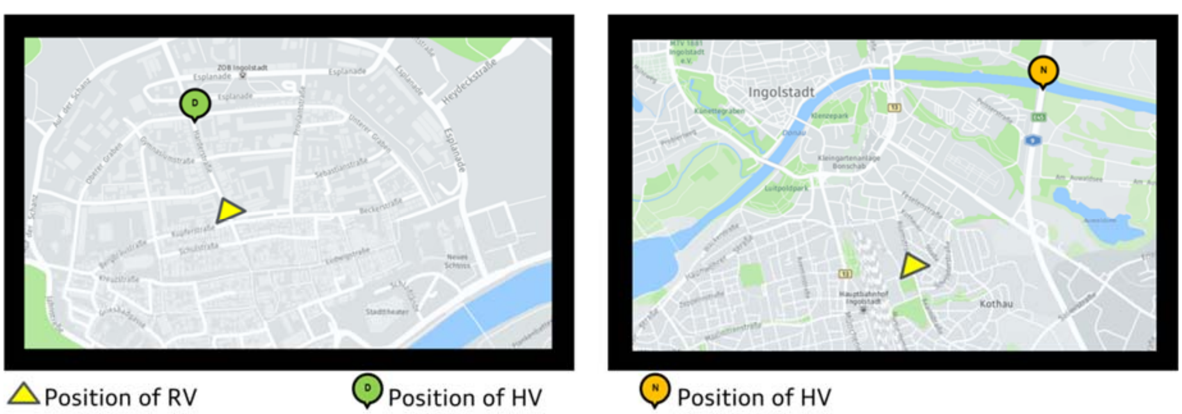

Figure 7.1-1: Navigational view from the perspective of RV - in direct and network mode

7.1.3 Description of relevant scenarios to investigate

The following traffic scenarios for the present use case will be investigated:

- Highway scenarios (A9)
    1) RV and HV travelling on the highway with varying distance. HV getting out of sight of RV. HV moving to motorway service area. Position is continuously depicted in the RV HMI such that following the leading vehicle is enabled.
    2) Extend scenario 1) to large distance case utilizing network (V2N) transmission.

- Rural/suburban/urban scenarios
    3) RV and HV travelling in urban scenario. HV gets to final destination and sends location via direct communication to RV. Navigation system calculates route and navigates to HV position.
    4) Extend scenario 3) to large distance case utilizing network (V2N) transmission.

Both above scenario groups require mutual authentication between RV and HV and an authorization by the driver of the HV.

7.1.4 Safety Considerations

An outage of the direct communication has to be detectable in order to switch back to the cellular communication and / or warn the driver. Use cases which might use a positioning service for further functional content require more detailed consideration and analysis.

7.1.5 Trial set up and requirements

7.1.5.1 Trial set up

The demonstration and evaluation of this use case requires two vehicles equipped with C-V2V and C-V2N functionality. C-V2I functionality is not needed in this use case.

An additional backend component which routes the location information from the subscribed vehicle to the subscription vehicle is furthermore required.

Since many internal functions in an automotive system use the internal GNSS position system, a position input from the car seems feasible. With the help of internal functions this position can be predicted and map-matched on an existing map layer.

7.1.5.2 Communication requirements

Since the use case involves network/cellular and direct communication a PC5 and Uu interface is required in the minimum scenario.

Additionally a system which detects failures and outages in the system are needed in an extended version.

7.1.5.3 Performance requirements

In order to make this use case work on a motorway the communication shall just work between cars which are heading in the same direction, and an absolute (and relative) speed of 250 km/h shall be supported.

7.1.6 Procedures

The *FollowMeInformation* service consists of an authentication and a location service. In the minimum scenario, the location service publishes the location via cellular/network communication and direct communication.

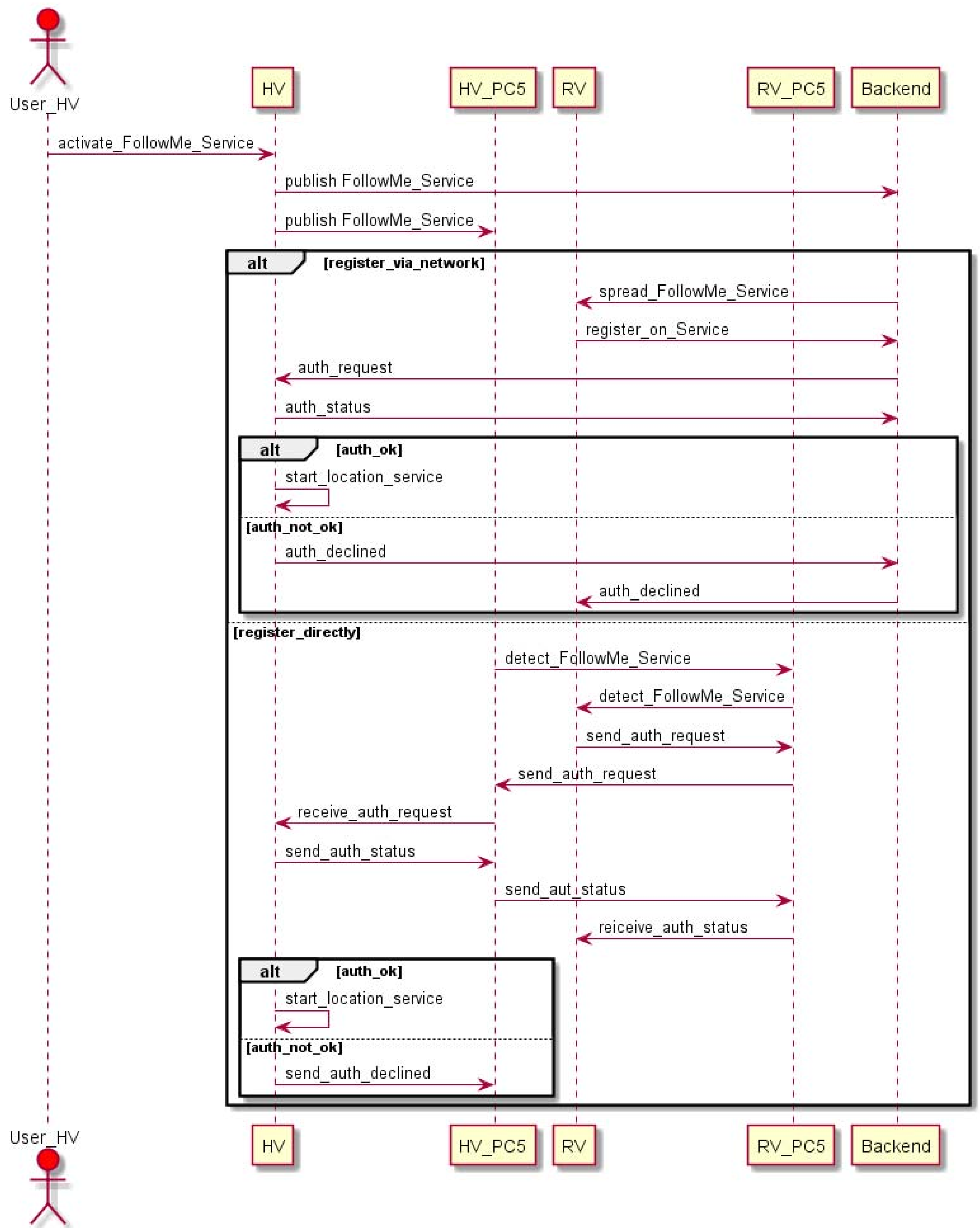

Figure 7.1-2: Enabling the FollowMeInformation service

The online location service is described as a P2P connection. In the first step the location service via direct link can be described as a C-ITS CA message since it matches the requirements for this use case. If there are additional requirements regarding this service this description might be changed in future versions.

However, the location service shall support extensions like information about confidence of the vehicle position and additional meta information.

In the initial setup the authentication can be handled via a whitelist for RVs the HV verifies a requested identifier with. This identifier can be a static number in a basic way.

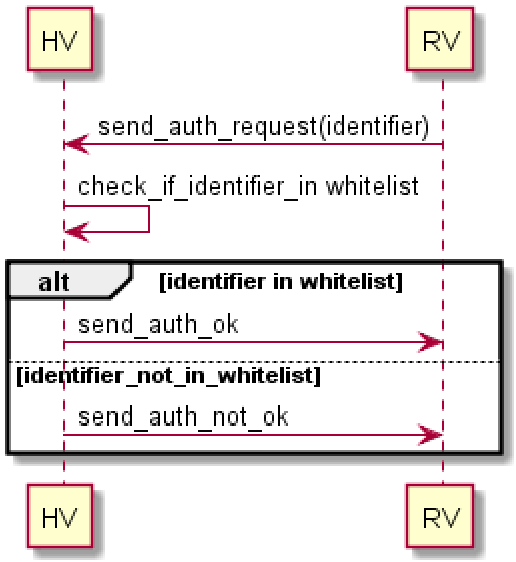

Figure 7.1-2 : Basic authentication

7.1.7 Measurements

A documented measurement value shall contain the geo location, a send time, and a receive time.

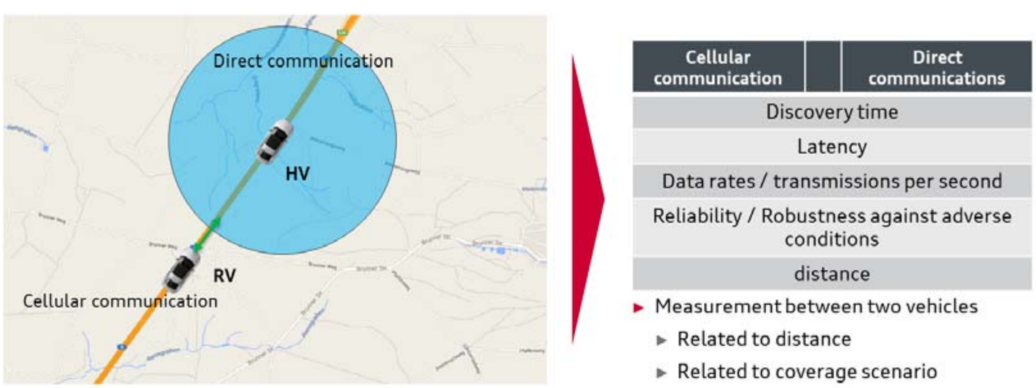

Figure 7.1-4: Measurement

7.1.8 Expected Outcome

Message delivery times and comparisons between cellular/network and direct communication. Locations in which the direct communication drops are more likely shall also be specified.

7.2 Cloud-based Sensor Sharing (Infrastructure & Vehicle)

7.2.1 General Description

Sharing of infrastructure & vehicle sensor systems allows for improved detection of relevant objects such as pedestrians, legacy vehicles & obstacles on the road, compared to individual in-vehicle processing. Aside from extending the perception range of each vehicle, information about an object can be improved (e.g. classification of pedestrian: child, adult, handicap, etc., or accuracy improvement w.r.t. position & size).

Compared to pure peer-to-peer-based sensor sharing, cloud-based sensor sharing allows improved orchestration capabilities of the whole system: less information has to be transmitted, as sensor systems can match detected objects with objects known centrally in a Dynamic Map, and the central processing unit can remove duplicates, enhance existing information, and distribute the information efficiently (e.g. using radio broadcasts).

An infrastructure sensor system would be static in its location, and optimized for observing a specific area (e.g. a crossing or the area around a school entrance). A vehicular sensor system would be a vehicle equipped with sensors (e.g. cameras & radar) and corresponding object detection software, where the vehicle needs to know its own position accurately.

7.2.2 Objective

The main objective of the use case is the efficient & scalable sharing & maintenance of safety-critical information in a Dynamic Map, without specific communication path requirements (e.g. V2N vs. direct V2I). Specifically, the use case enables:

- A more efficient distribution of warnings with local relevance, compared to pure V2V-based distribution of sensor information
- Real-time monitoring of traffic and statistical evaluation
- Support for a wide range of devices & delivery paths, in particular equipment of legacy cars
- Correlation of information from different sources, for refining position, movement etc., but also refining information about the nature of the object (e.g. kid, adult, handicap, etc.)
- Correlation with other road infrastructure information, e.g. traffic light phases

If a receiving car knows its positions only roughly, and only has a “normal” map, messages/warnings can be marked in the map.

If a receiving car knows its position accurately, but only has a “normal” map, additional information such as the distance to an object can be provided.

If a receiving car knows its position accurately, and has an HD map, further correlation with driving intention/path etc. can be exploited.

7.2.3 Description of relevant scenarios to investigate

Disclaimer: In the following graphics, humans are used as one tangible example for detectable objects, but the description is focusing on any kind of objects.

The following traffic scenarios for the present use case will be investigated:

- Urban scenarios:
  - Showcase Scenario 1: Object of interest to HV detected by RV (Figure 7.2-1)

- Showcase Scenario 2: Object of interest to HV detected by intersection sensor system (Figure 7.2-2)
- Showcase Scenario 3: Object of interest to HV detected by intersection sensor system and RV, and the object descriptions are merged in the corresponding cloud function (Figure 7.2-3)
- Complete Scenario: Permanent extension & maintenance of dynamic map based on both intersection & vehicle sensor system input (Figure 7.2-4)

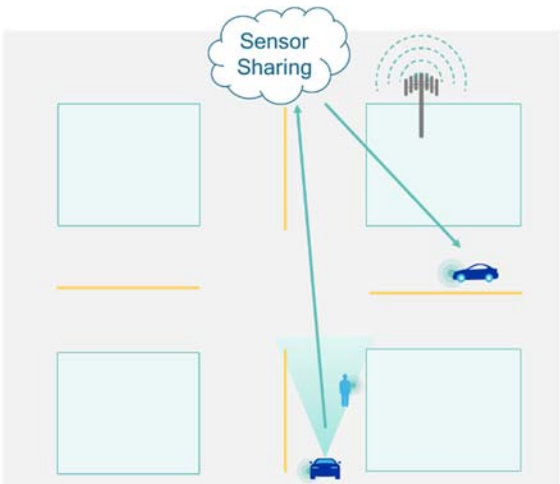

Figure 7.2-1: Vehicle sensor system detects object

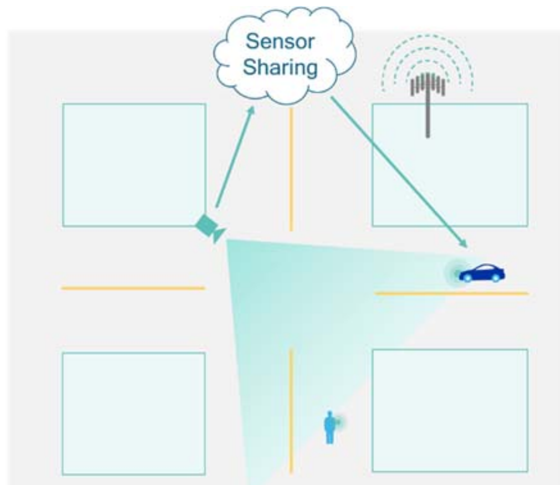

Figure 7.2-2: Infrastructure sensor system detects object

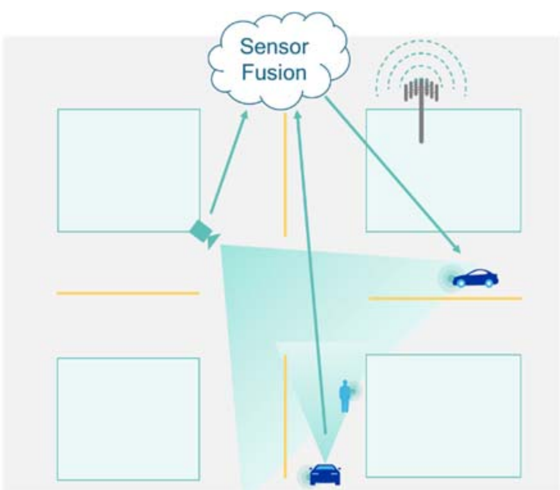

Figure 7.2-3: Sensor fusion of multiple sensor systems

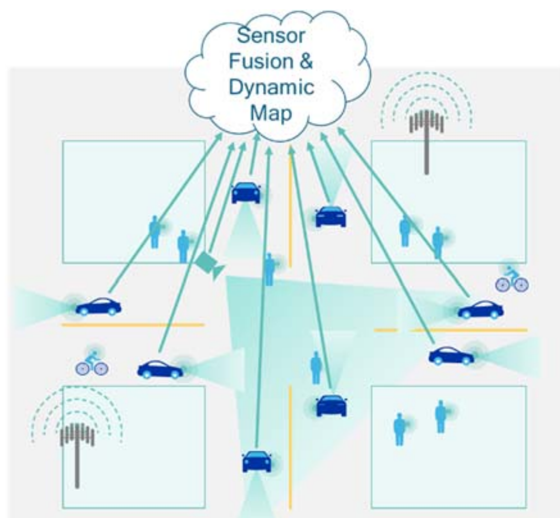

Figure 7.2-4: Central fusion & management of sensor output in dynamic map

7.2.4 Safety Considerations

Several other use cases can benefit from the improved efficiency for exchanging information provided by this use case. The safety benefit of general sensor sharing is to enhance the perception range of the HV, allowing earlier detection of potential threats.

7.2.5 Trial set up and requirements

7.2.5.1 Trial set up

The demonstration and evaluation of this use case requires up to two (2) vehicles equipped with V2N functionality, as well as sensor systems including object detection. The object detection mechanism in the vehicle is outside the scope of the project. Furthermore, one (1) camera with object detection, placed at an intersection is required. Additionally, at least one (1) object is required that should be detected. The setup is sketched in Figure 7.2-5.

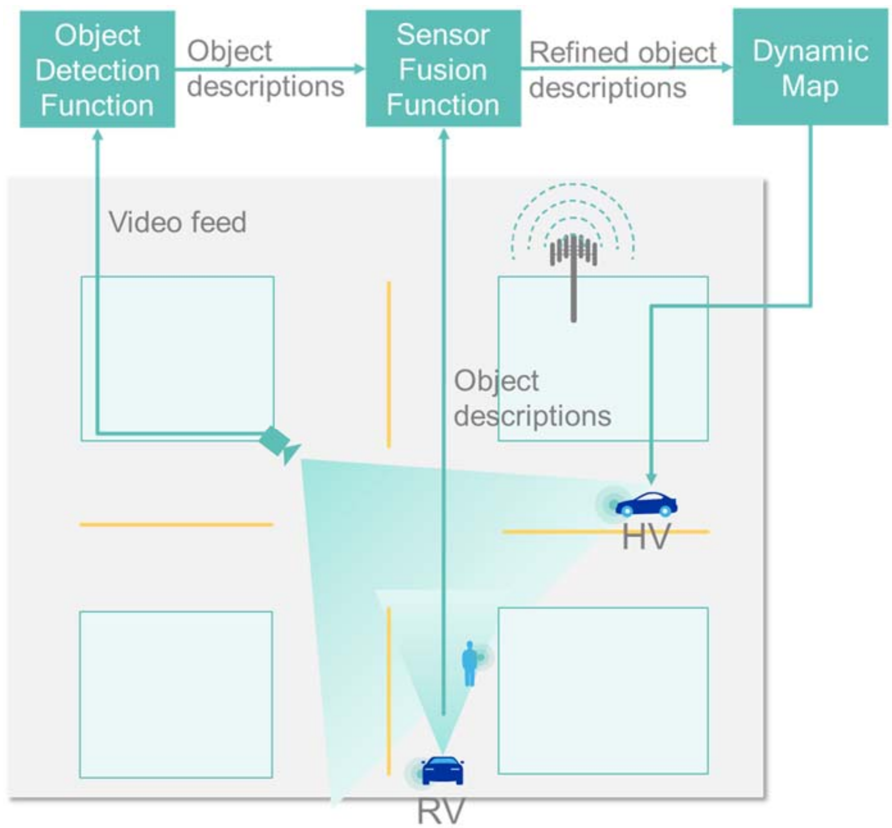

Figure 7.2-5: Architecture of the trial setup

7.2.5.2 Communication requirements

The cloud must be accessible by all sensor systems & both vehicles, in the simplest case using LTE Uu. Furthermore, the object description must be received by the HV early enough to react to the situation adequately.

7.2.5.3 Performance requirements

The position accuracy of objects detected by individual sensor systems must be accurate enough to correlate objects from different sources.

7.2.6 Procedures

A rough message sequence chart is shown in Figure 7.2-6. While only the video feed is delivered continuously, all other messages and processes happen on demand. Most messages and processes will effectively be continuous as well, if objects to detect are around. The object detection function, as well as the RV, will in fact periodically send object descriptions to the sensor fusion function for moving objects.

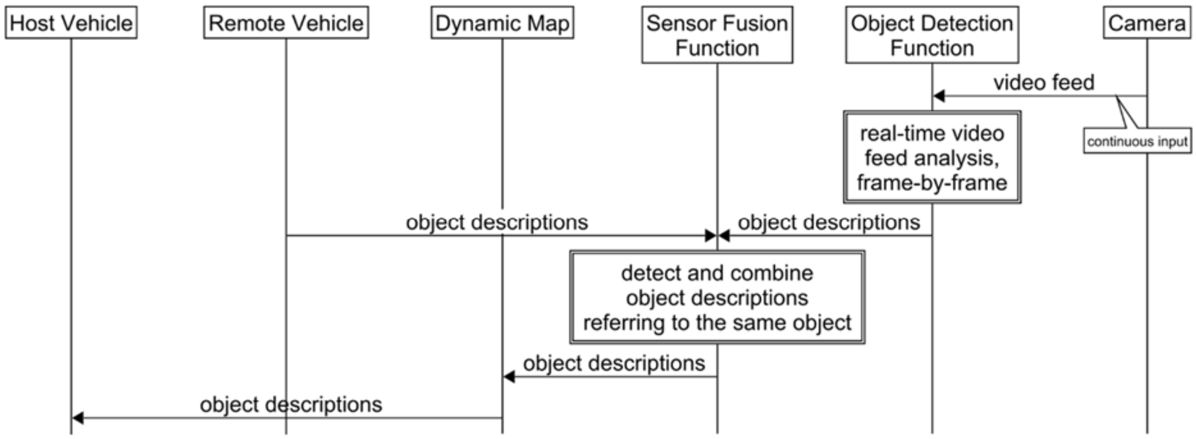

Figure 7.2-6: Message sequence chart for the use case

7.2.7 Measurements

KPI 1. The E2E latency from the first detection of an object by an RV or the infrastructure sensor system until the availability at the HV. The requirement here depends on the scenario that is supported by this use case.

KPI 2. The accuracy gain, i.e. the accuracy increase by combining information from multiple sensor systems, relative to the first description that is present. This can be calculated based on the accuracy indicated by the individual sensor systems in the object descriptions.

KPI 3. The total load, i.e. the number of bytes, generated on application layer by all associated nodes.

7.2.8 Expected Outcome

It is expected that the cloud-based sensor sharing will be superior to the direct sharing w.r.t. KPI 2, but will be inferior w.r.t. KPI 1. Furthermore, which realization is superior w.r.t. KPI 3 is expected to depend on our approach in the cloud-based realization.

7.3 Blind Spot Warning (BSW) / Lane Change Warning (LCW)

7.3.1 General Description

The BSW/LCW application will warn the driver of the host vehicle (HV) during a lane change attempt if the blind zone the HV intends to switch into is occupied or will soon be occupied by another vehicle (RV) traveling in the same direction. Besides, the application will provide advisory information to the driver whenever a vehicle in an adjacent lane is positioned in a blind spot zone of the HV.

7.3.2 Objective

This use case will demonstrate that an HV can be warned sufficiently early to indicate that in the current situation the HV should not change lane because of high probability that a crash may occur with one RV in the adjacent lane.

HV shall wait for a safe moment in time to proceed the intended change of lane.

Finally, the overall collective change of behavior shall increase safety for all directly and indirectly involved participants.

7.3.3 Description of Relevant Scenarios to Investigate

The following traffic scenarios for the present use case will be investigated:

- Rural/suburban scenarios (road with one or more lanes in each direction)
  - Lane Change Warning with RV approaching from behind at an adjacent lane (LCW-1)
  - Blind Spot Warning with RV in a blind spot zone of the HV (BSW-1)
- Highway / Autobahn scenarios (high speed road with multiple lanes for the same direction)
  - Lane Change Warning with RV approaching from behind at an adjacent lane (LCW-2). HV and RV at speeds larger than 100 km/h
  - Blind Spot Warning with RV in a blind spot zone of the HV (BSW-2). HV and RV at speeds larger than 100 km/h

The following variations and parameters can be considered:

- Different high speeds (HV, RV) at the highway
- Different weather conditions (snow, rain, dust, fog, etc.)
- LoS and non-LoS (e.g. curved road)

LCW should warn a driver of the HV intending to change lane when there is a RV in an oncoming lane of travel. Also in this sense, BSW should warn a driver of the HV if there is any RV in its blind spot zone, preventing imminent danger of a crash.

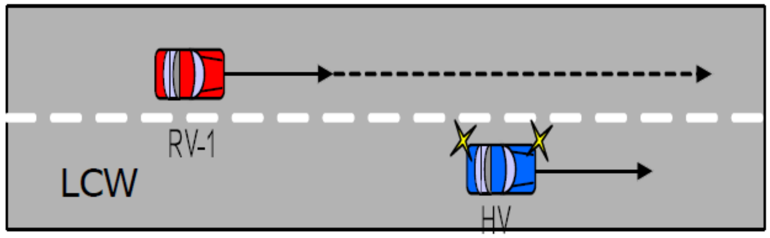

Figure 7.3-1: Lane Change Warning with RV approaching from behind at an adjacent lane (LCW-2)

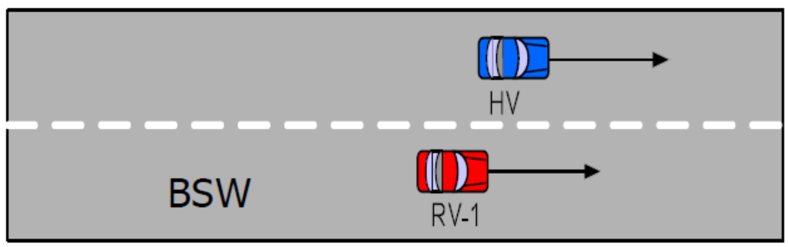

Figure 7.3-2: Blind Spot Warning with RV in the blind zone of the HV (BSW-2)

Figure 7.3-3 illustrates the blind spot zones left and right behind the HV for BSW/LCW with parametrized distance definitions. The blind spot zone is defined as an area which is, or will soon be, occupied by another vehicle traveling in the same direction in the immediate adjacent left or right lane behind the center of the HV, as indicated in Figure 7.3-3.

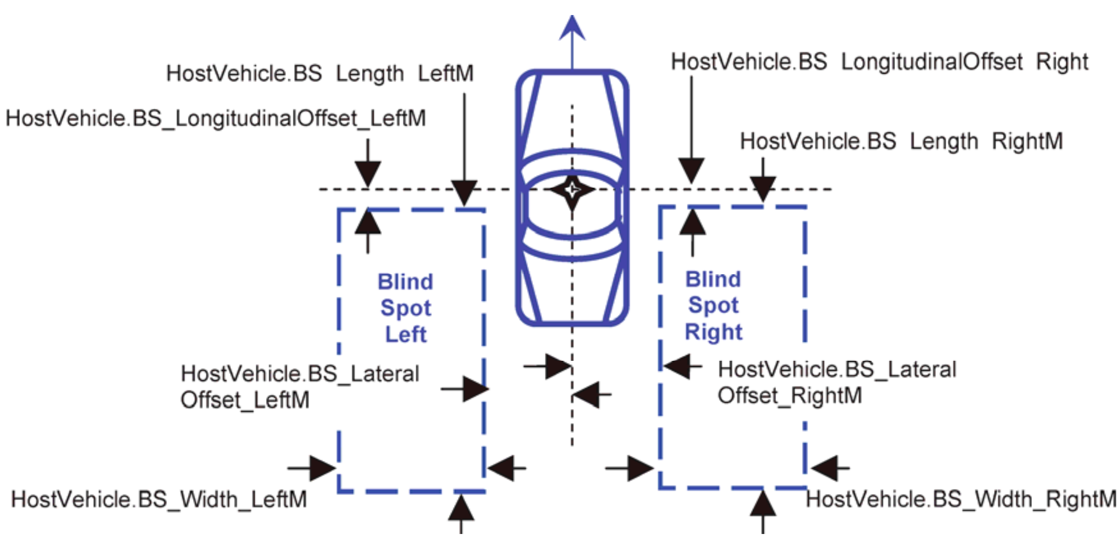

Figure 7.3-3: Blind spot zones for BSW/LCW

7.3.4 Safety Considerations

Blind spot collisions are a permanent threat in today's day to day traffic, especially at high speeds when reaction time may not be enough to prevent accidents. Besides, it is often the case that the HV driver underestimate the speed of an upcoming RV making a not safe lane change. In such situations, the BSW/LCW will provide a significant safety gain to a driver or may be a crucial element in future autonomous driving environments.

C-V2X is expected to provide additional safety gains compared to DSRC due to its superior connectivity, propagation and range characteristics.

7.3.5 Trial Set Up and Requirements

7.3.5.1 Trial Set Up

The demonstration and evaluation of this use case requires two vehicles equipped with C-V2V functionality.

The HV driver is made alerted that there is an in-path RV and can take corrective actions to avoid or mitigate collisions with the RV along the path.

The following variations and parameters can be considered:

- Different speeds (HV, RV)
- Line-of-Sight and Non-Line-of-Sight (e.g. curved road, if this can be safely executed)
- Right- and/or Left-behind RV

7.3.5.2 Communication Requirements

Capability for all concerned vehicles to receive and process V2X co-operative awareness messages (CAM) with basic container and Vehicle High Frequency container (see also next section).

7.3.5.3 Performance Requirements

The following performance requirements are considered for BSW+LCW:

- Minimum speed 10km/h (warnings not needed for very slow or stationary vehicles)
- Relative speeds between RV and HV up-to 200 km/h (assuming RV with max 250 km/h and HV with min. 50 km/h in a highway scenario)
- Blind spot zone length: < 20 m behind the center of the HV
- Bling spot zone width: < 4 m
- Maximum warning latency time: 200 ms. (The maximum warning latency will be the maximum application processing latency plus the maximum application warning status to the driver vehicle interface (DVI))
- BSW+LCW shall dismiss the warning no sooner than three (3) seconds after it is first classified as a threat. BSW+LCW shall dismiss the warning either after the warning times out (defined by DVI module), or after the RV is no longer a threat, whichever lasts longer.
- BSW+LCW shall consider a RV to be a threat if it will soon be in the blind spot zone. If a RV is predicted to be in the blind zone within 5 s (reaction time), that vehicle can be considered for a LCW.
- Distance range of operation: 300 m (> 5 s * 200 km/h). Should be aligned to the range up to when CAM can be received at a certain signal quality larger than a given reference

receiver sensitivity level, e.g. >-92 dBm @ packet error rate PER=10% (where the applicable receiver sensitivity level is to be defined)

- Minimum frequency of V2V co-operation awareness message: 10 Hz (determines the position accuracy of the RVs)
- The absolute position shall be accurate enough to support safety applications requiring lane-level accuracy. The accuracy requirement is based on the minimum Federal Highway Administration (FHWA) recommended width (3.0 meters) of any roadway equal to or wider than a collector roadway. According to SAE J2945/1, a 68% circular error probability (CEP) accuracy requirement under Open Sky Test Conditions should result in 95% confidence for relative positioning with lane-level granularity (to be confirmed)
- Vehicles relative positioning accuracy: <5m (<100 ms * 200 km/s = 5.5 m) with circular error probability CEP = 95% under Open-Sky Test Condition (to be confirmed)

7.3.6 Procedures

A BSW/LCW use case is triggered after an application processor detects the risk of collision for an intended lane change after computing the received CAM of RVs and the path of travel of HV. In that case, the driver will be alerted. Warnings can be realized in form of visual alerts on dashboard screen and/or sound notifications. The diagram below illustrates this flow.

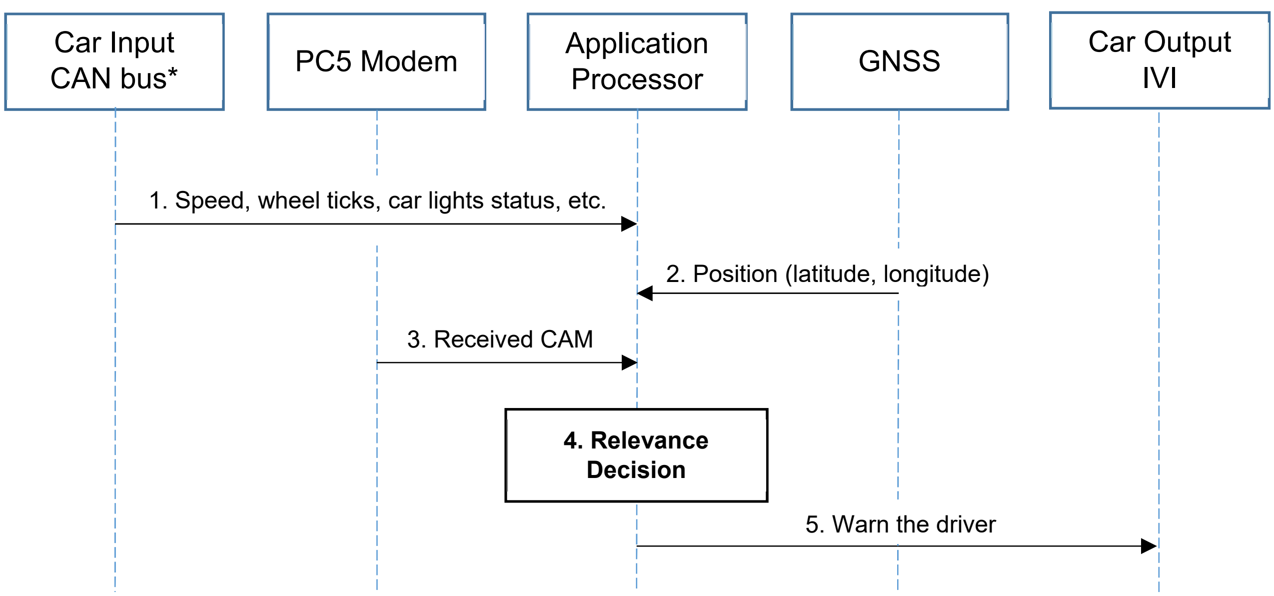

Figure 7.3-4: Sequence Diagram – HV ****or other physical I/F***

1) The speed and direction of movement of HV are constantly been fed into the application processor. Other parameters such as the car light status can also be included. Here the activation of the left/right indicator light can be used as a trigger point of the LCW use case.
2) The position (latitude and longitude) is also fed into the application processor at frequency of 10 Hz (to be confirmed).

3) CAMs from all RVs are received. CAM from vehicles contain the following mandatory fields:
   - Heading,
   - Speed,
   - Drive Direction,
   - Vehicle Length,
   - Vehicle Width,
   - Longitudinal Acceleration,
   - Curvature,
   - Yaw Rate,
   - Vehicle Latitude and Vehicle Longitude,
   - Position Accuracy
   - Timestamp,
   - Vehicle path history
   - Vehicle path prediction
   - Acceleration (lateral, longitudinal, vertical)
   - Steering wheel angle
   - Etc.

NOTE: steps 1, 2 and 3 can happen in any order.

4) The **Relevance Decision** procedure is part of an algorithm that considers the inputs from steps 1,2 and 3 and evaluates the position of each RV relative to the HV to determine if that RV is currently positioned within the HV's left or right blind-spot zone or if that RV will be soon positioned within the HV's left or right blind-spot zone for each RV that has been classified as behind left or behind right.

The threat status is set corresponding to each side (left and right) to inform if an RV is determined to be located in the corresponding left or right blind-spot zone and the HV is moving forward at a speed above a configurable threshold and if HV's left or right turn signal is active. Distance, speed, lane position, trajectory and light indicators are some of the variables taken into account for risk analysis.

5) If the Relevance Decision of the threat status is positive, the driver will be warned.

7.3.7 Measurements

In order to characterize the system and evaluate the performance, some measurements shall be made:

- Timestamps and GNSS coordinates of emitted CAMs of the RV (relevant for the warning)
- Timestamp when CAM is received by HV
- Timestamp when the warning is emitted to driver
- Calculation of distance between RV and HV, when CAM relevant for warning is emitted
- Absolute and relative speeds of RV and HV (from CAM)
- For Packet loss evaluation, number of packets sent from RV and received by HV

Furthermore, it should be evaluated if the warning was correctly triggered (no false alarm) as well as whether the first relevant CAM message was timely received.

Potential false alarms can include

- Remote Vehicle below Minimum Operational Speed
    - BSW+LCW shall not issue a warning for a RV that has a current speed lower than 10 km/h.
- Remote Vehicle not in Blind Spot Zone
    - BSW+LCW shall not issue a warning in regard to a vehicle that is outside of the blind spot zones, except for vehicles that are predicted to enter the blind zone within 5 seconds.
- Remote Vehicle not in the Same Travel Direction
    - BSW+LCW shall not issue a warning for a RV that is inside the blind spot zone but not traveling in the same direction.
- Incorrect Lane Classification of a BSW+LCW Threat
    - BSW+LCW shall not issue a warning when the threat vehicle is traveling in the same lane. BSW+LCW shall not issue a left-lane warning when the threat vehicle is traveling in the right blind spot, and vice versa.

NOTE: lower layer measurements for e.g. RF conditions (receive level, interference) etc. shall also be taken. Potentially additional metrics and measurements might be added according to the needs arising during the trial.

7.3.8 Expected Outcome

Prove that BSW/LCW is reliably working under all tested conditions.

Potential performance advantages versus DSRC are expected for range, specifically in non-Line-of-Sight scenarios, which might also translate into higher reliability or a higher speed range.

7.4 Do Not Pass Warning (DNPW)

7.4.1 General Description

The Do Not Pass Warning (DNPW) application is intended to warn the driver of the Host Vehicle (HV) during a passing maneuver attempt when a slower moving Remote Vehicle (RV), ahead and in the same lane, cannot be safely passed using a passing zone which is occupied by opposite lane vehicles (OLRV) in the opposite direction of travel. In addition, the application provides advisory information that is intended to inform the driver of the vehicle that the passing zone is occupied when a vehicle is ahead and in the same lane even if a passing maneuver is not being attempted.

7.4.2 Objective

This use case will demonstrate that a Host Vehicle (HV), that would like to overtake, gets warnings in sufficient time in case an Opposite Lane Remote Vehicle (OLRV) is too close, i.e., would occupy the needed space for overtaking at the corresponding time. The warning could, e.g., be displayed when the left indicator of the HV is operated. There will be no warning when the distance is sufficient.

The need for the warning would vary with the velocities of the vehicles involved in the scenario (higher speeds – higher distances needed), so the Use Case should be tested with different speeds and distances, and the result of Warning/no Warning compared with the theoretical calculation.

7.4.3 Description of Relevant Scenarios to Investigate

The following traffic scenarios of the DNPW use case illustrated in Figure 7.4-1 will be investigated:

- Rural/suburban scenarios (road with one lane in each direction)
    - HV in same lane as RV when OLRV (i.e. the approaching opposite lane RV) is approaching (DNPW-1)

The application is primarily targeting **rural overland road sections.** Speeds up to 100 km/h are envisioned. As partly mentioned following variations can be considered:

- Different speeds (HV, RV, OLRV)
- Line-of-Sight and No-Line-of-Sight (if this can be safely executed)
- Different road and weather conditions (snow, rain, dust, fog, etc.)

The DNPW feature will issue a warning if any portion of the vehicle within a lane adjacent to the DNPW-equipped vehicle is in the passing zone. At this moment, any cancellation of a started passing maneuver is not considered, a maneuver shall only be executed if it is safe to do.

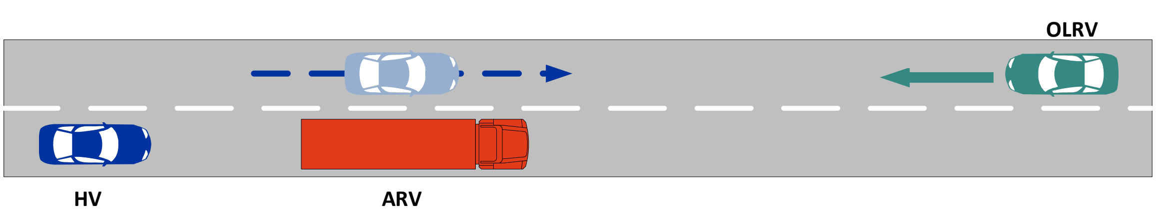

Figure 7.4-1: DNPW alerts drivers of vehicles (HV) not to pass a lower speed vehicle (ARV) if another vehicle (ORLV) is in the DNPW zone (DNPW-1)

Figure 7.4-2 illustrates the listed scenario in more detail. The HV driving at speed v1 is approaching a slower truck ARV (Ahead RV) running at speed v2 on the same lane in the same direction of travel.

The driver of HV wants to safely overtake ARV free of any hazardous maneuver involving OLRV on the opposite lane driving in the opposite path of travel at speed v3. Relevant locations of the potential maneuver defining distances between key events are denoted as H, A, C, D, B, R in the order from left to right with the following meaning:

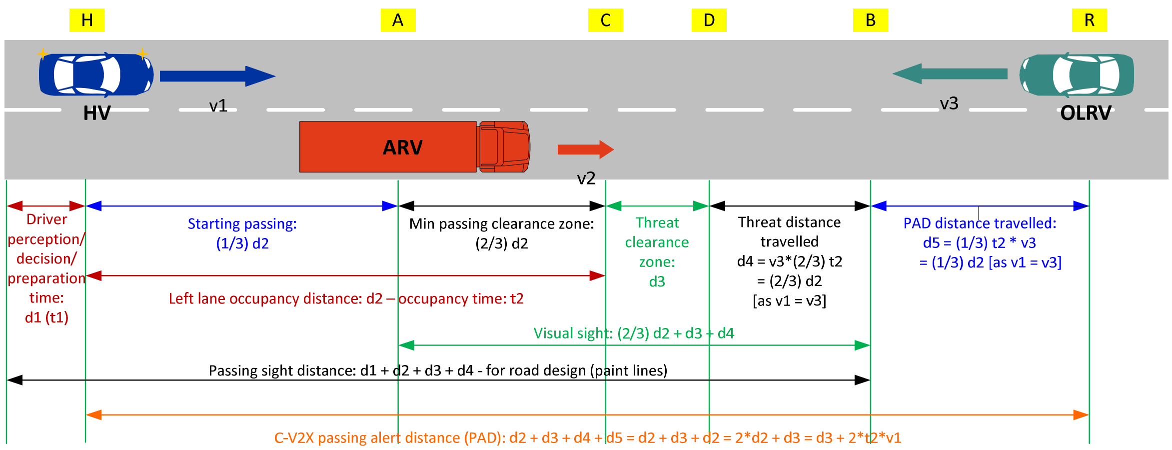

Figure 7.4-2: Relevant distances when HV in same lane as (A)RV and OLRV is approaching (DNPW-1)

- "H": Position of HV when starting the overtake maneuver and leaving its original lane
- "A": Current position of ARV and target position when HV is fully occupying the opposite lane
- "C": Target location of HV back to its original lane dedicated for its path of travel
- "D": Position of OLRV keeping the (adjustable) minimum "Threat clearance zone" *d3* when HV is at position C
- "B": Location of OLRV when having travelled the Passing Alert Distance (PAD) at its current speed *v3* from position R
- "R": Position of OLRV when HV has reached position H

Using above locations the following distances can be defined, again from left to right:

- *d1*: Distance HV has travelled at *v1* between driver decision and start of the overtake at H (preparation time / distance)
- *d2*: Left (opposite) lane occupancy distance as the difference C – A, i.e., the distance when HV is just entering the left (opposite) lane and leaving that lane again after the overtake maneuver
- *d3*: Threat clearance zone as the minimal tolerated (adjustable) distance or zone identified as the safety distance avoiding a collision of HV and OLRV
- *d4*: Threat distance travelled as the distance travelled by OLRV at speed *v3* when HV at speed *v1* has overtaken ARV at speed *v2* between positions A and C
- *d5*: PAD as the Passing Alert Distance which is the difference R – B that OLRV has travelled driving at *v3* in the time HV has passed the distance *d2*
- Some additional distances as sum of above basic distances are used and defined in the above figure

DNPW in the HV performs the following operations:

- Analyzes received CAM messages from the RV oncoming to the HV, among others with information about speed (*v3*), potentially acceleration (speeding up or braking) and current position and direction of travel.
- (If the ARV was also equipped with C-V2V functionality, the DNPW would additionally also consider CAM messaged from the ARV, e.g., about length of ARV, driving speed *v2* and potentially (de-) acceleration – see below.)
- Calculates the above listed distances *d1, d2, d3, d4, d5* based on all relevant information available.
- Determines whether under current conditions the threat clearance zone *d3* would keep an adjustable or pre-defined value above a minimum threshold.
- Identifies the principal hazard, if at least one RV is determined to be a threat for a collision.
- Provides a warning to the driver via a Driver Vehicular Interface (DVI) in case the overtaking maneuver would not the considered safe in case the driver of HV has activated the turn signal indicator.
- In case of additional sensors or infrastructure/broadcast information (DENM messages, e.g., road and weather conditions) and respective inputs the IMA could also take road and weather conditions into account which will impact acceleration performance and hazardous zones.

Mandatory C-V2V functionality in OLRV performs the following support of DNPW:

- Sends CAM messages toward HV about its current position, speed *v3*, potentially acceleration, and path of travel.

Optional C-V2V functionality in ARV may perform the following support of DNPW:

- Sends CAM messages toward HV about its current position, speed *v2*, potentially acceleration, and path of travel.

Especially for no-line-of-sight scenarios and high speeds, using V2N communication for message dissemination might be beneficial due to extended reach for high reliability, given that all involved communication endpoints are in coverage of a mobile network.

7.4.4 Safety Considerations

Collision hazards during overtake maneuvers especially in rural scenarios are a permanent threat in today’s day to day traffic. This holds the more if traffic conditions are tempting, if road paths are confusing, obstructed by other vehicles or road works, or the road and sight conditions at the intended maneuver are impacted by unfavorable weather situations such as snow, hale, fog or rain. In such situations, the DNPW will provide a significant safety gain to a driver or may be a crucial element in future autonomous driving environments.

C-V2X is expected to provide additional safety gains compared to DSRC due to its superior connectivity, propagation and range characteristics, especially in NLOS conditions. Early warning of the tentatively overtaking driver in such situations can clearly reduce collision hazards. The extended range of C-V2X will mark a significant safety factor in C-V2X based systems.

Depending on the verified/measured communication ranges, a maximum supported speed can be derived (and potentially show cased). Furthermore, for in-coverage situations, the cellular network can be used for even further extending the communication range.

7.4.5 Trial Set Up and Requirements

7.4.5.1 Advanced Trial Set Up

The demonstration and evaluation of this use case requires three vehicles (HV, ARV, OLRV), at minimum two C-V2V vehicles (HV, OLRV) equipped with DNPW and C-V2V support, respectively; the third vehicle (ARV) to overtake (car, truck) may not necessarily need to be equipped with C-V2X or DNPW functionality.

The HV driver is securely alerted about meeting vehicle ORLV in the path of intended travel and can take corrective actions to avoid or mitigate collisions with the OLRV in the forward path of travel. In the tested setup, all vehicles will run with their original (constant) speeds, *v1*, *v2*, *v3*, respectively. No acceleration scenarios will be tested.

Preferably this scenario would be tested on a closed road/track or a rural road with three lanes (e.g., B2 south of Nuremberg). Ideally, the closed track or public road layout would avoid any potential collision of cars as shown in Figure 7.4-3.

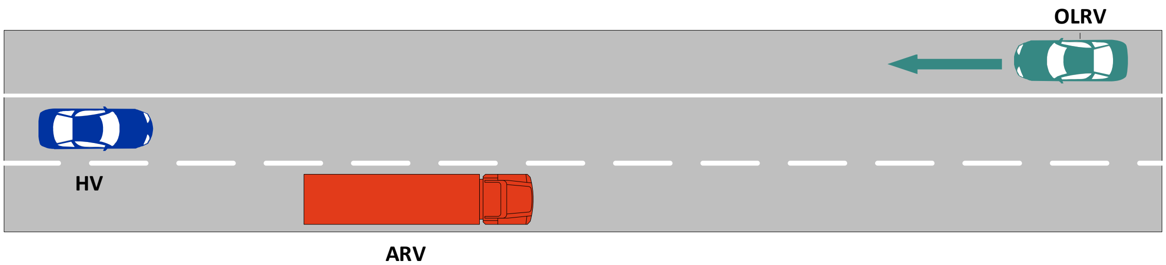

Figure 7.4-3: Intended advanced deployment/test scenario

If such closed tracks or public roads should not be feasible for a real drive test any maneuver would just be virtually indicated following above descriptions but never executed and thus would avoid any hazard or even collision. Still the test would require proper coordination between all involved cars to minimize the efforts for the execution. For this purpose, potential tracks should be evaluated beforehand in due time. During actual execution, all cars should be staffed with a driver focusing on safe driving only and one more engineer in each car coordinating the test activity via mobile continuous communication (using public mobile communication).

7.4.5.2 Reduced Trial Set Up

If the advanced trial setup described in the previous section would still appear too complex to be reliably and iteratively executed, the following simplified setup can be used to evaluate some basic performance characteristics in the DNPW use case.

Figure 7.4-4: Alternative reduced deployment/test scenario

As shown in Figure 7.4-4 no overtake car (truck) would be involved and no overtake maneuver would be executed. The two cars HW and OLRV would be approaching each other on a closed track or empty road. Respective car positions (e.g., from GNSS) would be constantly logged. Also, all messages and information as explained in section 7.4.6 would be logged. Car HV would indicate an intended but faked overtake maneuver (e.g., by setting the lane indicator) and the respective outcome of the action will be logged following the descriptions in section 7.4.6. For example, if the distance is large enough allowing a safe overtake maneuver the actual distance would be evaluated based on such logged position and event information. The test can be repeated at different speeds and distances in order to evaluate the distance and speed performance of the DNPW use case with C-V2V communication. It could be also described as speed dependent discovery procedure of HV detecting and identifying OLRV.

7.4.5.3 Communication Requirements

Respective communication between the different entities requires the capability for all concerned vehicles to transmit (OLRV, ARV) or receive (HV) and process V2X co-operative awareness messages (CAM). CAM messages [2], [5] will be used with basic container and vehicle high frequency container (see also next sections).

7.4.5.4 Performance Requirements

The following performance requirements are considered for HV, ARV and OLRV:

- Rural road scenario with speeds between 40 km/h and up to 100 km/h;
- ARV with lower speed of minimum difference 20 km/h compared to HV (and OLRV); for simplicity of test and calculations HV and OLRV travel with same speed in opposite directions;
- The following calculation applies for the distance/stretch of the road needed: $d2 = Lg * v1 / (v2 - v1)$, where Lg is the aggregated car lengths of HV and ARV including clearance zones (i.e., security distances which follow the general rule of ½ of the speed in km/h expressed as distance in meters; e.g., 100 km/h will require a security distance of 50 m). In case OLRV is approaching with the same speed $v3=v1$, the total distance or passing alert distance (PAD) including the threat clearance zone $d3$ will be $PAD = 2\ d2 + d3$;

  Table 7.4-1 shows a few example calculations for the PAD.

Table 7.4-1: Examples for Distances PAD

Example	Parameter	HV/OLRV	ARV	PAD [m]
1	Length [m]	5	20	1250
	Speed *v1* (*v3*) [km/h]	100	80	
	Security distance before [m]	50		
	Security distance after [m]	40		
	Threat clearance *d3* [m]	100		
2	Length [m]	5	20	625
	Speed *v1* (*v3*) [km/h]	100	60	
	Security distance before [m]	50		
	Security distance after [m]	30		
	Threat clearance *d3* [m]	100		
3	Length [m]	5	20	840
	Speed *v1* (*v3*) [km/h]	80	60	
	Security distance before [m]	40		
	Security distance after [m]	30		
	Threat clearance *d3* [m]	80		
4	Length [m]	5	20	560
	Speed *v1* (*v3*) [km/h]	80	50	
	Security distance before [m]	40		
	Security distance after [m]	25		
	Threat clearance *d3* [m]	80		
5[1]	Length [m]	5	20	1485
	Speed *v1* (*v3*) [km/h]	110	90	
	Security distance before [m]	55		
	Security distance after [m]	45		
	Threat clearance *d3* [m]	110		

In general, a maximum stretch of the rural road of 1.5 km would be requested if the typical "maximum" German rural road overtaking scenario should be demonstrated.

- Maximum distance range of operation (here: 1250 m): Need to be aligned to the range up to where CAM can be received at a certain signal quality larger than a given reference receiver sensitivity level, e.g., >-92 dBm @ packet error rate PER = 10% (where the applicable receiver sensitivity level is to be defined);
- Any coverage limitation may reduce above maximum parameters, especially the maximum allowable driving speed $v1 = v3$. The table above gives some indication about other potential parameter sets;
- Minimum frequency of V2V co-operation awareness message: 10 Hz (determines the position accuracy of the vehicles);
- The absolute position shall be accurate enough to support safety applications requiring lane-level accuracy as detailed in the respective section (e.g., the accuracy requirement could be

[1] Example 5 is listed for additional information purpose.

based on the minimum Federal Highway Administration (FHWA) recommended width (3.0 m) of any roadway equal to or wider than a collector roadway. Per SAE J2945/1, a 68% circular error probability (CEP) accuracy requirement under Open Sky Test Conditions should result in 95% confidence for relative positioning with lane-level granularity);

- Vehicles relative positioning accuracy: as outlined in the respective requirement section (e.g., <~3 m [<100 ms * 100 km/h = 2.8 m] with circular error probability CEP=95% under Open-Sky Test Condition);

7.4.6 Procedures

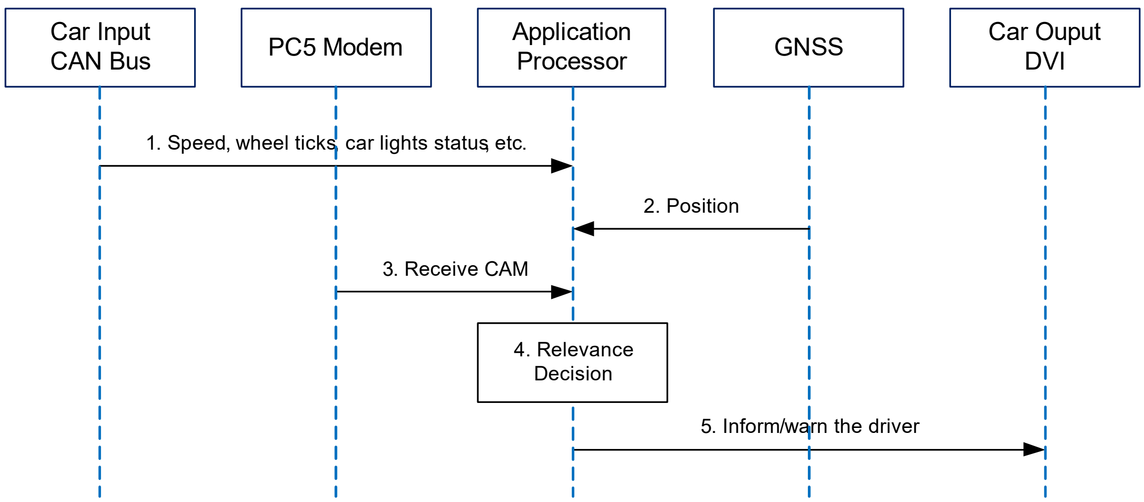

Figure 7.4-5 shows the decision sequence diagram of the overtaking vehicle HV:

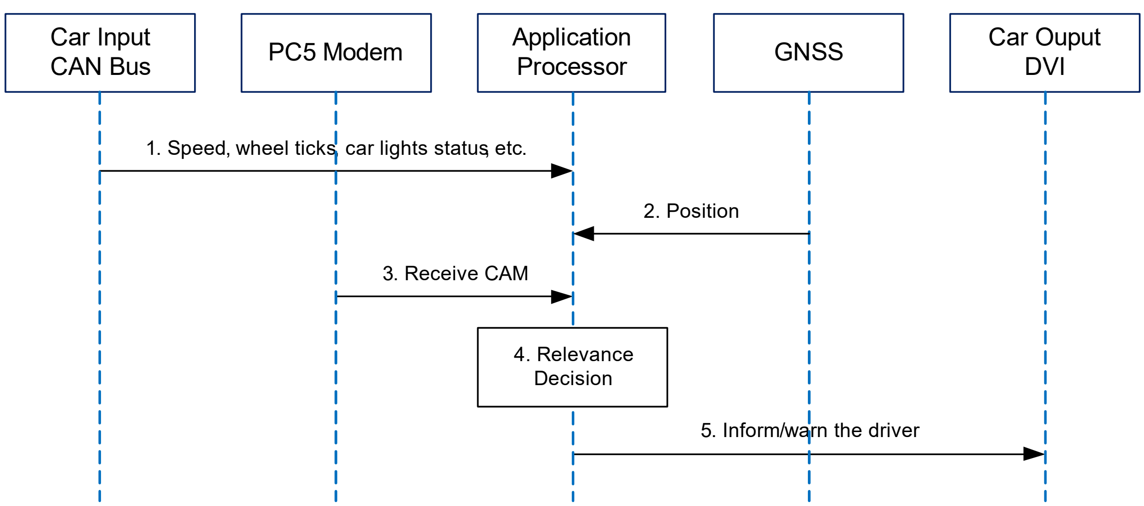

Figure 7.4-5: Sequence Diagram HV

1) The speed and direction of movement of HV are constantly been fed into the application processor. Other parameters such as the car light status, lane indicator status, etc. can also be included.

2) The position is also fed into the application processor at frequency of 10 Hz.
3) CAMs from RVs in vicinity and coverage of C-V2X are received. CAM from vehicles contain the following mandatory fields:
    - Heading;
    - Speed;
    - Drive Direction;
    - Vehicle Length;
    - Vehicle Width;
    - Longitudinal Acceleration;
    - Curvature;
    - Yaw Rate;
    - Vehicle Latitude and Vehicle Longitude;
    - Timestamp;
    - Etc.

NOTE: steps 1, 2 and 3 can happen in any order.

4) The **Relevance Decision** procedure is part of an algorithm that considers the inputs from steps 1, 2 and 3 and evaluates danger of collision during a potential overtaking maneuver. Distance, speed, lane position and trajectory of OLRV and potentially ARV are some of the variables to be considered for risk analysis.
5) In case CAM messages from ORLV are securely received or no such messages are received within the PAD, and in either case are properly analyzed, the following Relevance Decision messages can be issued to the driver of HV depending on the outcome:
    a. Issue a "DNPW"-alert that an overtake maneuver cannot be safely executed (since OLRV detected within reliable range of operation);
    b. Issue a clearance message (including a safety precaution notice) that at current speed an overtake maneuver can be executed although an ORLV is approaching; usual driver's responsibility for such a maneuver still apply;

In case no such message is received the following information can be displayed to the driver of HV:

c. No OLRV has been detected within the reliable range of C-V2X coverage. An overtake maneuver maybe executed at the driver's full responsibility applying the usual driver precaution needs;

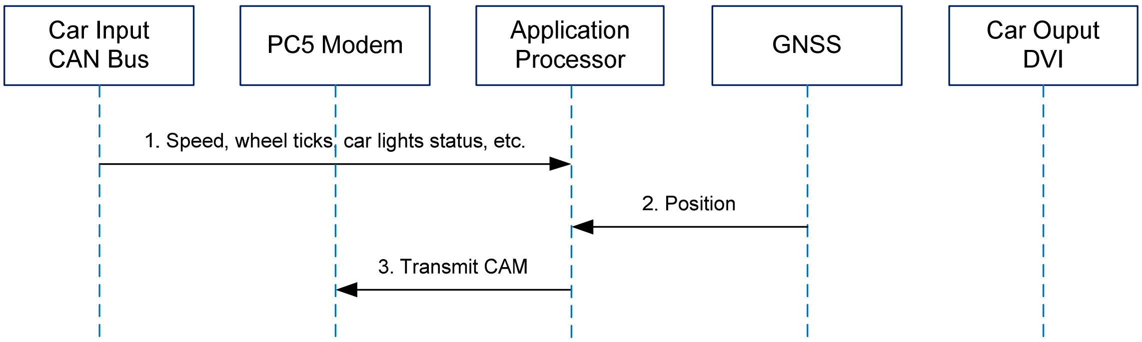

Figure 7.4-6 shows the transmission sequence diagram of the approaching vehicle OLRV and potentially the overtaken vehicle ARV:

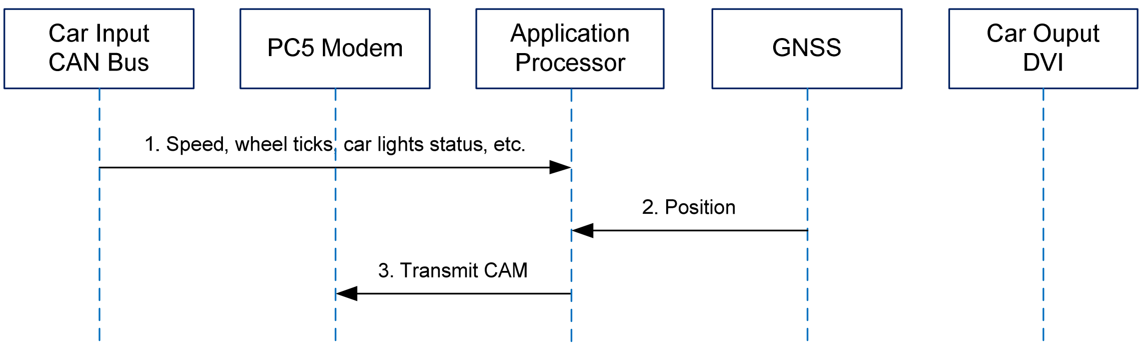

Figure 7.4-6: Sequence Diagram OLRV / ARV

1. The speed and direction of movement of OLRV/ARV are constantly been fed into the application processor. Other parameters such as the yaw information, car light status, lane indicator status, etc. may also be included.
2. The position from the GNSS receiver is also fed into the application processor at frequency of 10 Hz.
3. CAMs from OLRV/ARV are constantly transmitted at a frequency of 10 Hz. CAM from such vehicles contain the following mandatory fields:
   - Heading;
   - Speed;
   - Drive Direction;
   - Vehicle Length;
   - Vehicle Width;
   - Longitudinal Acceleration;
   - Curvature;
   - Yaw Rate;
   - Vehicle Latitude and Vehicle Longitude;
   - Timestamp;

- Etc.

NOTE: steps 1, 2 and 3 can happen in any order.

7.4.7 Measurements

In order to evaluate the performance, at minimum the following timestamped measurements shall be made:

At HV:

- Any incoming CAM from ORLV/ARV is detected and received;
- Any message to the driver is emitted;
- Number of packets sent and received;
- Position (e.g., WGS84);
- Speed;
- Other relevant info;

At OLRV/ARV:

- Any transmitted CAM message sent by OLRV/ARV;
- Other relevant events generated by OLRV/ARV;

NOTE: additional metrics and measurements may still be part of further investigations and discussion.

7.4.8 Expected Outcome

At minimum, the maximum allowable coverage range of CAM messages via C-V2V allowing the required PER performance will be explored and evaluated (Reduced Test Setup in section 7.4.5.2) proofing the expected higher maximum distance and/or speeds that can be covered by C-V2X compared to competitor solutions.

Preferably, virtual overtaking maneuvers as outlined in section 7.4.5.1 (Advanced Trial Set Up) would be “emulated” and executed including the respective messages displayed to the driver of HV.

Under all circumstances, safety of involved people and equipment has absolute priority and any damage must be avoided.

7.5 Emergency Electronic Brake Lights (EEBL)

7.5.1 General Description

The Emergency Electronic Brake Light (EEBL) application enables a vehicle to broadcast a self-generated emergency brake event to surrounding vehicles. Upon receiving the event information, the receiving vehicle determines the relevance of the event and if appropriate provides a warning to the driver in order to avoid a crash. This application is particularly useful when the driver's line of sight is obstructed by other vehicles or due to bad weather conditions (e.g., fog, heavy rain).

7.5.2 Objective

This use case will demonstrate that an HV can be warned sufficiently early of any sudden strong braking event triggered by an RV due to an unexpected dangerous event such as e.g. an accident, an obstacle on the roadway, a jam or slow traffic after a roadway slope.

7.5.3 Description of relevant scenarios to investigate

The following traffic scenarios for the present use case will be investigated:

Highway scenarios (to be trialed in the A9 test field):

Figure 7.5-1 shows a highway scenario with a host vehicle HV and two remote vehicles RV1 and RV2. RV1 drives in the same lane as HV. If RV1 brakes hard, the HV should receive a warning message if it is located within a distance $D < D_w$ behind RV1. The applicable warning Distance threshold D_w may be determined at the HV depending in its own speed v_{HV}. The driver of RV2 however should not be alerted since RV2 is driving in a different lane.

Figure 7.5-2 shows a highway scenario where the remote vehicle RV1 is braking mildly with deceleration less than the threshold b_{th}. In this case RV1 should not send a warning message.

The strength of the brake event can be determined in terms of the vehicle deceleration measured in m/s^2. A threshold b_{th} on deceleration strength can be used to differentiate a hard brake event from a mild brake event which should not trigger a warning message by the HV.

The threshold b_{th} can be defined as a fraction of gravity acceleration g = 9.81 m/s^2, e.g. $b_{th} = 0.5g$. The optimal threshold value should be determined in the field tests.

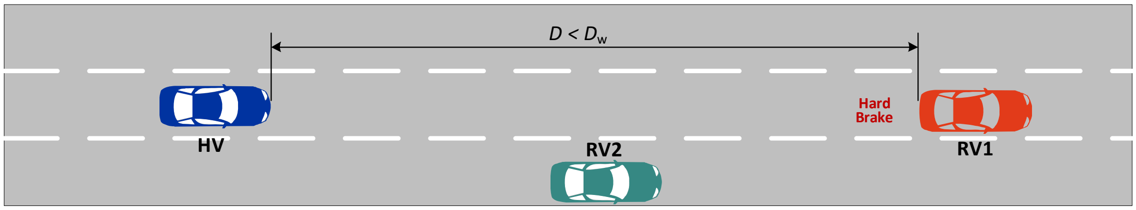

Figure 7.5-1: Highway scenario EEBL-1; RV1 braking hard, HV in the same lane to be alerted

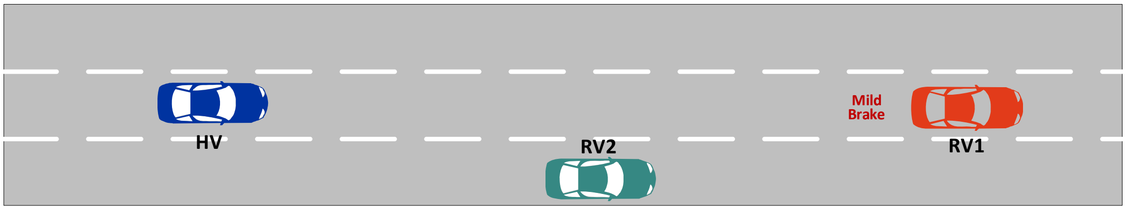

Figure 7.5-2: Highway scenario EEBL-2; RV1 braking mild, not sending a warning message

Rural scenarios:

Figure 7.5-3 shows a scenario on a rural road where the sight between HV and RV1 may be blocked due to a turn of the road. Figure 7.5-4 illustrates a scenario where the sight between a considered HV1 is blocked by another vehicle HV2. Provided HV2 is also equipped with V2X functionality it will also receive a warning message.

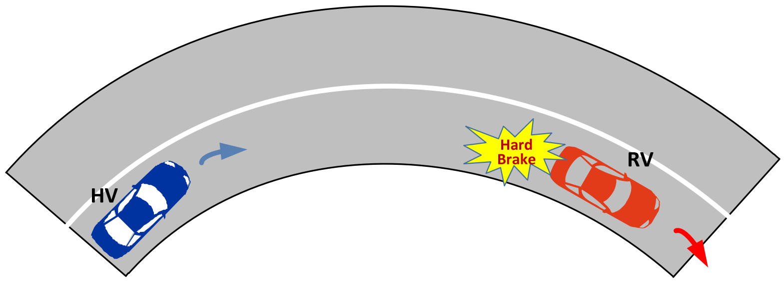

Figure 7.5-3: Rural road scenario: RV braking hard, sending a warning message

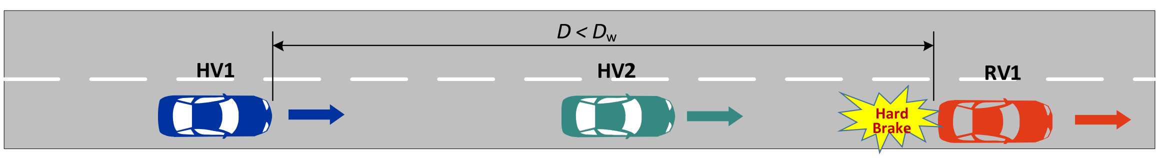

Figure 7.5-4: Rural road scenario: RV braking hard, sending a warning message

There are no principal functional differences for the EEBL use case between highway and rural scenarios. The EEBL feature warns the driver of the HV in the case of a hard-braking event by an RV that is ahead and in the same lane. In a multilane highway scenario, a warning may also be indicated to a HV driving in an adjacent lane, especially to the right of the RV.

In order to enable lane identification, the HV application must be able to differentiate between relevant RV zones. The relevant RV zones for the EEBL feature are illustrated in Figure 7.5-5. The EEBL feature is expected to function in both straight and curved roadway geometries, as illustrated in the figures above.

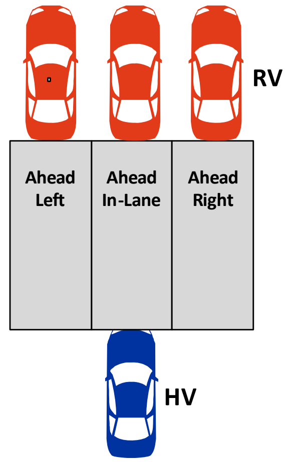

Figure 7.5-5: Illustration of RV zones from HV perspective

EEBL performs the following operations:

- The RV includes a hard-braking event in the broadcasted DENM during a hard-braking maneuver. Upon receiving such event information, the HV performs the following operations:
    - Determines which, if any, RVs have reported a hard-braking event.
    - For each RV that has reported a hard-braking event and is classified as "ahead in-lane," "ahead left," or "ahead right," determines if the distance between the vehicles is less than an implementation-specific threshold value.
    - Calculates the EEBL threat levels among all RVs identified above, determines the principal threat, and sets the appropriate threat status.
    - Provides a warning to the driver via a Digital Visual Interface (DVI), when appropriate.

7.5.4 Safety Considerations

EEBL represents an electronic implementation of combined actuation of brake lights and warning (blinking turn) lights. Especially if the line of sight between HV and RV is blocked, e.g. due to other vehicles, extreme weather conditions or roadway conditions (turns or rises) EEBL can be more effective than conventional warning-light based solutions. In the long-term perspective, EEBL can be regarded as an important component of an automated driving system where the speed of the HV is automatically decreased in case of receiving EEBL notifications from a relevant RV.

The main advantage of EEBL is achieved by saving of reaction time especially when several vehicles are moving in a row. For instance, in the scenario illustrated in Figure 7.5-4 where the sight between vehicles HV1 and RV is blocked by a third vehicle (HV2), the driver of HV1 would be alerted only after the reaction time of HV2, which in practical scenarios may be up to 4 seconds, depending on the mental conditions of the driver. Each additional vehicle between HV1 and RV adds another significant amount to the reaction time. The saving in reaction time is offset by the signaling delay and processing time until the warning message shows up at HV1. If this latency can be limited to around 200 ms, there is still substantial gain compared to the possibly accumulated reaction time.

Since heavy trucks have roughly 3 times the braking distance of a normal car and can do a lot of damage, the trial implementation should be extended for long-range communication, targeting such vehicles, e.g. using C-V2N functionality. Additionally, this would help in the prevention of shockwave propagation.

7.5.5 Trial set up and requirements

7.5.5.1 Trial set up

The demonstration and evaluation of this use case requires two vehicles equipped with C-V2V functionality. C-V2I and C-V2N functionality is not needed for this trial. A third vehicle (not necessarily equipped with C-V2V functionality) will be required to demonstrate scenarios where the sight between HV and RV is blocked as shown in Figure 7.5-4.

The HV driver is made alerted that there is an in-path vehicle and can take corrective actions to avoid or mitigate rear-end vehicle collisions in the forward path of travel.

The warning shall be issued as soon as the HV detects that the RV's deceleration exceeds the HV's pre-defined threshold. The HV driver receives the warning on the dashboard in form of a pre-defined icon and message together with an acoustic warning beep.

EEBL shall dismiss the warning once the threat vehicle's hard braking status is alleviated. The warning shall be suppressed if the driver of the HV is pressing the brakes at the time of the alert.

7.5.5.2 Communication requirements

The HV must be capable to create both the standard CAM and the special EEBL DENM messages. The application must be able to differentiate hard and mild brake events and to decide autonomously whether or not transmission of EEBL messages is required depending on available information about distance, driving direction and lane zone of C-V2X capable surrounding vehicles.

7.5.5.3 Performance requirements

Sending EEBL warning messages is most useful and effective in scenarios where two or more vehicles are driving at the recommended safety distance in meters equal to half the reading of vehicle speed in km/h (i.e. 100 km/h → 50 m recommended safety distance in rural traffic scenarios). The scenario becomes more critical if this recommended safety distance is undercut, and less critical, when the distance between the cars is larger.

For mathematical assessment of the vehicle movement we use the notation given in Table 7.5-1.

Table 7.5-1: Variables of vehicle movement

Variable / Parameter	Symbol
velocity (vehicle speed)	v
travelling/brake distance (displacement)	s
elapsed time	t
absolute value of acceleration or deceleration	a
distance between vehicles	d
reaction time	t_R
stopping time	t_S

For the variables defined in Table 7.5-1, the relations given in Table 7.5-2 apply.

Table 7.5-2: Relations applicable to vehicle movement

Ref.	Description	Formula
(1)	displacement at constant speed v_0	$s(t) = v_0 \cdot t$
(2)	displacement at constant deceleration a	$s(t) = 0.5\ a \cdot t^2, \quad 0 \le t(v = 0) \le t_S$, where $t_S = t(v = 0)$ = stopping time
(3)	velocity as function of time at constant deceleration	$v(t) = v_0 - a \cdot t$
(4)	stopping time for initial velocity v_0	$0 = v_0 - a \cdot t_S \rightarrow t_S = v_0/a$
(5)	stopping distance for initial velocity v_0	$s(t_S) = 0.5\ a \cdot t_S{}^2 = v_0^2 / (2 \cdot a)$

Two car scenario:

Consider two cars driving in the same lane at initial speed v_0 and at an initial distance of d_0 as illustrated in Figure 7.5-1 The RV driving in front brakes hard at $t_0 = 0$.

Assuming full emergency deceleration of $a = 10$ m/s^2 and an initial vehicle speed of $v_0 = 100$ km/h = 27.78 m/s, equations (4) and (5) of Table 7.5-2 yield stopping time and distance of $t_S = 2.78$ s and $s_2(t_S) = 38.58$ m for the RV.

If the HV does not react with braking itself within time interval t_S, it would travel at constant speed v_0 a distance of $s_1(t_S) = 2s_2 = 77.16$ m. Accordingly, the distance between HV and RV at t_S reduces to $d_1 = d_0 - s_1 + s_2 = d_0 - s_2 = d_0 - 38.58$ m. This means a rear-end collision is unavoidable for a reaction time of $t_R \ge t_S$ of the HV when the initial distance at brake $d_0 \le s_2$ (38.58 m). The term reaction time is assumed to cover the time required by the vehicle driver (sensation, perception/recognition, reaction) to push the brake as well as the brake engagement latency.

The warning distance threshold D_{th} should give HV1 sufficient time to stop safely when receiving an EEBL warning message. Assuming a highway scenario with maximum vehicle speed of $v = 250$ km/h (69.44 m/s), reaction time $t_R = 2$ s and moderate deceleration of $a = 0.6g$ results in an overall stopping distance of $\approx 140 + 400$ m = 540 m. The distance threshold D_{th} should be chosen in this order, depending on the vehicle speed. The range of V2X signal reception should be chosen to cover the worst case brake distance which according to the calculation above could be up to 540 m.

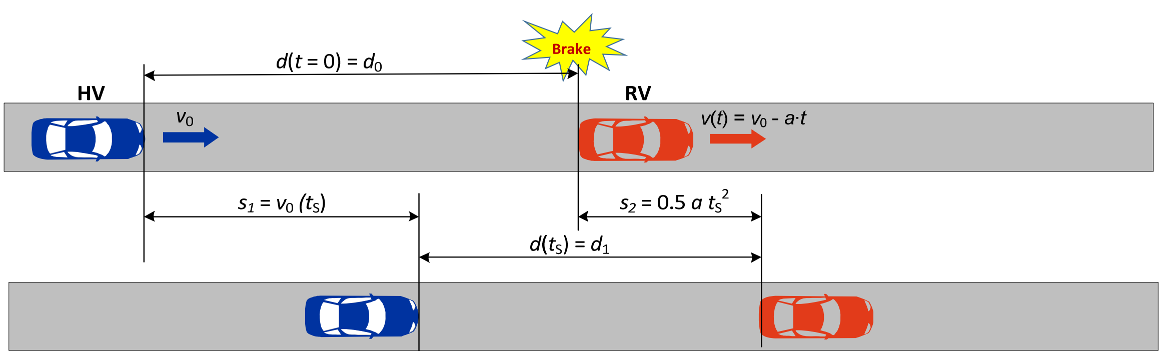

Figure 7.5-6: Evaluation of two car scenario

Multiple car scenario:

If multiple cars are driving in a convoy (as shown for three cars in Figure 7.5-4), the EEBL warning can be indicated directly to vehicles driving further behind the RV and whose sight to the RV might therefore be impaired. In this case the reaction time of the drivers of the intermediate cars is saved for the considered HV. The range requirement applicable to the two car scenario applies in a convoy scenario as well since, the brake distance required by each individual car in the convoy to stop safely does not change compared to the two car scenario.

7.5.6 Procedures

The EEBL use case is triggered at the RV side when a Hard Braking event occurs. The RV sends a DENM warning message which is received by the HV. The application of the HV checks the relevance of this message and alerts the driver in case of given relevance.

Warnings can be realized in form of a visual alert on the dashboard screen and/or acoustic warning. Figures 7.5-7 and 7.5-8 illustrate the sequence of messages and events. The procedure conforms with the functional requirements of the EEBL use case defined in ETSI TS 102 637 - 1 [4].

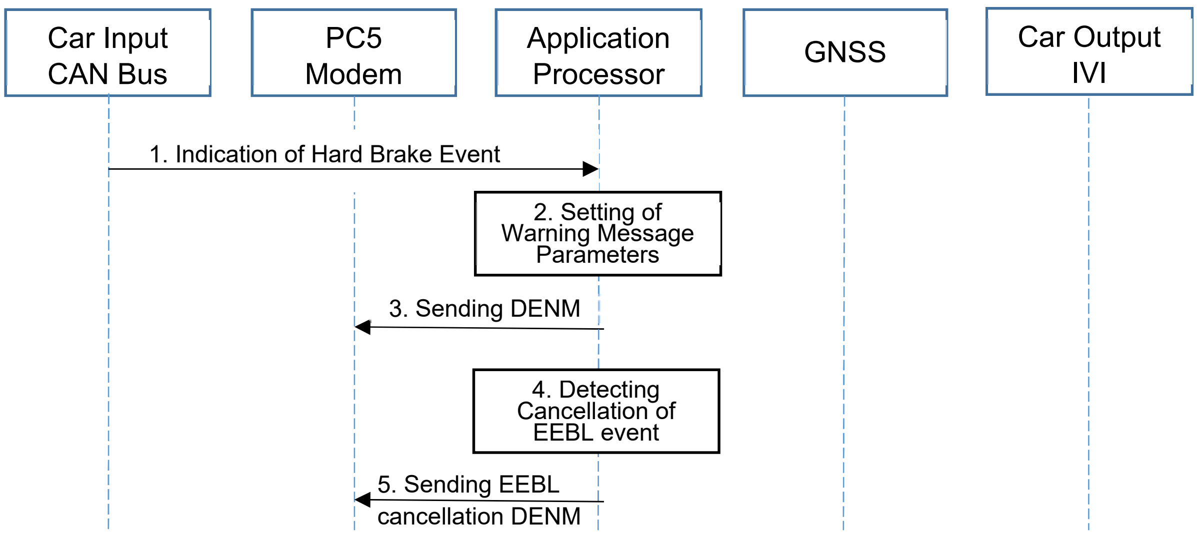

Figure 7.5-7: EEBL Message Sequence at RV side

1) The application processor receives a notification of a Hard Braking event. It is assumed that this trigger is received via the CAN bus. The trigger includes the deceleration parameter *d*.
2) The application processor derives the parameters of the warning message. The application reuses available position location information (message sequence for positioning data is not shown in this figure). The parameters of the DENM are the following:
    a. Frequency of transmission
    b. Estimated validity time of the EEBL event
    c. EEBL Event Identifier
    d. Current vehicle position as the event position with a location referencing sufficient for matching to a certain road section. The location reference includes the coordinates in the WGS84 coordinate system and heading information of the vehicle.
3) The EEBL DENM Warning is sent periodically for the given validity time
4) The originating ITS station may detect termination of the EEBL event

5) Triggered by step 4, it sends out a cancellation DENM. This new DENM includes a reference to the previous DENM.

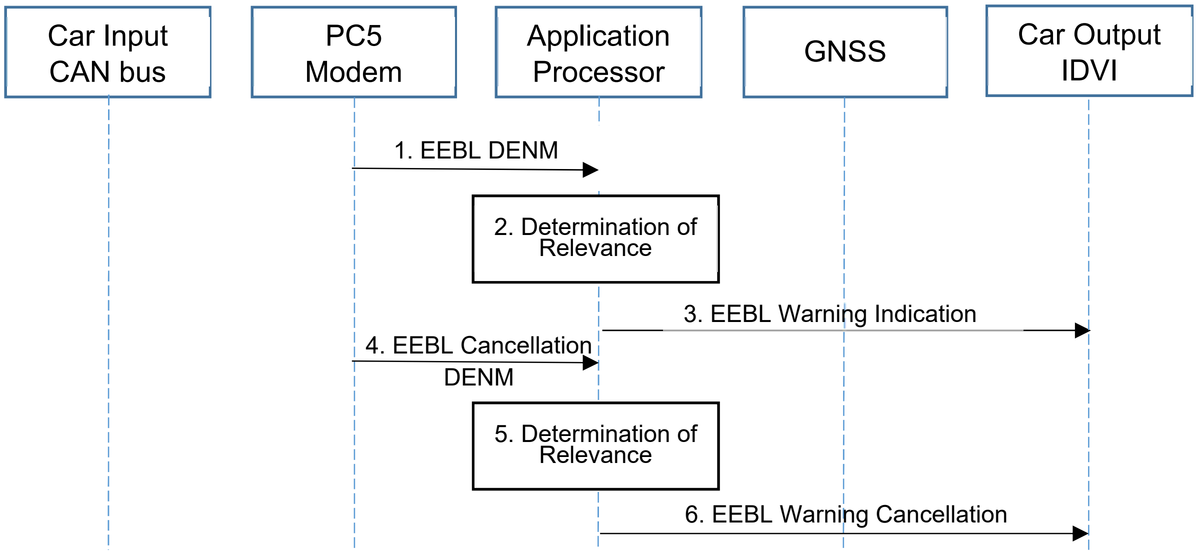

Figure 7.5-8: EEBL Message Sequence at HV side

1) The application processor receives a EEBL DENM.
2) The Application processor determines the relevance of the received DENM
3) If the received DENM is relevant to the HV, a warning is indicated to the DVI together with a validity time. After expiry of a given validity time, the warning indication is automatically cancelled at the DVI
4) In case a EEBL Cancellation of DENM is received, the previous steps 2) and 3) are repeated.
5) The Application processor determines the relevance of the received EEBL cancellation DENM
6) In case relevance of this message is detected, a warning cancellation is indicated to the DVI which stops indication of the previously issued warning immediately.

7.5.7 Measurements

To analyze transmission and processing latencies as well as reliability of message reception, it is sufficient to log all CAM and DENM sent and received by the two or three vehicles involved in the test scenario. It is assumed that all logged messages are time stamped using precise GNSS time information.

The requirements on position location accuracy defined in section 8.4 apply to this use case.

7.5.8 Expected Outcome

It is expected that testing of the EEBL use case in realistic traffic scenarios will provide more insight under which circumstances electronic alerts can improve safety even when used together with modern autonomous techniques such as adaptive brake lights and automatic emergency warning lights are supported by the RV.

It is expected to derive input for the specification of warning zones inside of which vehicles should receive a warning while vehicles outside of the warning zone should not be disturbed by such warning indications.

7.6 Intersection Movement Assist (IMA)

7.6.1 General Description

The IMA safety application warns the driver of an HV when it is not safe to enter an intersection due to a crash possibility with RVs crossing the movement path of the HV.

7.6.2 Objective

This use case will demonstrate that an HV can be warned sufficiently early and in unclear traffic situations to indicate that in the current situation the HV should not enter the intersection because of high probability of a collision hazard with one or multiple RVs approaching the intersection.

7.6.3 Description of Relevant Scenarios to Investigate

The following traffic scenarios for the present use case will be investigated:

- Rural/urban/suburban scenarios (road with one or more lanes in each direction)
    1. Basic Scenario 1: <u>Stopped</u> HV at intersection and RV crossing HV's path of travel at the intersection (IMA-B1)
    2. Basic Scenario 2: <u>Moving</u> HV into intersection and RV crossing HV's path of travel at the intersection (IMA-B2)
    3. Advanced Scenario 3: Moving HV into intersection and RV-L and RV-R crossing HV's path of travel at the intersection from two opposite directions (IMA-A3)
    4. Derived Scenarios: More complex situations can be created (e.g., involving more cars on multiple lanes, and/or turning cars, bicycle lanes, pedestrian crossings and priorities, etc.)

IMA warns the driver of the HV when there is imminent hazard of a crash with one or multiple RV(s) that is (are) approaching the same intersection.

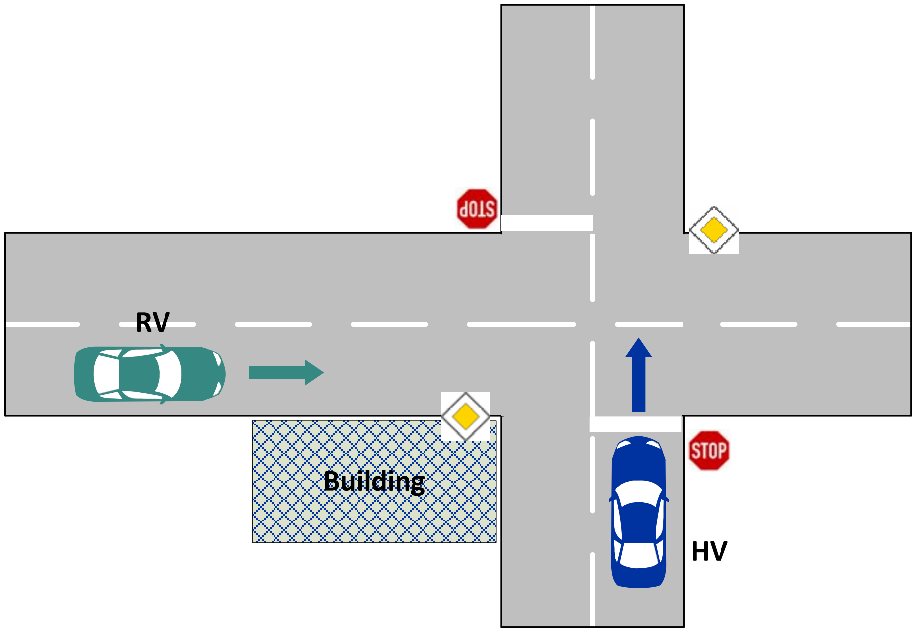

Figure 7.6-1: Stopped HV at intersection (with obstructed prioritized) RV crossing intersection (IMA-B1)

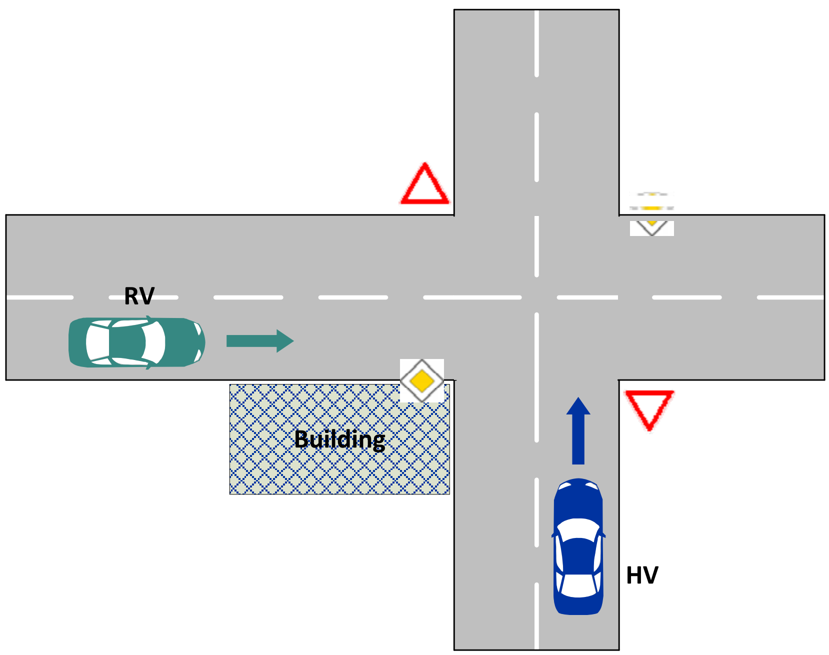

Figure 7.6-2: Moving HV into intersection (with obstructed prioritized) RV crossing intersection (IMA-B2)

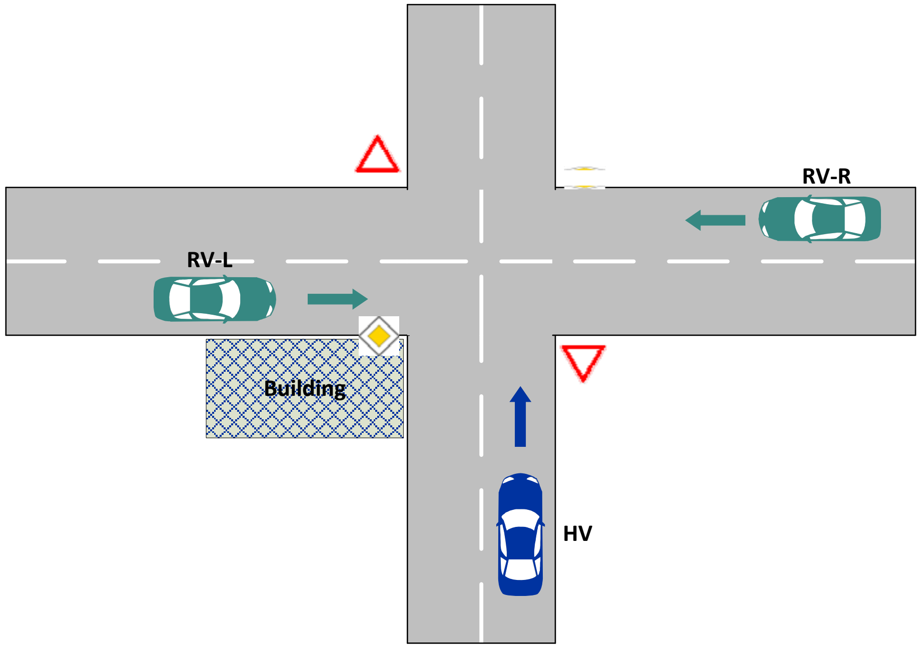

Figure 7.6-3: Moving HV into intersection and prioritized RV-L and RV-R crossing intersection from opposite directions (IMA-A3)

The relevant HV and RV zones for the IMA feature are illustrated below. The HV is characterized by its current speed vHV and acceleration aHV, RV-L and RV-R by their respective parameters vRV-L, vRV-R, aRV-L and aVR-R, respectively. In case of scenario IMA-B1 this would be based on a current speed vHV=0 and a positive acceleration aHV. In case of IMA-B2 and IMA-A3 the HV speed would be non-zero and with a negative acceleration. Together with the respective current intersection distances ISHV-L, ISHV-R, ISRV-L and ISRV-R this will determine the current potential collision location. Naturally, these respective distances must be considered by the IMA in a way that it would allow sufficient driver (or in case of automated driving - system) reaction time to avoid such collision.

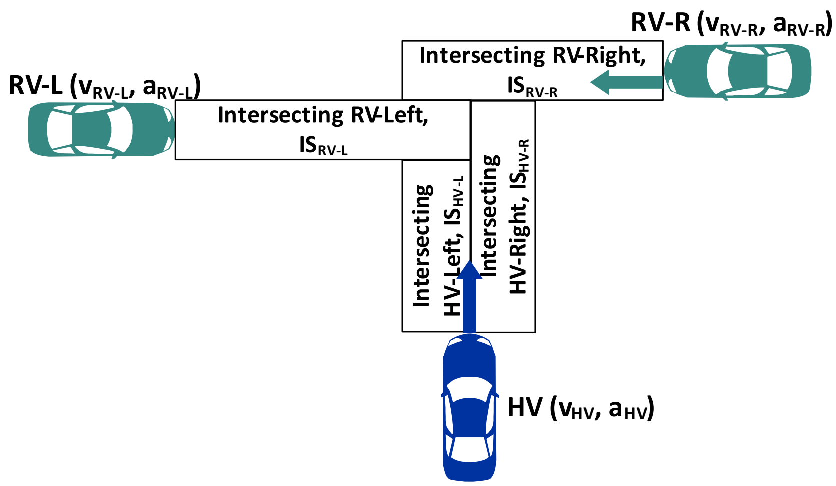

Figure 7.6-4: Relevant HV and RV zones/distances for IMA feature

IMA (in the HV) performs the following operations:

- Analyzes received CAM from RVs approaching the intersection and determines which of the RVs are classified as “intersecting left” or “intersecting right”.
- Determines which, if any, RVs classified as “intersecting left” or “intersecting-right” are within a lateral range threshold based on the current speed and acceleration characteristics of HV and RVs.
- Calculates time-to-intersection (TTI) and distance-to-intersection (DTI) for each “intersecting left” or “intersecting right” RV to determine if the HV is at risk of being involved in a crash with an RV traveling toward the same intersection.
- Identifies the principal hazard, if at least one RV is determined to be a threat.
- Provides a warning to the driver via a Driver Vehicular Interface (DVI).
- In case of additional sensors or infrastructure/broadcast information (DENM, e.g., road and weather conditions) and respective inputs the IMA could also take road and weather conditions into account which will impact acceleration performance and hazardous intersecting zones.

7.6.4 Safety Considerations

Collision hazards at intersections are a permanent thread in today’s day to day traffic. This holds the more if intersections are confusing, obstructed by buildings, parking/standing vehicles or road works, or the road and sight conditions at the intersection are impacted by unfavorable weather situations such as snow, hale, fog or rain which are impacting the potential TTI and DTI results. In such situations, the IMA will provide a significant safety gain to a driver or may be a crucial element in future autonomous driving environments.

C-V2X is expected to provide additional safety gains compared to DSRC due to its superior connectivity, propagation and range characteristics. Looking “around the corner” or overcoming sight blockings (buildings, cars, road works, etc.) or eventually also communicating to vulnerable road users like pedestrians or bikers will provide additional safety margins in such intersecting scenarios and situations.

7.6.5 Trial Set Up and Requirements

7.6.5.1 Trial Set Up

The demonstration and evaluation of this use case requires up to three (3) vehicles equipped with C-V2V functionality covering the IMA-B2 scenario. Scenarios IMA-B1and IMA-A3 to be trialed with lower priority.

The HV driver is made alerted that there is one or more in-path RV(s) and respective direction(s) and can take corrective actions to avoid or mitigate collisions with the RV(s) crossing the HV's path of travel.

The following variations and parameters can be considered:

- Different speeds (HV, RV)
- Line-of-Sight and Non-Line-of-Sight (if this can be safely executed).

7.6.5.2 Communication Requirements

Modules capable of sending, receiving and processing CAM with basic container and Vehicle High Frequency container.

7.6.5.3 Performance Requirements

With the IMA-B2 scenario in mind (HV with priority intends to cross an intersection), a simple calculation was made to identify at which distance is safe to complete the crossing. Therefore, some assumptions were used:

- HV and RV have the same speed
- Car length: 5 m
- Lane width: 5 m (3m lane plus 2m buffer zone due to GNSS accuracy)

The clearance time is calculated as the time needed for HV to cross the lane in which RV is approaching. The result can be seen in the table below.

Speed (km/h)	Clearance time (s)
30	1.2
50	0.72
70	0.52
100	0.36

A safe zone can be calculated which is defined as being the minimum distance at which RV should be to allow HV crossing without the need of braking of any of the cars involved. Rounding the clearance time to 1s after considering the 50 km/h speed the most relevant scenario and adding a safety margin, the safe zones are:

Speed (km/h)	Safe Zone (m)
30	8.3
50	14
70	19
100	28

The warning to HV driver should be triggered if RV entered the safe zone. Those values provide therefore an estimation of the distances to be tested. Depending on the actual implementation, distance variations regarding the safe zone limits are expected. There could also be visual notifications in case RV inside a so-called alerting zone, which is determined by an additional safety margin to the safe zone. Outside those areas, no warning nor notification is expected.

7.6.6 Procedures

An Intersection Movement Assist use case is triggered after an application processor detects the risk of collision at an intersection after computing the received CAM of RVs and the path of travel of HV. In that case, the driver will be alerted. Warnings can be realized in form of visual alerts on dashboard screen and/or sound notifications. The diagram below illustrates this flow.

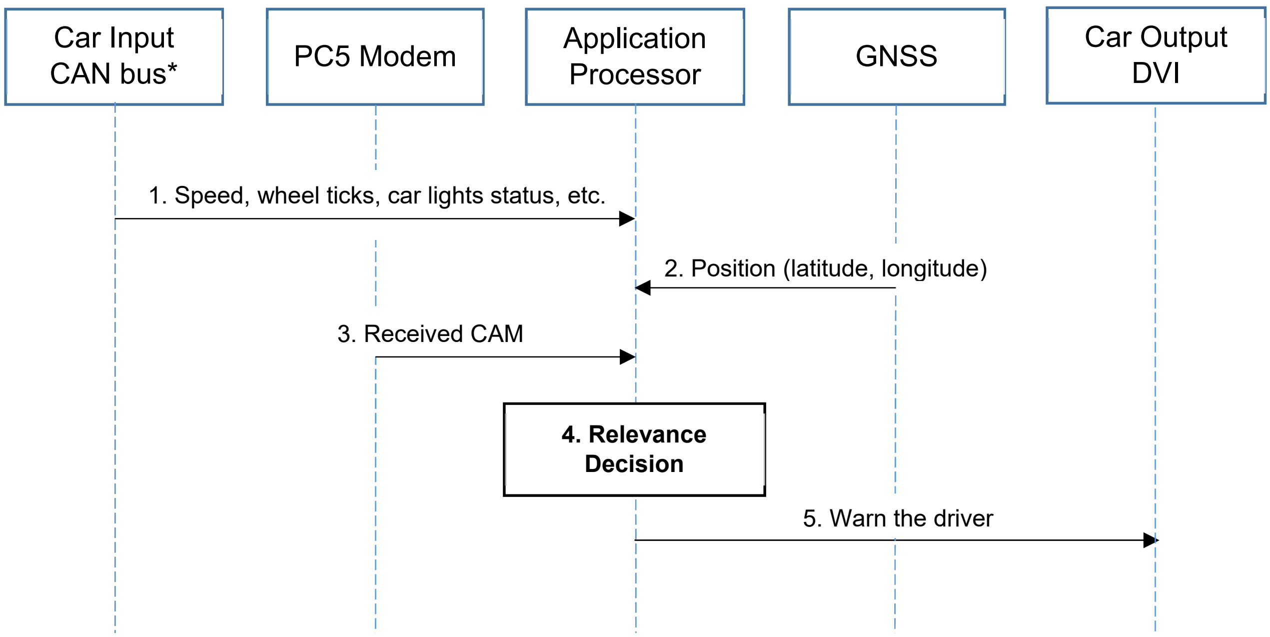

Figure 7.6-5: Sequence Diagram – HV ***or other physical I/F***

1) The speed and direction of movement of HV are constantly been fed into the application processor. Other parameters such as the car light status can also be included.
2) The position (latitude and longitude) is also fed into the application processor at frequency of 10 Hz (to be confirmed).
3) CAMs from all RVs are received. CAM from vehicles contain the following mandatory fields:
    - Heading,
    - Speed,
    - Drive Direction,
    - Vehicle Length,
    - Vehicle Width,
    - Longitudinal Acceleration,
    - Curvature,

- Yaw Rate,
- Vehicle Latitude and Vehicle Longitude,
- Timestamp,
- Etc.

NOTE: steps 1, 2 and 3 can happen in any order.

4) The **Relevance Decision** procedure is part of an algorithm that considers the inputs from steps 1, 2 and 3 and evaluates danger of collision at an intersection. Distance, speed, lane position and trajectory are some of the variables taken into account for risk analysis.
5) If the Relevance Decision is positive, the driver will be warned.

7.6.7 Measurements

In order to characterize the system and evaluate the performance, some measurements shall be made:

- Timestamps and GNSS coordinates of emitted CAMs of the RV (relevant for the warning)
- Timestamp when CAM is received by HV
- Timestamp when the warning is emitted to driver
- Calculation of distance between RV and HV, when CAM relevant for warning is emitted
- Speed of RV and HV (from CAM)
- For Packet loss evaluation, number of packets sent from RV and received by HV

Furthermore, it should be evaluated if the warning was correctly triggered (no false alarm) as well as for the first relevant CAM received (timely).

NOTE: lower layer measurements for e.g. RF conditions (receive level, interference) etc. shall also be taken. Potentially additional metrics and measurements might be added according to the needs arising during the trial.

7.6.8 Expected Outcome

Prove that IMA is reliably working under all tested conditions.

Potential performance advantages versus DSRC are expected for range, specifically in non-Line-of-Sight scenarios, which might also translate into higher reliability or a higher speed range.

7.7 Left Turn Assist (LTA)

7.7.1 General Description

The LTA safety application warns the driver of a vehicle (HV) when it is not safe to do a left turn at an intersection due to a crash possibility with other vehicles (RVs).

7.7.2 Objective

This use case will demonstrate that an HV can be warned sufficiently early to indicate that in the current situation the HV should not do a left turn because of high probability that a crash may occur with one or multiple RVs approaching the location of the intended left turn.

HV shall adapt its own speed following the warning received and wait for a safe moment in time to proceed his intended path of travel.

Finally, the overall collective change of behavior shall increase safety for all directly and indirectly involved participants.

7.7.3 Description of Relevant Scenarios to Investigate

The following traffic scenarios for the present use case will be investigated:

- Rural/suburban scenarios (road with one or more lanes in each direction)
    1. Left Turn Assist across path with RV approaching from the side (LTA-1)
    2. Left Turn Assist across path with RV approaching from the opposite path of current travel (LTA-2)

The following variations and parameters can be considered:

- o Different speeds (HV, RV)
- o Line-of-Sight and Non-Line-of-Sight (if this can be safely executed)
- o Different road and weather conditions (snow, rain, dust, fog, etc.)

LTA should warn a driver of the HV intending to make a left turn across an intersection path when there is imminent danger of a crash with an RV in an oncoming crossing or opposite lane of travel.

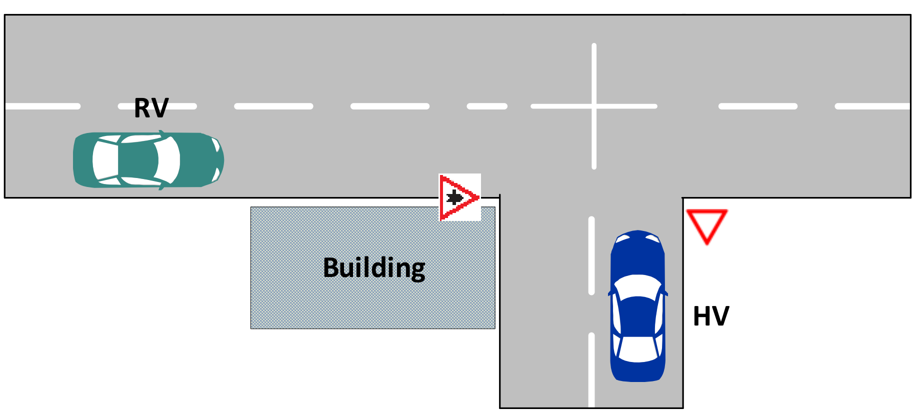

Figure 7.7-1: Left Turn Assist across path with RV approaching from the side (LTA-1) – here shown with an obstructive building (NLOS)

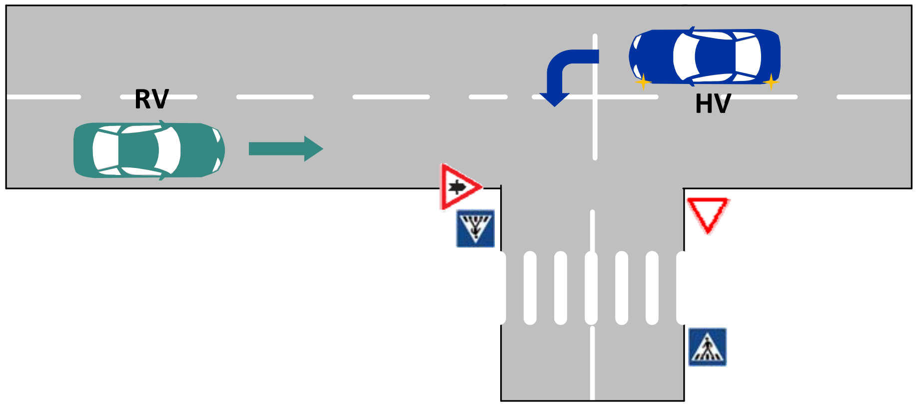

Figure 7.7-2: Left Turn Assist across path with RV approaching from the opposite path of current travel (LTA-2)

The relevant HV and RV zones for the LTA feature are illustrated below. For LTA-1, the distance of the HV toward a potential location of collision is denoted as $OS_{HV\text{-}L}$ which is determined by the current speed v_{HV} and acceleration a_{HV} of the HV. Similarly, the distance of the RV approaching from the left side is denoted as $OS_{RV\text{-}L}$ which is determined by the current speed v_{RV} and acceleration a_{RV} of the RV.

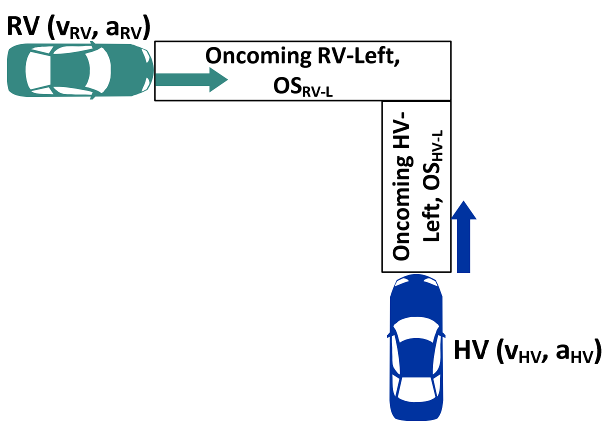

Figure 7.7-3: Relevant RV and HV zones for LTA-1 feature

For LTA-2, the distance between HV and RV marking a non-secure left turn margin is denoted as OS_{RV} which is determined by the current speeds of HV and RV, v_{HV} and v_{RV}, and accelerations, a_{HV} and a_{RV}, of the HV and RV, respectively.

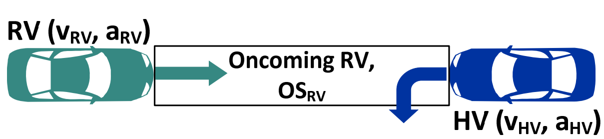

Figure 7.7-4: Relevant RV and HV zones for LTA-2 feature

LTA performs the following operations:

- Analyzes received CAM from the RVs approaching the intersection or location of potential left turn and determines which of the RVs are classified as closest "Oncoming RV" in order to determine if the HV is at risk of being involved in a left turn crash with an RV approaching in an oncoming lane of travel.
- In case of multiple lanes of oncoming multiple RVs, LTA determines which, if any, RVs classified as "oncoming left" or "oncoming far left" are within a range threshold.
- Calculates the clearance gap for each "oncoming" RV to determine potential intersecting crash threats.
- Identifies the principal threat, if at least one RV is determined to be a threat.
- Provides a warning to the driver via a Driver Vehicle Interface (DVI).

7.7.4 Safety Considerations

Collision hazards at left turns are a permanent threat in today's day to day traffic. This holds the more if left turn scenarios are confusing, obstructed by buildings, parking/standing vehicles or road works, or the road and sight conditions at the intended location of a left turn are impacted by unfavorable weather situations such as snow, hale, fog or rain. In such situations, the LTA will provide a significant safety gain to a driver or may be a crucial element in future autonomous driving environments.

C-V2X is expected to provide additional safety gains compared to DSRC due to its superior connectivity, propagation and range characteristics. Looking "around the corner" or overcoming sight blockings (buildings, cars, road works, etc.) or eventually also communicating to vulnerable road users like pedestrians or bikers will provide additional safety margins in such intersecting scenarios and situations (as indicated in the Figure for LTA-2).

7.7.5 Trial Set Up and Requirements

7.7.5.1 Trial Set Up

The demonstration and evaluation of this use case requires two vehicles equipped with C-V2V functionality. The prerequisite for entering into this use case is, that the left indicator of the HV is activated.

The HV driver is made alerted that there is an in-path RV and can take corrective actions to avoid or mitigate collisions with the RV along the left turn path.

The following variations and parameters can be considered:

- Different speeds (HV, RV)
- Line-of-Sight and Non-Line-of-Sight (if this can be safely executed).

7.7.5.2 Communication Requirements

Modules capable of sending, receiving and processing CAM with basic container and Vehicle High Frequency container.

7.7.5.3 Performance Requirements

A simple calculation was made to identify at which distance it is safe to complete the left turn in order to provide guidelines for field testing. Therefore, some assumptions were used:

- The path length HV needs to travel from its starting point to reach the safe zone is 10 m

- HV accelerates from 0 to make the turn (worst case). Acceleration in this case is 3.5 m/s^2

⇨ The travel time needed in those conditions is 2.4 s. For safety, travel time of 3 s is used (which is equal to clearance time)

- RV drives at constant speed

A safe zone can be calculated which is defined as being the minimum distance at which RV should be to allow HV turn left without the need of braking of any of the cars involved. The safe zones are:

Speed (km/h)	Safe Zone (m)
30	25
50	42
70	57
100	84

The warning to HV driver should be triggered if RV entered the safe zone. Those values provide therefore an estimation of the distances to be tested. Depending on the actual implementation, distance variations regarding the safe zone limits are expected. There could also be visual notifications in case RV inside a so-called alerting zone, which is determined by an additional safety margin to the safe zone. Outside those areas, no warming nor notification is expected.

7.7.6 Procedures

A Left Turn Assist use case is triggered after an application processor detects the risk of collision for an intended left turn after computing the received CAM of RVs and the path of travel of HV. In that case, the driver will be alerted. Warnings can be realized in form of visual alerts on dashboard screen and/or sound notifications. The diagram below illustrates this flow.

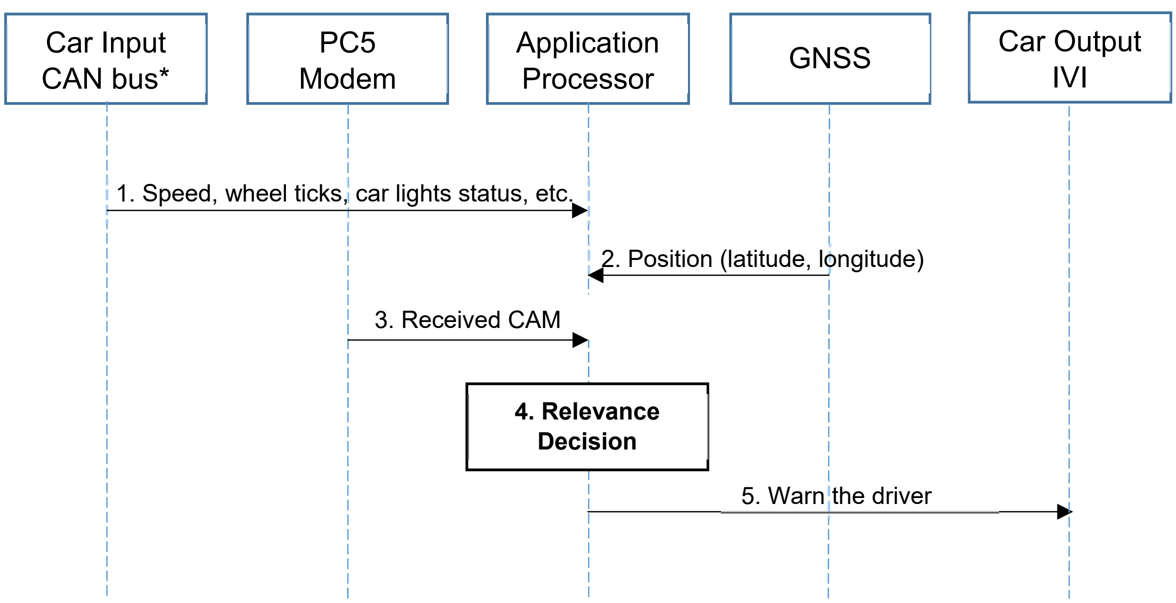

Figure 7.7-5: Sequence Diagram – HV ***or other physical I/F**

1) The speed and direction of movement of HV are constantly been fed into the application processor. Other parameters such as the car light status can also be included. Here the activation of the left indicator light is used as the starting point of the use case.
2) The position (latitude and longitude) is also fed into the application processor at frequency of 10 Hz (to be confirmed).
3) CAMs from all RVs are received. CAM from vehicles contain the following mandatory fields:
   - Heading,
   - Speed,
   - Drive Direction,
   - Vehicle Length,
   - Vehicle Width,
   - Longitudinal Acceleration,
   - Curvature,
   - Yaw Rate,
   - Vehicle Latitude and Vehicle Longitude,
   - Timestamp,
   - Etc.

NOTE: steps 1, 2 and 3 can happen in any order.

4) The **Relevance Decision** procedure is part of an algorithm that considers the inputs from steps 1,2 and 3 and evaluates danger of collision during the left turn. Distance, speed, lane position and trajectory are some of the variables taken into account for risk analysis.
5) If the Relevance Decision is positive, the driver will be warned.

7.7.7 Measurements

In order to characterize the system and evaluate the performance, some measurements shall be made:

- Timestamps and GNSS coordinates of emitted CAMs of the RV (relevant for the warning)
- Timestamp when CAM is received by HV
- Timestamp when the warning is emitted to driver
- Calculation of distance between RV and HV, when CAM relevant for warning is emitted
- Speed of RV and HV (from CAM)
- For Packet loss evaluation, number of packets sent from RV and received by HV

Furthermore, it should be evaluated if the warning was correctly triggered (no false alarm) as well as for the first relevant CAM received (timely).

NOTE: lower layer measurements for e.g. RF conditions (receive level, interference) etc. shall also be taken. Potentially additional metrics and measurements might be added according to the needs arising during the trial.

7.7.8 Expected Outcome

Prove that LTA is reliably working under all tested conditions.

Potential performance advantages versus DSRC are expected for range, specifically in non-Line-of-Sight scenarios, which might also translate into higher reliability or a higher speed range.

7.8 Vulnerable Road User (VRU) Warning

7.8.1 General Description

This use case concerns extension of the safety benefits of V2X technology to pedestrians, bicyclists, and road workers, which are collectively referred to as Vulnerable Road Users (VRUs). While there are numerous variations of this use case, in general, it is assumed that both vehicles and VRUs are equipped with V2X technology capable of sending and/or receiving safety/awareness messages that are broadcast to other devices within some proximity. In the more common case, it is assumed that the VRU broadcasts a safety/awareness message (e.g., containing position, speed, trajectory, etc.) that is received by a nearby vehicle, allowing the vehicle to determine if there is a risk of collision and alert the driver. This can be particularly valuable when the VRU (e.g., pedestrian) is somewhat obscured from the driver's point of view (e.g., emerging from between parked cars along the side of the road).

7.8.2 Objective

This use case will demonstrate that an HV can be warned sufficiently early of a potentially dangerous situation involving a VRU to avoid collision.

7.8.3 Description of relevant scenarios to investigate

The following scenarios for the present use case will be considered:

- Highway scenarios (A9)
    - Road worker in a construction area along the highway.
- Rural/suburban scenarios
    - Pedestrian crossing the roadway at a marked crosswalk
        - Vehicle proceeding straight through the intersection, pedestrian crossing the roadway on which the vehicle is traveling
        - Vehicle turning right at intersection, pedestrian crossing the roadway onto which the vehicle is turning
        - Vehicle turning left at intersection, pedestrian crossing the roadway onto which the vehicle is turning
    - Pedestrian crossing the roadway at an unmarked point along the roadway
        - Clear visibility condition
        - Obscured visibility condition (e.g., pedestrian emerging from between parked cars along the roadway)
    - Pedestrian/bicyclist traveling along the roadway

Figure 7.8-1 illustrates examples of use cases in rural/suburban environments where a pedestrian is crossing a roadway.

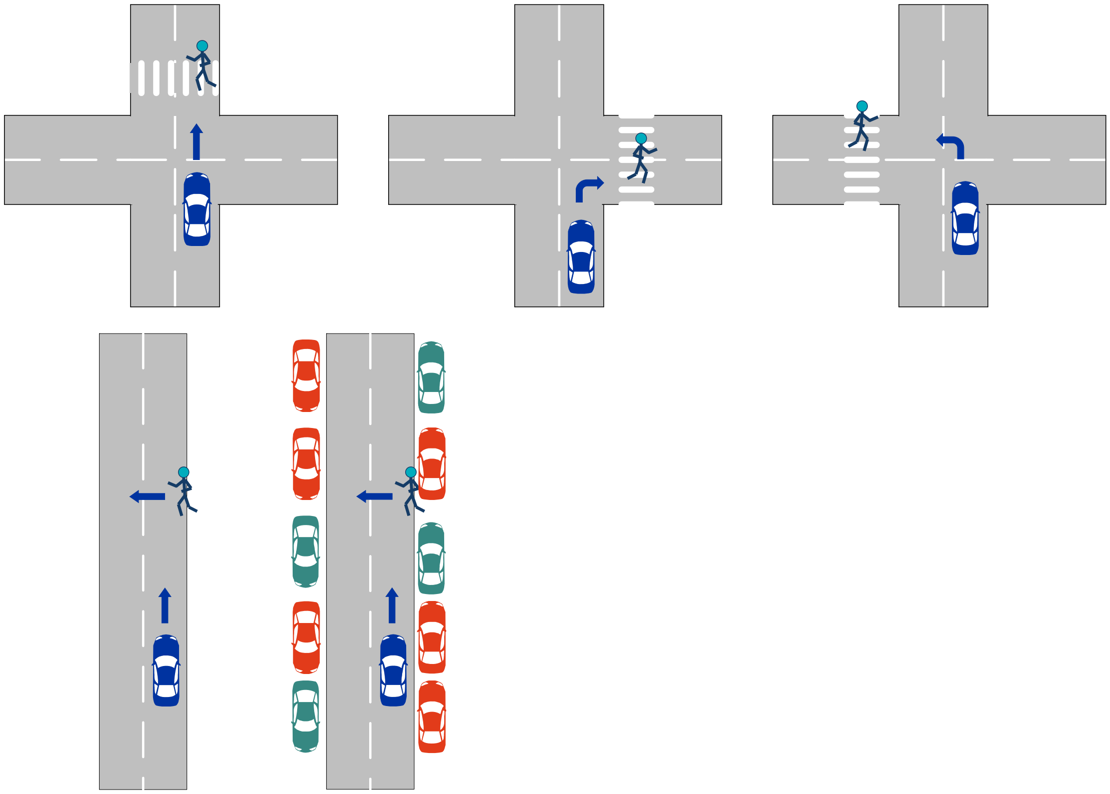

Figure 7.8-1: Example test scenarios for VRU use cases

7.8.4 Safety Consideration

Almost 50 % of the fatal road casualties are motorcyclists, bicyclists and pedestrians (in Germany 701 motorcyclists, 383 bicyclists and 537 pedestrians of 3241 road users killed in an accident in 2015 [20]). In addition there are more than 120.000 injured VRU users alone in Germany every year. The vast majority of accidents involving VRUs are with vehicles (passenger vehicles, trucks and busses).

Warning vehicle drivers of VRUs in their proximity has the potential to reduce the number of accidents substantially and save life.

The main technical challenge of VRU use cases lies in designing the applied algorithms and detection mechanism such that unnecessary warning indications are generally avoided while hazardous traffic situations are detected with probability bordering certainty.

7.8.5 Trial set up and requirements

7.8.5.1 Trial set up

The demonstration and evaluation of this V2P use case requires one vehicle equipped with C-V2X functionality and one VRU (pedestrian, bicyclist) equipped with C-V2X functionality. Note that the VRU may be emulated by some equipment to avoid putting a real pedestrian into a potentially dangerous situation. Additional vehicles (without the need for C-V2X functionality) may be used as cars parked along the roadway to support the obscured visibility condition scenario.

7.8.5.2 Communication requirements

The VRU equipment is capable to send CAMs periodically which includes an identification of the type of VRU and its position location information. The periodicity of sending CAMs may be adapted automatically to the traffic situation. For instance transmission of the VRU should stop when the user is in a safe environment (in e.g. buildings, in pedestrian area).

7.8.5.3 Performance requirements

When a warning is indicated to a vehicle it should have enough time to stop after detecting a VRU. Assuming a maximum speed of 100 km/h, the communication range of 60 m appears to be sufficient. Nevertheless, for special VRU types such as road workers, a larger range may be applicable (although it can be assumed that e.g. in road work areas, a speed limit will be imposed by other V2X applications).

It is expected that realization of adequate position location accuracy will be a major challenge for most VRUs. This is because typically a portable VRU device will be carried in a pocket, bag or backpack. For most VRU use cases, determination of accurate information on speed and direction of movement will be difficult to obtain. It is therefore not possible to define general requirements on position location accuracy for VRUs. One goal of the ConVeX project is to derive input for the further discussion and specification of practical requirements.

Since a portable VRU device will be battery-powered, it is important that VRU applications are designed to enable power saving features. Requirements related to power consumption are expected to be investigated in this project.

7.8.6 Procedures

The VRU portable equipment sends periodically CAM messages which includes the following information

- identification of the type of VRU, e.g. pedestrian, road worker, bicyclist, motorbike,
- speed of movement,
- trajectory of movement (if available).

The portable device could include mechanisms to detect whether a VRU is in a potentially dangerous situation or not and stop sending CAM messages if a collision with other road users can be ruled out

VRU use cases are typically triggered at the HV side when, based on received CAM messages, the HV ITS station detects a potentially dangerous situation due to the presence or approaching of a VRU.

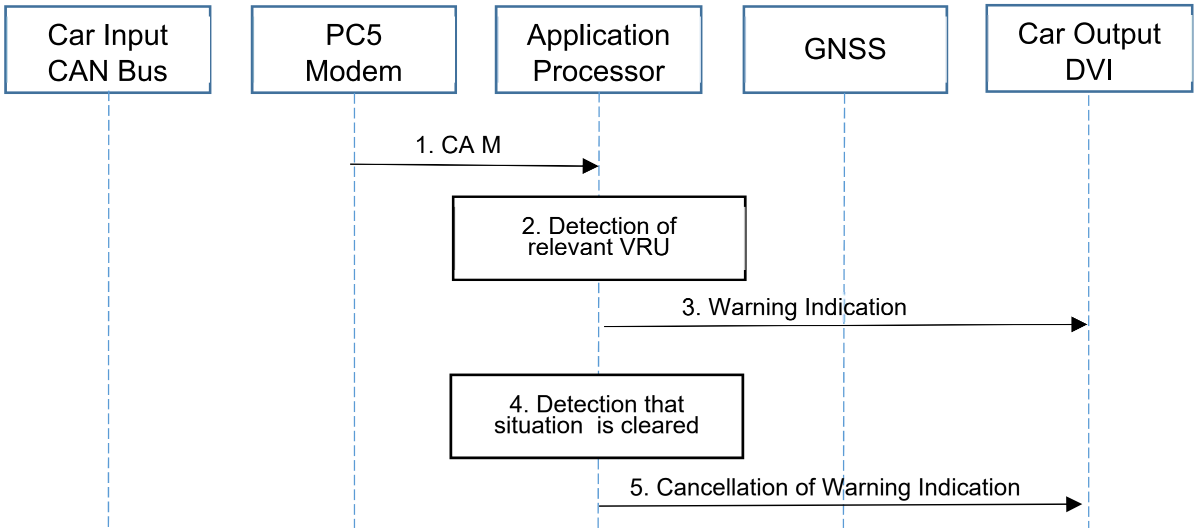

Figure 7.8-2: Message Sequence at HV side

1) The application processor receives CAM messages.
2) The application processor detects that there is a potentially hazardous situation due to a VRU user in the proximity.
3) A warning is indicated to the DVI together with a validity time. After expiry of a given validity time, the warning indication is automatically cancelled at the DVI.
4) It is detected that the hazardous situation has disappeared before the previously indicated expiry time has elapsed
5) A warning cancellation is indicated to the DVI which stops indication of the previously issued warning immediately.

7.8.7 Measurements

To analyze transmission and processing latencies as well as reliability of message reception, it is sufficient to log all CAM sent and received by the VRU station(s) and the vehicular ITS station(s) involved in the test scenario. It is assumed that all logged messages are time stamped using precise GNSS time information.

The Position location accuracy as defined in Section 8.4 is assumed to be sufficient even for VRU use cases. However, it is expected that this requirement in many practical situations cannot be fulfilled due to unfavorable conditions for GNSS signals. Derivation of practical requirements on position location accuracy is one of the objectives for the trials of VRU use cases.

7.8.8 Expected Outcome

This use case will demonstrate the safety benefit which can be obtained when VRUs, such as e.g. road workers, pedestrians and bicyclists are willing to carry portable devices supporting V2X technology. Compared to other V2X technologies, C-V2X has the inherent advantage that it can be expected to be integrated more easily and more cost efficient into mobile phones targeting at the mass market. This would make it feasible that potentially every individual carrying a mobile phone which supports C-

V2X can acquire the safety benefits. If the integration of V2P into ordinary phones is not feasible, this use case will be limited only to a special class of traffic participants, such as e.g. road workers.

The trial of this use case is also expected to provide very useful findings and awareness, how to manage the communication due to V2P use cases when this service is enabled in areas with very large penetration, e.g. cross-walks in cities.

7.9 Shockwave Damping (SWD)

7.9.1 General Description

Traffic bottlenecks lead to capacity reduction, high traffic volume and local disruptions (e.g. caused by accident) lead to traffic jam. A measure for the homogenization of the traffic flow is an effective reduction of the congestion wave.

Shockwave damping (SWD) avoids the creation or extension of shockwaves (sudden traffic jam ends moving upstream against the traffic flow) in high saturated traffic conditions.

The principle is to detect locations (stretches of roads / lanes) where such shockwaves occur or are likely to occur. For these locations and upstream to these locations a speed recommendation / advice is provided. When (highly automated) vehicles adapt to this speed, shockwaves are avoided.

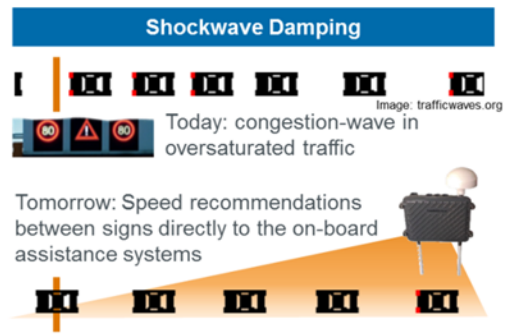

Figure 7.9-1: Road-Side-Unit Range

The function targets in-vehicle functions such as Adaptive Cruise Control (ACC). In a low-end solution even showing recommendations to drivers can be beneficial. The application also must be aware of dynamic speed limits in existing lane control systems (when these exist).

7.9.2 Objective

There are two objective layers we pursue:

L1) The simulation layer shall study the traffic-related Use Case Objective: How can the benefit to the traffic scenario be measured in terms of which settings lead to which quantifiable effects in homogenizing traffic and mitigating or even avoiding shockwaves.

L2) The practical trial layer targets to demonstrate a sub-set of the complete function in order to validate key elements such as in-field the protocol definition and vehicle implementation aspects.

7.9.3 Description of Relevant Scenarios to Investigate

The following traffic scenarios for the present use case will be investigated:

The application is primarily targeting **highway-alike road sections.** They are characterized by controlled entry/exit and physically separated driving directions. Within these scenarios comprise

- Traffic with shockwave risks on road sections without entry/exit in vicinity

Figure 7.9-2: Road Section without entry/exit in vicinity

- Traffic with shockwave risks on main road near entry/exit ramps

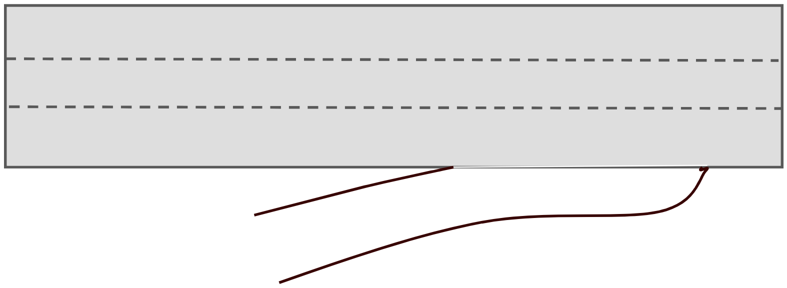

Figure 7.9-3 Road Section near entry/exit in vicinity

- Traffic with shockwave risks on a dedicated lane due to special usage (HGV dominated lane or long entry/exit slip road on highway crossings)

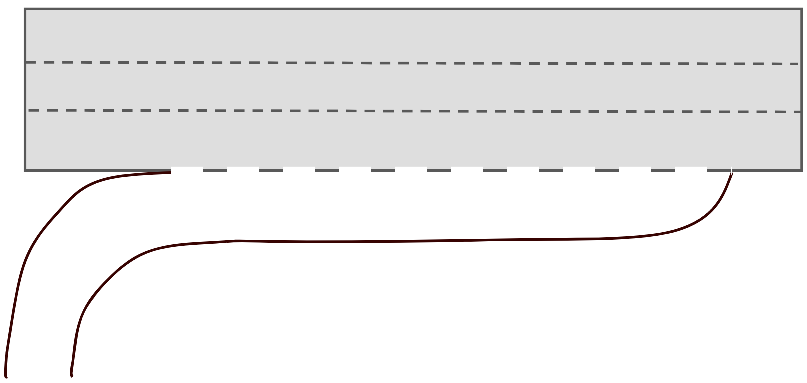

Figure 7.9-4 Road Section with long entry/exit slip road on highway crossings

Secondary (rural / urban) scenario (not planned to be tested)

- Long road-sections with no entry/exit or one entry/exit after a long section where such waves have been observed as a safety risk (e.g. waves originating from vehicles which enter/exit and ‘interrupt’ the flow, causing a local speed drop which is hardly seen by oncoming traffic due to local concisions (bad visibility; local psychological effect to proceed with higher speed and reduced attention on potential interruptions)

In all scenarios two key aspects are subject of research / test in ConVeX:
Aspect one - Penetration and effect: How many vehicles in the collective are needed to create quantifiable damping effects for shockwaves

Aspect two - Message transmission and processing: What is the best regime in terms of communication protocol used and management of the message dissemination (involving V2I / V2N and Traffic Management Centre).

7.9.4 Safety Considerations

The aspect of safety is not easy to prove (e.g. reduction of number/ severity of accidents). The focus shall be on the homogenization of traffic flow (uniformity of distance between vehicles and their speed).

The magnitude of the homogenization effect in relation to penetration and local situation (see Scenarios above) shall be determined in the simulation.

7.9.5 Trial Set Up and Requirements

7.9.5.1 Trial Set Up

The environment for a field test with shockwaves is not easy to reproduce. For this reason the trial test is in a simulated environment. The simulation environment is created with a simulation software. TUKL and SWARCO cooperate in generating and running the simulation environment.

In the field test, Audi cars on motorway A9 shall receive speed recommendations (and optional traffic jam warnings representing the shockwave location) and the car reacts by carefully reducing speed / increasing headway (and possibly display shockwave/jam ahead warning for showcase the demo).

Extended demo: A second car ahead (can be carrying an OBU test kit in normal car) is acting as “sensor” and provides its speed profile to the infrastructure. Speed reductions with high gradient (e.g. approaching a truck and reducing speed faster than well anticipated driving would do) triggers a reaction at the infrastructure side.

7.9.5.2 Communication Requirements

The trial needs local RSUs along the motorway to perform “CAM Aggregation” – i.e. evaluation of speeds recorded by V2X equipped vehicles and sent via PC5. Alternatively, the CAM Aggregation function can also be located in a cloud environment, reachable from the vehicles via Uu, but this case is not implemented for the trial.

The results of the RSU pre-evaluation must be communicated to the Traffic Control Center (TCC). This requires Uu connection between RSU and TCC.

Finally for the “downlink” from TCC to vehicles, the TCC requires Uu and the RSU requires PC5 connectivity to vehicles. The downlink can be complemented by Uu-based transmission to further host-vehicles, providing speed recommendation (IVI message) and the optional warnings (DENM).

7.9.5.3 Performance Requirements

Following performance indicators are relevant:

- Measurement of density of traffic flow before Shockwave Damping
- Latency associated with messages send to Host Vehicles to control their speed

Requirements on these indicators to achieve adequate Shockwave Damping performance will be assessed by simulation studies and confirmed in the field trials where applicable.

7.9.6 Procedures

A traffic Jam is detected by TCC (e.g. using host vehicle cams, to detect congestion by evaluating the braking behavior of the preceding cars). To avoid a shockwave, the information about the jam is send as IVI message via host RSU to a TCC. The information comes back via the road side unit to Host Vehicles which approach shock wave damping by adapting their speed.

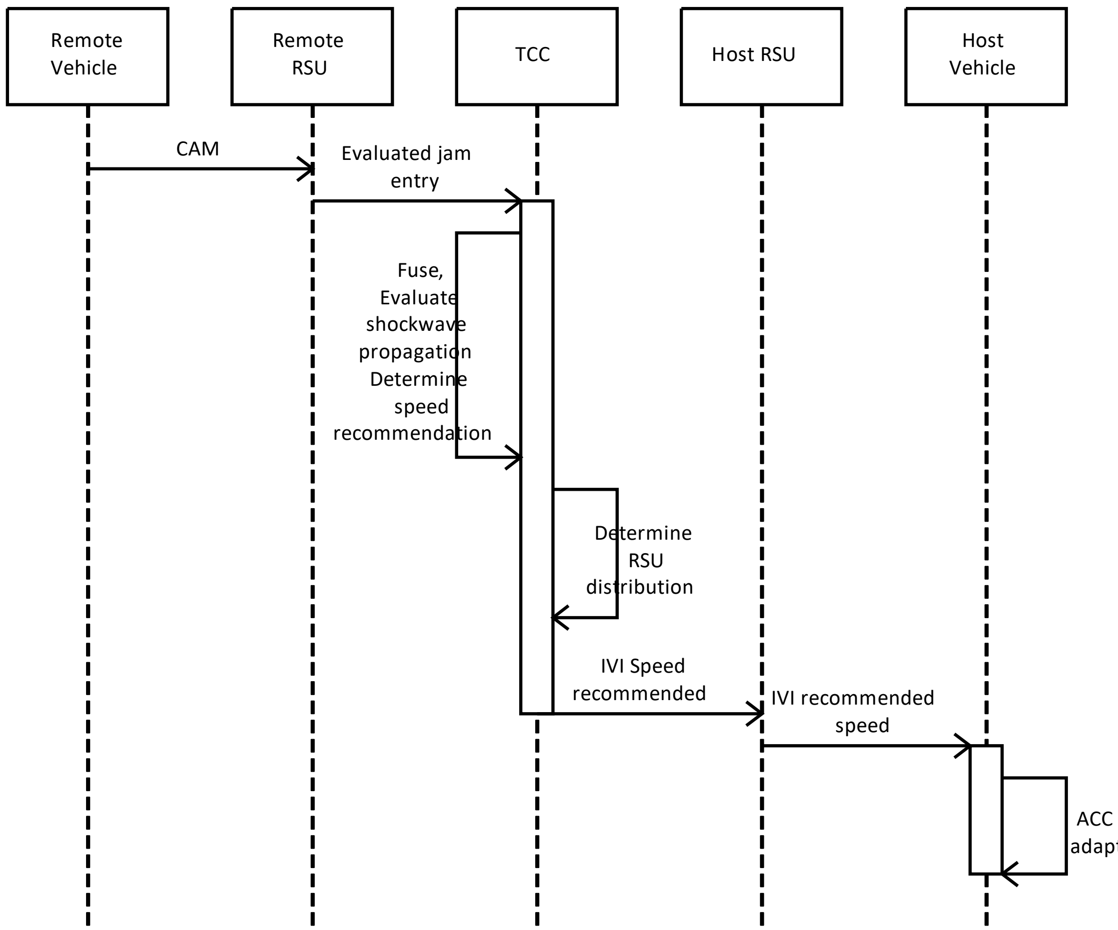

Figure 7.9-5: Message flow for Shockwave Damping

The signal about traffic jam starts from the remote vehicle as CAM to the remote RSU and goes to the Traffic Control Center (TCC). When vehicle acts as a sensor there is CAM evaluation by the infrastructure. The evaluation of the CAM is used in the TCC to determine a speed recommendation. The IVI speed recommendation is distributed via host RSU to the host vehicle. When jam warning is included, it is sent as a DENM. The vehicle adapts its speed through a modified ACC function.

7.9.7 Measurements

To analyze transmission and processing latencies as well as reliability of message reception, it is sufficient to log all CAM, DENM and IVI messages sent and received by the ITS Stations (vehicles, RSUs, Centers) involved in the test scenario. It is assumed that all logged messages are time stamped using precise GNSS time information.

For the simulation scenarios, measurements must include the location of the shockwave and the size of the jam both in terms of location and time.

The number of vehicles participating in a SWD scenario as “actors” must be documented. Further simulation characteristics which characterize a scenario set (e.g. parameters given to the model) have to be determined while developing and executing the simulation (e.g. traffic density before shockwave (damping) is starting to build up, speed of the shockwave).

7.9.8 Expected Outcome

Prove that protocols and communication involved in SWD are reliably working under all tested conditions.

Quantifying key indicators showing, when shockwave damping can generate a positive effect on traffic (e.g. minimum penetration of SWD “host” vehicles, traffic conditions under which the effect becomes effective).

7.10 In Vehicle Information (IVI)

7.10.1 General Description

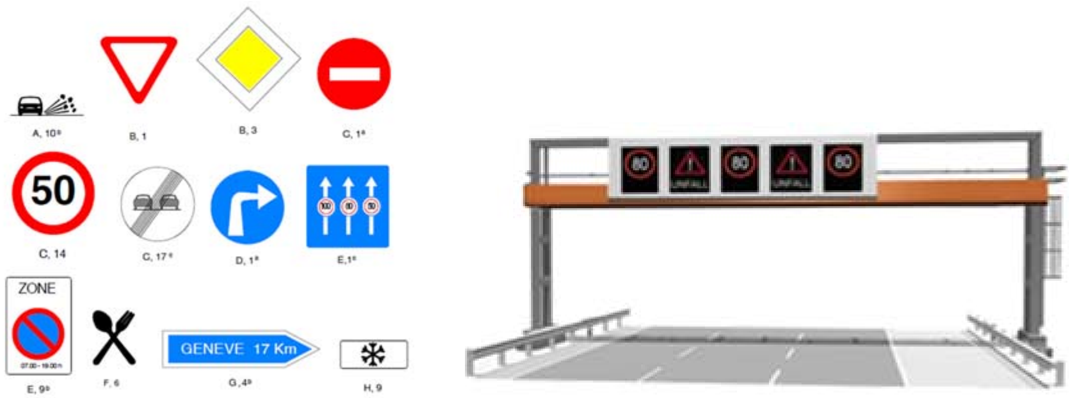

Figure 7.10-1: IVI Signs

In Vehicle Information (IVI) brings the information of traffic signs into the vehicle in an electronic way. These messages complement the information that is generated by traffic sign detecting video cameras with an additional, redundant mechanism. In case of autonomous cars, this additional information is increasing functional safety.

Vehicle Information Standard is ISO/TS 19321 content of (dynamic) road signs.

7.10.2 Objective

In Vehicle Information (IVI) has the following objectives: it supports highly automated driving functions, improves functional safety (confirmation of sign-posted rules by a second secure channel) and enables that more detailed information may be provided to the vehicle.

7.10.3 Description of Relevant Scenarios to Investigate

The following traffic scenario shall be investigated: Transmission of an indicated speed limit (from a virtual roadside signals) or any other sign content which can be encoded in an IVI message.

The scenario can be demonstrated on motorway and on rural roads, eventually in cities.

A vehicle approaches an area governed by a traffic sign (e.g. speed limit zone) and receives an In-Vehicle Information message (IVI message). The processing of the sign information (e.g. presentation to the driver via the HMI / adapting ACC speed) has to be performed in due time (considering distance of the vehicle to the traffic sign and speed of the vehicle), sufficient for reacting timely to adapt the vehicle, e.g. its speed, accordingly, and in all cases not later than the traffic sign becoming applicable to the given vehicle.

This use case does not address the different HMI types and possibilities to present the information (visual, speech, etc.). The HMI possibilities shown in **Error! Reference source not found.** are just illustrative examples.

Figure 7.10-2: Example IVS from user's perspective

From Road Operator's perspective one of the possible scenarios is illustrated in Figure 7.10-3. Not every traffic sign needs to be equipped with an individual RSU. A single RSU can emit IVS messages related to all traffic signs located in its radio coverage area.

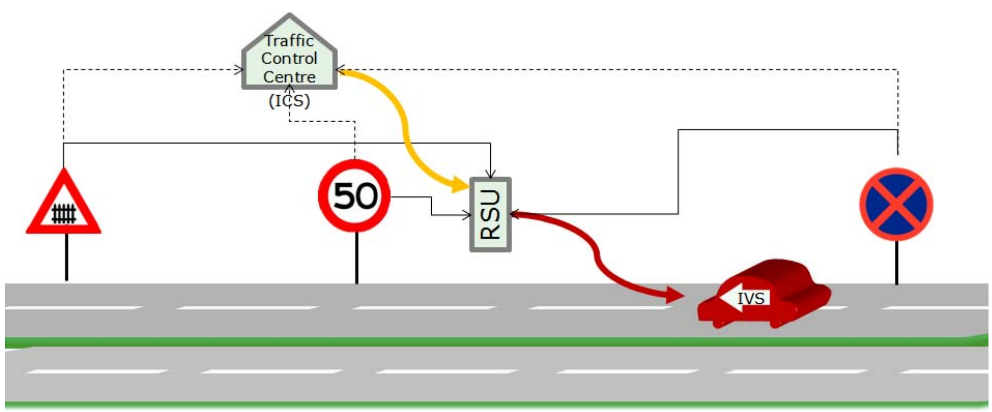

Figure 7.10-3: RSU handling IVS messages of multiple traffic signs

7.10.4 Safety Considerations

The transmission of In Vehicle Information (IVI), and especially as In Vehicle Signage (IVS) can enhance the level of safety, yet it will not be sufficient as single source for safety relevant actions. Typically, it could be verified with the information obtained with a different mechanism, e.g. by using video-detection functions of the vehicle. The reliability and validity of each individual information source needs to be approved to get a classification, if the necessary level of safety can be reached for the use case [28].

Transmitting IVI messages over both, V2I PC5 and V2N Uu communication links simultaneously may be investigated to improve radio reception reliability.

7.10.5 Trial Set Up and Requirements

7.10.5.1 Trial Set Up

The demonstration and evaluation of this use case requires at least one (1) vehicle, equipped with V2I functionality. On infrastructure side there is a need for at least one (1) signal unit placed on roadside on the motorway testbed on the A9, which is connected to the virtual Traffic Control Center (TCC).

7.10.5.2 Communication Requirements

Modules capable of sending, receiving and processing IVI-Messages in a secured way on both Uu and PC5-link.

7.10.5.3 Performance Requirements

The In-Vehicle Information service should provide the following data and information. Note: the message sets contain both, the information on the sign itself but also additional, contextual information.

At least the following information needs to be sent by the R-ITS-S:

- Signage (identification / code)
    - Type of signage (danger, priority, prohibitory, mandatory etc.);
    - Identification of signage (e.g. against a catalogue);
    - Content (e.g. max. 100 km/h);
    - Time validity;
    - Message Priority;
    - Message type (informative or mandatory);
    - Vehicle classification.
- Coverage
    - Ideally road and direction of relevance, at least the exact position of the signs
    - Minimum area and direction of awareness expressed as waypoints on the approach to which the vehicle can match its own trajectory (traces)

Also some concrete physical information need to be defined and set:

- The location where the R-ITS-S is installed, having direct impact on where and when the information will be transmitted from the R-ITS-S, taking into account the awareness and relevance areas.

Additional information (e.g. messages only relevant further away) should be transmitted at the same location as the “relevant” information. Due to capacity restrictions on the transmission channel, additional information may however not be sent out at all.

7.10.6 Procedures

Sending signage information from the TCC to the vehicles

When sign switching is triggered in the TCC, in addition to sign normal control actions (not part of the virtual demonstration center) IVI messages are created. They are forwarded to geographically relevant R-ITS-S and sent out via PC5 (or Uu) at these locations. Vehicles driving through the coverage area of such an R-ITS-S receive these IVI messages.

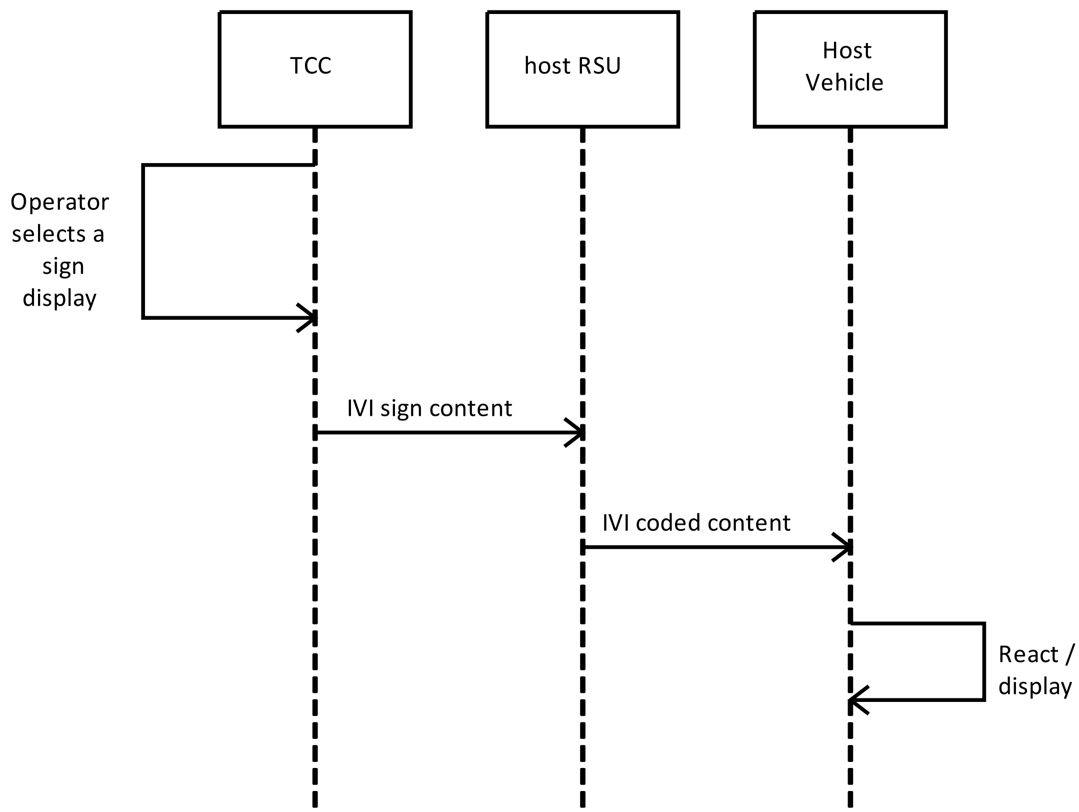

Figure 7.10-4: IVI System drawing

IVI Location Encoding

The geographic validity of electronic signage on the highway / inter-urban network starts at the sign gantry displaying the electronic signs itself and ends at the beginning of the next sign gantry, as depicted in Figure 7.10-5 Static Signage is either based on the same principles or simply has explicit start and endpoints and therefore will not be addressed individually in this document.

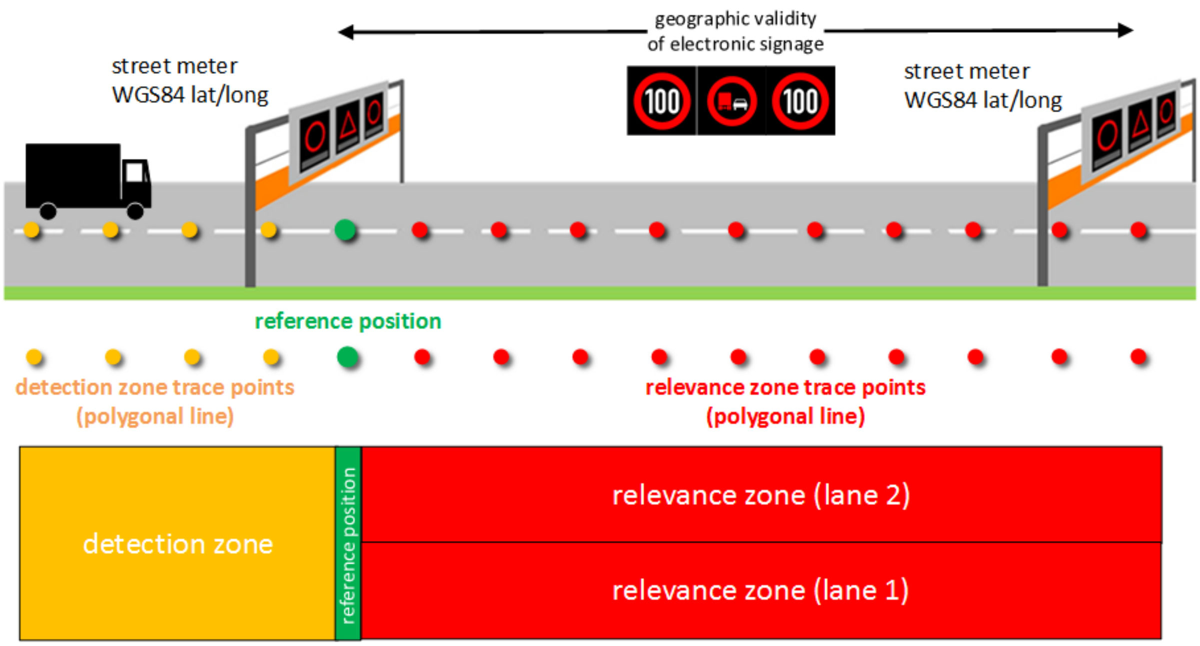

Figure 7.10-5: IVI Location Encoding

The middle of the carriageway at the exact position of the sign gantry is then used as the **reference position** of the IVI message depicting the content of the electronic signage.

In approach to this reference position, a **detection zone** is provided as a polygonal line of WGS84 latitude / longitude coordinates, resulting in several detection zone trace points.

The **relevance zone** covers the area where the IVI message is applicable, again using a polygonal line of WGS84 latitude / longitude coordinates, resulting in multiple relevance zone trace points, starting at the reference position and ending at the reference position of the next sign gantry. Relevance zones can either be specified for the whole direction of traffic / carriageway or further narrowed down into lane specific relevance zones.

Location encoding is primarily based on street meter values. Several projections onto geographical map databases allow for the automated retrieval of WGS84 latitude / longitude coordinates for every street meter value. WGS84 coordinates needed for the reference point and the trace points that make up the polygonal lines for both detection zone as well as relevance zone(s) can therefore be provided directly by the TCC when passing Electronic Signage data to the C-ITS-S.

Until Release 2 (March 2015), available automated projections at the TCC were based on older systems and requirements. Since Release 3, a better, more precise projection based on GIP (the Austrian nationwide transport graph) is available.

7.10.7 Measurements

In order to characterize the system and evaluate the performance, some measurements shall be made:

- Timestamp when the IVI message is emitted to the car
- Timestamp when the signs change (only in case of VMS)

7.10.8 Expected Outcome

Prove that IVI is reliably working in combinations of PC5 and Uu under all tested conditions.

Potential performance advantages versus DSRC are expected for range, specifically in non-Line-of-Sight scenarios, which might also translate into higher reliability or a higher speed range.

7.11 Roads Works Warning (RWW) & other warnings

7.11.1 General Description

Figure 7.11-1: Road Works Warning

Hazard warning, today often realized in RDS-TMC or TPEG2-Service, is a key element in connected driving.

Roadworks warning (RWW) at construction zones is realised using Decentralized Environmental Notification Messages (DENM).

Warnings may be emitted just from the safety-trailer using its sign shown. In addition a Traffic Control Center can add further information on the roadworks layout or the entire situation.

RWW is a fully agreed use case in C-ITS corridor countries and beyond.

Usage of DENM/warnings inject local “electronic knowledge” on risk to our safety systems.

In average, every warning trailer gets involved in an accident approximately every 2 years, with often injuries or even fatalities occurring. With the RWW system the lifetime of the trailer and the security of construction zones are increased.

7.11.2 Objective

RWW has the following objectives:

- improve safety of construction zones
- increase lifetime of warning trailers
- make warning trailers easier to recognize in the traffic.

7.11.3 Description of Relevant Scenarios to Investigate

The scenarios can be demonstrated on motorway and also inter-urban environment.

In the minimum trial setup scenario a local road works warning message is to be exchanged between a road works warning trailer (represented by a "Trailer-"RSU) and the Host Vehicle. Messages are directly exchange locally using PC5.

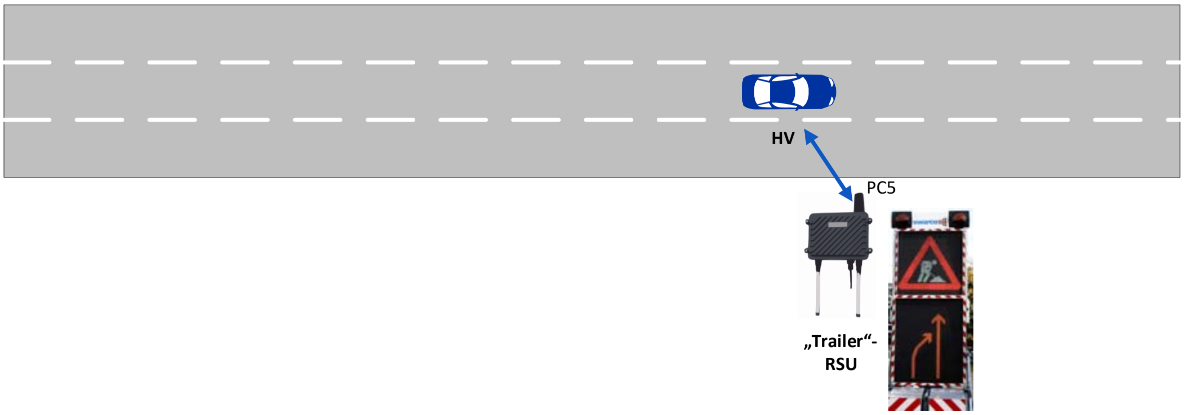

Figure 7.11-2: RWW simple scenario

In the extended / "General Warning" scenario warning messages may be sent by either a remote vehicle and/or the Traffic Management Centre. Message Transmission involves both PC5 and Uu communication.

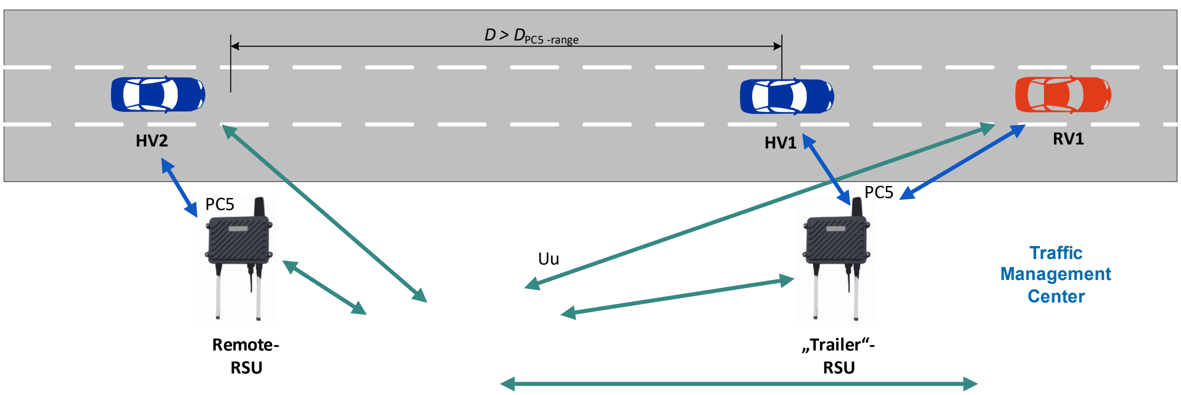

Figure 7.11-3: RWW extended scenario

7.11.4 Safety Considerations

Warning Trailer and other Warnings are used:

- to improve safety at hazardous locations
- to allow detection of incidents issued by vehicle and use them in traffic management and –control
- to increase reach out of warnings disseminated from traffic services in addition to classical dissemination technologies.

7.11.5 Trial Set Up and Requirements

7.11.5.1 Trial Set Up

The minimum trial setup involves a Roadside Unit ("Trailer-"RSU) acting as a Roadworks Warning Trailer and a Host Vehicle (HV) to interact in a "standalone RWW" scenario. In this scenario the RSU provides a Roadworks Warning message to the vehicle.

In the extended / General Warning Setup the "Trailer-"RSU is connected to the network service as well as to a Traffic Management Centre (TMC). Furthermore another Vehicle (Remote Vehicle RV) and another RSU (remote RSU) can be added in order to show scenarios on

- Message origination from the Traffic Management Centre
- Message origination from the Remote Vehicle RV
- Combined Message distribution via V2I/I2V and V2N managed by the network service

7.11.5.2 Communication Requirements

In the minimum scenario "Trailer-"RSU and HV need to connect via PC5 independent from any network.

In the extended scenario, the distance of the two vehicles shall be larger than the V2V PC5 communication range. Thus, the RV or at least the remote RSU in its vicinity shall be connected by Uu to the message service of the network as well as the Traffic Management Centre (TMC).

7.11.5.3 Performance Requirements

The warning scenarios shall be designed to test latency at high vehicle speeds on German motorways (up to 250 km/h)

Some scenarios in times and speeds assuming braking-acceleration and no reaction time are presented in the following table:

Table 7.11-1: RWW performance constraints

speed v_0		V2X range assumed	in range	acceleration a	target speed v1 (speed limit) v_1	time to target speed $\frac{v_1 - v_0}{a}$
250 km/h	69,44 m/s	800 m	11,5 s	-6,0 m/s	100 km/h	6,9 s
250 km/h	69,44 m/s	500 m	7,2 s	-6,6 m/s	80 km/h	7,2 s
150 km/h	41,67 m/s	204 m	4,9 s	-4,0 m/s	80 km/h	4,9 s
100 km/h	27,78 m/s	500 m	18,0 s	-2,0 m/s	60 km/h	5,6 s

This shows that communication ranges and latency measures are relevant: In case of high speeds distance / time may be too short in combination with low acceleration or low range.

7.11.6 Procedures

Roadwork Warning: The Trailer with RSU sends Information to the cars when it is activated. The RSU gets additional information by the traffic control center. The trailer with RSU send DEN-messages to host vehicle. Host vehicle reacts (warn driver and/or slow down).

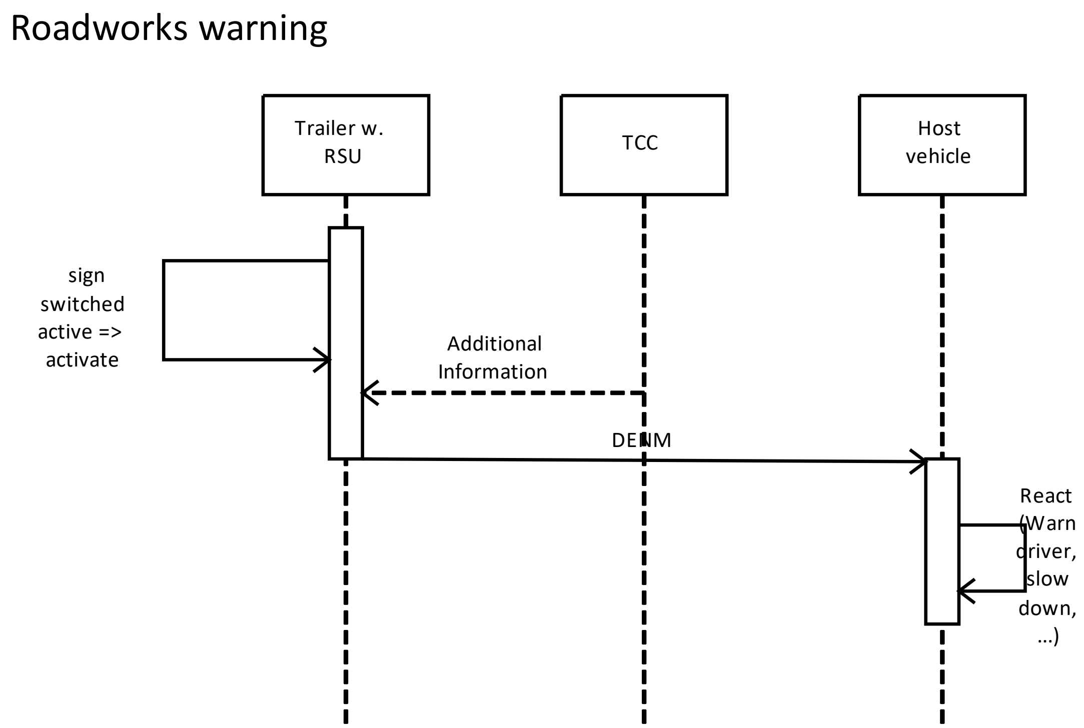

Figure 7.11-4: Procedures Roadworks Warning basic

Vehicle Hazard Warning: DEN-Message (e.g. on heavy rain) is issued in the Remote Vehicle. A RSU nearby receives the message and sends it to Traffic Control Center. There the message is processed (e.g. shown in the Centre) and sent to a RSU in the vicinity of the relevant warning location where a Host vehicle receives the warning. In the scenario the Host vehicle is too distant from the remote vehicle so that it would have missed the warning on a direct way if there was no infrastructure / network support.

In a second scenario the message issued from the remote vehicle is delivered directly to the host vehicle (i.e. no local RSU or center is involved).

In third case a message originating from the TCC is distributed by the network to the host vehicle (i.e. here no RSU is involved).

The TCC can either distribute the messages via the RSUs using PC5, or over the mobile network using radio broadcast on Uu.

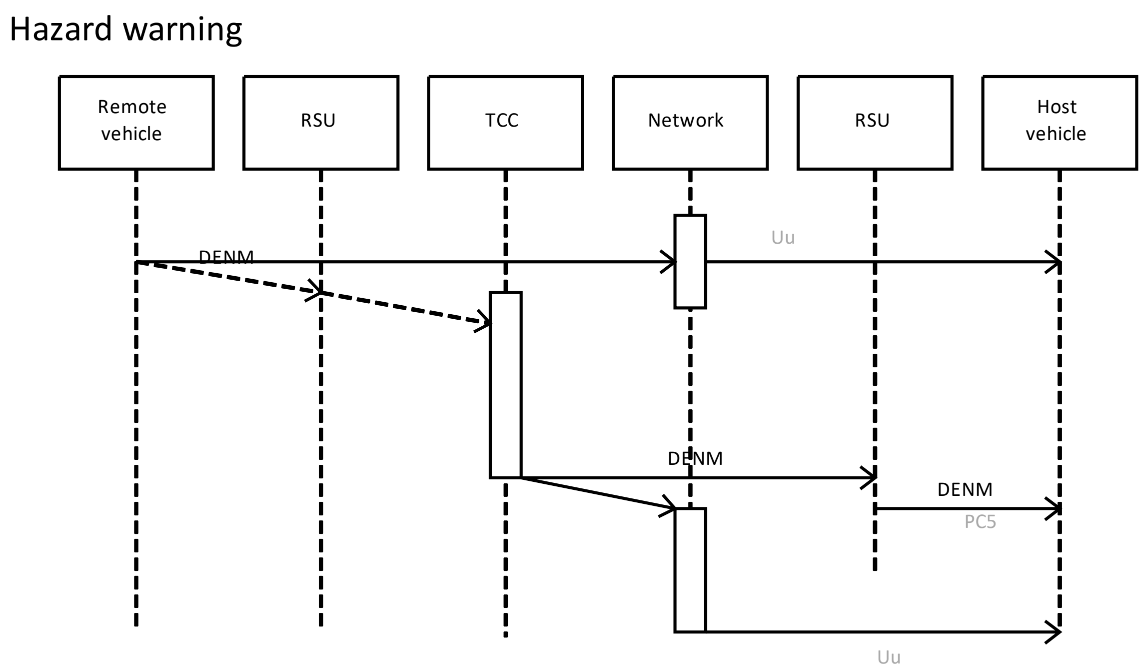

Figure 7.11-5: Procedures Roadworks Warning extended

7.11.7 Measurements

To analyze transmission and processing latencies as well as reliability of message reception, it is sufficient to log all CAM and DENM sent and received by the ITS Stations (vehicles, RSUs, Centers) involved in the test scenario. It is assumed that all logged messages are time stamped using accurate precise GNSS time information.

7.11.8 Expected Outcome

Message delivery times and comparisons between scenarios.

It is expected that the dissemination of messages via PC5 and Uu in any combination is fast (exact latency measurement to be determined) and that the dissemination performs regardless if message is issued by center or vehicle over all channels in the respective Geo-Area for which the message is valid.

7.12 Network Availability Prediction

7.12.1 General Description

V2V services require that a very high percentage of safety messages are successfully delivered to other traffic participants within a certain deadline. The failure to comply with these requirements renders the road safety service completely useless and even harmful to the users relying on it. Current wireless communication systems are typically not designed to provide reliability at all times and in every reception scenario, as this would result in an overdesigned system with an inefficient air interface in terms of data rate and power consumption. However, the future wireless solutions especially for vehicular networking must be able to guarantee a certain level of reliability almost 100% of the time (e.g., Co-ordinated driving). This mode of operation which is currently not supported by today's systems is called the Ultra-Reliable Communication (URC).

The METIS project identifies two classes based on the latency requirements [25] [26]. They are

1. URC over a long term (URC-L) dealing with applications that require a minimal rate over a longer period (>10 ms). Examples of such applications include V2I/V2N Teleconferencing, over the air software update (OASU) etc.
2. URC over short term (URC-S) dealing with applications having stringent latency requirements (≤10 ms), such as V2V safety messages etc.

An alternative approach is to enable such URC applications only when the link conditions are favorable enough and also provide explicit warnings to the driver / service when the reliable link is absent. This makes the communications system functionally safe in the sense that it can safely manage any potential link failures. This requires the wireless communication systems design to include some form of predictive analytics that would calculate the network availability (defined as the presence/absence of link reliability) with a certain guarantee [24].

7.12.2 Objective

This use case will demonstrate that the HV can warn the driver/service sufficiently early of any future V2V, V2I or V2N link failures along the trajectory ahead and if necessary, take corrective measures in order to mitigate the risks associated with those link failures.

7.12.3 Description of relevant scenarios to investigate

Link prediction in general can be applied to any kind of links (V2N, V2V, V2P and V2I). However, due to the short time nature of the V2V and V2P links and also due to the unavailability of link quality information for the V2V CAM messages, we focus only on V2N links. In this regard, the following traffic scenarios will be investigated:

1. The communication link between the vehicle and the RSU or the Network (V2I or V2N) is not available for 't' seconds starting from T_S

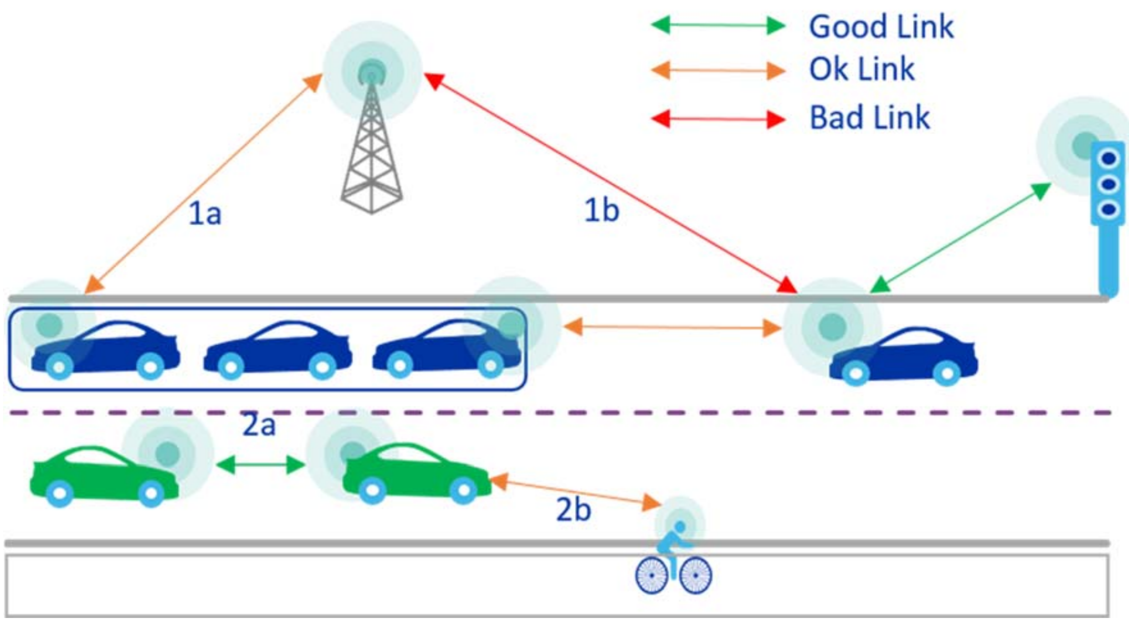

Figure 7.12-1: Network Availability Prediction for different Vehicular Links

Figure 7.12-1 shows some example availability indications for different vehicular links. A *Good* link is defined as the link that satisfies the reliability and latency constraints of all types of applications (including ultra-reliable applications such as network coordinated autonomous driving, safety messages etc.) for the intended duration of its usage. An *OK* link is the link that allows continued usage of the link in degraded mode (applications with moderate to low latency and reliability requirements). A *Bad* link is defined as a link that does not provide any kind of guarantee for the transmission success but can still be used to send and receive non-critical information. (e.g., internet browsing)

7.12.4 Safety Considerations

Wireless communication technologies such as 802.11p, Bluetooth and ZigBee have already found widespread use in the vehicular and industrial domain but use cases for safety-related applications are still rare. One major reason for this is the unpredictability of the wireless channel and secondly, due to the lack of comprehensive risk and hazard analysis of such wireless communication technologies.

Having an indication of the link reliability for the subsequent transmission intervals would improve the overall reliability and safety of the application in the sense that suitable corrective measures can be employed in case of bad link conditions. Presently, such a kind of approach is used intrinsically by network operators in the form of adaptive Modulation and Coding (MC) using CQI mapping table to make a prediction on the next time slots and depending on the prediction, apply the appropriate MC scheme. However, making such mechanism explicit and visible to the application would also allow the V2V service to take corrective measures locally thereby enhancing the overall safety and reliability.

7.12.5 Trial set up and requirements

7.12.5.1 Trial set up

The demonstration requires at least two cars equipped with V2X modules that are connected simultaneously with the network (V2N), Infrastructure (V2I) and to each other (V2V). The link quality is measured by means of the available link statistics such as RSSI, SNR, Packet Delivery Ratio etc. For link prediction, additional information such as Radio Coverage maps are also necessary.

For the purpose of trail, URC-L applications such as Over the Air Software Update (OASU – V2N), V2V Video Calling can be demonstrated.

7.12.5.2 Communication requirements

Capability for all concerned vehicles to receive and process V2X co-operative messages (CAM) with basic container and Vehicle High Frequency container. Additionally, the following communication requirements apply

- Minimum SNR
- Maximum Packet Error Rate (PER)
- Maximum tolerable Latency

7.12.5.3 Performance requirements

For the availability estimation, the following performance requirements apply

- Maximum HV Speed

7.12.6 Procedures

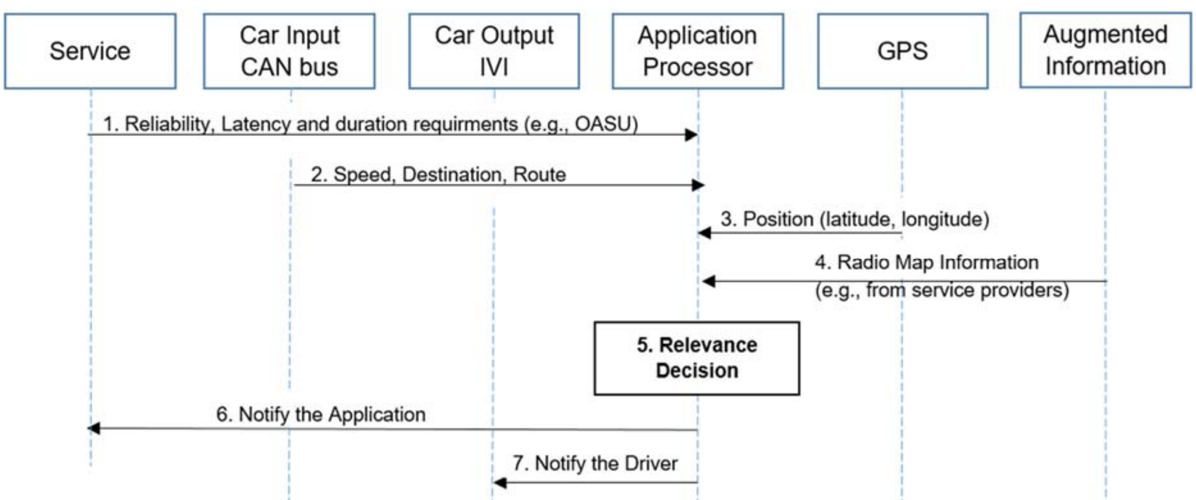

Figure 7.12-2: Sequence Diagram - HV

An application requests a Reliable Transmission Link (RTL) by sending an Availability Request (AR) to the Application Processor. Depending on the implementation details, the AR contains information such as the packet size, the maximum acceptable delay until successful reception or the maximum tolerable error probability. The Availability Estimation Mechanism (AEM) in the application processor is designed to indicate to the application the availability of the RTL for the forthcoming transmissions given the AR requirements. For the availability estimation, the AEM needs to monitor the channel conditions, e.g., by evaluating the Signal-to-Noise and Interference Ratio (SINR) and/or the ACK/NACK statistics of the retransmission protocols used at link level. Typically, the Al is a binary value, i.e., either RTL available (AI=1) or unavailable (AI=0). After indicating the RTL availability, the application will be able to use it by transmitting data packets over the RTL.

7.12.7 Measurements

The following measurements from the HV are needed in order to compute the availability of RTL.

1. Receiver SNR
2. RSSI
3. ACK/NACK statistics
4. Location information (GNSS) and Velocity

7.12.8 Expected Outcome

To show that the wireless technology is functionally safe in the sense that it can handle potential link failures and go into a fail-safe mode. In any other cases, it would explicitly warn the service and the driver about its inability to deliver data according to the application requirements.

8 Performance Evaluation

8.1 Introduction

This section describes the performance evaluation methodology and the information to be logged by the trial system to enable offline validation that the KPIs defined for each individual use case are fulfilled. The KPIs itself are defined in Section 6. The requirements applicable to each individual use case are given in Section 7. General requirements on position location performance which are applicable for all use cases are defined Section 8.5.

8.2 Logging Data

Every CAM and DENM sent or received via V2V, V2I and V2P by a device will be logged by the Measurement Subsystem together with the following information for every ITS device participating in the test setup (including vehicle and roadside ITS stations as well as V2P devices involved in the test):

- Timestamp set to precise absolute time obtained by the GNSS component of the system when a message was transmitted or received
- Position location coordinates of the device sending or receiving a message
- Identity of the ITS device
- Velocity of the ITS device
- Transmit power (if not fixed)
- Received signal strength, Signal to Noise Ratio and or C/I

Data radio transmission latencies, packet and message error ratios and range information can be assessed by offline processing of the logged measurement data.

In order to enable assessment of end-to-end latencies, also information received on the CAN bus and messages sent to the Driver Vehicle Interface (DVI) should be timestamped and logged by the measurement system together with appropriate message identifiers.

8.3 Evaluation of Position Location Performance

Since there is no reference information available in the trial system which allows assessment of the position location accuracy for each logged message, it is envisaged to evaluate the position location performance by means of specialized test procedures.

For stationary devices (RSUs, stagnant vehicles) and very slowly moving V2P devices the exact reference position can be determined with high-precision GNSS instruments.

The reference position of a vehicle in movement could be logged by executing test drives with one or two onboard video camera(s) with accurate time information inserted into the camera video pictures. From the camera pictures and the known positions of visible landmarks (e.g. reflector posts) along the drive way it is possible to compute a reference position for the vehicle. The accurate timing information allows correlating the reference position obtained from the video with the position location information included in the logged CAM messages sent by the vehicle during a test drive.

Since position location accuracy likely depends on the vehicle speed and environment, such tests need to be executed at different vehicle speeds, traffic scenario (urban, suburban, highway) and possibly different weather conditions (e.g. clear sky versus heavy rain).

With this approach, position location performance is essentially assessed separately by means of an "offline procedure". The position measurements in the actual trial of a specific use case could then be trusted with the confidence level obtained in the offline procedure.

8.4 Position location performance requirements

Position location should be accurate enough to support safety applications requiring lane-level accuracy. According to [8], lane-level accuracy requires the position of V2X devices to be accurate to within 150 cm of the vehicle's actual 2-D horizontal Position Reference over 68% of test measurements under Open Sky Test Conditions. The elevation accuracy should be within 300 cm. Open Sky Test Conditions describe an environment in which there are minimal obstructions to the device's view of the sky (see definition in Annex A.7 of [8]). The 68% accuracy requirement under Open Sky Test Conditions results in 95% confidence for relative positioning with lane-level granularity.

8.5 Typical Measurement Setup

An evaluation and detailed analysis of the performance of each individual use case will require sophisticated measurement tools and setups in addition to the specific requirements and processes as outlined earlier in this document for the different use cases. This section gives a brief introduction into such general test setup allowing the capture and logging of important messages (so-called log packets) which carry a precise time-stamp and can be geo-referenced to the vehicles position at the accuracy of the underlying positioning methods and precision available.

8.5.1 Communication Platform Configuration

It is important to document the type/version of the Qualcomm communication platform's firmware and software versions used in the testing. If applicable, any 3rd party firm- or software should be documented as well:

Table 8.5-1: Basic Set of Applications

C-V2X Platform	Manufacturer	Firmware / SW Release
Add respective component name	e.g., Qualcomm	Add respective FW/SW version
Add respective component name	e.g., 3rd Party	Add respective FW/SW version

8.5.2 Measurement Test Equipment Setup

The typical measurement setup is shown in Figure 8.5-1. A test laptop is connected via USB interface to the C-V2X Communication Platform. A specific logging software (e.g., Qualcomm QxDM™ [1]) will be executed on the laptop capturing various information as somewhat detailed further below. Optionally, in addition the laptop can be connected to an external GNSS antenna to log and reference the position of the test vehicle – this might be the case if the logging of the C-V2X platform data would not allow to log and reveal such position data.

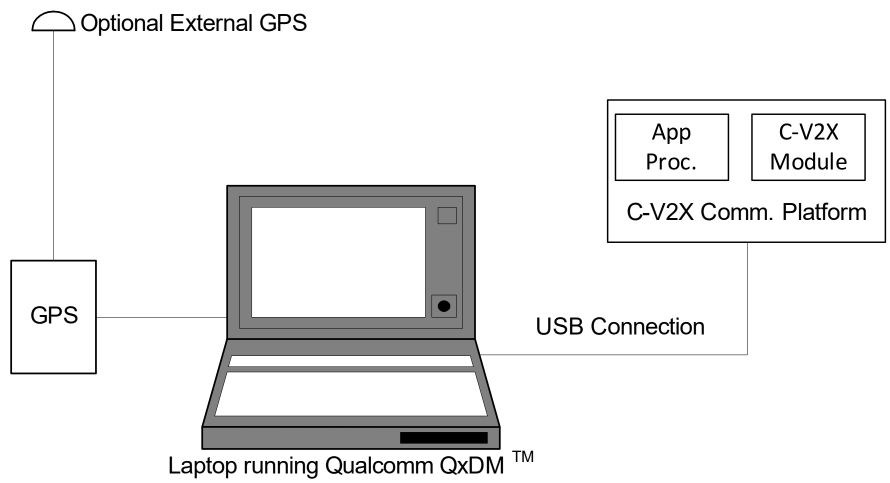

Figure 8.5-1 Test Equipment Setup

Ideally such logging would allow access to the whole protocol stack from application layer via facilities layer down to physical layers. Naturally, also Uu and PC5 interfaces would be logged accordingly. Such logging is called “diagnostic logging”.

8.5.3 Diagnostic Logging

As described above, diagnostic logging of the communication platform will be enabled during execution of the individual test cases. Diagnostic logging follows a so-called “Log Mask”. Appropriate configuration of the log mask will allow to capture all relevant information while irrelevant information may not be logged. Definition of appropriate log masks will be task of the field test teams and will be described in more detail in the relevant documentation. To the purpose of the underlying document only a few potential areas and categories have been listed in table 8.5-2 below.

Table 8.5-2: Basic Set of Applications

Area	Protocol / Layer	Data
Location (GNSS)		GNSS (latitude, longitude, elevation, time)
LTE Uu	TCP/IP PDCP, RLC RRC MAC, Physical Layer	User/application data User/application data LTE system control data user/application data and control data; lower layer, LTE resource usage, delays, …
PC5	ProSe Protocol PDCP, RLC, MAC RRC MAC, Physical Layer	User/application data User/application data V2X system control data User/application and control data
ITS	Application Facility UDP/TCP/IP	Use case/system apps data CAM, DENM ITS lower layer data

It is important to note that all diagnostic logging will be executed using timestamps with a minimum resolution of 1 ms.

8.5.4 Other Test Considerations

Typically, several additional test considerations may apply when executing test cases. A few such considerations are listed below:

1. **Test morphology**: The test morphologies under which the tests will be performed are not specified in the test procedures. It is recommended that the tests be performed at the sites and locations appropriate to the use case.
2. **Network delay**: All testing conducted will be limited to data transfer between the respective entities involved (communication platform, vehicles, RSUs, LTE network). Any external delays or quality of service issues introduced due to some parts or, e.g., public Internet should be considered and negative impacts on tests and performance should be avoided.

3. **Vehicular testing**: Test cars used must have calibrated test equipment. The communication platform used for the tests will be agreed. Details of the test setup will be agreed upon between the parties before commencement of the RF performance acceptance, (e.g., it should be possible to evaluate cable losses etc. induced by the car or other setup).
4. **Drive routes**: Routes should be defined before the test execution and will be used for the respective mobility use test cases.
5. **Laptop operating system**: The expected operating system for the test computers is Windows 7 or 10.
6. **Local time setup in the phone**: It is recommended that the tester set up the internal time of any involved equipment to GNSS time (if not already automatically provided by the tool or equipment) to aid in post processing of the log to debug/analyze results.

9 Summary and Conclusions

This document summarizes the main results of Work Package 1 of the ConVeX project. In this work package the most important use cases for V2X applications have been screened and collected based on extensive literature study which includes results from relevant projects, industry fora and standards organizations, as well as own work based on experience of the participating project partners and perceived customer demand.

The use cases have been categorized and analyzed to derive their key performance indicators which need to be complied by the implementation.

The detailed use case descriptions in this document focus on those applications which are planned to be demonstrated in the ConVeX trial and demonstration system. However, this does not exclude that a number of additional use cases may be implemented and demonstrated in the later stages of the project duration.

It is therefore expected that this document will require updates of existing descriptions as well as additional use case descriptions in the course of the project. Whenever it becomes appropriate, a new revision of this document will therefore be issued.