Fifth Generation Communication Automotive Research and innovation

Deliverable/Report D5.1
Demonstration Guidelines

Version: v1.0

2018-05-31

http://www.5g-ppp.eu

Deliverable D5.1
Demonstration Guidelines

Grant Agreement Number:	761510
Project Name:	Fifth Generation Communication Automotive Research and innovation
Project Acronym:	5GCAR
Document Number:	5GCAR/D5.1
Document Title:	Demonstration Guidelines
Version:	v1.0
Delivery Date:	2018-05-31
Editors:	Bastian Cellarius (Ericsson) Sandip Gangakhedkar (Huawei) Jürgen Otterbach (Nokia)
Authors:	Nadia Brahmi, Tobias Frye (Bosch) Diego Martiñan, Pablo Dafonte, Xavier Abad, Marga Sáez (CTAG) Bastian Cellarius (Ericsson) Sandip Gangakhedkar, Hanwen Cao (Huawei) Luis Sequeira (KCL) Karine Berger, Rémi Theillaud (Marben) Jürgen Otterbach, Artjom Grudnitsky (Nokia) Bernadette Villeforceix, Sylvain Allio, Mathieu Lefebvre, Jean-Marc Odinot (Orange) Jérôme Tiphene, Alain Servel, Antonio Fernández (PSA) Hellward Broszio, Kai Cordes (VISCODA) Taimoor Abbas (Volvo Cars)
Keywords:	5GCAR, Testbeds, Use Cases, Interfaces, Integration Plan, Lane Merge Coordination, See-Through, Sensor Sharing, VRU Protection, Cooperative Maneuver, Cooperative Perception, Cooperative Safety
Status:	Final
Dissemination level:	Public

Abstract

The 5GCAR project demonstrates three different use cases, namely lane merge coordination, cooperative perception for maneuvers of connected vehicles, and vulnerable road user protection. For each use case, this document explains the demonstration scenario, highlights the respective key concepts, and introduces the key performance indicators to be used for the demonstration evaluation. Furthermore, the document illustrates how the demonstrations will be executed and presented during the final 5GCAR project presentation.

The lane merge coordination demonstration optimizes the process of entering a motorway in a cooperative approach. This is enabled by a camera system with object recognition capabilities monitoring the corresponding motorway ramp, and a lane merge coordination entity reachable via the cellular network. This entity plans the cooperative maneuver and distributes corresponding instructions to connected vehicles, while the behavior of unconnected vehicles is predicted and considered.

The cooperative perception demonstration uses vehicle-to-infrastructure and vehicle-to-vehicle communication for enabling long-range and short-range sensor sharing between vehicles for safer and more efficient maneuvers. The long-range sensor sharing uses an on-board camera for object detection and shares this information with other connected vehicles. The short-range sensor sharing is enabled by a "see-through" application which uses low-latency video streaming from an on-board camera of a vehicle to allow a rear vehicle to see through it over a direct communication link between the vehicles.

The vulnerable road user protection demonstration uses a network-based positioning and collision prediction system for preventing collisions that cannot be predicted with in-vehicle sensors only. This is the case when pedestrian and vehicle are not in line of sight to each other. To achieve this, the vehicle and the pedestrian send out broadband 5G reference signals to several synchronized base stations. A central network element estimates the absolute positions using the individual time difference of arrival measurements. These measurements are fused with any available sensor data from the vehicle and the pedestrian to predict the trajectories of the users based on a motion model and a map. In case the trajectories indicate a potentially critical situation an alert message is triggered.

Executive Summary

The 5GCAR project will demonstrate three different use cases, namely:

1. Lane merge coordination,
2. Cooperative perception for maneuvers of connected vehicles, and
3. Vulnerable road user protection.

For the implementation of the respective demonstrations, parties from the telecommunication and the automotive industry are involved, as well as academia and Small and Medium-sized Enterprises (SMEs), covering a diverse set of demonstrated aspects. Towards the end of the project, these demonstrations will be shown on the UTAC-CEVA test track in Montlhéry, France, as part of a larger event.

The lane merge coordination demonstration is a cooperative maneuver for optimizing the process of entering a motorway, for a mixture of vehicles that can and cannot communicate. This is enabled by having a camera system with object recognition capabilities monitoring the lane merge area. Furthermore, the vehicles send information about themselves to a central coordination entity, which first combines this information with the camera output, and then devises a maneuver in real time. Corresponding driving instructions are subsequently communicated to the affected vehicles, next to background traffic such as entertainment video streaming. The coexistence of these two data traffic types is enabled using Network Slicing and Quality of Service, combined with a distributed cloud deployment and a messaging hub for efficient communication over the cellular network. While the use case itself targets autonomously driving vehicles, and the communication KPIs are formulated accordingly, the demonstration will be presented using human drivers. A human-machine-interface will be used for giving driving instructions to the respective driver.

The cooperative perception demonstration shows the benefit of vehicle-to-infrastructure and vehicle-to-vehicle communication for enabling, respectively, long-range and short-range sensor sharing between vehicles for safer and more efficient maneuvers. The long-range sensor sharing is enabled by an on-board camera and sensor-fusion system that detects all, connected as well as unconnected, vehicles in the vicinity and shares this information over the cellular network to nearby vehicles. Thus, the perception of the latter is extended resulting in more informed maneuver decisions, particularly while navigating blind intersections. The short-range sensor sharing scenario is enabled by a "see-through" application which uses low-latency video streaming from an on-board camera of a vehicle to allow a rear vehicle to see through it, thereby enabling a safer or more efficient overtaking maneuver. The low-latency video streaming is realized by highly reliable and low latency direct communication between the two vehicles. Both scenarios utilize a driver interface to demonstrate the benefit of the aforementioned key concepts and provide a preview of how 5G integrates into the connected vehicle.

The vulnerable road user protection demonstration aims at extending today's vehicle-internal VRU protection systems, which are limited in challenging scenarios such as dense urban settings with non-line of sight between vehicle and VRU, which is a limitation of vehicles' on-board

sensors. To address this, a network-based positioning and collision prediction system is established. The targeted scenario is a crosswalk over an urban road, where a pedestrian is walking toward to zebra-crossing from one side of the street, and the vehicle approaches the zebra-crossing, although many other scenarios are possible and under discussion before the final demonstration. The vehicle and the pedestrian send proprietary broadband 5G uplink reference signals to several base stations, and each base station then measures the time of arrival of the signals to allow triangulation of the vehicle and pedestrian positions. Additionally, the vehicle and the pedestrian provide sensor data, such as GPS measurements, speed, yaw rate, and orientation. All this information is fused in a network element which estimates the trajectories of the users based on a motion model and a map. Finally, an alert message is triggered if a potentially critical situation is detected, and a corresponding warning is transmitted from the network to the vehicle and the pedestrian. A special human machine interface in the vehicle and communication device at the pedestrian makes them aware about the upcoming dangerous situation. All tests are executed off public roads, where privacy laws are respected, and the safety of all participants is ensured. The pedestrian VRU in the demo specifically will be a dummy.

Contents

List of Abbreviations and Acronyms

3GPP	Third Generation Partnership Project
5G-NR	5G New Radio
5G-PPP	5G Private Public Partnership
BS	Base Station
CAN	Controller Area Network
CPU	Central Processing Unit
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPU	Graphics Processing Unit
HMI	Human-Machine Interface
HDmap	High Definition map
ICMP	Internet Control Message Protocol
IMU	Inertial Measurement Unit
ITS	Intelligent Transportation Systems
ITU	International Telecommunication Union
IVT	Inter-Vehicle Time
JSON	JavaScript Object Description
KPI	Key Performance Indicator
LOS	Line Of Sight
LS	Location Server
MBB	Mobile Broadband
MEC	Mobile Edge Computing
NLOS	Non-Light Of Sight
OBU	OnBoard Unit
OTDOA	downlink Observed Time Difference Of Arrival

PDCMS	Pedestrian Detection and Collision Mitigation Systems
PRS	Positioning Reference Signal
QoS	Quality of Service
RAT	Radio Access Technology
ToA	Time of Arrival
TTFF	Time To First location Fix
UC	Use Case
UE	User Equipment
RSU	RoadSide Unit
RTK	Real-Time Kinematic
RU	Road User
TDMA	Time Division Multiple Access
TX	Transmitter
SDU	Service Data Unit
SMEs	Small and Medium-sized Enterprises
SNR	Signal to Noise Ratio
UE	User Equipment
UTDOA	Uplink observed Time Difference Of Arrival
V2I	Vehicle-to-Infrastructure
UTAC-CEVA	United Test and Assembly Center Ltd - Centre d'Essais pour les Véhicules Autonomes (i.e. test center for autonomous vehicles)
V2V	Vehicle-to-Vehicle
V2N	Vehicle-to-Network
V2N2V	Vehicle-to-Network-to-Vehicle
V2X	Vehicle-to-Everything
V-UE	Vehicular User Equipment

1 Introduction

The 5GCAR project will demonstrate three use cases among the ones defined in Deliverable D2.1 [5GC17-D21]. This document presents the demonstrations that will be executed in detail, highlights the respective key concepts, and introduces the key performance indicators (KPIs) to be used for evaluating the success of the implemented solution. Furthermore, a set of demonstration guidelines is included, elaborating on how the demonstration will be executed and presented as part of an event at the end of the 5GCAR project.

Finally, it should be noted that all demonstrations will be executed on dedicated testing areas, i.e. off public roads, where privacy laws will be respected. Additional safety measures are taken to ensure that humans will not be endangered. The details are elaborated in Annex A.

1.1 Objective of the Document

In this document, each planned demonstration is described in detail w.r.t. the demonstration scenario, the key concepts involved, and how the respective demonstration will be executed and presented.

The purpose of the document is to illustrate the necessity of the corresponding use case, elaborate on the different features needed for the solution that will be implemented, and most importantly form a baseline for the execution, evaluation, and presentation of the demonstrations. Specifically, as Deliverable D5.2 of the 5GCAR project will elaborate on the feasibility of the implemented solutions, this document provides the baseline for the corresponding evaluation process.

Furthermore, this document is a teaser for an event planned towards the end of the 5GCAR project, where all demonstrations will be presented. To this end, the corresponding test track is introduced, and plans on how to showcase the demonstrations are described.

1.2 Structure of the Document

Every demonstration is described in a dedicated section in this document:

- Lane merge coordination in Chapter 2,
- Cooperative perception for maneuvers of connected vehicles in Chapter 3,
- Vulnerable road user protection in Chapter 4.

For each demonstration, the scenario, key concepts, and demonstration guidelines are included as sections in the respective demonstration chapter.

The scenario description includes not only a summary of the demonstration story, flow, and scope, but also elaborates on requirements on the maneuver, as well as derived requirements on the communication. Furthermore, concrete KPIs for evaluating the implemented solution are defined, which will be used later in the project.

Also, the key concepts of each demonstration are highlighted, and briefly explained. These are partly communication concepts, but also cover other aspects, such as video streaming, object recognition, and collision prediction.

Finally, a set of demonstration guidelines is included, describing how the demonstrations will be executed and evaluated. This includes, e.g., descriptions around how a maneuver will be implemented by using drivers instead of autonomously driving cars, i.e. how the human-machine-interface (HMI) will look like, and how the KPIs defined earlier will be measured in the demonstration setup.

After the demonstration descriptions, plans about an event towards the end of the project are described in Chapter 5, including a brief description of the selected test track, but also how the demonstrations will be presented to an audience.

Document: 5GCAR/D5.1

Version: v1.0

Date: 2018-05-31

Status: Final

Dissemination level:
Public

2   Lane Merge Coordination

2.1   Scenario

The lane merge coordination use case deals with the automated creation of gaps for cars entering a lane, using cellular communication and a centralized lane merge coordination. In the planned setup, a fixed camera installation near the intersection is used to detect road users that are not connected, and thus cannot receive instructions or communicate information about themselves. The setup is depicted in Figure 2.1.
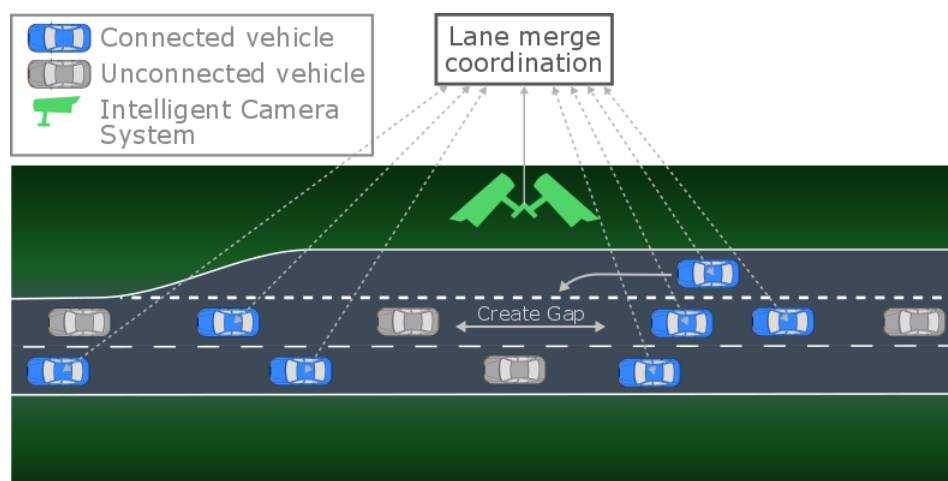

Figure 2.1: In the lane merge coordination use case, a central coordination entity plans the creation of a gap for vehicles entering a lane.

The lane merge coordination procedure is illustrated in four steps in Figure 2.2, and explained in the following.

1. The lane merge coordination gathers a description from each connected vehicle, as well as the descriptions of road users detected by the intelligent camera system. As these descriptions are partially redundant, they are fused to have only one description per user.
2. The lane merge coordination analyzes the road situation and devises a cooperative maneuver when the need arises. In this case, it sends out a maneuver recommendation to each connected vehicle that shall take part in the maneuver.
3. The respective connected vehicles indicate back to the lane merge coordination whether they are willing and capable to comply with the recommendation. If a vehicle does not accept the maneuver recommendation, the traffic orchestrator proposes a different maneuver.
4. A vehicle may decline the execution of a maneuver, but no vehicle does, the maneuver is executed as planned. In this example, the vehicle on the entering lane accelerates and drives onto the target lane, where a gap is created by two connected vehicles that decelerate.
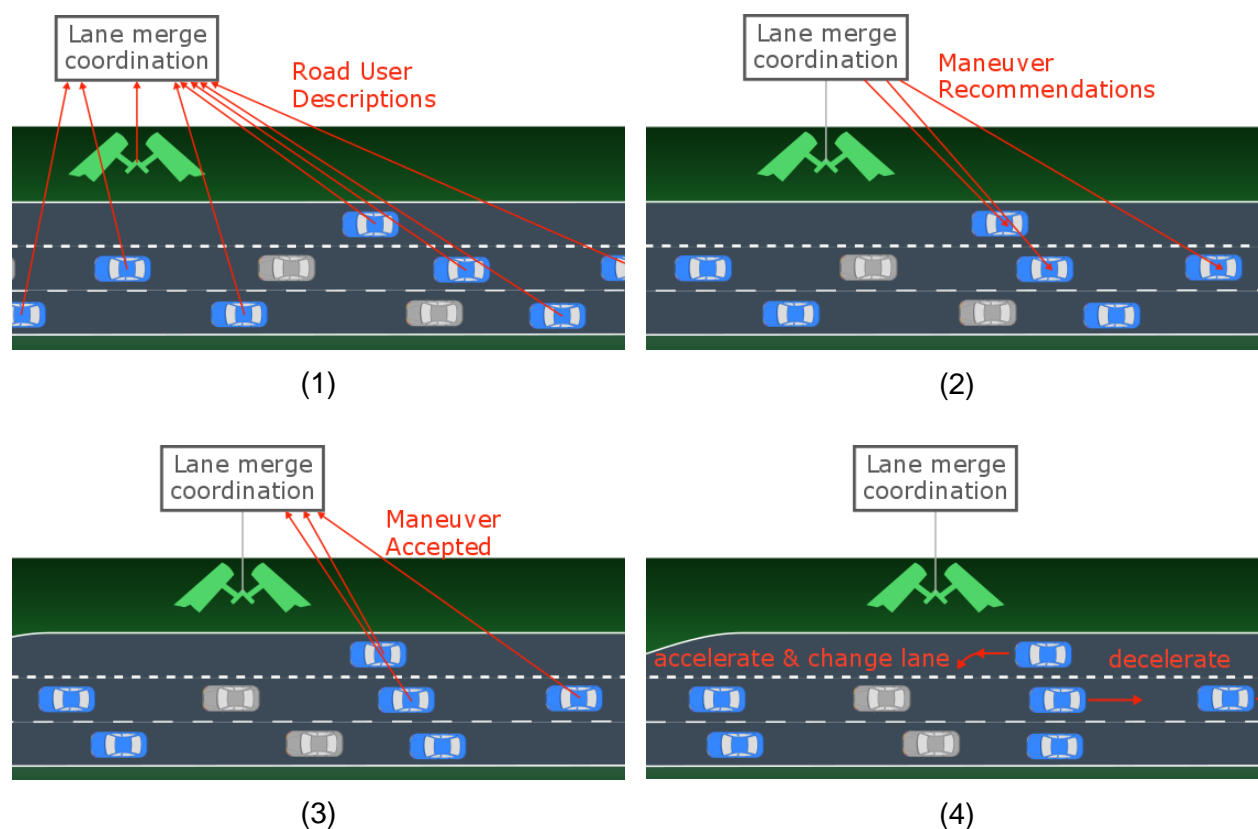
Figure 2.2: The lane merge coordination procedure in 5GCAR is executed in four basic steps, as illustrated in the four pictures.

The gap on the motorway could also be created by making a vehicle change to the left lane, or by making a vehicle on the motorway accelerate. However, the lane change solution has less stringent requirement, and the acceleration solution is often not applicable due to traffic jams or other vehicles in the front, which is why we focus on the solution where a vehicle decelerates to create a gap.

To simulate a real-world scenario, lane merge related messages and background traffic (e.g. HD map download) are sent over the same network in parallel. For maintaining the required end-to-end communication performance, several mechanisms are used as elaborated on in Section 2.2.3.

In principle, the developed solution targets autonomously driving cars. However, in the scope of the 5GCAR project, the driving function will be executed by human drivers, receiving detailed instructions from the vehicle, as described in Section 2.3.1.

For the lane merge, there are requirements on the actual maneuver (e.g. maneuver execution duration, see Section 2.1.1), and requirements on the communication (e.g. maneuver distribution duration, see Section 2.1.2). For the evaluation of the lane merge maneuver, KPIs are defined which measure if the stated requirements are met (see Section 2.3.2).

2.1.1 Maneuver Requirements

In Deliverable D2.1 of the 5GCAR project, several communication requirements are mentioned for the lane merge use case, specifically in Table B.6 [5GC17-D21]. For this demonstration, the requirements on localization (longitudinal and lateral), inter-vehicle distance, maneuver completion time, and relevance area are of special interest. On top of the D2.1 requirements, the acceleration & deceleration should be low enough to be comfortable for passengers, although this is of secondary priority. However, a lower acceleration & deceleration leads to a longer maneuver completion time.

The localization requirement comes from the maneuver coordination. Namely, the lateral localization must allow for a clear association of each vehicle to a lane, while the longitudinal localization must be accurate enough to correctly consider and establish inter vehicle distances, as well as to align vehicles with designated gaps.

The inter vehicle distance must be large enough so that vehicles can stop in time, in case of an emergency. This requirement is not use case specific but must be considered at any given time during the maneuver.

The maneuver completion time and the relevance area are closely related, as the relevance area must cover the whole stretch of road that the vehicles need for executing the maneuver. The entering vehicle exhibits an acceleration phase, while the vehicle on the road exhibits a deceleration phase in our picked scenario, as illustrated in Figure 2.3. Both vehicles converge towards a common target speed. The maneuver completion time and relevance area then refer to the difference between the earliest time and place of action, and the maneuver completion.
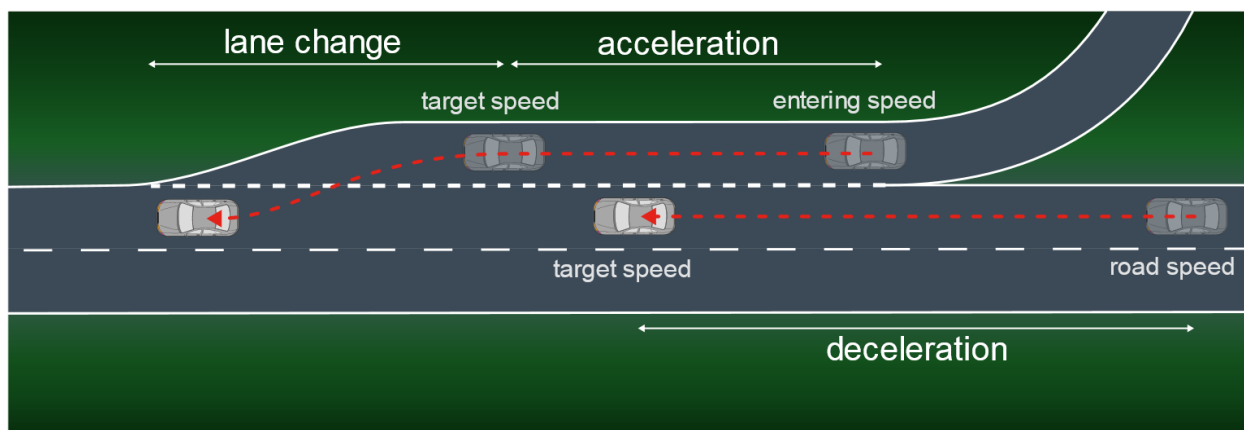

Figure 2.3: The target speed (usually the speed on the motorway) and the initial speed of the entering lane influences the maneuver length for entering a motorway.

Aside from the different speeds, the maneuver length and duration are also influenced by the inter-vehicle time (IVT), i.e. the distance between vehicles in seconds at the current speed of the rear vehicle, and of course the acceleration of the entering vehicles. Furthermore, for the cooperative approach we focus on, the deceleration of vehicles on the motorway, which can happen in parallel, also influences the maneuver length and duration.

In Table 2.1, the maneuver length and duration are shown for different cases, considering human driving and autonomous driving, as well as different target and entering speeds (80 km/h and 130 km/h), and different decelerations of the vehicles on the road.

Table 2.1: Length and duration of the maneuver for human and autonomous driving, for different vehicles speed and accelerations.

Speeds (km/h)	Acceleration (m/s²)	Human driver (standard IVT: 2s)	Autonomous driving (standard IVT: 0.3s)
on road: 80 entering: 60	on road: -2 entering: 2	Duration: 5.3 s Length: 163 m	Duration: 2 s Length: 53 m
on road: 130 entering: 100	on road: -2 entering: 2	Duration: 6.9 s Length: 319 m	Duration: 2.8 s Length: 112 m
on road: 80 entering: 60	on road: -1 entering: 2	Duration: 6.7 s Length: 194 m	Duration: 3 s Length: 75 m
on road: 130 entering: 100	entering: -1 on road: 2	Duration: 8.9 s Length: 393 m	Duration: 4.1 s Length: 159 m

Based on these requirements, the following automotive KPIs have been selected to evaluate the demonstration:

- Minimum inter vehicle distance shall be 2 seconds, with a possibility to be reduced to 0.9 seconds for a maximum duration of 3 seconds, as we are using human drivers in the demonstration, and this is the more challenging lane merge case.
- Maximum acceleration or deceleration shall be 2 m/s² in longitudinal direction and maximum lateral speed shall be 1 m/s (maximal lateral acceleration: 1.5 m/s²) to ensure smooth maneuvers.
- The relevance area shall be 400 m to ensure a complete coverage of the lane merge area and the planning of a smooth maneuver, for all covered cases.

2.1.2   Communication Requirements

In Deliverable D2.1 of the 5GCAR project, several communication requirements are mentioned for the lane merge use case, specifically in Table B.6. [5GC17-D21]. Among these, for evaluating the performance of a service, the primary requirements are availability, reliability, and latency, while the other mentioned requirements are secondary requirements, i.e. they have an impact on the primary requirements, but are not needed to assess the service quality.

The system availability denotes the percentage of time that the system is operational & fully working. This includes (but is not limited to) the communication range, i.e. the maximum distance between a transmitter and its intended receiver with a targeted latency and reliability.

The reliability describes the percentage of messages that are correctly received within a given time window, namely the latency requirement of the service. Congestion and radio interference

are major contributors to low reliability. Both are affected by the overall load, i.e. data rate that all services generate together, and indirectly the respective service data unit sizes.

The latency requirement in the lane merge use case is driven by the need to plan the maneuver in time (i.e. within the maneuver completion time), as well as to react to unforeseen deviations from a planned maneuver (e.g. vehicles driven differently than expected or agreed). This latter scenario poses the most challenging latency requirement, namely the time from when such a deviation is detected, until a corresponding maneuver correction is available at the vehicles.

The corresponding data rate generated by the use case must be supported. The requirement on average data rate per vehicle comes from the service data unit (SDU) size and the periodicity at which it is sent. The requirement on peak data rate on the other hand comes from SDU size and the latency requirement: In order to meet the latency requirement for each packet, packet must be delivered over a channel within this latency. As other latency contributions can be significant depending on the concrete setup (e.g. propagation latency for a centralized lane merge coordination entity), the bitrate needs to support even lower latencies.

Based on these requirements, the following communication KPIs have been selected to evaluate the demonstration, aiming to also satisfy the requirements of autonomous vehicles performing the lane merge maneuver.

- Communication range around lane merge area shall exceed 400m, in order to cover the whole relevance area devised in Section 2.1.1.
- Availability shall be high, i.e. at least 99%, as defined in D2.1.
- Reliability shall be very high, i.e. at least 99.9%, as defined in D2.1.
- Latency shall be less than 30 ms per message, as defined in D2.1. It corresponds to the elapsed time from devising a maneuver in the lane merge coordination system until all concerned vehicles receive the corresponding instructions.
- The SDU size shall be less than 1200 bytes for safety messages and less than 16000 bytes for maneuver messages, at application layer, as defined in D2.1.
- Average data rate shall be lower than 96 kbps per vehicle in uplink, and lower than 128 kbps per vehicle in downlink. This is under the assumption that road user description messages sent at 10 Hz in uplink, and Maneuver messages sent at 1 Hz in downlink.
- Peak data rate shall be at least 320 kbps per vehicle in uplink, and at least 4.27 Mbps per vehicle in downlink, for a latency requirement of 30 ms and road user description messages being sent in the uplink, while maneuver messages are sent in the downlink. For an upper peak data rate bound, an upper bound for other latency contributions must be derived, which depends on the concrete setup.

2.2   Key Concepts

In this section, several key concepts are presented that play major roles in the demonstration. Figure 2.4 depicts the setup with in a little more detail than Section 2.1, and marks the following key concepts:

1. The intelligent camera system incorporates a mechanism to detect vehicles in a live video sequence and estimate their real-world position, as well as other parameters of interest. This is elaborated on in Section 2.2.1.
2. The data collected from the intelligent camera system and from the connected vehicles is partially redundant. Thus, road user descriptions that refer to the same vehicle are identified and merged. This functionality is further described in Section 2.2.2.
3. Based on the collected information on road users in the area of interest, the central lane merge coordination entity devises a cooperative maneuver for the lane merge and sends out individual maneuver recommendations to affected vehicles. How this is done is described in Section 2.2.3.
4. For communicating all the information between the different entities sufficiently fast and reliably, the cellular network is optimized in several ways, while the context-aware V2X Gateway provides a scalable solution for communication between different groups of interest and networks (road authorities, vehicle manufacturers, mobile operators, and others), as described in Section 2.2.3.
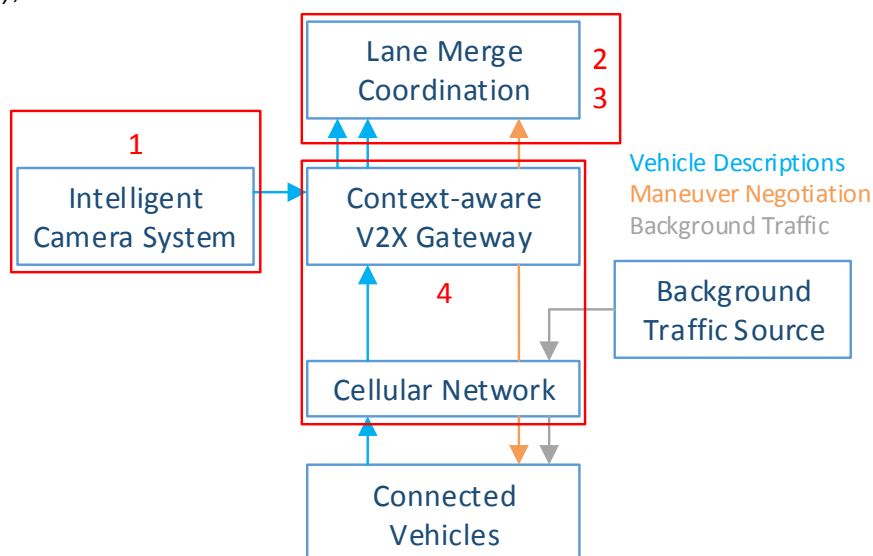

Figure 2.4: The demonstration features four key concepts, as marked in the figure and explained in the text.

2.2.1   Detection of Road Users by Intelligent Camera System

For the lane merge application, it cannot be assumed that every road user is connected to the network. Thus, non-connected road users must be detected, and corresponding descriptions must be communicated. To fulfill this task, an intelligent camera system is installed next to the road (cf. Figure 2.5). The system consists of monocular video cameras observing the relevant scene content which is required for the lane merge. The observed area includes all lanes within a certain visual range. As described in Section 2.1.1, a length of approximately 300m is needed. To cover the required visual range of all lanes in the camera images, three cameras are required. These cameras are mounted on a rig which is attached to a mast at the demonstration course. The cameras are calibrated to the GPS coordinate system to enable measurements in a common

coordinate system. The image signal is processed frame by frame in order to detect and track the vehicles continuously. The developed algorithms estimate the information required for describing each vehicle adequately and generating a corresponding message. This includes parameters such as position, orientation, size, and speed of the road user. Additionally, accuracy measurements for the estimated attributes are provided. These messages are transmitted to the context-aware *V2X Gateway* which is used for the efficient distribution of the messages. The transmitted temporal resolution is given by the temporal resolution of the cameras. Connected vehicles and unconnected vehicles are not distinguished by the camera system. This is done in a *Data Fusion* step as explained in Section 2.2.2.
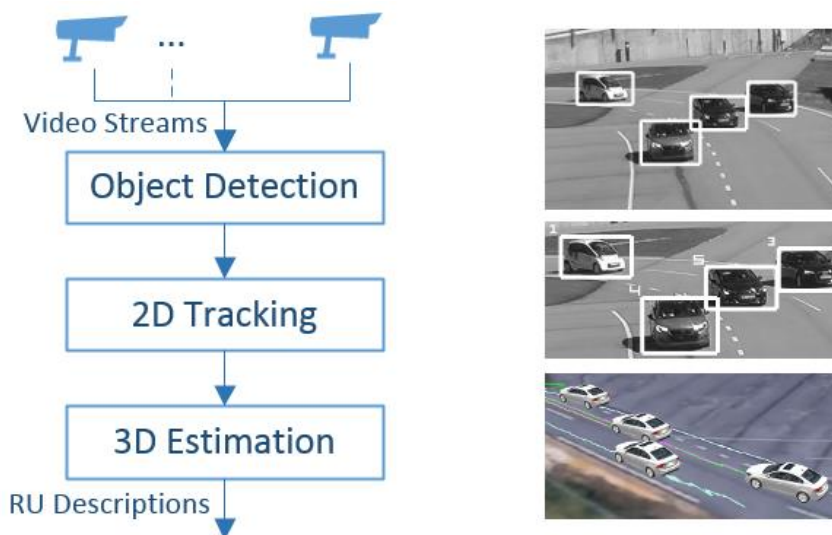

Figure 2.5: The intelligent camera system estimates vehicle attributes, such as position and orientation with respect to the world coordinate system.

2.2.2   Data Fusion

The *Data Fusion* function evaluates vehicle descriptions from different sources with various update rates, based on information carried in the descriptions. The aim is to provide the optimal fusion of incoming information which is used for the lane merge maneuver planning. The *Data Fusion* consists of three main steps as shown in the left part of Figure 2.6:

1. The *Data Synchronization* aligns vehicle descriptions from different sources, taking into account delays and the data processing durations on each system, in order to process all information in the same temporal reference.
2. The *Data Association* matches objects from different sources. This is important since the intelligent camera system provides descriptions for connected and non-connected vehicles. A process of cost minimization is followed, using a cost function based on Euclidean distance or another cost function involving more variables than position (for example, orientation of objects), as illustrated in the right part of Figure 2.7.
3. The final step determines the temporal *Tracking* of the vehicles. For a reliable tracking, object attributes such as position and orientation are predicted using Kalman Filters. A key

point is managing the creation of new tracks in the scene and destruction of tracks going out of it.

The resulting vehicle descriptions are used for the planning of the lane merge maneuver as explained in the following section.
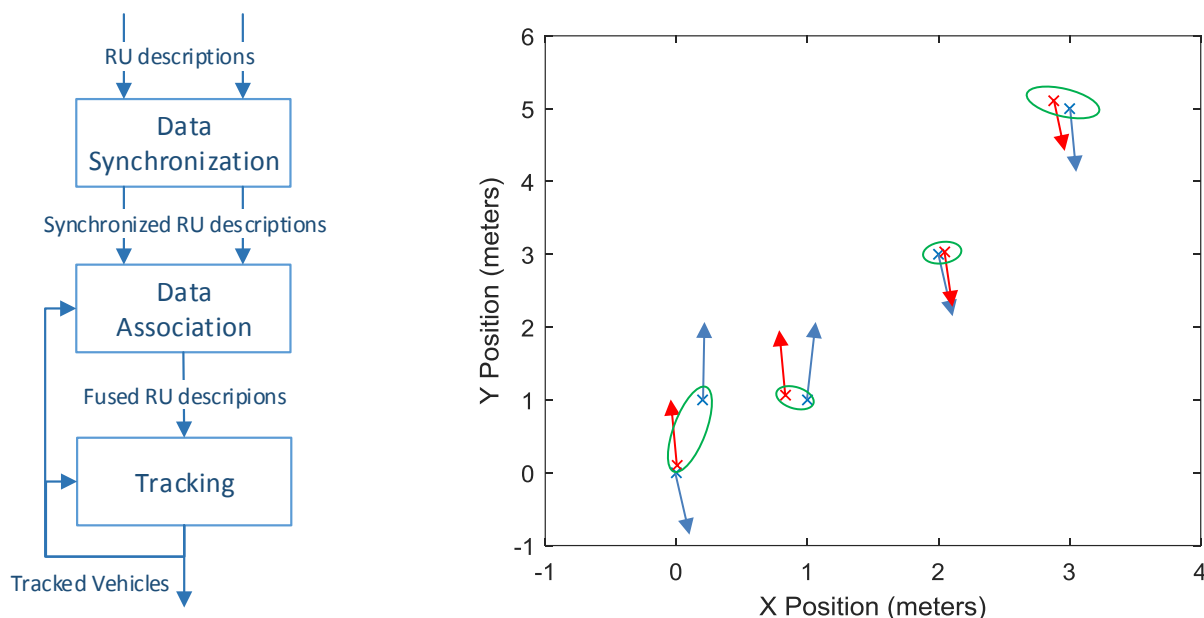

Figure 2.6: Architecture of the data fusion function (left), and illustration of the data association step.

2.2.3 Lane Merge Maneuver Planning

The lane merge maneuver planning function has the purpose of devising maneuvers for individual connected cars in the lane merge demonstration, on the basis of road user information provided by the intelligent camera system and the connected vehicles. The unconnected vehicles influence the traffic flow in the vicinity. For this reason, the maneuver planning function will provide a predictive model for unconnected vehicles that is used to recommend actions to connected vehicles involved in the lane merge. In this context, the maneuver planning function takes into account the information provided by the Data Fusion function (explained in Section 2.2.2), which contains positioning and movement information, and the vehicle status (connected or unconnected) to suggest the corresponding actions. Then, the maneuver planning function will assess their impact on vehicles involved in the maneuver, after this, all maneuver recommendations for the connected vehicles can be adapted accordingly. Each connected vehicle will evaluate the maneuver recommendation and will send back a maneuver feedback with the decision (accept/refuse). If the maneuver is refused by a vehicle, the maneuver planning function would plan a new cooperative maneuver. In case a maneuver was accepted, it might be aborted later, in case the vehicle detects that the driver does not follow the instructions.

For the maneuver planning process, four different states are considered, namely: initial, pre-display, pre-maneuver and target (see Figure 2.7). The initial state (v0,x0,t0) of each vehicle is

known by the maneuver planning function and consists of the available information of both connected and unconnected cars (e.g., velocity and position information), this information is provided by the Data Fusion and was initially obtained by the Intelligent Camera System. The maneuver planning function sends the maneuver recommendations out to the respective vehicles, putting vehicles into the pre-display state (v1,x1,t1), in which each vehicle displays the recommended maneuver. The pre-maneuver (v2,x2,t2) state for each vehicle is based on a reaction (accept/refuse) time estimated in approximately 2 seconds. The respective driver starts executing the displayed maneuver (acceleration, deceleration, lane change) towards the target state (v3,x3,t3) that was predicted by means of the road situation assessment and using the road user descriptions of connected and unconnected vehicles.
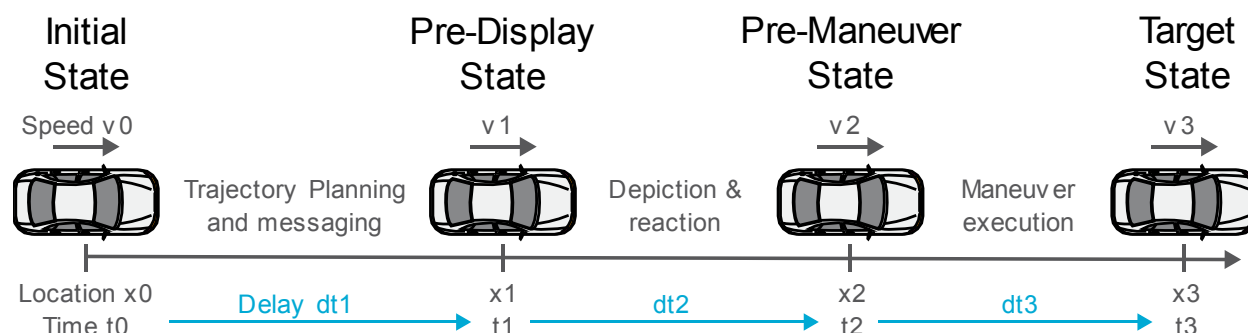

Figure 2.7: Vehicle states during maneuver planning.

2.2.4 Optimized Message Delivery

The basic interconnection between the vehicles and the lane merge coordination used in the demonstration is illustrated in Figure 2.8 (please note that this is a simplified depiction). The communication is established via a cellular network, which consists of the radio access and the core network which may be deployed elsewhere. For the optimization of the communication performance, the following techniques are used.

The core network consists of a user plane, through which all data traffic between vehicles and applications must pass, and a control plane, which is orchestrating the radio access and the core network user plane (e.g. handovers between cells, QoS management, service authentication & authorization). The application space refers to a domain which is outside of radio access and core network. For the demonstration, a specific set of applications that are part of the lane merge coordination runs in the application space.
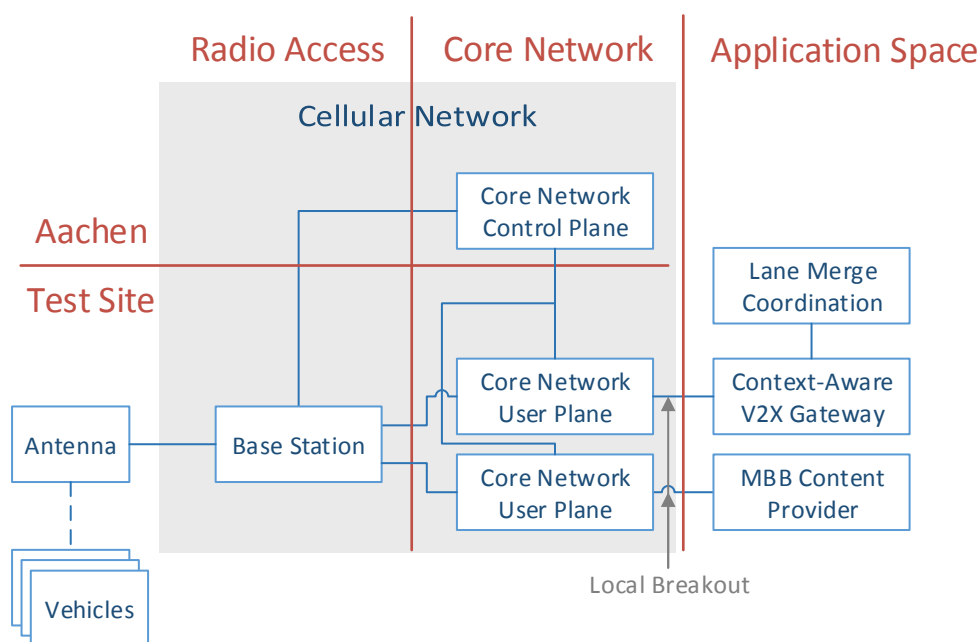
Figure 2.8: The communication between vehicles and entities in the application space is established via the cellular network, consisting of radio access and core network.

Optimized Network Deployment

A fundamental latency contribution comes from the transport of data traffic through the core network user plane, and from there to corresponding application servers. For a centralized core network user plane, i.e. a user plane that is instantiated far away from the radio access, traffic does not only experience extra delay for the transmission but may also suffer from an increased delay jitter caused by network congestion in case of heavy load, if not managed properly. This issue can be mitigated by deploying a local breakout, i.e. a core network user plane close to the radio access, as depicted in Figure 2.8, reducing the transport network distance and disturbance by other data traffic. To fully leverage on this performance increase, application servers must then be collocated with the local breakout.

For the performance increase, only user plane traffic (i.e. the data generated by applications) needs to be optimized, while control plane traffic (i.e. signaling data for mobility, QoS, UE attach, etc.) is served sufficiently well when deployed centrally. Consequently, while the user plane is deployed close to the radio access, enabling a local breakout, the control plane is deployed centrally.

Isolation and Prioritization of Data Traffic

For isolating the mission-critical lane merge communication from other traffic, two Network Slices are instantiated, i.e. the traffic treatment of these traffic types is isolated from each other. Since a private, experimental network is used for the demonstration, there is no other traffic by default. Thus, background traffic is generated by streaming video and/or 3D map data in up- and downlink. As illustrated in Figure 2.8, two different core network user planes are used for the two different Network Slices.

On top of the isolation of data traffic using network slicing, Quality of Service (QoS) is applied for traffic prioritization. This mechanism influences scheduling decisions, where specifically some packets may be sent over a link before other packets that arrived earlier. To facilitate the traffic treatment, different traffic types are associated to QoS classes. While the mission-critical traffic is using a dedicated, prioritized QoS class, the background traffic is served on best effort. Furthermore, the two traffic classes are isolated by using two different Network Slices. Each network slice is linked to one QoS class in this setup, thus effectively prioritizing the mission-critical lane merge communication in one network slice over the background data traffic in the other network slice.

Context-Aware V2X Gateway

The context-aware V2X gateway is used for the efficient distribution of messages within the demonstration setup, as well as for anonymization of vehicle-specific information. Concretely, the V2X gateway is capable of anonymizing messages coming from vehicles, and forwarding them to the lane merge coordination function, as well as distributing messages to vehicles in a defined area, e.g. by application layer multicast.

2.3 Demonstration Guidelines

In this section, guidelines on how to present the demonstration are summarized. This includes human machine interface aspects, as well as KPI measurements.

2.3.1 Maneuver Assistance Interface

Professional human drivers perform the lane merge coordination demonstration. To ensure a precise response to the maneuver instructions sent by the lane merge coordinator, the drivers are notified of the maneuvers in advance on a specifically developed HMI.
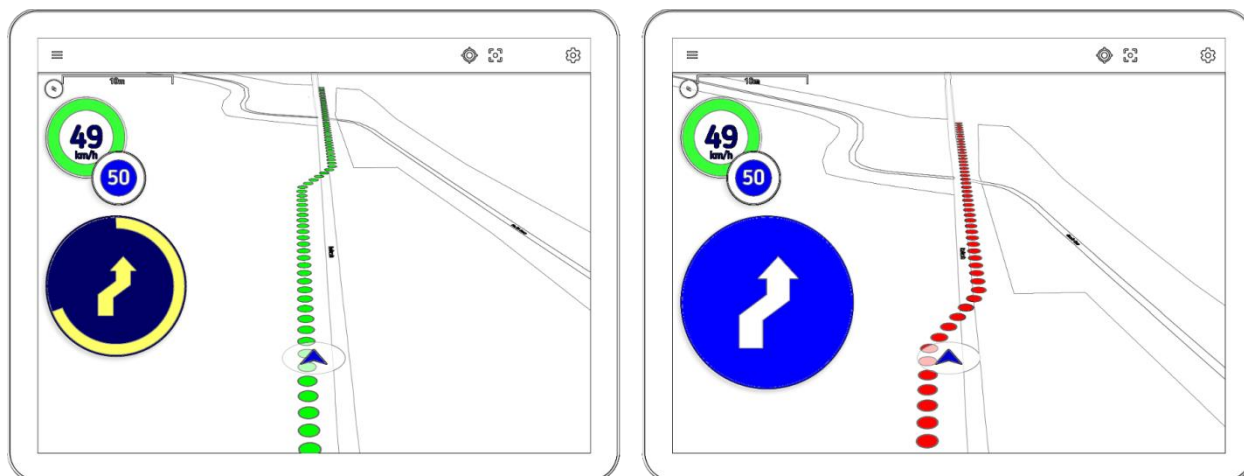

Figure 2.9: HMI prototype displaying maneuver instructions. Here: lane change to the right with 50km/h target speed. The trajectory turns red if the driver deviates from it.

The central coordination entity plans the maneuvers with sufficient margin to ensure the drivers have enough time to prepare and execute them, as already elaborated on in Section 2.2.1.

2.3.2 KPI Measurements

The demonstration will be evaluated based on the KPIs defined in Sections 2.1.1 and 2.1.2. The purpose of the demonstration is to obtain results matching or exceeding these requirements, and to understand what needs to be improved if some requirements were not fulfilled.

Automotive requirements will be evaluated based on post-processing of the information logged in all the vehicles involved in the maneuver. Logged information consist of multiple dynamic parameters, including acceleration and position. The distances between vehicles can be calculated by comparing the coordinates of their respective positions.

Network requirements will be evaluated with live measurements of latencies and data rates, followed by a more detailed post-processing analysis of logged measurements to evaluate the reliability and availability attained by our solution. Latencies will be measured from the lane merge coordination function to the vehicles, by integrating time measurements in the corresponding messages, and tightly synchronizing the respective clocks.

3   Cooperative Perception for Maneuvers of Connected Vehicles

3.1   Scenario

The cooperative perception demonstration showcases the extension of vehicles' situation awareness for enhancing both safety and traffic efficiency. The extended perception is achieved in two ways: see-through sensor sharing using direct V2V communication and long-range sensor sharing using V2I communication. Both approaches rely on on-board vehicle sensors, in particular, front cameras together with local sensor fusion algorithms to perceive objects in the environment. This perception is cooperatively shared to other vehicles in the vicinity to enhance their awareness of the traffic conditions in order to enable safer maneuvers. This section describes the two demo scenarios in greater detail.
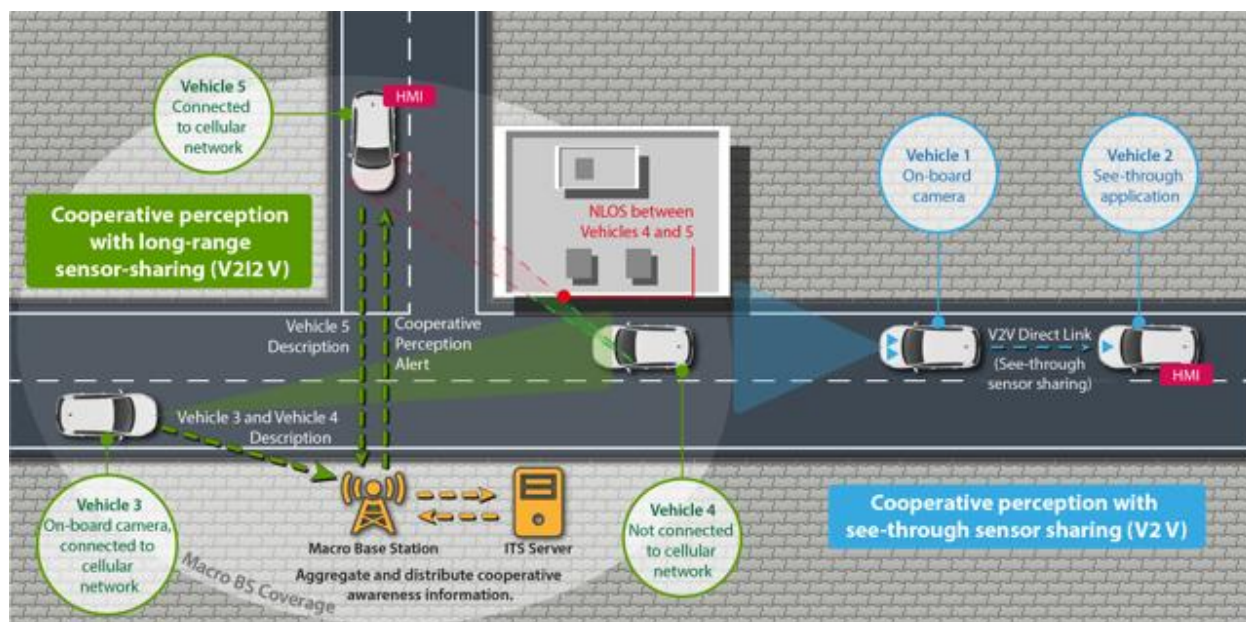
Figure 3.1: Overall demo scenario for 5G-enabled cooperative perception.

The first scenario (right half of Figure 3.1) consists of two cars Vehicle 1 and Vehicle 2 on an urban road going in the same direction. A see-through application utilizing a direct V2V communication link between Vehicle 1 and Vehicle 2 allows the latter to "see-through" the former, enhancing its perception and enabling a safer maneuver (overtaking, in this case). A forward-facing camera on Vehicle 1 streams a real-time video to Vehicle 2, based on the relative positions of the two cars. The video stream is received and displayed on an HMI in Vehicle 2. The see-

through sensor sharing can help a vehicle to visualize the spot which is blocked by another vehicle driving in the front, so a maneuver decision can be made safely.

The second scenario (left half of Figure 3.1) consists of an urban intersection with 3 cars, Vehicle 3, Vehicle 4, and Vehicle 5 approaching the intersection from three directions. Vehicle 3 and Vehicle 5 are connected to the cellular ITS infrastructure and Vehicle 4 is not connected to the network. An on-board camera on Vehicle 3 detects Vehicle 4 and estimates its relative distance and speed and sends this information to an ITS server, together with its own position, speed and heading. Vehicle 5 sends its own position, speed and heading to the ITS server. Depending on the perceived threat, the ITS server sends a cooperative perception alert to Vehicle 5, informing it of the approaching Vehicle 4, thus enabling more coordinated and efficient maneuvers (in this case, an intersection assist, or left-turn assist maneuver). Hence, a long-range cooperative sensor sharing using cooperative alert messages allows to extend the vehicle perception beyond the scope and range of on-board sensors like Radar, LiDAR etc.

3.1.1 See-Through Sensor Sharing
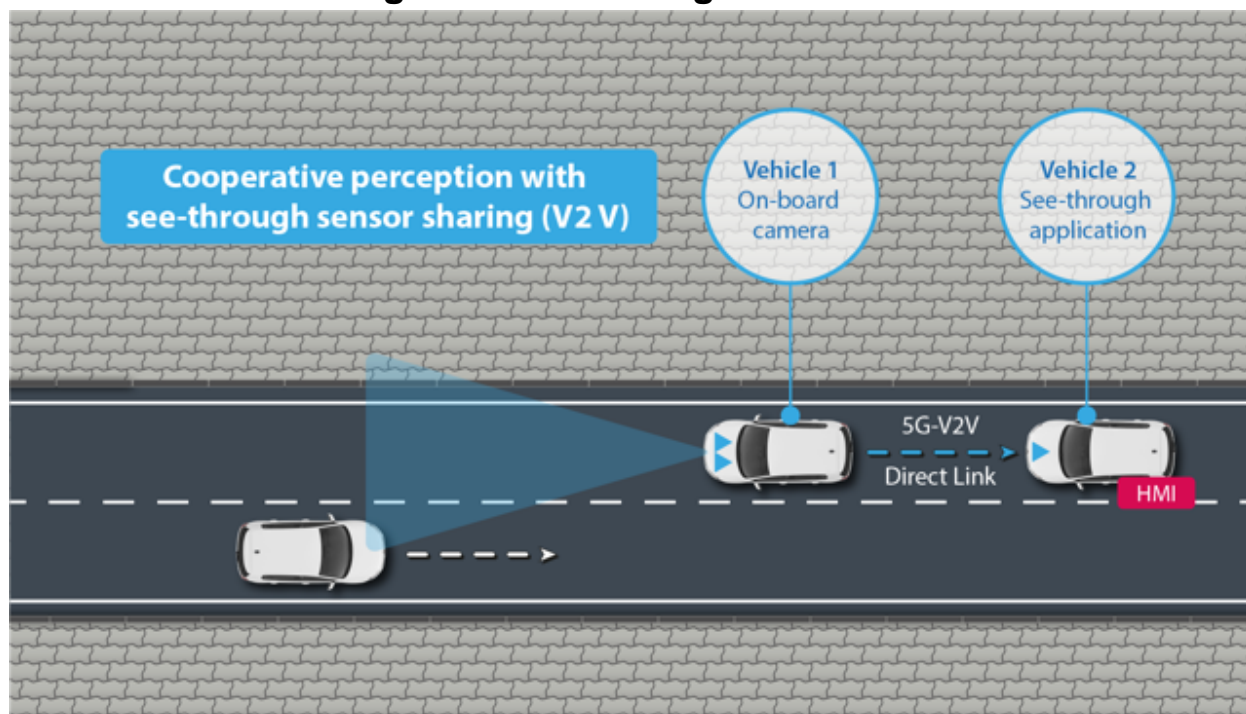
Figure 3.2: See-through sensor-sharing scenario.

In the see-through sensor sharing scenario, a vehicle (Vehicle 1) equipped with a front-facing see-through camera system will drive along a road and a second vehicle (Vehicle 2) equipped with the see-through HMI will follow behind. The distance between the vehicles can vary with time but will be limited to a maximum distance of around 100 meters. This is due to the fact that the see-through application is intended for situations where the rear vehicle's field-of-view is partially occluded by the front vehicle – the occluded area decreases with increasing distance between the vehicles. During the demonstration, the HMI in the rear car will show the 'see-through' view

as if the front car was transparent. A third oncoming car which cannot be normally detected by Vehicle 2 will be shown in the HMI and Vehicle 2 may overtake Vehicle 1, as a measure of the demo's success.

The demo is evaluated based on a combination of application and communication system requirements or KPIs.

The communication system requirements are based on [5GC17-D21] and consist of the following:

- Data rate of up to 10 Mbps for supporting compressed video streaming
- Maximum latency of 50 ms with lower latencies preferred
- Packet transmission reliability of at least 99%.
- Network availability of 99% meeting the associated reliability, data rate and latency requirements.
- A maximum communication range of 100 meters for non-urban driving.

The application KPIs consist of three main aspects:

- Good image quality of the see-through video overlay in the rear car, which can be influenced by image resolution and compression. These two values can be adopted to the link quality and available bandwidth of the V2V transmission.
- Good fit of the position of the see-through video overlay over the front car which should be hidden. This aspect is depending on a good relative positioning and a low packet error rate during the transmission of the car poses.
- Low latency of the see-through video overlay. This latency can be recognized when the video content in the video overlay coming from the front car is not perfectly aligned with the rest of the video. This is especially visible in corners where the position of the front car relative to the rear car is moving fast. This latency can result from transmission delays and processing times in the algorithm.

3.1.2 Long-Range Sensor Sharing

Figure 3.3: Long-range sensor sharing scenario.

In this scenario, three vehicles approach an intersection (or T-junction). Vehicle 3 (Blue car) and Vehicle 5 (Yellow car) are connected to the ITS infrastructure consisting of a test network with 4G radio access, enhanced with cooperative-ITS server in the core network. Vehicle 4 (Red car) is not connected to the network. Vehicles 4 and 5 cannot see each other due to a large obstruction like a building. Vehicles 3 and 5 periodically report their position, velocity, and other dynamics to the ITS server. An on-board computer vision system on Vehicle 3 detects the approaching Vehicle 4 and estimates its position and speed using image processing algorithms, and artificial intelligence and sends this information to the ITS Server. The cooperative perception application in the ITS Server processes the received information about the three cars and decides to send an alert to Vehicle 5 based on a predicted safety event (collision or speed advisory etc.). The demo success is measured by the reception of the cooperative perception alert in Vehicle 5 before the Vehicle 4 is visible to Vehicle 5.

The considered automotive requirements for the long-range sensor sharing demonstration are derived from the capabilities of the on-board object detection system and the requirements of cooperative maneuvers defined in [5GC17-D21], as follows:

- Absolute vehicle speed shall be comprised between 0 and 80 km/h.
- The maximum range of the camera detection shall be between 80-100 meters in clear line-of-sight conditions.
- The average probability of vehicle detection shall be around 80% for vehicles occupying an area greater than 20000 pixels
- Latency of the camera system shall be between 85 and 125 ms. This is the time elapsed between frame acquisition to object creation, including image processing.
- Relevance area of sensor sharing shall be greater than 250 meters to ensure a greater coverage than vehicle on-board sensors. The relevance defines where the messages must be distributed to ensure the automotive service.

The considered network requirements are similarly derived from [5GC17-D21] by considering a related use-case of high definition local map acquisition:

- Communication range around 250 meters to allow the coverage of the relevance area. The communication range is the maximum distance between a transmitter and its intended receiver with a targeted latency and reliability.
- Application layer Service Data Unit Size (SDU) shall be less than 1200 bytes for position messages.
- Average data rate at application layer shall be lower than $(n+1)*96$ kbps per vehicle in uplink, n being the number of sensor-detected road users, and $m*96$ kbps per vehicle in downlink, m being the number of road users in the relevance area. This is considering that road user description messages are sent at 10 Hz in both uplink and downlink.
- Peak data rate at application layer shall be lower than $(n+1)*384$ kbps per vehicle in uplink, n being the number of sensor-detected road users, and $m*384$ kbps per vehicle in downlink, m being the number of road users in the relevance area. This is considering a strict latency requirement of 50 ms.
- Latency between vehicles at application layer shall be in the range of 50 to 100 ms.
- Reliability shall be medium, i.e. at least 99%.

3.2 Key Concepts

3.2.1 Low-Latency and Highly Reliable V2V Communication

The see-through application described in the previous section requires a stable low latency communication link with low packet error rates, which needs to be sustained during high vehicle mobility. This is achieved using a flexible and reconfigurable radio design [CGA+16] based on the ongoing standardization of 5G-NR sidelink (as of May 2018).

In particular, the following features ensure that the application requirements are met:

- High flexibility in frame structure and numerology definition

- Reliability through customizable numerology, flexible pilot density/strength, flexible sync preamble length/strength, Discrete Fourier Transform (DFT) spreading and Receive diversity
- Tight synchronization using dedicated in-band synchronization signals, optionally with GPS-disciplined oscillator (GPSDO)
- Slotted-TDMA scheme with fixed user allocations

3.2.2   See-Through Sensor Sharing System

The main idea of the see-through application is to use a stereo vision system mounted on the front car to generate a local 3D map of the environment, in which the rear car could localize itself using a 2D-3D feature tracking algorithm. Based on the information about the relative pose of the rear car, the front car generates a new synthetic image from the rear car's view, from which only the region of interest concerned by the occlusion is transferred to the rear car to be displayed (cf. Figure 3.4).
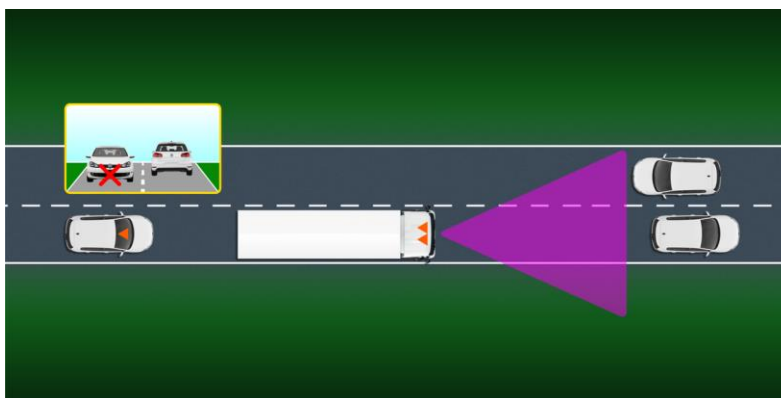

Figure 3.4: See-through for overtaking assistance.

For this, a four steps approach is defined:

- **Step 1: Local 3D Map generation**
  This step consists of the usage of visual odometry approach to generate 3D map points and their feature descriptors at every new stereo image acquisition on the front car. The generated 3D map points and the descriptors are transmitted regularly to the rear car to update its 3D map of environment.
- **Step 2: Localization of the rear car**
  Using the new 3D map updates, the rear car will update its 3D map and performs in parallel its localization, i.e., computes its relative pose localization, within this map. This information is transferred back to the front car.
- **Step 3: Image synthesis**
  Based on the relative pose provided by the rear car, the front car computes a new synthetic, un-occluded image where the front car is completely transparent from the rear car's view. From this image, only a region of interest corresponding to the occluded part of the image is then transferred to the rear car. The size of the image can be adapted

based on the distance between the two cars. The closer the distance is, the higher is the number of pixels required to cover the occluded area. The synthetic image is then sent to the rear car for display purpose.

- **Step 4: Image stitching and display**
  An appropriate cropping of the received synthetic image is performed by the rear car in order to stitch it onto the current image on the rear car's front camera and display it overlaying the occluded area.

3.2.3   On-Board Object Detection and Sensor Fusion System

The on-board object detection and sensor fusion system, depicted in Figure 3.5, consists of a forward-facing camera, located behind the windshield, in the upper part next to the rear-view mirror. The vehicle will have the necessary hardware and software to do the following tasks:

- Detect the following elements of interest: car, bus, truck, pedestrian, motorcycle, and bicycles of an image with an algorithm of artificial intelligence and classify them among vulnerable and non-vulnerable users.
- When the artificial intelligence algorithm detects and classifies one of the aforementioned elements in three consecutive frames, it will proceed to calculate by image processing, the distance and velocity at which the detected is located. These measures will have an intrinsic error.
- With the information of on-board object detection, on the one hand, and connected vehicles on the other hand, a stage of sensor fusion can be implemented, both in-vehicle or on the infrastructure (see lane merge use case for infrastructure data fusion, section 3.2.2). Data fusion algorithms can be different, considering the data from camera systems may have different accuracy (on-board camera system includes intrinsic error from the object detection itself, as well as the ego vehicle positioning system; this does not happen on infrastructure camera system, where error comes only from object detection).

The latency of the camera detection is composed of three components. Camera frame capture latency, in the worst case is 40 ms, image processing algorithms take 80 ms using NVIDIA 1050 TI GPU and Intel i7 6700 CPU, and building message takes 5 ms time. Therefore, in the worst case, the latency is 125 ms and in the better case it is 85 ms (camera frame capture latency ~0 ms). When an element is detected in 3 consecutive frames, the element is considered to exist, and its velocity can be estimated.
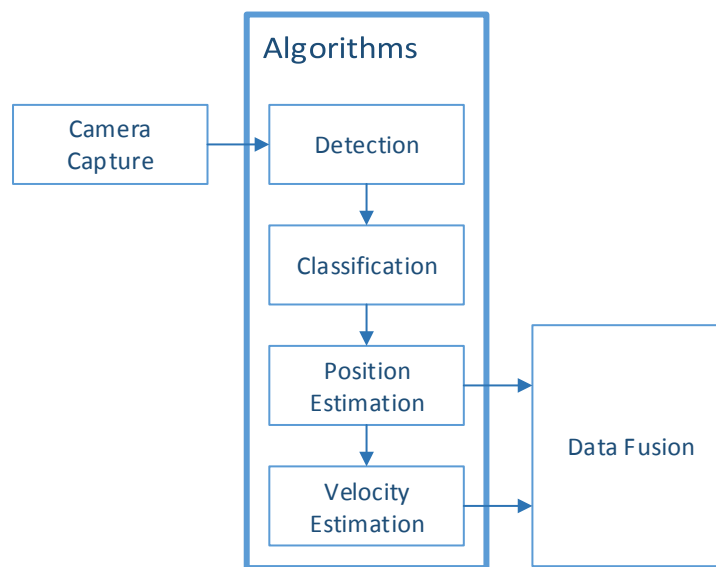
Figure 3.5: Smart camera & data fusion architecture.

3.2.4   Long-Range Sensor Sharing over Network

The long-range cooperative perception is based on vehicles sharing their processed sensor information across the network, in the form of data objects. This use case uses V2N2V communications instead of direct V2V.

Today, a vehicle A equipped with sensors is not always able to detect all the surrounding vehicles because of buildings or vehicles blocking its line-of-sight. The idea is that other vehicles can detect the vehicles which are relevant for vehicle A, and vice-versa.

This use case is based on the modular network architecture developed for the lane merge use case, as it fits perfectly to the task of exchanging information between road users.
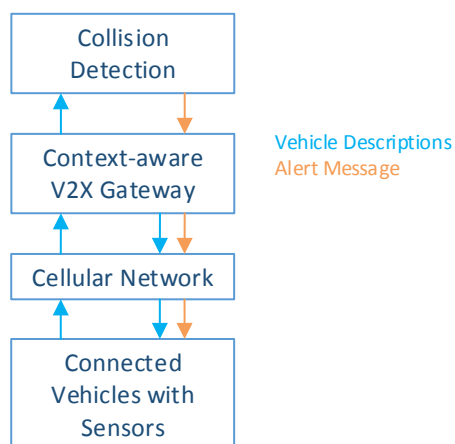

Figure 3.6: Modular network architecture, allowing road users to send their description along sensor-detected objects, and to receive relevant information in return.

The flow of events is the following:

- **Step 1: Sensor detection**
  Vehicles equipped with sensors detect other road users and create objects representing them, using image recognition and sensor fusion.
- **Step 2: Sending objects to the network**
  Each vehicle sends its own description to the context-aware V2X Gateway through the cellular network; along with the descriptions of the road users it has detected.
- **Step 3: Data fusion**
  All the road user descriptions are processed in the Context-aware V2X Gateway by a data fusion module to avoid multiple instances of them. The fused objects are then stored in a database.
- **Step 4: Sending relevant objects to the vehicles**
  The context-aware V2X Gateway sends relevant vehicle descriptions back to the vehicles needing them, based on mechanisms such as the relevance area.
- **Step 5 [optional]: Sending collision alerts to the vehicles**
  A network-based collision detection application processes objects stored in the database and sends targeted alerts to the vehicles showing a risk of collision.

This approach complements the direct V2V solution in the following ways:

- Longer range of communication between vehicles.
- Data fusion from multiple sources in the network avoids data redundancy and increases the quality of the data sent back to the vehicles.
- Network-based applications can provide useful inputs based on the large and robust dataset available in the database, such as collision alerts and traffic optimization.

3.3 Demonstration Guidelines

3.3.1 Demo Evaluation

See-Through Sensor Sharing Scenario

The see-through sensor sharing demonstration is evaluated based on two factors:

- Connectivity situation *viz.* availability of see-through application
- Maneuver situation *viz.* status of overtaking maneuver

Once started, the see-through application is active as long as there is a stable connectivity and the connectivity requirements are met. Hence the demonstration can be evaluated based on availability of the see-through application and the underlying connectivity. The maneuver situation can be categorized into three types, based on the relative positions and velocities of the involved vehicles: safe overtaking maneuver, potentially dangerous overtaking maneuver, no overtaking maneuver possible.

We first describe the overtaking maneuver dynamics, followed by the three maneuver situations in more detail.

The overtaking maneuver is characterized by a lane change, followed by an acceleration phase, and ending with a second lane change. With reference to Figure 3.7, let t_0 and t_1 denote respectively the start time and end time of the overtaking maneuver and t_{cross} denote the time when Veh3 and Veh1 cross each other.

Figure 3.7 describes the Overtaking maneuver dynamics using the Scenario of Figure 3.2. Vehicle 1 (Veh1) and Vehicle 2 (Veh2) are assumed to travel at 36 km/h (i.e. 10 m/s) with a 0.9 second headway between them which corresponds to a gap of 9 meters. The overtaking maneuver begins at time $t_0 = 0$ s and each lane change lasts for 2 s (assuming a lateral acceleration of 2 m/s^2 with a lane width of 4 m). A maximum longitudinal acceleration of 2 m/s^2 is assumed. The second lane change is affected after a headway of 0.9 s between Vehicle 1 and Vehicle 2 is met. The total maneuver duration is the sum of the times required for the three phases of the maneuver. The initial distance between Vehicle 1 and Vehicle 3 (Veh3) is assumed to be 300 m. Figure 3.7 shows the distance traveled by the three vehicles from the point of view of Vehicle 1.
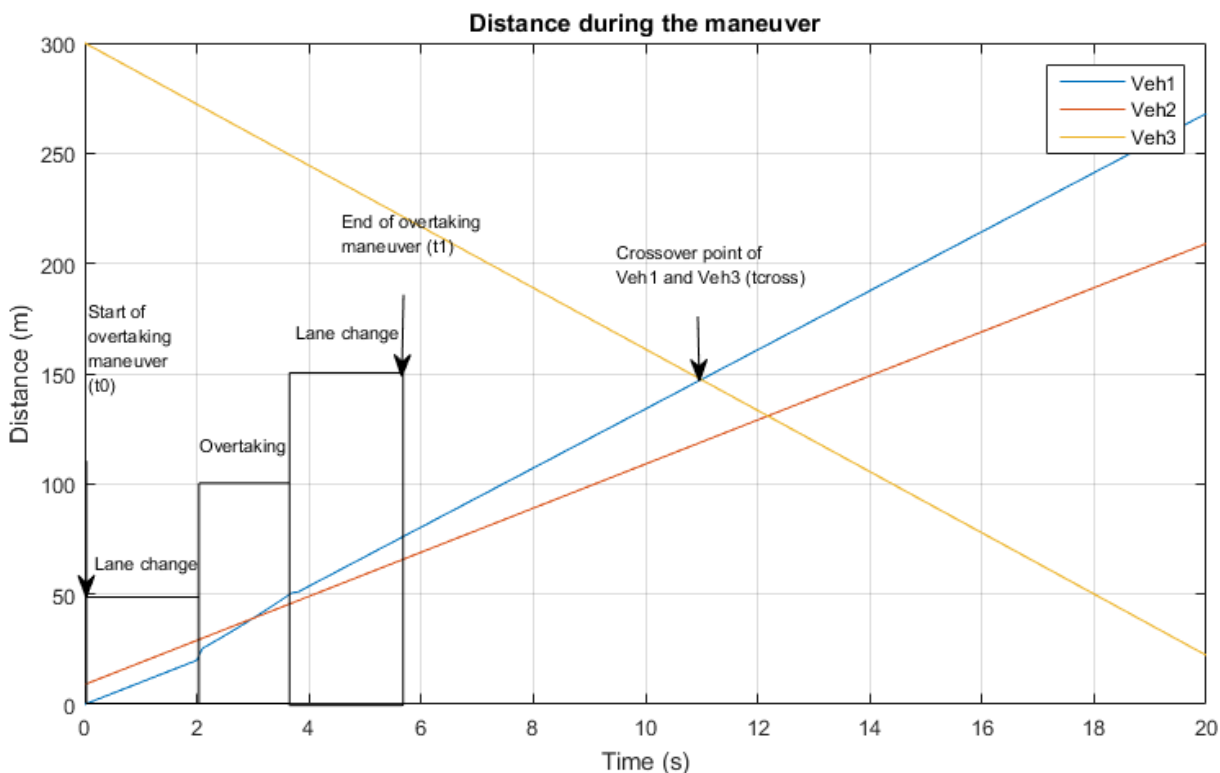

Figure 3.7: Dynamics of overtaking maneuver.

Safe overtaking maneuver: A safe overtaking maneuver implies that the oncoming vehicle Veh3 is located at a far-enough distance to not affect the maneuver, that is $t_{cross} - t_1 > \delta_{relevance}$, where $\delta_{relevance}$ is the headway between Veh1 and Veh3 corresponding to the relevance area for the maneuver.

Potentially dangerous overtaking maneuver: A potentially dangerous overtaking maneuver implies that the oncoming vehicle Veh3 is within the relevance area but has sufficient headway δ_α with Veh1, provided Veh1 accelerates above α m/s^2, i.e. $\delta_\alpha < t_{cross} - t_1 < \delta_{relevance}$.

No overtaking maneuver: No overtaking maneuver is possible if there is insufficient headway between Veh1 and Veh3 at the start of the maneuver, i.e. $t_{cross} - t_1 < \delta_{min}$, where δ_{min} is the minimum headway for safe driving.

The various test cases for the demo are shown in Figure 3.8. The connectivity situation is shown on the Row-axes with two options: Connectivity available and Connectivity not available. The three maneuver situations described earlier are organized along the columns. The Labels OK and Not OK (NOK) refer to the situation where an overtaking maneuver is or is not possible. The Label OK/NOK denotes the situation where overtaking is feasible (within the constraints of vehicle speeds and acceleration) but needs some minimum conditions to be met as described earlier. For the final demo, only a subset of these cases will be shown with the goal of showcasing the benefit of the implemented connectivity solutions. In particular, the cases shaded in the darker hue are useful to showcase the benefit of the V2V connectivity and see-through application for the overtaking maneuver.

		Maneuver situation		
		Safe overtaking	**Potentially dangerous overtaking**	**No overtaking**
Connectivity	**Available**	OK	OK/NOK	NOK
	Not available	OK	OK/NOK	NOK

Figure 3.8: Test cases for overtaking maneuver with and without connectivity.

Long-Range Sensor Sharing Scenario

The long-range sensor sharing demonstration showcases the benefits of sharing sensor-detected objects over cellular network in an urban environment, where buildings often block the line-of-sight of vehicles sensors and greatly diminish the range of V2V communications. Three vehicles are involved in the demonstration; two of them are connected to the network. One of the connected vehicles is equipped with the on-board object detection and sensor fusion system.

The demonstration scenario is to show a vehicle driving towards an intersection with no clear line-of sight to the perpendicular road, in different configurations, i.e. with and without connectivity,

and with and without the sensor sharing system. For the final demonstration a subset of these scenarios will be shown.

- **Driving through a blind intersection without connectivity:**
  A vehicle drives towards the intersection and only sees incoming vehicles on the left and the right when visual line-of-sight is cleared.
- **Driving through a blind intersection with connectivity and without sensor sharing:**
  A connected vehicle drives towards the intersection and receives in advance the position of an incoming connected vehicle on one side of the intersection, but only sees the incoming unconnected vehicle when the visual line-of-sight is cleared.
- **Driving through a blind intersection with connectivity and sensor sharing:**
  A connected vehicle drives towards the intersection and receives in advance the position of an incoming connected vehicle on one side of the intersection. This incoming vehicle uses its sensor system to detect the unconnected vehicle coming from the other direction and sends its position to the blinded vehicle which is now aware of all the incoming vehicles.
- **[optional] Driving through a blind intersection with connectivity, sensor sharing and collision alert system:**
  Same case, with additional collision alert system warning the driver of the connected vehicle of an upcoming danger at the intersection.

3.3.2   HMI Aspects

See-Through Sensor Sharing

In the HMI of the rear-driving car, the real time video recorded by its own camera system is shown. The see-through system is running transparently in background and the video overlay can be activated on demand. In Figure 3.9 it is possible to see a preliminary version of the see-trough system running in the Bosch location in Hildesheim. In the left part of Figure 3.9, it is possible to see through the front blue car. The black horizontal bar is due to the field of view of the camera system in the front car.

Figure 3.9: HMI of the see-through system in the rear car. In the left picture the see-through video overlay is activated and in the right picture the overlay is deactivated.

Long-Range Sensor Sharing

To showcase the long-range cooperative perception based on sensor sharing, the HMI displays the road users with different colors according to their origin, e.g. green for self-signaled connected vehicles, red for sensor-detected unconnected vehicles and blue for its own vehicle.
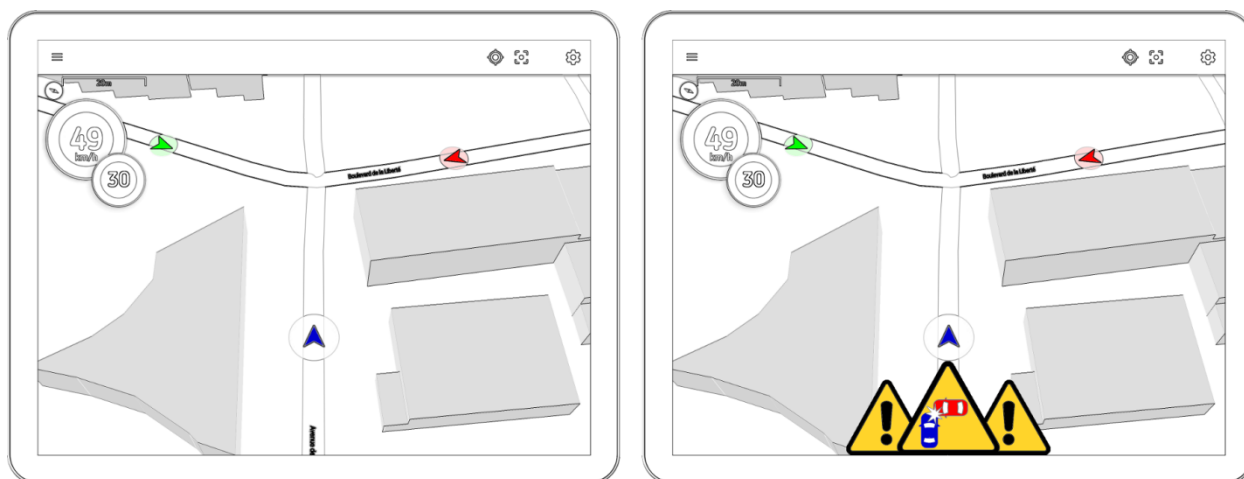
Figure 3.10: Cooperative perception HMI prototype. Both displays show the connected vehicle in green and unconnected vehicle in red. The right display shows additional collision alert.

In Figure 3.10, the green vehicle detected the red vehicle with its sensors and shared its own position along with the red vehicle's position over the network. Note that the buildings in grey prevent our vehicle represented in blue to detect both the green and red vehicles with its sensors.

Additionally, collision alerts can be displayed if converging trajectories are detected in the vehicle or the network.

4 Vulnerable Road User Protection

4.1 Scenario

In [5GC17-D21], several use cases (UC) are defined and this specific VRU protection use case is one of the three demo cases selected for final demo in the 5GCAR project with the focus on traffic safety. This use case includes safety features such as road hazard warnings, pedestrian detection and tracking mainly for collision avoidance.

The main field for this demo case is improved traffic safety for VRUs, like pedestrians or cyclists by means of a highly flexible design of 5G positioning reference signals.

Vehicle-internal VRU protection systems today are limited in challenging scenarios such as urban settings with non-line of sight (NLOS) between vehicle and VRU, which is a limitation of vehicles' on-board sensors. To address this, a network-based positioning and collision prediction system is demonstrated.

The VRU demo will be setup inside a City-like Area on the test-track Montlhéry (cf. Section 5.1) chosen for the final demo.

Figure 4.1: Side view typical city area, snap-shot taken as example at AstaZero test track in Sweden.

A crosswalk over an urban road will be selected at the final test site as shown in Figure 4.1. In a top view this is depicted as example in Figure 4.2. The pedestrian is walking toward to zebra-crossing from one side of the street, the vehicles are approaching the zebra-crossing from the left. Many other scenarios are possible and are under discussion before the final demonstration.

For the final demo, both non-critical and critical situations will be shown. Only in the critical situations, a warning message shall be triggered.

The basic element of this VRU protection demo is 5G waveform-based positioning. Complementary techniques like image processing (CCTV) are showcased in other demos and can in real life be used in parallel to this technique to increase the overall reliability and availability of the VRU protection system. Many other scenarios are possible and under discussion before the final demonstration.
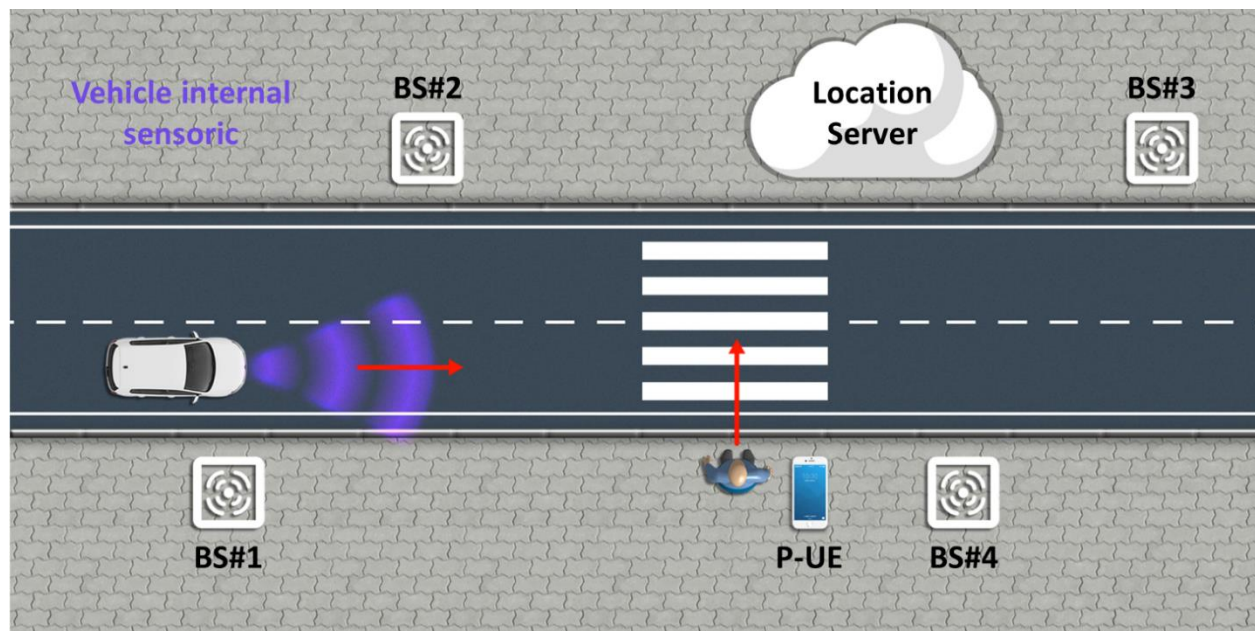

Figure 4.2: Top view for the VRU scenario.

The vehicle and the pedestrian send proprietary broadband 5G uplink waveform signals to the four Base Stations (BS) labeled as BS#1-BS#4. Each BS then measures the time of arrival (ToA) of the signals to allow triangulation of the vehicle and pedestrian positions. All the receiver antennas at four BSs, BS#1-BS#4 will provide coverage of the relevant city area including the crossing section.

The road has a sufficiently long section before the zebra-crossing (on the left side in Figure 4.2) so that the vehicle can accelerate and approach the area of interest with a defined speed. Several speed parameters, 30 / 50 and 70 km/h will be chosen for the final demo according to performance results.

4.1.1 Key Performance Indicators

In previous work in the 5GCAR project on use cases, several KPIs like update latency, reliability, communication range, message update rates and position accuracy were identified, and are summarized in [5GC17-D21]. In this demonstrator, these KPIs are evaluated. Of particular interest are the position accuracy and the reliability of the warning message. The final performance of the demonstrator will be subject to final measurements. The demo requires fast and precise

positioning of VRUs, as well as fast communication in between VRUs to network and vehicles to network. Advanced VRU protection idea is possible by 5G localization methods using Time of Arrival measurements (ToA) and network information fusion. In dense urban city environments GPS reception is often disturbed by bridges, reflective high-rise buildings or other constructions leading to no clear sky link. Automotive sensors, radars and camera systems have difficulties to detect pedestrians well ahead in some exceptional cases, such as NLOS to the VRUs or when there is snow or heavy mud. Typical localization errors, due to poor GPS reception and obstruction of on-board sensors, are in the range of several meters, particularly in non-ideal propagation conditions like in forests, close to rock faces, or in urban canyons, for example. Another disadvantage is the relatively long time to first location fix (TTFF), which is in the range of several minutes. Today newest vehicle on market provides pedestrian detection systems but with certain limitations due to physics. This kind of PDCMS (Pedestrian Detection and Collision Mitigation Systems) performs automatic emergency braking to avoid the collision. As this emergency braking is very intrusive for the driver and passengers of the car, but also for the following vehicles, it is only launched if the risk of impact is confirmed. This means that it should be too late to avoid the collision for every vehicle speed. Under a vehicle speed of about 30km/h, the impact will be avoided, but if the initial speed is over 30km/h, the impact will only be reduced. The help of a VRU warning is to prepare the driver, which could, for example, reduce his speed before the collision confirmation.

This demo highlights some key scenarios to demonstrate how new 5G radio-based localization methods could complement existing solutions and provide better detection of the VRUs under these challenging conditions. In the demo the vehicle is equipped with on-board communication units (OBUs) and the pedestrian carries communication devices such as a smartphone and has connectivity to the network infrastructure, e.g. via 4G or later 5G system. First, a rough location estimation will be done by triangulation through exploiting multiple ToA measurements, and secondly by additional knowledge of vehicle parameters like speed and yaw rate from the OBU as well as IMU sensor data from the pedestrian. Data fusion will then take place in a 5G network entity called Location Server to improve this initial location position accuracy by enhanced tracking algorithms. Based on the evaluation of the estimated trajectories, a warning message will be released in case of a potentially critical scenario. At the final phase of the project 5GCAR several critical and non-critical scenarios will be evaluated and demonstrated. More details are described in the following section and in [5GC18-D31].

4.2   Key Concepts

4.2.1   Time of Arrival and Triangulation Principle

For this project demonstration Uplink Time of Arrival (ToA) measurements technique is used. Algorithm research conducted in 5GCAR will provide solution to enable the improved localization techniques and will be implemented inside the Location Server, shown in Figure 4.3. The vehicle transmits 5G proprietary waveforms and the receiving antennas BS1-BSn will process these signals. Each BS antenna is connected via fibers to the Location Server. The same transmitter unit is used inside the pedestrian user (VRU) not shown in Figure 4.3.
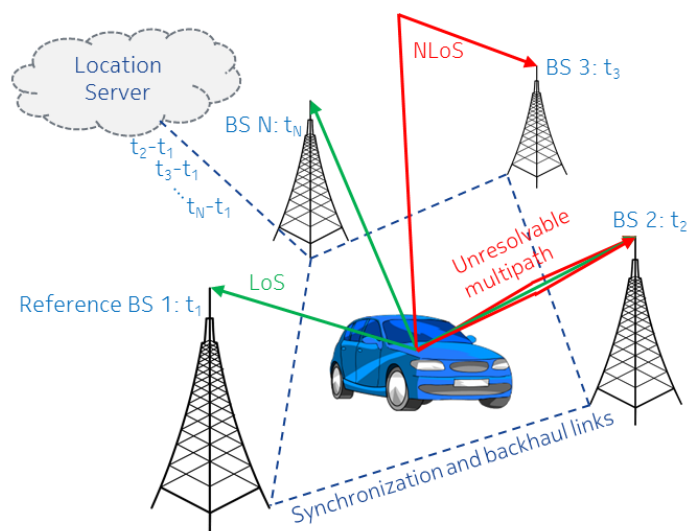
Figure 4.3: Time of Arrival measurements using Uplink principle.

This location technique is able to deal with LOS as well as with NLOS connectivity, see illustration Figure 4.3.

4.2.2   Communication using 4G to Network Infrastructure

A communication system is shown in Figure 4.4 and used as overlay. This will enable data exchange between vehicle to infrastructure and VRU to infrastructure using e.g. 4G bidirectional communication channels. Vehicle specific CAN bus data or VRU specific IMU sensor data are transmitted to the infrastructure using an LTE device connected to the V2X gateway.
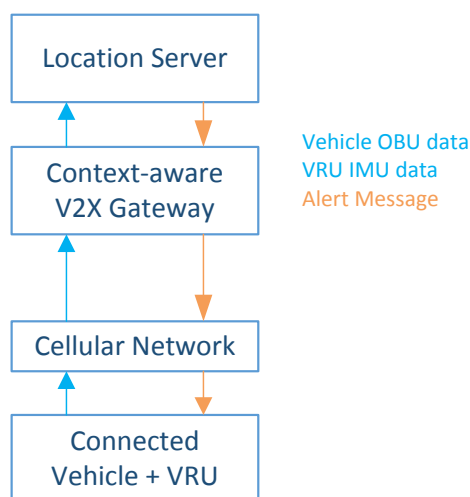

Figure 4.4: Communication links for message exchange.

4.2.3   Data Fusion - Collision Prediction

All known data like speed, acceleration, deceleration, and yaw rate of vehicle, etc. will be present at the Location Server and enable to apply prediction and increase the precision of the uplink

derived location position. This prediction of the vehicle and pedestrian position together with map data makes it possible to generate a so-called Alert message and avoid an upcoming accident by alerting the test driver.

4.3 Demonstration Guidelines

4.3.1 Safety Remarks

> *All humans involved in the demo needs to be behind a secured area during the experiment phase and final demonstration. The pedestrian user in this VRU scenario will be realized by a dummy, e.g. according to EURO NCAP. The vehicle will be operated by a test driver with appropriate driver permission. All measured data are non-personal data and anonymous. The details are elaborated in Annex A.*

The full VRU setup has a small form factor and is manipulated wirelessly by using remote controlled small robots operated in a secured manner by appropriate means.

4.3.2 Arrangement of Setup

Figure 4.5 provides a view on the arrangement and the relevance area for this VRU demo.
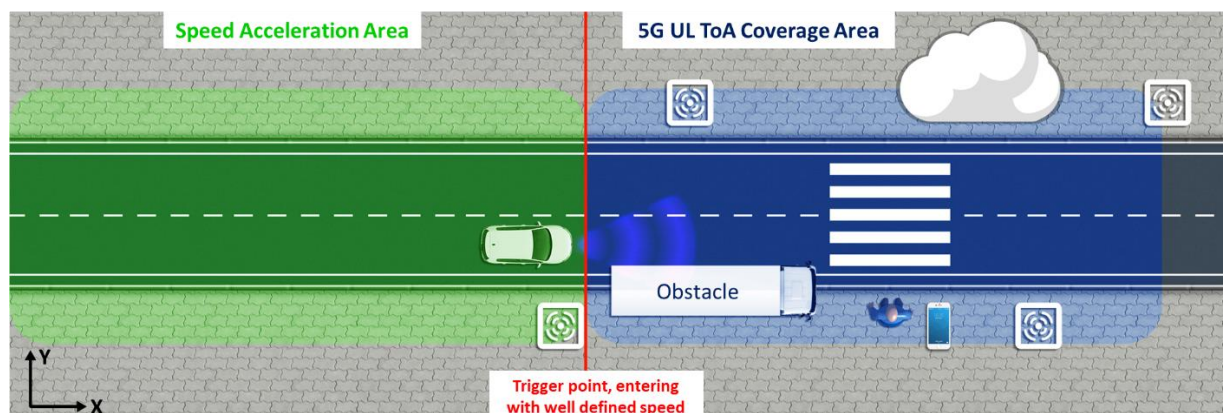

Figure 4.5: Trigger point for VRU scenario.

The road will have an incoming section shown in green in the figure allow the vehicle to accelerate to a defined speed using a speed limiter inside the vehicle. This defined velocity is foreseen when entering the ToA coverage area, see Figure 4.5.

Several speed parameters, like 30, 50 and 70 km/h will be chosen for the final demo accordingly. Crossing a light barrier control shown in red in figure by a vehicle will trigger an event. The robot controlled pedestrian dummy will start moving according to the selected scenario to be demonstrated.

The Use Case assumes one pedestrian carrying a personal device (a smartphone in this example) walking next to a road being accurately localized by several BS receiver units deployed at the relevance area, as shown in the right part of Figure 4.5.

The current positions of the VRU as well as the vehicle will be obtained using 5G waveforms. All this processing will be done in the Location Server. Other information sources (vehicle GPS, IMU sensor data, camera pictures etc.) are transmitted to the Location Server (LS). The final position estimate and VRU trajectory estimate will be determined inside the LS in the network. The LS will compare and fuse data including HDmaps and will detect upcoming dangerous situation. The LS will transmit status information to the connected parties. For instance, a specific Alert Message to the vehicle will be triggered in case of pedestrian moving too close to the road. This warning message can be displayed to the driver who can potentially break hard, as the access to the auto break function in the vehicle is not yet foreseen. The Alert message will also be sent in parallel to the VRU to make him aware of this upcoming dangerous situation.

4.3.3 Critical and non-Critical VRU Scenario for Evaluation

On the parking lane, a parked vehicle will block the line of sight from the vehicle to the pedestrian. The pedestrian will move toward the street behind this obstacle, invisible to Radar/Lidar/camera systems or other current sensors inside the upcoming vehicle. The pedestrian will be moved in a controlled manner e.g. by a remote controlled VRU platform or by other means to the street with a well-defined speed and position. Other scenarios are under discussion and optimized for the final demo.

Example of one non-critical scenario:

The pedestrian is walking parallel to the street according to a well-defined trajectory T1 without visibility by the LIDAR/radar/cameras inside the vehicle. The VRU will stop and will not enter the road. So far, no dangerous situation occurs, as can be seen on Figure 4.6. Similar non-critical scenario is shown with trajectory T2 when the pedestrian walks perpendicular to the zebra crossing and stops before entering the street.

The demonstrator should not detect this as dangerous and should avoid sending an Alert message. Too many false alarms would disappoint and generate irritation for the traffic participants in the vehicle and the pedestrian.
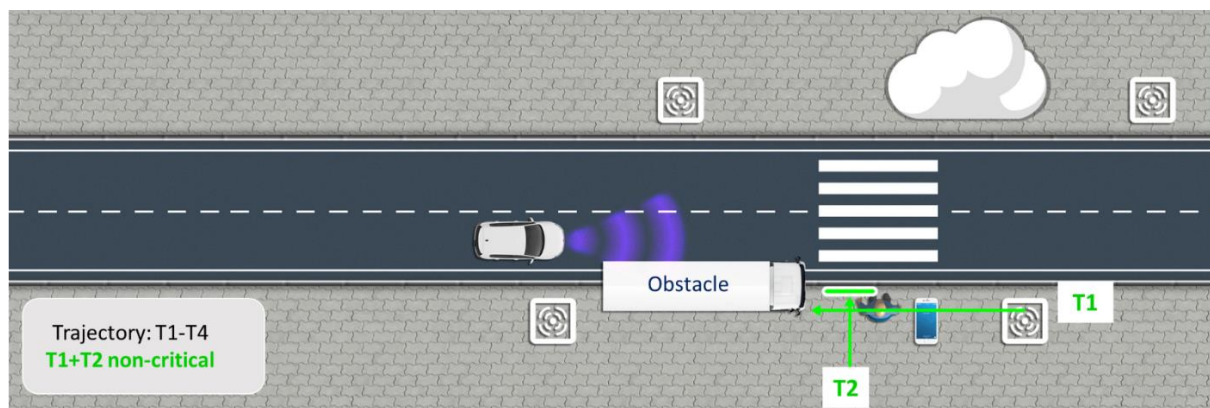
Figure 4.6: non-critical Scenario T1 / T2 for VRU safety.

Critical scenario:

In another scenario the pedestrian is assumed to walk according to a predefined trajectory T3 or T4 shown in Figure 4.6. The pedestrian is walking without visibility/detectability by the sensors LIDAR/radar/cameras located inside the vehicle. The pedestrian is hidden e.g. behind a parked truck or similar obstacle as can be seen on Figure 4.7 and not considered as an upcoming dangerous event.

The demonstrator should detect this scenario as dangerous and is designed to transmit Alert messages to the vehicle and the pedestrian to avoid impact under any circumstances. This Alert message is to be generated by the Location Server most reliably (lowest false alarm rate) and is subject of performance optimization inside the final testing phase.
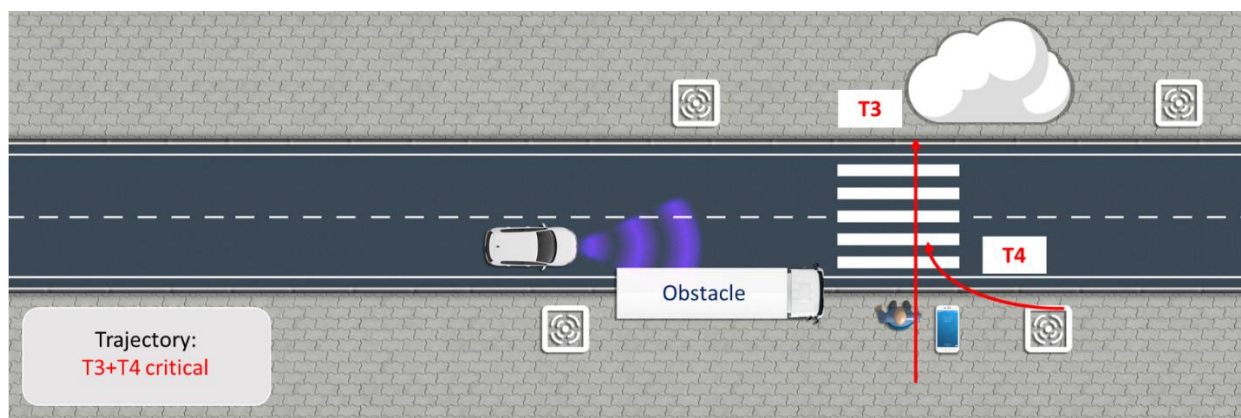

Figure 4.7: Critical Scenario T3/T4 for VRU safety.

The demonstrator will gain experience with this performance evaluation and will show the limitations e.g. by entering the street too close and / or generating too many false alert messages. This is part of the evaluation phase and performance optimization. The predictive algorithm that is described in [5GC18-D31] will be tested here on this platform and optimized, to send or not

send alert messages for this final demonstration with these multiple scenarios shown in Figure 4.6 and Figure 4.7.

4.3.4 HMI Aspects

To showcase the protection of vulnerable road users such as pedestrians and cyclists, the HMI displays the VRU detected by the location server as well as collision alerts. The vulnerable users which are not at risk of collision are shown in green, and the ones at risk are pictured bigger and in red to attract attention.
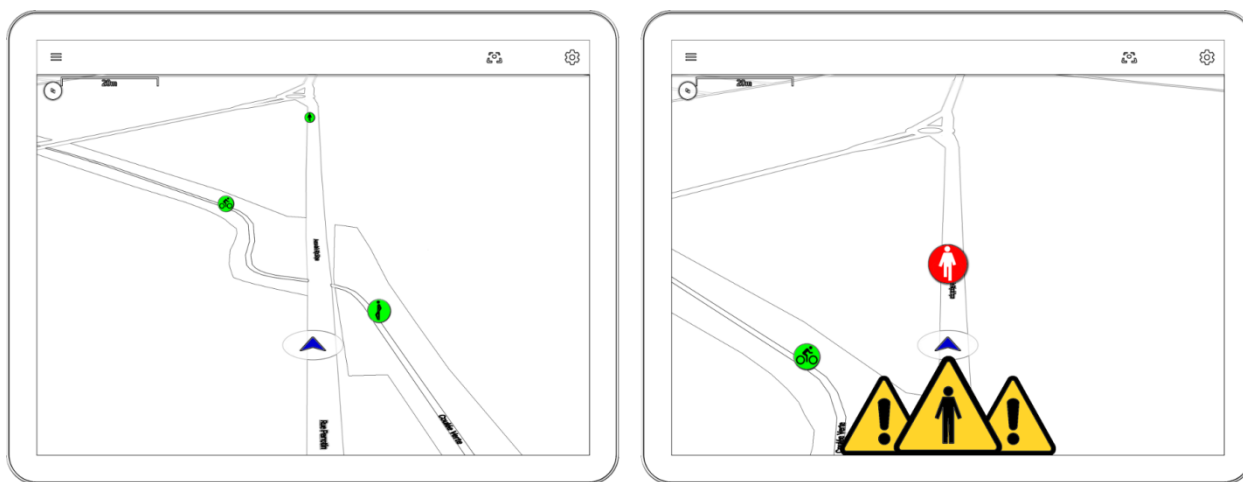

Figure 4.8: VRU protection HMI prototype. The left display shows non-critical VRUs in green, and the right display shows a critical pedestrian in red, along with a collision alert.

In case of a collision alert, an audio warning is also triggered in addition to the visual alert. The pedestrian and cyclists are equipped with a smartphone app which also receives an alert from the location server in case of danger, triggering phone vibration and loud audio warning.

5   Public Demonstration

This section provides the elements of public demonstration that will be shown towards the end of the project. The public demonstration of the three use-case will be to showcase what has been achieved within the project. The demonstrations will be executed on the test track UTAC-CEVA (United Test and Assembly Center Ltd - Centre d'Essais pour les Véhicules Autonomes) near Paris, France. In the following, the test track, and possible ways to visualize the demonstrations are explained for all three use-cases.

5.1   Test Track

The UTAC-CEVA test track is known worldwide by its capacity to prove safety improvement in targeted use cases with autonomous vehicles and is currently equipped with multiple mobility environments (city, country road, highway), to enable the support of various vehicular use cases. An aerial picture of the test track is shown in Figure 5.1. It is located in France, south of Paris, as illustrated in Figure 5.2.

Figure 5.1: Topology of UTAC CEVA test track.

Main objectives of UTAC-CEVA in certification of autonomous driving are the following:

- To prove safety improvement in targeted use cases with autonomous vehicle
- To push forward regulatory and normative frameworks to experiment and commercialize autonomous vehicle
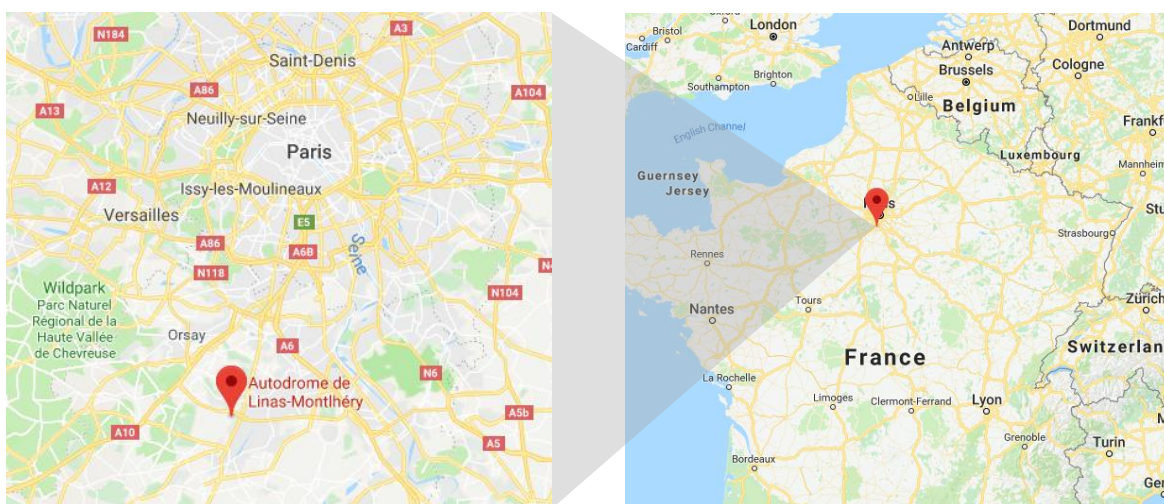
Figure 5.2: The UTAC-CEVA test track is located in Montlhéry, south of Paris.

UTAC-CEVA test track will offer possibly 3 independent networks (optical fiber) for the testing of V2X connectivity, and the various mobility environments are equipped with different access technologies, as shown in Figure 5.3.

Figure 5.3: V2X connectivity in UTAC-CEVA.

In the context of 5GCAR, and in order to assess the performance of future 5G technologies, an experimental platform has been set up in the footprint of UTAC-CEVA, to lead vehicular connectivity studies on 5G. These studies are relying on an innovative experimental network architecture operated by Ericsson, as described in Section 2.2.4. The coverage is provided by one 4G (LTE) radio site with two cells.

The experimental 5G network deployed in UTAC-CEVA will support communication where the user plane will be operated at the local breakout in France, while the control plane will be operated

in Aachen. A business VPN link is used to interconnect the radio access and core network in France to the core network in Germany.

5.2 Visualizations of Demonstrations

5.2.1 Driver Interface

The driver interface will be used for driver assistance, i.e., an HMI, where assistance information, warnings, maneuver planning and so forth will be shown to the driver during the demonstrations. The planned demonstration involves both OEM vehicles and legacy vehicles. OEM vehicles are the core vehicles used for the demos that are equipped with communication devices (OBUs) and HMI for driver information, HMI could either be a built-in HMI or a stand-alone tablet-based HMI mounted in the vehicle, while legacy vehicles used in the demos are the ones that are without any communication and driver assistance notification capabilities but will be used either to create an obstruction or a specific traffic situation.

Figure 5.4 shows an example of the integration of messages in the built-in HMI.

Figure 5.4: Built-in HMI example. The left picture shows a display directly in front of the driver, while the right picture depicts a display centered between driver and co-driver, where driving instructions can be depicted on both.

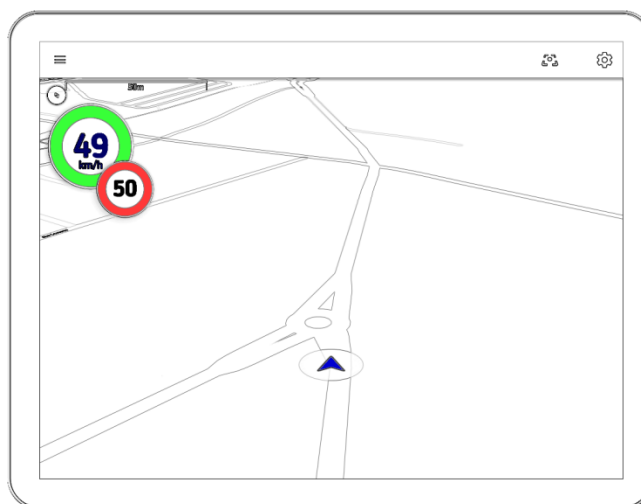Figure 5.5 shows an illustration of the tablet HMI prototype.

Figure 5.5: Tablet HMI prototype.

The built-in HMI and the tablet HMI will show the vehicle location on a map. Depending on the different needs of the use case, the positions of other vehicles and road users can also be shown on the map, along with warnings, speed advice, maneuver advice, and so on.

5.2.2 Showcase Presentation

On the public demonstration event, the demonstrations are executed on the test track whereas the observers monitor it from the control room or booth. Live video streaming from the inside of the demo vehicles enable the tracking of the scenario for the observers. It will consist of live video recording, via camera or phones mounted inside each vehicle, shared with the booth over a different network slice of the LTE network used for the demonstrations. This will add some background traffic to the complete lane merge demonstration. The benefit of this live stream in the booth is to create a live view of what is happening on the track.

In addition to the live video stream, a duplicate of the vehicle HMI is shown to present the information displayed to the drivers in the vehicles. It includes live data such as GPS positions and velocities of each vehicle and pedestrians involved, as well as inter-vehicular distances, drivers' maneuver instructions and so forth. The aim is to create a view of the vehicle HMI in the booth, replicating the driver's view in real-time.

Example:

The lane-merge use case is used as an example, to showcase the implementation of such a presentation: It is explained in detail in Chapter 2. For each vehicle two cameras are mounted in the vehicle, one in the front and one in the rear (cf. Figure 5.6). However, on the screens in the booth only the most relevant videos will be shared, e.g. the front camera of vehicle C which creates space for the merging vehicle and the cameras of vehicle B which is entering the highway from the merging lane.
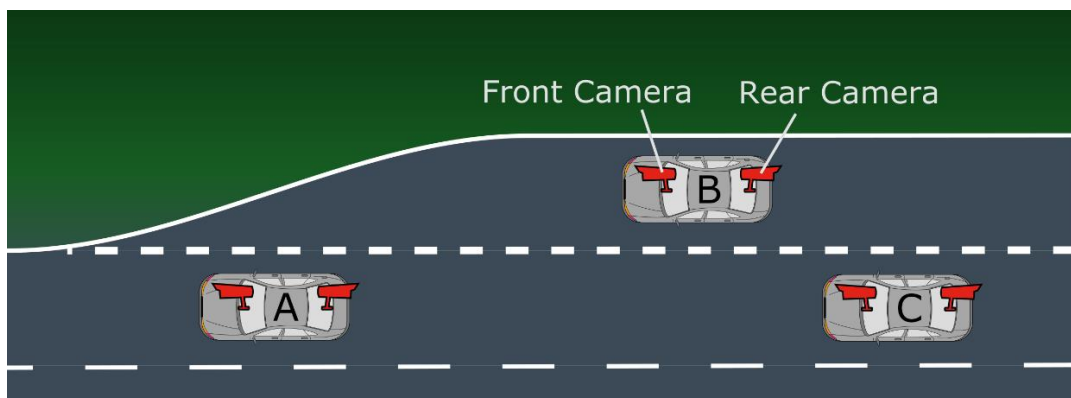
Figure 5.6: For presenting demonstrations to the audience outside the car, in-vehicle cameras might be mounted, streaming to the showroom.

Furthermore, a 3D rendering framework will be used to illustrate the communicated information. This is done by rendering 3D models of the vehicles onto a virtual plane representing the test track and replicating the vehicle movements in real time. Based on this visualization, more detailed information such as planned maneuvers and position accuracies, are highlighted.

6 Summary and Future Work

As part of 5GCAR, three demonstrations are executed and evaluated:

1. Lane merge coordination
2. Cooperative perception for maneuvers of connected vehicles
3. Vulnerable road user protection

The corresponding use cases were specified in detail, including a breakdown of the respective maneuvers, the key concepts, and a set of demonstration guidelines. Towards the end of the project, the demonstrations will be shown on the UTAC-CEVA test track in Montlhéry, France, as part of a larger event. To this end, ways of executing and presenting the demonstrations were described.

For the implementation of the respective demonstrations, parties from the telecommunication and the automotive industry are involved, as well as academia and SMEs, covering a diverse set of demonstrated aspects. This can be observed in the wide range of key concepts in the different demonstrations.

The lane merge coordination demonstration is a cooperative maneuver for optimizing the process of entering a motorway, for a mixture of cars that can and cannot communicate. This is enabled by a camera system with object recognition capabilities monitoring the maneuver. Furthermore, the vehicles send information about themselves, which is correlated with the output of the camera system. Based on this information, a maneuver is devised centrally, and corresponding driving instructions are communicated to affected vehicles, in parallel to background traffic such as entertainment video streaming. Several 5G features are used to optimize the cellular network for meeting the use case requirements. While the use case realization and KPI requirements target autonomously driving cars, the demonstration is performed using human drivers. A human-machine-interface is used for giving driving instructions to the respective driver. In the upcoming months, the lane merge maneuver planning logic will be discussed in further detail, and after the development of all demonstration functionalities will be available in a first version, the overall setup will be integrated. Since the testing in a live scenario requires much effort, multiple iterations are not feasible, which will be considered when planning these tests.

The cooperative perception demonstration shows the benefit of 5G-enabled V2I and V2V communication for enabling, respectively, long-range, and short-range sensor sharing between vehicles for safer and more efficient maneuvers. The long-range sensor sharing is enabled by an on-board camera and sensor-fusion system that detects both connected and unconnected vehicles in the vicinity and shares this information over the cellular network to nearby vehicles. This cooperative sharing over 5G infrastructure enhances the vehicle perception, especially while navigating blind intersections. The short-range sensor sharing scenario is enabled by a "see-through" application which uses low-latency video streaming from an on-board camera of a vehicle to allow a rear vehicle to see through it, thereby assisting the driver for an overtaking maneuver. The low-latency video streaming is realized by highly reliable and low latency direct communication link between the two vehicles, based on the emerging 5G-V2X standard. Both scenarios utilize a driver interface to demonstrate the benefit of the aforementioned key concepts

and provide a preview of how 5G integrates into the connected car. Further optimizations on the 5G-V2V radio system and see-through HMI are expected for the short-range sensor sharing demo for a more seamless driving experience. Furthermore, major development and integration work for the long-range sensor sharing is planned.

The VRU protection demonstration aims at extending today's vehicle on-board VRU protection systems, by extending detection range and accuracy in more challenging scenarios. To address this, a network-based positioning, tracking, and collision avoidance system is established. The targeted scenario is mainly urban roads, where pedestrians are walking toward a zebra-crossing. The vehicle and the pedestrian send out proprietary broadband 5G uplink waveform signals to several synchronized base stations, and each base station then measures the time of arrival of the signals to allow triangulation of the vehicle and pedestrian positions. Additionally, the vehicle and the pedestrian provide sensor data, such as GPS measurements, speed, yaw rate, and orientation. All this information is fused in a network element called Location Server which estimates the trajectories of the users based on a motion model and a map. Finally, an alert message is triggered if a potentially critical situation is detected, and a corresponding warning message is transmitted from the network to the vehicle and the pedestrian. A special HMI in the vehicle and communication device at the pedestrian will make them aware about the upcoming dangerous situation. This approach is superior to conventional VRU protection systems which rely on vehicle sensors only and can be applied independent from GPS coverage, i.e. in tunnels, urban street canyons and parking garages, independent from any line of sight relation between vehicle and VRU. We assume full flexibility of the design of the 5G positioning reference signal with respect to bandwidth, periodicity, power setting spatial re-use and transmission on sidelink resources for future 5G related work. The next steps for the demonstration will be the offline verification of the implemented algorithms. However, the main focus during the second year of the project will be the integration of all testbed components. We will test the behavior of the collision prediction and warning system by emulating both critical and non-critical situations. Based on that we will iteratively finetune the algorithms.

All in all, while substantial work was already put into planning the functional architecture of each demonstration, including the interworking and combination to a complete solution of a use case that has the potential to fulfil the identified KPIs, the focus in the rest of the project will be further development and integration of demonstration components, as well as the execution, evaluation, and presentation of the demonstrations as described in this deliverable.

7   References

[5GC17-D21]   5GCAR, Deliverable D2.1 Version 1.0 "5GCAR Scenarios, Use Cases, Requirements and KPIs", August 2017.

[5GC18-D31]   5GCAR, Deliverable D3.1 Version 1.0 « Intermediate 5G V2X Radio », May 2018

[CGA+16]   H. Cao, S. Gangakhedkar, A. R. Ali, M. Gharba and J. Eichinger, "A 5G V2X testbed for cooperative automated driving," *2016 IEEE Vehicular Networking Conference (VNC)*, Columbus, OH, 2016

A Data Protection Report

The 5GCAR Data Protection Report is a text used to ensure that all data collection and processing will be carried out according to EU and national legislation.

The 5GCAR trials will only be conducted in confined test sites, i.e. only on test sites that are outside of public roads. The safety regulations of each test site will be respected and followed. All participants in the trials will consist of people that are working within the 5GCAR project. These people are participating voluntarily and will be selected on knowledge basis and availability. The data to be collected will be known on beforehand by the people involved in the trial. Each person is free to choose not to participate in any trial. The data to be collected within the project is not considered as sensitive. The data will only be stored in 5GCAR project tools among 5GCAR partners. Selected parts will be used to create publications.

In the 5GCAR vulnerable road user (VRU) demonstration, only equipment and VRUs, or rather VRU mock-ups, provided by the partners of 5GCAR will be positioned and tracked. No real humans will serve as VRUs in the demonstrations. Instead movable carts with communication equipment will be used to model VRUs in the scope of the demonstration.