C-V2X Use Cases Volume II: Examples and Service Level Requirements

5GAA Automotive Association

White Paper

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Executive Summary

5G Automotive Association (5GAA) has defined a methodology to describe solution agnostic automotive use cases (UC) and application requirements referred to as Service Level Requirements (SLR).

This White Paper applies the defined methodology to describe use cases, and includes advanced UCs that require complex interactions among vehicles as well as between vehicles and infrastructure in relation to self-driving (autonomous) vehicles. Different road scenarios, actors and service flows are considered in the defined use cases. Detailed analysis of the derived Service Level Requirements is also provided.

The use cases support different needs and provide benefits related to seven identified areas (or categories): Safety, Vehicle Operations Management, Convenience, Autonomous Driving, Platooning, Traffic Efficiency and Environmental Friendliness, Society and Community.

1. Introduction

5GAA bridges the automotive and telecommunication industries in order to address society's connected mobility and road safety needs with applications such as automated driving, ubiquitous access to services, integration into intelligent transportation, and traffic management. The 5GAA's Working Groups (WG) develop the frameworks, practical aspects, required standards, and business cases for 5G and the future application of connected mobility solutions. 5GAA has seven WGs: WG1 - Use Cases and Technical Requirements, WG2 - System Architecture and Solution Development, WG3 - Evaluation, Testbeds, and Pilots, WG4 - Standards and Spectrum, WG5 - Business Models and Go-To-Market Strategies, WG6 - Regulatory and Public Affairs, WG7 - Security and Privacy.

This White Paper is the second report of 5GAA Work Group 1 and its scope is to present recent WG1 work which includes advanced Cellular V2X (C-V2X) use cases (UC) with complex interactions that require more advanced protocols than available today. Many of these use cases have challenging requirements for communication systems (e.g. likely requiring optimised systems and applications).

This document adopts 5GAA methodology introduced in the first White Paper of WG1 used to create solution agnostic descriptions facilitating the selection of the most suitable technology to develop use cases and detailed application requirements, referred to as Service Level Requirements.

In Section 2 the Paper briefly describes the 5GAA methodology for defining use cases and associated Service Level Requirements, applying the use case and the service level description templates presented in Annex A. Section 3 gives a quick summary of use cases covered by this White Paper, providing enough information to follow the SLRs presented in Section 4. Detailed description of each use case can be found in Annex B. This Paper also lists (Annex C) how use cases correspond to the 5GAA White Paper: *'A visionary roadmap for advanced driving use cases, connectivity technologies, and radio spec-trum needs'*. The White Paper concludes with a summary in Section 5 and briefly presents the planned future work.

2. Overview of WG1 Methodology

The 5GAA WG1 methodology includes the definition of solution agnostic automotive use cases for C-V2X and the derivation of Service Level Requirements from the use cases.

Following the methodology that has already been introduced in 5GAA's first WG1 White Paper, all use case descriptions in this Paper are written from the vehicle perspective and in a solution agnostic manner. It should be noted that many of the use cases are applicable to both driven and autonomous vehicles (AV), and they do not preclude applications performing various tasks, such as collecting infor-mation, analysing data, etc.

The C-V2X use cases are described using a template applicable to a wide range of UCs with detailed descriptions supporting the SLRs. The template is presented in Annex A.1 with the correspond-ing explanation of the different fields. 5GAA WG1 has defined Service Level Requirements that describe C-V2X use case requirements in a technology and implementation agnostic way. The list of considered SLRs is provided in Annex A.2.

Each C-V2X use case belongs to one or more groups according to the different needs they are called on to fulfil, as well as the stakeholders benefiting from them:

- Safety
- Vehicle Operations Management
- Convenience
- Autonomous Driving
- Platooning
- Traffic Efficiency and Environmental Friendliness
- Society and Community

A detailed description of the above groups is provided in the first 5GAA WG1 White Paper.

3. C-V2X Use Case Descriptions

This section contains a short description of example use case descriptions developed by 5GAA WG1. Each use case can be composed of multiple scenarios, which differ in terms of road configuration, actors involved, service flows, etc.

A more detailed description of the use cases is provided in Annex B.

Safety

Cooperative Traffic Gap: A vehicle intends to pull into a certain lane and needs to cross multiple lanes so it asks vehicles already circulating on the road to cooperate by opening a gap to allow the host vehicle (HV) to enter the traffic and cross (manoeuvre) safely.

Interactive VRU Crossing: A vulnerable road user (VRU), such as a pedestrian or cyclist, signals his or her intention to cross a road and interacts with vehicles approaching the area in order to improve safety for VRUs and awareness for vehicles.

Vehicle Operations Management

Software Update of Reconfigurable Radio System: A Vehicle's reconfigurable radio system has its software or firmware updated (i.e. a feature set, new standard release) to comply with regional requirements, etc.

Convenience

Automated Valet Parking - Joint Authentication and Proof of Localisation: Enable access control to a parking facility for autonomous vehicles. Vehicles deposited in a drop-off area are authorised for autonomous navigation within the parking area.

Automated Valet Parking (Wake Up): A parked 'sleeping' vehicle in a parking facility should be autonomously moved for (re)parking pick-up. For this purpose, the vehicle receives a wake-up call.

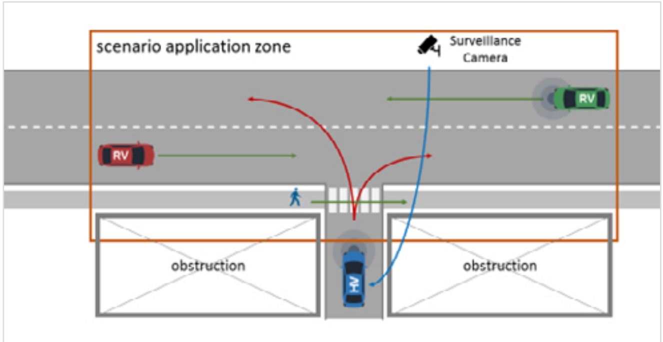
Awareness Confirmation: The host vehicle is sending out messages (e.g. basic safety messages or in the future more advanced 'evolved' message types) indicating whether it would like to receive confirmation. The HV receives confirmation from the remote vehicles and uses this information for various purposes (e.g. adapts its driving style).

Cooperative Curbside Management: A pedestrian and a vehicle are planning a pick-up at a crowded curbside to improve the efficiency and safety of this densely populated area.

Cooperative Lateral Parking: A vehicle identifies a free parking space on the side of a road and cooperates with neighbouring vehicles to inform them of the planned parking action and asks them to 'make room' in order to carry out an efficient and fast parking manoeuvre.

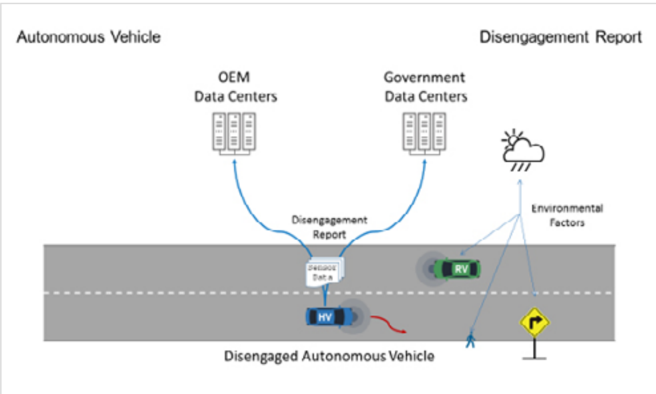
In-Vehicle Entertainment (IVE): Entertainment content delivery to the passengers of a moving or stationary vehicle (e.g. video, gaming, virtual reality (VR), office work, online education). It is applicable to both automated and non-automated vehicles, where in the latter the driver is restricted in the content he or she is safely allowed to consume.

Obstructed View Assist: A HV needs an unobstructed view to proceed safely. This view can be provided by a camera or other vehicles with a better view.



Vehicle Decision Assist: This feature helps a vehicle to decide whether it should overtake a stationary vehicle it detects in front.

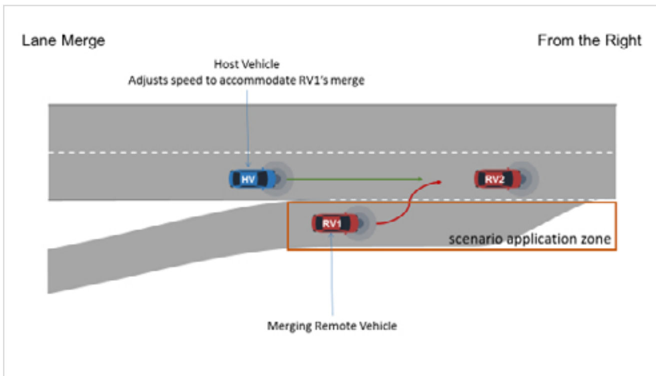
Autonomous Driving



Automated Intersection crossing: An autonomous vehicle goes through an intersection with traffic light. The AV goes through or stops, taking into consideration the timing of the traffic light signal. When stopping at the intersection, the AV can be put into the correct position.

Autonomous Vehicle Disengagement Report: When a HV's autonomous 'virtual driver' system disengages, it submits a disengagement report containing a time-windowed recording of vehicle systems data, rich sensory information and dynamic environmental conditions to the original equipment maker (OEM) and government data centres.

Cooperative Lane Merge: A host vehicle accommodates a remote vehicle that is merging into the HV's traffic lane.



Cooperative Manoeuvres of Autonomous Vehicles for Emergency Situations: An Autonomous Vehicle identifies a dangerous situation (e.g. collision with a moving object) and undertakes to coordinate with neighbouring AVs in order to decide and perform their manoeuvres jointly.

Coordinated, Cooperative Driving Manoeuvre: A HV wants to perform a certain action (e.g. lane change) and shares this intention with other traffic participants potentially involved in the manoeuvre. The informed traffic participants confirm or decline the planned manoeuvre with the main traffic participant which then informs a superset of the traffic participants whether it plans to perform the manoeuvre.

HD Map Collecting and Sharing: Vehicles equipped with LIDAR or other HD sensors can collect environment information around them, and share it with a HD map provider (e.g. cloud server). The HD map provider analyses the collected information and merges or combines it in order to build a regional HD map. This allows the construction of HD maps that are dynamically updated with more accurate data.

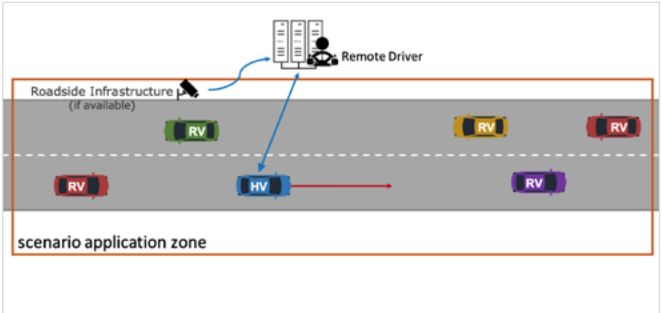
Infrastructure Assisted Environment Perception: When an automated vehicle enters a section of the road that is covered by infrastructure sensors it subscribes to receive information from the infrastructure containing environment data from dynamic and static objects on the road. This data is used to increase the trust level of the cars own sensor observations and extends its viewing range.

Infrastructure-Based Tele-Operated Driving: Infrastructure (e.g. sensors, cameras) support the remote driver by providing a real-time picture of the road environment centred around the HV. Based on the perceived situation and the capabilities of the car, the remote driver can provide the appropriate trajectory and manoeuvre instructions to help the autonomous vehicle move to a safer location.

Remote Automated Driving Cancellation (RADC): The High Automated level of an AD vehicle has to be immediately cancelled for safety reasons. This can be triggered for a number of reasons and criteria, including lack of network coverage, insufficient KPI SLA possibilities, unusual and/or unsafe driving conditions, etc.

Tele-Operated Driving (ToD): A remote driver undertakes the control of the vehicle and drives it efficiently and safely from the current location to the destination.

Tele-Operated Driving Support: An autonomous vehicle asks for the support of a remote driver in order to resolve a situation where uncertainty is high and it cannot make the appropriate decision for a safe and efficient manoeuvre. The vehicle then switches back to the normal autonomous driving mode without the remote driving support.



Tele-Operated Driving for Automated Parking: When a vehicle arrives at its destination parking area, the driver leaves the vehicle and it is parked by a remote driver located in a tele-operation centre.

Vehicle Collects Hazard and Road Event for AV: Vehicles collect hazard and road event information based on vehicle sensor data for further use by AVs and V2X application servers (V2X AS).

Platooning

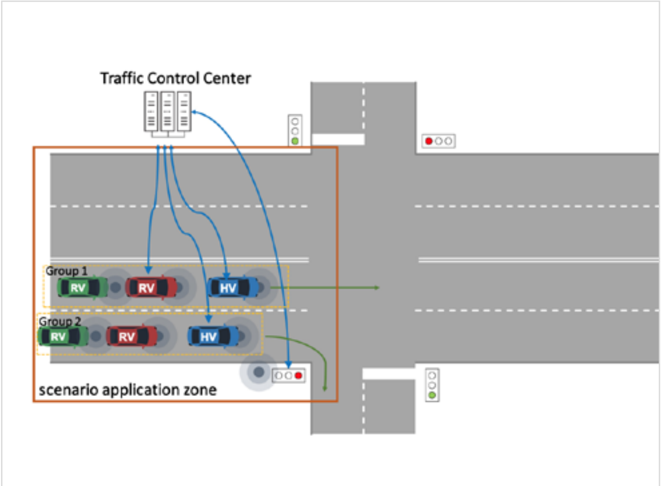
Vehicles Platoon in Steady State: A group of vehicles (e.g. trucks that travel from warehouse facilities to a transportation area) drive closer in a coordinated manner to decrease fuel consumption, increase efficiency and reduce traffic congestion.

Traffic Efficiency and Environmental friendliness

Bus Lane Sharing request: Temporary access to bus lanes can be granted to certain vehicles by a road authority/city, in order to improve road usage and traffic efficiency.

Bus Lane Sharing Revocation: Revocation of access to bus lanes granted to certain vehicles if a set of vehicles are likely to disturb/obstruct a bus that is approaching.

Continuous Traffic Flow via Green Lights Coordination: A series of traffic lights (usually three or more) are dynamically coordinated to allow continuous traffic flow over several intersections in one main direction. Any vehicle travelling along with the 'green wave' will see a progressive cascade of green lights, and does not have to stop at the intersections.



Group Start: Self-driving or semi-automated vehicles form a group to jointly start at a traffic light.

Society and Community

Accident Report: When host vehicles are involved in a traffic incident an accident report containing a time-windowed recording of vehicle systems data, rich sensory information, environmental conditions and any available camera views is sent to government and private data centres.

Patient Transport Monitoring: Paramedics, patient-monitoring equipment, trauma centres and doctors share vital patient telemetry data, images, voice and video during patient transport.

4. Service Level Requirements of C-V2X Use Cases

This section provides the Service Level Requirements of the example C-V2X use cases developed by 5GAA WG1. For some of the use cases different 'user stories' have been presented with different SLRs.

4.1 Cooperative Traffic Gap

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	On straight road segment: 1310 On road segment involving intersections: 2200	We assume that the speed for multi-lane roads where this use case makes sense does not exceed 22 m/s [50 mph]. To find an estimate for the range, we further assume that the vehicles take 5 seconds to synchronise their driving (e.g. synchronise to a line) and shall create a gap of 100 m length. Assuming that they create the gap by reducing their speed by around 10% (2 m/s), they will take 50 seconds to create the gap. This results in a distance of d = 22 m/s * 55 s = 1210 m. Adding the gap of 100 m results to a total of 1310 m. The second value of 2200 m is determined with the same assumptions of speed (22 m/s) and 50 seconds and 5 seconds to execute the 100 m gap, but it also considers the possibility that other RVs are involved and enter road from the side (i.e. intersections or access roads). Assuming the distance between the intersection and HV is approximately 200 m (100 m is the required gap), another 110 m is required for the gap creation of the RVs for a period of 5 s. This would leave 50s to create the gap and synchronise over a distance of 1100 m. If the synchronised vehicles are driving from opposite directions, and then merge into parallel lanes on the same road (thus executing the manoeuvre together), the distance they need to cover in order to synchronise is doubled to 2200 m.
Information Requested/ Generated	Quality of information/ Information needs	2 Mbps	(Precise Positioning, Trajectory, Vehicle Tag, Maximum Possible Speed, N/ACK) Precise position and intended route needed to find a group of supporting vehicles. Sequence of messages, low (for acknowledge messages) to high (for sensor data) payloads depending on the message.
Service Level Latency	[ms]	100 ms for communication to host vehicle 50 ms for communication within supporting group.	Complex interaction expected to form the group and coordinate the driving manoeuvre within, hence the strict latency requirement. The host vehicle will be continuously informed by the remote vehicles, hence the standard latency requirement of 100 ms

Service Level Reliability	%	99.9	This number refers to the case that the host vehicle has been informed about an upcoming gap and an ETA has been given. A failure here is treated as an abort. (PIRT and PRR as supporting KPI for implementation)
Velocity	[m/s]	22, [corresponding to 50 mph]	See range calculation for details.
Vehicle Density	[vehicle/ km^2]	Participants actually forming a traffic gap: 400 No. of potential participants in 1 km^2: 2000	10 requesting and 4*10 supporting vehicles per road of 1 km * 2 directions * 4 roads (e.g. parallel roads in urban city grid) = 400 vehicles. Use case seems unnecessary with a vehicle density which is too low. Some coordination with all potential participants might be necessary, even if the vehicles actually performing the use case in the end are only partially represented. Therefore, vehicle density of 2000/km^2 reflects a downscaled version of the upper end of urban vehicle density (=10,000).
Positioning	[m]	1.5 m (3σ) Lateral inter-vehicle distance 1 m	Longitudinal absolute positioning. Lane-level accuracy for lateral distance (relative).
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability due to different OEMs. Regulation is needed, e.g. for setting limits to the properties. A standardised protocol is needed.

4.2 Interactive VRU Crossing

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	500	Message does not need an extreme range, as it only needs to reach nearby vehicles that should stop for a pedestrian. However, vehicles on high-speed roads will need adequate time to stop.
Information Requested/ Generated	Quality of information/ Information needs	64 kbps	Pedestrian must send a ‘heartbeat’ message (including location data e.g. PSM) after a small ‘request’ message; the vehicle only needs to send acknowledgment.
Service Level Latency	[ms]	100	Exchange of messages must happen quickly, but a manoeuvre will only be initiated upon agreement, so slow messaging is not necessarily a safety risk.
Service Level Reliability	%	99.9	Again, since a manoeuvre will only be initiated upon agreement, dropped messages will not result in an immediate and significant safety risk.
Velocity	[m/s]	19.4 m/s	Upper end of the speed that a vehicle will be driving at on a road with a pedestrian crossing (70 km/h).

Vehicle Density	[vehicle/ km^2]	730	Assumes vehicles within 500 m radius of roads with 2 lanes of traffic in each direction.
Positioning	[m]	0.2 (3σ)	If a pedestrian is standing next to a roadway, it only takes a slight position error to place them in the middle of the street on a map, or directly in the trajectory of a vehicle. Alternatively, if the pedestrian is crossing, a small error could falsely indicate to a nearby vehicle that the pedestrian is on the sidewalk .
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability due to different OEMs and mobile device manufacturers. Regulation is needed to determine when a vehicle must respond to a VRUs intent to cross, and when they may not. A standardised protocol is needed.

4.3 Software Update of Reconfigurable Radio System

User Story #1 (Upgrade of Feature-Set)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Within network service provider coverage	In principle, the user story is applicable in the network service provider coverage area.
Information Requested/ Generated	Quality of information/ Information needs	Up to 200 MB per update	Depending on the size of the feature-set in the new release, several blocks of the radio system need to be upgraded with a database possibly attached to the feature-set. Normally, the process of downloading the radio software update occurs in the background and should defer to more latency sensitive applications.
Service Level Latency	[ms]	N/A	Software updates themselves are not latency sensitive.
Service Level Reliability	%	99	Radio software updates should successfully transfer but this can occur over an extended period, as above. Exceptions would be when a vehicle is persistently out-of-range (for example, in long-term underground parking), or only sporadically within range (such as a farmer who only occasionally drives into town), in which case priority may be given to a more rapid download when in range.
Velocity	[m/s]	U19.4	This is a typical maximum city speed (70 km/h), where it will be helpful to collect radio software updates over time. Note that a consistent download rate is not required, since the download may collect parts of the software image as available, and pause and continue downloading as needed.

Vehicle Density	[vehicle/ km^2]	1500 vehicles/km^2	Ideally, with all vehicles in a dense area employing reconfigurable radio systems, all should be updated almost simultaneously .
Positioning	[m]	30 (1σ)	Depending on regional radio regulations, the vehicle only needs to know in which region it is located.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/ Yes/No	Different OEMs may employ different providers of radio software. Radio regulations need to determine under which conditions a new release can be deployed.

User Story #2 (Addressing Vulnerabilities)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Within network service provider coverage	In principle, the user story is applicable in the network service provider coverage area.
Information Requested/ Generated	Quality of information/ Information needs	Few MB up to 100 MB	Depending on which software module the vulnerability is encountered, the specific module needs to be replaced.
Service Level Latency	[ms]	1 hour to deliver 'critical update required' message	The most stringent requirement is to deliver the 'critical update required' message. The human driver is still responsible for safe vehicle operation.
Service Level Reliability	%	99	Radio software updates should successfully transfer but this can occur over an extended period, as above. Exceptions would be when a vehicle is persistently out-of-range (for example, in long-term underground parking), or only sporadically within range (such as a farmer who only occasionally drives into town), in which case priority may be given for a more rapid download when in range.
Velocity	[m/s]	Up to 19.4	This is a typical maximum city speed (70 km/h), where it will be helpful to collect radio software updates over time. Note that a consistent download rate is not required, since the download may collect parts of the software image as available, and pause and continue downloading as needed.
Vehicle Density	[vehicle/ km^2]	1500/km^2 10%-30% of the vehicles	By assuming a dense urban environment, many vehicles need to have their system updated due to a high penetration of the same radio system.
Positioning	[m]	30 (1σ)	Depending on regional radio regulations, the vehicle only needs to know in which region is located.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/Yes/No	Different OEMs may employ different providers of radio software. Radio regulations need to determine if and when the replacement of the vulnerable radio system block can be deployed.

4.4 Automated Valet Parking - Joint Authentication and Proof of Localisation

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	HV to Parking Garage: 50	Assuming direct communication, communication is needed between a vehicle and a barrier. Assuming network connection, no value is specified.
Information Requested/ Generated	Quality of information/ Information needs	Data rate is very low, we assume 1000 bytes in 500 ms, resulting to 16 kbps	Proof of identity by the vehicle. The position of the vehicle might come from the vehicle or be inferred by the infrastructure.
Service Level Latency	[ms]	500	There is no particular constraint on Service Level Latency, hence the high number.
Service Level Reliability	%	99	The failure probability is so low that there is no significant delay in entering the parking structure.
Velocity	[m/s]	Moving in drop-off zone to barrier: 6.9	25km/h is assumed as the maximum velocity.
Vehicle Density	[vehicle/ km^2]	50	It is assumed that there is only one drop-off zone in the given km^2 and that 50 vehicles are lining up in that zone.
Positioning	[m]	1 (3σ)	Relative positioning between a barrier and a vehicle.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability due to different OEMs. Regulation is needed, e.g. maximum speed in drop-off area. A standardised protocol is needed for this use case.

4.5 Automated Valet Parking (Wake Up)

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	For direct communication: 1000 For Cellular: N/A	In the direct communication case, a distance of 1000 m should be provided to equip parking structures adequately. When cellular communication is used, the range is indicated as N/A as a larger range is possible.
Information Requested/ Generated	Quality of information/ Information needs	Authenticated wake-up signal	Data rate 3.2 Kbps

Service Level Latency	[ms]	500	This is a very loose requirement because all automated driving actions occurring after the wake-up call need more time to initiate.
Service Level Reliability	%	99	This is the probability that the car owner or infrastructure initiate a wake-up call and the vehicle does not reply within the Service Level Latency. This should be high enough to prevent the user from losing trust in the service.
Velocity	[m/s]	0	The car is parked during a wake-up call.
Vehicle Density	[vehicle/ km^2]	15,150	Assuming a parking space is 2.30 m wide and 5 m long (plus 3.5 m on each side to reach the spot), approximately 434 x 117 (50,500) parking spots on one square kilometre are needed. Assuming six levels that comes to an estimated 303,000 spots. The total number of vehicles that need to be woken up in the same area can be estimated. Assume between 1% and 5% of the vehicle parking spaces need to be 'woken up' simultaneously, the parking area coverage comes to 3030-15,150.
Positioning	[m]	N/A	Not applicable.
Power Consumption	[mW]	30	Assume 30 mW for the ECU to keep this service available for two weeks.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/No/Yes	Interoperability due to different OEMs and different infrastructures. Regulation is not needed. A standardised protocol is needed for this use case.

4.6 Awareness Confirmation

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	1000	The range for messages related to awareness confirmation shall not be below the range of regular messages, such as BSMs.
Information Requested/ Generated	Quality of information/ Information needs	Request for confirmation itself as well as corresponding settings, such as Type of Message, Feedback Rate, etc.	Maximum 40 Kbps - vehicle requesting confirmation from all messages. Frequency requirements: Maximum 50 in the case of an event.
Service Level Latency	[ms]	According to settings in request Typical value: 20	The latency between sending a message and receiving its confirmation. A maximum value in the request that can help the receiver of the message to decide how fast a confirmation needs to be sent out.
Service Level Reliability	%	99 for regular and 99.9 for reliable channel	The settings allow for confirmation messages to be sent over a regular channel or a reliable channel. The Service Level Reliability is set accordingly.

Velocity	[m/s]	138.8, what corresponds to 500 km/h	As this is a general concept, it is not advisable that other use cases build on it, so it describes the maximum relative speed between two cars.
Vehicle Density	[vehicle/ km^2]	9000	Confirmations should not be sent in congested situations, hence the maximum vehicle density is set to 9000 vehicle/km^2. This is an intermediate value based on vehicle density values of 4500 (highway), 9000 (rural), and 12,000 (urban).
Positioning	[m]	1.5 (3σ)	The positioning must allow to separate the vehicles from each other, such that it can be identified which vehicle sends what.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability due to different OEMs. Regulation is needed, e.g. for setting limits to the properties. A standardised protocol is needed.

4.7 Cooperative Curbside Management

User Story #1 (Upgrade of Feature-Set)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	800 10,000	Range needs to be long enough to communicate pick-up instructions to approaching vehicles (i.e. just before they reach pick-up lanes). Longer range is necessary to initiate pick-up with a vehicle that is still far away from curbside area
Information Requested/ Generated	Quality of information/ Information needs	(Sequence of messages including Acknowledgment messages)	Data from a HV and pedestrian will be low in volume (mostly identifiers); data from Traffic Management Entity (TME) will be more intense, at peak including granular vehicle path data along with metadata such as Time-To-Live (TTL).
Service Level Latency	[ms]	100 5000	As a vehicle approaches the curbside area, there is some time for the TME to send a 'coordination message' before it formally enters the densely crowded zone. When a vehicle is initially indicating to a TME that it will be executing a curbside manoeuvre, it may still be several kilometres away, in which case the messages are not urgent (no 'time urgency').
Service Level Reliability	%	99.9	Dropped packets or connections could result in vehicle trajectory conflicts.
Velocity	[m/s]	22.4	(80 km/h) Some pick-up areas have high-speed approaches where vehicle communication with a TME will begin (e.g. highway off-ramp, airport access road).
Vehicle Density	[vehicle/ km^2]	2000	Assumes 1 km x .25 km U-shaped pick-up area with 4 lanes, and vehicle spaces only 1 m apart, which fits 410 cars per lane * 4 lanes = 1640, plus extra cars entering or leaving the pick-up area.

Positioning	[m]	1 (3σ)	Since vehicles are in close proximity to one another, positioning must be extremely precise to prevent overlapping vehicle paths or pick-up areas.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/No/Yes	Interoperability due to different OEMs and mobile device manufacturers. The use case is largely driven by efficiency and convenience, so it may only be deployed as needed in areas with extremely high-volume traffic. A standardised protocol is needed.

4.8 Cooperative Lateral Parking

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	50	The range of the messages is very low as only vehicles in the direct surrounding of the parking spot need to be reached.
Information Requested/ Generated	Quality of information/ Information needs	27 Mbps	Assuming an ultrasonic sensor with 38,400 baud rate with 16 Bit resolution = 614.4 kbps per sensor. For 10 front (5) and rear (5) US sensors, the data rate required on the direct links would be 6 Mbps. The data may be compressed at a rate of 2, which yields 3 Mbps. Compressed video camera data from two cameras (one at the front and one at the rear of the host vehicle) results in a data rate of 24 Mbps. Hence, the required data rate of both sensor types on the direct links is about 27 Mbps.
Service Level Latency	[ms]	100 manoeuvre 10 for cooperative manoeuvre	100 ms for messages preparing the manoeuvre. 10 ms while multiple vehicles are performing a cooperative manoeuvre.
Service Level Reliability	%	99.9	
Velocity	[m/s]	1.38	Vehicles move very slowly during parking manoeuvres (corresponding to 5 km/h).
Vehicle Density	[vehicle/ km^2]	1000	Downscaled value of 12 k vehicles that is used as the maximum density estimated in a dense urban grid. This number is calculated for 1 lane in each direction and 20 m inter-vehicle distance.
Positioning	[m]	0.2 (3σ)	Relative positioning longitudinally.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes / Yes / Yes	Interoperability due to different OEMs. Regulation is needed, e.g. for setting limits to the properties. A standardised protocol is needed.

4.9 In-Vehicle Entertainment (IVE) - High-Definition Content Delivery, On-line Gaming and Virtual Reality

User Story #1 (High-Definition (HD) Content Delivery, On-line Gaming and Virtual Reality - High-End Service for Cars)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Depends on the new or alternative definition of range. In principle, the use case is applicable to the service provider coverage area.
Information Requested/ Generated	Quality of information/ Information needs	Quality of Experience 4 streams of 8 k resolution video with estimated up to 250 Mbps per stream	The information need reference is also applicable to immersive entertainment, such as virtual reality (VR). The instantaneous data rate will probably vary during operation.
Service Level Latency	[ms]	20	This is the maximum latency tolerable for online gaming and for a VR or augmented reality (AR) immersive experience. For on-demand services a higher latency may be tolerable. (See alternative user story).
Service Level Reliability	%	99	The reliability here should be sufficient to guarantee Quality of Experience (QoE) for both gaming and VR/AR.
Velocity	[m/s]	69.4	Maximum speed on highways is 250 km/h and the content should also be delivered at all possible speeds up to this maximum.
Vehicle Density	[vehicle/ km^2]	500 vehicles/km^2	Assumes an overall vehicle density of 1500 vehicles/ km^2 and that one third of them have up to four passengers accessing HD content.
Positioning	[m]	30 (1σ)	It is typically enough for the service provider to identify in which street/road and approximate position along this street/road.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/No/No	The content format and content distribution platform (service level) does not need to be standardised.

User Story #2 (High-Definition (HD) Content Delivery - Low-End Service for Cars)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Not applicable.
Information Requested/ Generated	Quality of information/ Information needs	Quality of Experience 2 streams of 4 k resolution video with estimated 50 Mbps per stream	The requirement here is that the passengers served should achieve an absolute minimum QoE.

Service Level Latency	[ms]	150	This is the maximum latency supported for interactive video, such as video conferencing.
Service Level Reliability	%	90	The reliability here should only meet minimal requirements for video streaming with guaranteed QoE.
Velocity	[m/s]	41.6	The low-end variant may be applicable to vehicles that cannot reach very high speeds (up to 150 km/h)
Vehicle Density	[vehicle/ km^2]	500 vehicles/km^2	Assumes an overall vehicle density of 1500 vehicles/ km^2 and that one third of them have up to two passengers accessing HD content.
Positioning	[m]	50 (1σ)	It is typically enough for the service providers to identify in which street and the approximate position along this street.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/ No/No	The content format and distribution platform (service level) do not need to be standardised.

User Story #3 (High-Definition (HD) Content Delivery - Bus Passenger Service)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Depends on the new or alternative definition of range. In principle, the use case is applicable in the service provider coverage area.
Information Requested/ Generated	Quality of information/ Information needs	Quality of Experience Up to 30 streams of 4 k resolution video with estimated up to 50 Mbps per stream	The requirement here is that the passengers served should achieve an absolute minimum QoE.
Service Level Latency	[ms]	150	This is the maximum latency supported for interactive video, such as video conferencing.
Service Level Reliability	%	90	The reliability here should only meet minimal requirements for video streaming with guaranteed QoE.
Velocity	[m/s]	27.8	A fully occupied bus would have a limited maximum speed (up to 100 km/h).
Vehicle Density	[vehicle/ km^2]	30 vehicles/km^2	Assumes an overall vehicle density of 1500 vehicles/ km^2 and that 1/50 of them are buses that have up to 30 passengers accessing HD content.
Positioning	[m]	50 (1σ)	It is typically enough for the service providers to identify in which street/road and approximate position along this street/road.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/No/No	The content format and distribution platform (service level) does not need to be standardised.

4.10 Obstructed View Assist

User Story #1 (Provision of Video Stream Via CCTV)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	100	The communication range required between cameras and vehicle. For big intersections in metropolitan environments, cameras might still be rather far away, thus more than 100 m may be needed.
Information Requested/ Generated	Quality of information/ Information needs	5 Mbps	Video streaming: ~5 Mbps are needed to transmit a progressive high-definition video signal with resolution 1280 x 720, frame-rate 30 Hz, colour depth 8 bit, 24 bit resolution, sub-sampling 4:2:2 and a typical compression of 1:30 (e.g. with H.264).
Service Level Latency	[ms]	50	This value represents the end-to-end communication latency, without any application-layer processing like coding, decoding, etc. This latency should be kept; lower values would enhance the experience for users and provide safety improvements.
Service Level Reliability	%	99	Reliability of 99% at the communication layer for video frames is needed to avoid massive artefacts that may lead to degradation of video quality for assisted driving. The video will support the decision of the driver to perform a certain manoeuvre and should thus be provided in high enough quality to support that.
Velocity	[m/s]	2.8	The cameras are stationary, the velocity of the HV will be slow. If obstructed view is handled before a complete stop, then HV speeds might still be in the range of 10 km/h.
Vehicle Density	[vehicle/ km^2]	12000	Obstructed view might happen in dense metropolitan areas with a lot of vehicles around.
Positioning	[m]	2 (3σ)	The position of the HV does not need to be too accurate, as long as it can be determined which camera(s) should provide a video stream to get the most out of the use case.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/ Yes/Yes	Interoperability between different OEMs is not needed, since only I2V communication is happening. Regulation and standardisation is needed; a common video format, coding/decoding scheme, etc. should be used by all vehicles and cameras.

User Story #2 (Provision of Video Stream Via RVs)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	200	The communication range required between HV and other vehicle. Suitable RVs will in most cases be moving towards the HV, so a higher communication range is recommended in order to provide a sufficient safety margin to make use of the RVs detected (notwithstanding where they already passed the spot where a video stream might be helpful for the HV).

Information Requested/ Generated	Quality of information/ Information needs	5 Mbps	Video streaming: ~5 Mbps are needed to transmit a progressive high-definition video signal with resolution 1280 x 720, frame-rate 30 Hz, colour depth 8 bit, 24 bit resolution, subsampling 4:2:2 and a typical compression of 1:30 (e.g. with H.264).
Service Level Latency	[ms]	50	This value represents the end-to-end communication latency, without any application-layer processing like coding, decoding, etc. This latency should be kept; lower values would enhance the experience for users and provide safety improvements.
Service Level Reliability	%	99	Reliability of 99% at the communication layer for video frames is needed to avoid massive artefacts that may lead to degradation of video quality for assisted driving. The video will support the decision of the driver to perform a certain manoeuvre and should thus be provided in high enough quality to support that.
Velocity	[m/s]	27.8	The velocity of the HV will be slow. If obstructed view is handled before a complete stop, then velocities of the HV might still be in the range of 10 km/h. The RVs might be driving at normal speed (for all roads except highways), so a maximum expected speed of 100 km/h seems reasonable.
Vehicle Density	[vehicle/ km^2]	12000	Obstructed view might happen in dense metropolitan areas with a lot of vehicles around.
Positioning	[m]	1.5 (3σ)	Requirement driven by positioning accuracy for RVs. Here, a lane-level resolution might be needed in order to be able to determine which RVs are most suitable for video stream provision.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability is needed between HV and RVs to understand query, response, and demand for video stream, respectively. Regulation and standardisation is needed, since a common video format, coding/decoding scheme, etc. should be used by all vehicles.

4.11 Vehicle Decision Assist

User Story #1 (RV Waiting for a Short Period of Time)
User Story #2 (RV Broken Down)
User Story #3 (Bus Having to Wait)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	500	500 m potentially allows the vehicles to exchange information, derive a decision, and coordinate an overtake manoeuvre together with the oncoming traffic.
Information Requested/ Generated	Quality of information/ Information needs	1000 bytes	For stationary vehicle decision assist, not that much information is likely to be needed (duration of stay, accident, need for help, etc.).

Service Level Latency	[ms]	100	Stationary vehicle decision assists is not a time-critical use case, therefore 100 ms should be enough.
Service Level Reliability	%	99.9	In general, there is some requirements related to reliability. However, overly strict requirements might not be necessary for this group of use cases.
Velocity	[m/s]	69.4	A worst-case scenario as foreseen might be a stationary vehicle (v=0) on a highway, where HV's velocity v=250 km/h.
Vehicle Density	[vehicle/ km^2]	1000	Downscaled value of 12 k vehicles that is used as the maximum density estimated in a dense urban grid. This number is calculated for 1 lane in each direction and 20 m inter-vehicle distance.
Positioning	[m]	1.5 (3σ)	Lane-level accuracy would be helpful. Higher accuracy should not be needed.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability is needed. Regulatory measures would improve implementation speed. Standardisation is needed especially for the way information is requested and described.

User Story #4 (Slow Vehicle en Route)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	500	500 m potentially allows vehicles to exchange information, derive a decision, and potentially coordinate an overtake manoeuvre together with the oncoming traffic.
Information Requested/ Generated	Quality of information/ Information needs	Few bytes to few MB	Depending on the amount and nature of information exchanged, quite a range might be assumed here.
Service Level Latency	[ms]	100	In most foreseen situations, this use case will not be applied in a time-critical way. One criterion is that, for arbitrary information, the RV may not be able to process/understand the request. Here, it would be too great a risk to perform such requests in time-critical emergency situations.
Service Level Reliability	%	99.9	In general, there is some requirements related to reliability. However, overly strict requirements might not be necessary for this group of use cases.
Velocity	[m/s]	69.4	The worst-case scenario for this use case, as foreseen, might be a stationary vehicle (v=0) on a highway, where the HV's velocity v= 50 km/h.
Vehicle Density	[vehicle/ km^2]	10,000	The worst-case scenario could be every vehicle in a dense urban grid requests some kind of information from another vehicle.
Positioning	[m]	1.5 (3σ)	Lane-level accuracy would be helpful. Higher accuracy should not be needed.

Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability is needed. Regulatory measures would improve implementation speed. Standardisation is needed especially for the way arbitrary information is requested and described.

4.12 Automated Intersection Crossing

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	500	With a relative speed of 160 km/h, in order to provide Time-To-Collision (TTC) of 10 sec. plus headway time of 2 sec. around 500 m of communication range is needed.
Information Requested/ Generated	Quality of information/ Information needs	300-450 bytes per vehicle 100 bytes for traffic light information 1000 bytes for intersection geometry information 400 bytes for intersection manager data	• 300-450 bytes per awareness message (vehicles) e.g. CAM, BSM (≤ 10 Hz) • Traffic light information e.g. SPaT: 100 bytes (1 Hz). • Intersection geometry information e.g. MAP: 1000 bytes in 1 sec. • Intersection manager data: 400 bytes (e.g. trajectory information/planned velocity/vehicle).
Service Level Latency	[ms]	10	Coordination and intersection manager messages might be issued within a short period of time.
Service Level Reliability	%	99.9999	High reliability is needed due to safety reasons.
Velocity	[m/s]	Urban: 19.4 Rural: 33.3	Different maximum speeds for the road environment where this use case could be realised or put into effect.
Vehicle Density	[vehicle/ km^2]	3200	Assumes that at one intersection (urban environment) there are up to 8 groups of 10 vehicles each (80 vehicles). Further assuming that there are up to 40 intersections per km^2 (e.g. in Manhattan), the result is 3200 vehicles/km^2 as an upper bound. Present VRUs per km^2: ~10000 Concerned VRUs are the ones near streets, not counting workers in offices or the like. However, to calculate the total network load, etc., all VRUs in the given area have to be considered.
Positioning	[m]	0.15 (3σ)	For autonomous vehicle control.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability is necessary between OEMs and infrastructure elements. Regulation is needed because authorities may need to specify the maximum speed, minimum accuracy, etc.

4.13 Autonomous Vehicle Disengagement Report

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Needs to reach a cloud centre.
Information Requested/ Generated	Quality of information/ Information needs	Detailed sensor report immediately before the disengagement	Collect detailed sensor data 15 sec. prior to disengagement. The estimate is on the order of 2 GB. Assuming 10 min. transmission time result in 26.7 Mbps.
Service Level Latency	[ms]	Est. 10 minutes	Not highly time critical.
Service Level Reliability	%	High/99.99	A high degree of reliability is needed for data transfer.
Velocity	[m/s]	69.4	The maximum speed considered on a highway, although speed SLR is not critical for this use case.
Vehicle Density	[vehicle/ km^2]	12000	Maximum assumed density in an urban situation.
Positioning	[m]	1.5 (3σ)	Required for accurate understanding where the disengagement occurred.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/Yes/No	Interoperability with the government cloud would be needed, but interoperability is not required between vehicles.

4.14 Cooperative Lane Merge

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	300	Maximum range assuming the maximum speed on a highway.
Information Requested/ Generated	Quality of information/ Information needs	300 bytes	Message with location and path information is assumed to be sent from the RV1 to the HV, and also from the HV to the RVs. The size of this message, considering the length of location, speed and path information, is maximum 300 bytes. In this use case acknowledgement messages are sent from the RV1 to notify the HV about a manoeuvre, to gain acceptance before initiating it.
Service Level Latency	[ms]	20	Cooperation among the vehicles is needed to optimise lane merging. Low communication latency is needed among the vehicles to coordinate their expected trajectory without delays, where HV or RVs may face a new road situation or condition that requires another iteration to agree and start implementing the agreed manoeuvres and/or speed adjustments. According to the analysis provided in the 5GCAR project, a value that is <30 ms should be considered for autonomous vehicles.

Service Level Reliability	%	99.9	Reliability of 99.9% should be enough for zero-error lane changing, or the perception thereof. False positives are more problematic and dangerous than false negatives.
Velocity	[m/s]	Urban: 19.4 Rural: 33.3 Highway: 69.4	Different maximum speeds for corresponding road environment; here, the maximum speed of the HV is presented. Whether the cooperative lane merge will take place depends on vehicles' decisions and regulation e.g. speed.
Vehicle Density [vehicle/km^2]	xxx	4500 (Highway) 9000 (Rural) 10000 (Urban)	Depends on the road environment.
Positioning	[m]	1.5 (3σ)	Typical positioning accuracy to confirm traffic lane.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Vehicles of different OEMs should cooperate for successful lane merging. Regulation is needed because authorities may need to specify the maximum speed, minimum accuracy, etc.

4.15 Cooperative Manoeuvres of Autonomous Vehicles for Emergency Situations

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	150	Assuming that a vehicle (i.e. HV), including inter-vehicle gap is 15 m, and 10 vehicles are involved in the cooperative manoeuvres, the resulting range is 150 m.
Information Requested/ Generated	Quality of information/ Information needs	48 Kbps	Rate for continuous stream of messages after initial message exchange (cf. UC description).
Service Level Latency	[ms]	10	Very low latency is needed for messages that should be exchanged fast (e.g. share of intents, RV notification), since it is directly related with vehicles' safety and ability to avoid collisions where even few centimetres could be important.
Service Level Reliability	%	95	In the continuous stream of messages, some could be lost, therefore the Service Level Reliability should be approximately 99.9%, as stated in the user case description. For message retransmission, then the probability of losing both copies of one message is 0.05*0.05=0.0025, equivalent to an Service Level Reliability of 99.75%, which is good enough.
Velocity	[m/s]	Urban: 19.4 Rural: 33.3 Highway: 69.4	Different maximum speeds for corresponding road environments where this use case could be implemented.

Vehicle Density	[vehicle/ km^2]	4500 (Highway) 9000 (Rural) 12000 (Urban)	Maximum density of vehicles considered in the different road environments where this use case could be implemented.
Positioning	[m]	0.2 (3σ)	Very high position accuracy is needed, since the goal is to avoid collision among vehicles and/or with an object.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes / Yes/ Yes	This use case is possible for different brands. Regulatory oversight for safety related questions is needed. Standardisation on the application layer (message set and flow control).

4.16 Coordinated, Cooperative Driving Manoeuvre

User Story	Coordinated, Cooperative Driving Manoeuvre
Cooperative Lane Change	The main traffic participant is a host vehicle. It wants to perform a lane change, but there are remote vehicles already there. Therefore, it issues a Manoeuvre Intent Message (MIM) to ask for a lane change. RV1 right next to the HV as well as RV2 coming behind RV1 send Manoeuvre Feedback Messages (MFMs) containing rejections, but RV3 behind RV2 sends confirmation. After processing the three feedback messages, the HV sends an affirmative Manoeuvre Decision Message (MDM) including a time instant far enough in the future in order to give RV1 and RV2 enough time to overtake the HV. RV3, after sending a Manoeuvre Acknowledgement Message (MAM), might already have slowed down to make room for the HV which then changes lane in front of RV3.
Pedestrian Crossing Road	A pedestrian wants to cross a road with broken traffic lights. His/her mobile device sends out a MIM indicating an intention to cross the road. A vehicle approaching the road sends a confirming MFM. After his/her phone sends an affirmative MDM and the pedestrian receives the respective MAM, he/she starts crossing the road, knowing that the vehicle will decelerate - if necessary - in order not to hit him.
Road Blockage	One lane of a rural road is blocked by a traffic accident. Traffic heading in the other direction prevents blocked vehicles from driving around the obstacle. An HV approaching the obstacle sends a MIM indicating it wants to drive around the obstacle. While some vehicles reject this request (sending respective MFMs), a relatively small vehicle sends a confirming MFM. It drives to the outermost part of the lane or stops in front of the obstacle, making enough room for the blocked HV to navigate around. The HV sends a MDM indicating that it will drive around the obstacle when the small vehicle is near enough. The small vehicle sends a MAM to acknowledge participation.

NB: The SLRs mentioned in this use case are illustrative but concrete examples incorporating the Coordinated, Cooperative Driving Manoeuvres use case. Individual SLRs will have to be developed for each further use case in the future.

User Story #1 (Cooperative Lane Change)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	500	For a lane change, 500 m of range would make up for a time window of $t = \frac{s_{range}}{v_{rel}} = \frac{500\ m}{150\ km/h} * 3.6\ {}^{s}/_{h} = 12\ s$ in the event relative velocity is roughly 150 km/h, this should give enough time for cooperation.
Information Requested/ Generated	Quality of information/ Information needs	Manoeuvre description, time horizons, and respective intentions of participants Intent: 5-10 kB Feedback: 5-10 kB Decision: 5-10 kB Ack: 200-500 bytes > max. 50 kB	As described in the main event flow of this use case, the data needed to be exchanged might encompass trajectories and planned positions. Data rate requirements in the urban environment (assuming a communication range of 100 m) with 314 vehicles in communication range and average sending frequency of 50 kB every 5 seconds. Data rate requirements in highway environment (communication range = 500 m) with 7850 vehicles in communication range and average sending frequency of 50 kB every 10 seconds. > data rate within communication range = 64 Mbps
Service Level Latency	[ms]	4 * 40	Since the lane change described here is not an overly critical use case scenario, 4 times 40 ms should leave enough time for processing each car.
Service Level Reliability	%	99.9	In order to be able to plan manoeuvres, all messages should be received, reliably.
Velocity	[m/s]	41.67 (=150 km/h)	Since this user story only deals with relative velocities of vehicles driving in the same direction.
Vehicle Density	[vehicle/ km^2]	12000 for urban 4500 for highways	Use case applicable to highly congested urban areas. NB: In general, this use case should be applicable to all environments and driving situations. However, in high traffic scenarios, generating even more traffic by applying this use case should be avoided.
Positioning	[m]	1.5 (3σ)	In order to deal with cars with lane accuracy.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability across multiple OEMs is required. Regulations are needed in order to derive limits for parameters involved. A common, internationally standardised protocol is needed.

User Story #2 (Pedestrian Crossing)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	300	Range of 300 m sufficient to leave $t = \frac{s_{range}}{v_{rel}} = \frac{500\ m}{120\ km/h} * 3.6\ {}^{s}/_{h} = 15\ s$ of reaction time, which should be enough for a pedestrian crossing the road.
Information Requested/ Generated	Quality of information/ Information needs	Manoeuvre description, time horizons, and respective intentions of participants Intent: 5-10 kB Feedback: 5-10 kB Decision: 5-10 kB Ack: 200-500 bytes > max. 50 kB	As described in the main event flow of this use case the data needed to be exchanged might encompass trajectories and planned positions. Data rate requirements in the urban environment (assuming communication range of 100 m) with 314 vehicles in communication range and average sending frequency of 50kB every 5 seconds. > data rate within comm. range = 24 Mbps Data rate requirements in highway environment (communication range = 500 m) with 7850 vehicles in communication range and average sending frequency of 50 kB every 10 seconds. > data rate within comm. range = 64 Mbps
Service Level Latency	[ms]	4 * 20	Due to - low velocity of VRU when crossing the road - probably smaller processing power on VRU's UE communication latency should still be kept to a rather small value in order to give enough time for processing and for the VRU to cross the road.
Service Level Reliability	%	99.9	In order to be able to plan manoeuvres, all messages should be received, reliably.
Velocity	[m/s]	33.3 (=120 km/h)	Expected relative velocity between pedestrian and vehicle driving on urban road.
Vehicle Density	[vehicle/ km^2]	12000	This number reflects the maximum number of vehicles present within 1 km^2 of the urban road grid. The number of pedestrians trying to cross the streets has not been included in this consideration in order to be consistent with other SLRs mentioned in this White Paper.
Positioning	[m]	1.0 (3σ)	In order to deal with cars with lane accuracy and correctly identify pedestrians along the road.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability across multiple vehicle OEMs and UE manufacturers is required. Regulations are needed in order to derive limits for parameters involved. A common, internationally standardised protocol is needed.

User Story #3 (Road Blockage)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	300	For a lane change, 500 m of range would make for a time window of $t = \frac{s_{range}}{v_{rel}} = \frac{500\ m}{150\ km/h} * 3.6\ {}^{s}/_{h} = 12\ s$ in the event relative velocity is roughly 150 km/h, this should give enough time for cooperation.
Information Requested/ Generated	Quality of information/ Information needs	Manoeuvre description, time horizons, and respective intentions of participants Intent: 5-10 kB Feedback: 5-10 kB Decision: 5-10 kB Ack: 200-500 bytes > max. 50 kB	As described in the main event flow of this use case the data needed to be exchanged might encompass trajectories and planned positions. Data rate requirements in urban environment (assuming communication range of 100 m) with 314 vehicles in communication range and average sending frequency of 50 kB every 5 seconds. > data rate within comm. range = 24 Mbps Data rate requirements in highway environment (communication range = 500 m) with 7850 vehicles in communication range and average sending frequency of 50 kB every 10 seconds. > data rate within comm. range = 64 Mbps
Service Level Latency	[ms]	4 * 20	Due to the acceleration needed when driving around the obstacle (starting from stationary position/waiting), the communication latency should be kept rather low.
Service Level Reliability	%	99.9	In order to be able to plan manoeuvres, all messages should be received, reliably.
Velocity	[m/s]	33.3 (=120 km/h)	This use case should work under all circumstances and for all types of manoeuvres that build on it.
Vehicle Density	[vehicle/ km^2]	400	Assume ~20 vehicles involved in this use case (1 at the head of the queue of waiting vehicles, 19 lined up the different direction), then up to 20 obstacles could block rural roads within 1 km2 at the same time, as might be the case after a storm, for example.
Positioning	[m]	1.5 (3σ)	In order to deal with cars with lane accuracy.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability across multiple OEMs is required. Regulations are needed in order to derive limits for parameters involved. A common, internationally standardised protocol is needed.

4.17 High-Definition Map Collecting and Sharing

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	City: >500 Highway: >1000	In a city, 500 m range is about two blocks around the vehicle. An AV can depend on at least two blocks of dynamic HD map use for trajectory planning and avoiding collisions/congestions. While on the highway, because of higher speeds and less surrounding road information than in the city, 1000 m will be a suitable range.
Information Requested/ Generated	Quality of information/ Information needs	UL: Case 1: 47 Mbps Case 2: 4 Mbps DL: 16 Mbps	Case 1: Unprocessed but compressed sensor data are provided from a HV to the HD map provider. 47 Mbps is derived from: H.265/ HEVC HD camera ~8 Mbps + LIDAR ~35 Mbps + other sensor data. Case 2: Processed sensor data (interpreted objects) are provided from the HV to the HD map provider. We can assume 1 kB/Object/100 ms. So if we assume 50 objects per end up with 4 Mbps. HD maps of 500 m * 500 m in a city or 1000 m * 1000 m on a highway are about 2 M. Assumes the RV downloads the HD map within 1 sec. So It requires about 16 Mbps.
Service Level Latency	[ms]	100	End-to-end, 100 ms is needed for the HD map to perform in real time.
Service Level Reliability	%	99	For safety related information, timely and reliable communication is needed. The HD map data from the HV or HD map provider is not the only way for RVs to receive surrounding information.
Velocity	[m/s]	City: 19.4 Highway: 69.4	Assume the maximum speed in city is 70 km/h, and maximum speed on highways is assumed to be 250 km/h. The max speed will meet the traffic flow needs in different regions.
Vehicle Density	[vehicle/ km^2]	12000	Maximum assumed density in urban situation.
Positioning	[m]	0.1m~0.5 m (3σ)	AVs need high absolute location positioning to estimate surrounding objects' relative location to avoid collision.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No / Yes / No	Typically, those HD map-collection and -sharing solutions are proprietary. Regulatory oversight for safety related issues is needed.

4.18 Infrastructure Assisted Environment Perception

User Story #1 (Data Distribution about Objects on the Road in Form of Object Lists or Occupancy Grids)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	500	Typical sensor range expected for one of several roadside infrastructure nodes.
Information Requested/ Generated	Quality of information/ Information needs	From RADAR to local compute unit for sensor fusion 40-160 kbps From cameras to local compute unit 40-120 Mbps per camera (video streaming): ~8 Mbps compressed video per camera From LIDAR sensors to local compute unit: 35Mbps pro sensor From Infrastructure to HV 40 – 4000 kbps From edge to edge 40 – 4000 kbps.	Assumes RADAR sensors already generate object lists for observed vehicles, then the required bandwidth depends on traffic density. The number of cameras needed depends on the complexity of the roads including the number of lanes. Each camera is separately connected to the edge computer. This assumes also H264 compression. Video pre-processing, detection and classification of objects by camera is computationally intensive, therefore connecting more than two cameras to a state-of-the-art server is currently unlikely. Assuming each LIDAR sensor creates point clouds and not object lists. The value depends on whether object lists or occupancy grid information is transmitted. Object lists can contain dynamic information about speed and direction. This also depends on how many objects are reported. Each edge node is responsible for a certain section of highway, for example 1-2 km in length. Sensors on this section of the road are connected to at least one edge node which is then generating an environmental map for this 1-2 km road section. While vehicles travel on the highway they pass through different sections consecutively. Likewise, the knowledge about these vehicles needs to travel from edge node to edge node. The first edge node transmits the information about all observed objects to the next node in line. This node then starts to observe relevant objects using its own sensors and needs to match these observations with the information it receives from the previous edge node. This is necessary in order to continuously track and guide each vehicle. Therefore, edge nodes need some form of wired or wireless connection to each other. The data rate requirement is similar to a edge-to-vehicle transmission, in the case of broadcasting the objects detected on the road.
Service Level Latency	[ms]	From infrastructure to HV 100	Total from sensor detection to vehicle including sensor fusion on the edge = 100 ms. Depends on the reaction time needed, which is directly related to the maximum driving speed allowed. For instance, at a speed of 50 km/h, the HV will move 0.27 m within 20 ms.

Service Level Reliability	%	From sensors to edge compute node: 99 Infrastructure to HV: 99.99 (Very high)	This is comparable to the sensor inside the car. This use case applies augmented sensor data that the car retrieves itself resulting in slightly relaxed requirements compared to User Story #2. This service is still regarded as safety critical. If the infrastructure fails it must 'fail silently' or provide quantitative data about the service degradation (e.g. position precision falls from 10 to 100 cm).
Velocity	[m/s]	69.4	~250 km/h is the maximum relative speed between infrastructure and vehicles. Common assumptions of 500 km/h are not needed here because the infrastructure cannot move away from the vehicle.
Vehicle Density	[vehicle/ km^2]	1,200 vehicles/km2 at 20 km/h A maximum of around 400 vehicles (200 in each direction), i.e. 2% of this density receive the service	Around 200 vehicles will fit in 1 km highway strip with three lanes in each direction. Assumptions: • lane width of 3m (for the two directions around 20m) • inter-vehicles distance required in traffic jam (max speed 20 km/h): 11 meters • average vehicle length of 4.5 m Also assumes three highway crossings (bridges).
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane, and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	The same infrastructure needs to interact with all vehicle types. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy etc.

User Story #2 (Individual Data Transmission in Form of Trajectories or Actuation Commands)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	500	Typical sensor range expected for one of several roadside infrastructure nodes.
Information Requested/ Generated	Quality of information/ Information needs	From RADAR to local compute unit for sensor fusion 80-160 kbps Kbps From cameras to local compute unit 40-120 Mbps per camera (video streaming): ~8 Mbps compressed video per camera From LIDAR sensors to local compute unit: 35 Mbps pro sensor From Infrastructure to HV 80 Mbps From edge to edge 400 – 4000 Kbps.	Assuming RADAR sensors already generate object lists for observed vehicles then the required bandwidth depends on traffic density. The number of cameras needed depends on complexity of road including number of lanes. Each camera is separately connected to the edge computer. This assumes also H264 compression. Video pre-processing, detection and classification of objects by camera is computationally intensive, therefore connecting more than two cameras to a state-of-the-art server is currently unlikely. Assuming each LIDAR sensor create point clouds and not object lists. When transmitting trajectories, and assuming 10 waypoints plus velocity per trajectory, one trajectory is 1664 bytes in size. For instance, when sending every 100 ms to 500 cars this results in a bandwidth need of 8 Mbyte/s. Each edge node is responsible for a certain section of highway, for example 1-2 km in length. Sensors on this section of the road are connected to at least one edge node which is then generating an environmental map for this 1-2 km road section. While vehicles travel on the highway they pass through different sections consecutively. Likewise the knowledge about these vehicles needs to travel from edge node to edge node. The first edge node transmits the information about all observed objects to the next node in line. This node then starts to observe relevant objects using its own sensors and needs to match these observations with the information it receives from the previous edge node. This is necessary in order to continuously track and guide each vehicle. Therefore, edge nodes need some form of wired or wireless connection to each other. The bandwidth requirement is similar to the one for the edge-to-vehicle in the case of broadcasting the detected objects on the road.
Service Level Latency	[ms]	From infrastructure to HV 100	Total from sensor detection to Vehicle including sensor fusion on edge = 100 ms. Depends on the reaction time that is needed, which is directly related to the maximum driving speed allowed. For instance in a speed of 50 km/h, the HV will move 0.27 m within 20 ms.
Service Level Reliability	%	From sensors to edge compute node: 99 Infrastructure to HV: 99.999 (Very high)	This is comparable to the sensor inside the car. The requirement here is very high since the HV is following the trajectory blindly.

Velocity	[m/s]	35	~120 km/h is an average convenient speed for longer distance on the highway. Assuming dedicated lanes for this use case, the infrastructure is basically coordinating all vehicles, with all vehicles in those lanes being HV. Therefore, it is comparable to platooning and the danger of collision between HVs is reduced.
Vehicle Density	[vehicle/ km^2]	1200 vehicles/km2 at 20 km/h A maximum of around 400 vehicles (200 in each direction), i.e. 2% of this density have the service provided to them	Around 200 vehicles will fit in 1 km highway strip with three lanes in each direction. Assumptions: • lane width of 3 m (for the two directions around 20 m) • inter-vehicle distance required in traffic jam (maximum speed 20 km/h): 11 m • average vehicle length of 4.5 m • three highway crossings (bridges)
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	The same infrastructure needs to interact with all vehicle types. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc. may need to specify maximum speed, minimum accuracy etc.

4.19 Infrastructure-Based Tele-Operated Driving

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	1000	Maximum driving distance from the start of an emergency until safe stop.
Information Requested/ Generated	Quality of information/ Information needs	From RADAR to local compute unit for sensor fusion 80-160 Kbps From cameras to local compute unit 5-8 Mbps per camera (video streaming) From LIDAR sensors to local compute unit: 35Mbps per sensor From Infrastructure to Remote driver: Stream of environmental data after sensor fusion at the edge From Remote driver to HV: Up to 1000 Bytes per message (up to 400 Kbps) (Commands from Remote driver)	Assumes RADAR sensors already generate object lists for observed vehicles, then the required bandwidth depends on traffic density. The number of cameras needed depends on the complexity of the road including number of lanes. Each camera is separately connected to the edge computer. This assumes also H264 compression. Video pre-processing, detection and classification of objects by camera is computationally intensive, therefore connecting more than two cameras to a state-of-the-art server is currently unlikely. Assuming each LIDAR sensor create point clouds and not object lists. This could happen on the same compute node. Therefore this speed requirement will be handled by local buses like Peripheral Component Interconnect Express (PCIe). Pre-processed environment model data e.g. in form of object lists that contain among others vehicle types, sizes, speed and direction requires only limited bandwidth, depending on the number of objects in the environment model this is estimated between 50 -500 kBytes/s. From remote driver to HV: A machine-based remote driver will most likely transmit trajectories instead of direct actuation commands. The size of commands depends on information, for example: turn steering wheel, direction, angle, etc., b) apply the brake, brake pressure, etc. including appropriate security headers. The command messages will be sent every 20 ms (maximum 50 messages per second).
Service Level Latency	[ms]	From infrastructure to remote driver: 50 From remote driver to HV: 50	Round trip time = 100 ms From remote driver to HV: Depends on the reaction time needed, which is directly related to the maximum driving speed allowed. For instance, at a speed of 50 km/h, the HV will move 0.27 m within 20 ms.
Service Level Reliability	%	From sensors to edge compute node: 99 From remote driver to HV: 99.999 (Very high)	This is comparable to the sensor inside the car. From remote driver to HV: The transmission of commands or paths from the remote driver requires a very high level of reliability because this affects the safe and efficient operation of the AV. In addition, the video streams and/or sensor information should be sent with ‘high reliability’ to make sure that the remote driver has the correct (current) view of the surroundings.
Velocity	[m/s]	2.78	<10 km/h is considered the maximum speed for remote steering under highly uncertain conditions.

Vehicle Density	[vehicle/ km^2]	1,200 vehicles/ km2 @ 20km/h A maximum or around 10 vehicles, i.e. 0.05% of the total density, have the service provided to them.	Around 200 vehicles will fit in 1 km highway strip with three lanes in each direction. Assumptions: • lane width of 3 m (for the two directions around 20 m) • inter-vehicles distance required in traffic jam (maximum speed 20 km/h): 11 m • average vehicle length of 4.5 m • three highway crossings (bridges) Vehicle density reflects the number of HVs. Many more RVs could be present.
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability and standardisation is needed between the infrastructure (e.g. camera) and the ToD server. It is possible, however, that the edge servers are configured as a multi-tenant system where each car OEM runs its own system. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc.

4.20 Remote Automated Driving Cancellation (RADC)

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	> 1000	Notification range from communication network for the need of an AD change in order to have enough time to change AD mode to a lower mode and inform a passenger to undertake the driver's role (this last transition time can last 20s-30s)
Information Requested/ Generated	Quality of information/ Information needs	From network to the AD vehicle: ~ 300 bytes (DL) And Feedback from vehicle to network < 300 bytes (UL)	Network message size for notification of a basic safety message. And message from a car as feedback (a handshake) on the safety message. Note 1: the message assumes no trajectory or polygon information about the route or area with AD degradation, or multiple Quality of Service (QoS) degradation levels on the trajectory or area involved. Note 2: the message frequency assumes: 0.02 Hz.
Service Level Latency	[ms]	100	Considering the maximum assumed speed (250 km/h) and the handover time required to switch from the automated driving mode to a human driver, 100 ms is the estimated required time for transmitting the remote automated driving cancellation .

Service Level Reliability	%	99.999	Reliability to be reached until the HV arrives at the QoS degradation area.
Velocity	[m/s]	69.4	This use case could be applied to all types of road environments. The maximum speed in highway areas is considered to be 250 km/h.
Vehicle Density	[vehicle/ km^2]	1500	Vehicle density reflecting the number of HVs (all of them driving in the same direction) would need this QoS degradation notification message.
Positioning	[m]	10 (1σ)	The notification should be precise enough in terms of position to allow early RADC, and it also depends on the road environment (proportional to HD map resolution).
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	At a first implementation phase, an OEM can instruct its vehicles to deactivate the AD mode, but in the future a third party may undertake this role, hence interoperability and standardisation are required. Regulation is also required, since safety procedures are involved.

4.21 Tele-Operated Driving

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	10000	Assuming V2N: Communication range within the coverage of a macro cell.
Information Requested/ Generated	Quality of information/ Information needs	From HV to remote driver: 32 Mbps (video streaming) Or From HV to remote driver: 36Mbps (if video streaming and Object information is sent) From remote driver to HV: Up to 1000 bytes per message (up to 400 kbps) (Commands from Remote driver)	From HV to remote driver: ~8Mbps are needed for a progressive high-definition video/camera (h.264 compression). Four cameras are needed (one for each side): 4*8=32Mbps. From HV to remote driver (optional): Sensor data (interpreted objects) are also provided from the HV to the parking remote drive. Assuming 1 kB/object/100 ms and 50 objects, the result is 4 Mbps. From remote driver to HV: The size of command messages, e.g. a) turn steering wheel, direction, angle, etc., b) apply the brake, brake pressure, etc. including appropriate security headers. The command messages will be sent every 20 ms (maximum 50 messages per second).
Service Level Latency	[ms]	From HV to remote driver: 100 From Remote driver to HV: 20	From remote driver to HV: Depends on the reaction time needed, which is directly related to the maximum driving speed allowed. For instance, at a speed of 50 km/h, the HV will move 0.27 m within 20 ms.
Service Level Reliability	%	From HV to Remote driver: 99 From Remote driver to HV: 99.999 (Very high)	From remote driver to HV: The transmission of commands or paths from the remote driver requires a very high level of reliability because this affects the safe and efficient operation of the AV. In addition, the video streams and/or sensor information should be sent with 'high reliability' to make sure that the remote driver has the correct (current) view of the surroundings.

Velocity	[m/s]	13.9	50 km/h is considered the maximum speed for remote steering under highly uncertain conditions.
Vehicle Density	[vehicle/ km^2]	10	Vehicle density reflects the number of HVs. Many more RVs could be present.
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No / Yes / No	Typically, these ToD solutions are proprietary implementations. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc.

4.22 Tele-Operated Driving Support

User Story #1 (Remote Steering)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	10000	Assuming V2N: Communication range within the coverage of a macro cell.
Information Requested/ Generated	Quality of information/ Information needs	From HV to Remote driver: 32 Mbps (video streaming) Or From HV to remote driver: Optional: 36 Mbps (if video streaming and object information is sent) From remote driver to HV: Up to 1000 bytes per message (up to 400 Kbps) (Commands from remote driver)	From HV to remote driver: ~8 Mbps are needed for a progressive high-definition video/camera (h.264 compression). Four cameras are needed (one for each side): 4 * 8 = 32 Mbps. From HV to remote driver (optional): Sensor data (interpreted objects) are also provided from the HV to the parking remote drive. Assuming 1 kB/object/100 ms and 50 objects, the result is 4 Mbps. From remote driver to HV: The size of command messages, e.g. a) turn steering wheel, direction, angle, etc., b) apply the brake, brake pressure, etc. including appropriate security headers. The command messages will be sent every 20 ms (maximum 50 messages per second).
Service Level Latency	[ms]	From HV to Remote driver: 100 From Remote driver to HV: 20	From remote driver to HV: Depends on the reaction time needed, which is directly related to the maximum driving speed allowed. For instance at a speed of 50 km/h, the HV will move 0.27 m within 20 ms.
Service Level Reliability	%	From HV to Remote driver: 99 From Remote driver to HV: 99.999 (Very high)	From remote driver to HV: The transmission of commands or paths from the remote driver requires a very high level of reliability because this affects the safe and efficient operation of the AV. In addition, the video streams and/or sensor information should be sent with 'high reliability' to make sure that the remote driver has the correct (current) view of the surroundings.
Velocity	[m/s]	2.78	<10 km/h is considered the maximum speed for remote steering under highly uncertain conditions.

Vehicle Density	[vehicle/ km^2]	10	Vehicle density reflects the number of HVs. Many more RVs could be present.
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No / Yes / No	Typically, these ToD solutions are proprietary implementations. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc.

User Story	Detailed description, specifics and main differences to the user story in the main template	
User Story Title #2 **Tele-Operated Driving Support: Remote Driving Instructions** **Pedestrian Crossing Road** **Road Blockage**	User Story:	There are also situations where doubts are raised due to uncertain detection from one of the sensors (e.g. unresolved objects). For instance, a segment of road construction has just been set up or changed, and with that the road direction and lane markings have changed or are confusing. Such situations might need human intervention (teleoperator) to be resolved. The difficult situation is managed by a remote driver who advises the HV how to proceed with the autonomous driving task. The remote driver will provide instructions to the HV which will then execute them in its autonomous driving mode. The remote driver does not take over control of steering and acceleration. The remote driver retains the ability to control the braking.
	Other Actors' Roles:	Remote driver (human or machine) undertakes to send driving commands or instructions remotely (e.g. 'ignore lane marking', 'pass car blocking the road on the right/left') to the HV for a short period of time in order to deal with a dangerous or complex situation.

User Story #2 (Remote Driving Instructions)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	10000	Assuming V2N: Communication range within the coverage of a macro cell.
Information Requested/ Generated	Quality of information/ Information needs	From HV to remote driver: 32 Mbps (video streaming) or From HV to remote driver: Optional: 36 Mbps (if video streaming and object information is sent) From remote driver to HV: Up to 1000 bytes per message (up to 400 Kbps) (Commands from remote driver) or From remote driver to HV: Up to 25 Kbps (Path from remote driver)	From HV to remote driver: ~8 Mbps are needed for a progressive high-definition video/camera. Four cameras are needed (one for each side): 4 * 8=32 Mbps From HV to remote driver (optional): Sensor data (interpreted objects) are also provided from the HV to the parking remote driver. Assuming 1 kB/object/100 ms and 50 objects, the result is 4 Mbps. From remote driver to HV: The size of command messages, e.g. a) turn steering wheel, direction, angle, etc., b) apply the brake, brake pressure, etc. including appropriate security headers. The command messages will be sent every 20 ms (maximum 50 messages per second). From remote driver to HV: The data of provided paths are several kbps (e.g. 100 points and 32 bytes for each point).

Service Level Latency	[ms]	From HV to remote driver: 100 From remote driver to HV: 200	From remote driver to HV: With only the instructions to be transmitted from remote driver to the HV, latency requirements are more relaxed.
Service Level Reliability	%	From HV to remote driver: 99 From remote driver to HV: 99.999 (Very high)	From remote driver to HV: The transmission of commands or paths from the remote driver requires a very high level of reliability because this affects the safe and efficient operation of the AV. In addition, the video streams and/or sensor information should be sent with 'high reliability' to make sure that the remote driver has the correct (current) view of the surroundings.
Velocity	[m/s]	2.78	<10 km/h is considered the maximum speed for remote steering under highly uncertain conditions.
Vehicle Density	[vehicle/ km^2]	10	Vehicle density reflects the number of HVs. Many more RVs could be present.
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No / Yes / No	Typically, those ToD solutions are proprietary implementations. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc.

4.23 Tele-Operated Driving for Automated Parking

User Story #1 (Remote Driving Paths)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Depends on the new or alternative definition of range. In principle, the use case is applicable in the network service provider coverage area.
Information Requested/ Generated	Quality of information/ Information needs	From HV to Remote driver: 4 Mbps (Reporting from HV to Parking Remote driver) From remote driver to HV: Up to 25 Kbps (Path sent from parking remote driver)	From HV to remote driver: Sensor data (interpreted objects) provided from the HV to the parking remote driver. Assuming 1 kB/object/100 ms and 50 objects, the result is 4 Kbps. From remote driver to HV: The size of driving trajectory for the available parking slot sent from parking remote driver. The data of trajectories are several KBytes and the trajectory are only sent once (e.g. 100 waypoints of a route and 32 bytes for each waypoint).
Service Level Latency	[ms]	From HV to Remote driver and From Remote driver to HV: 100	From remote driver to HV: With only the trajectories to be transmitted from the parking remote driver to the HV, latency requirements are more relaxed. Driving at 20 km/s means 0.5 m between two commands.

Service Level Reliability	%	From HV to remote driver and from remote driver to HV: 99.999 (Very high)	From remote driver to HV: The transmission of commands or paths from the remote driver requires a very high level of reliability because this affects the safe and efficient operation of the AV. In addition, the video streams and/or sensor information should be sent with 'high reliability' to make sure that the remote driver has the correct (current) view of the surroundings.
Velocity	[m/s]	5.5	<20 km/h is the maximum considered speed inside the parking area.
Vehicle Density	[vehicle/ km^2]	100	The number of vehicles that need to be remotely driven in the same area. Assumes 5%-10% of the parking spaces for the number of remote driving vehicles in large parking area (1000 vehicles) resulting in about 50-100 places.
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/Yes/No	Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc. Inter-operability and standardisation are also preferred since vehicles from different OEMs will be supported by the remote parking service.

User Story #2 (Remote Steering)

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Depends on the new or alternative definition of range. In principle, the use case is applicable in the network service provider coverage area.
Information Requested/ Generated	Quality of information/ Information needs	From HV to remote driver: 32 Mbps (video streaming) Or From HV to remote driver (optional): 36 Mbps (if video streaming and object information is sent) From remote driver to HV: Up to 1000 bytes per message (up to 400 Kbps) (Commands from remote driver)	From HV to remote driver: 15-29 Mbps are needed for a progressive high-definition video/camera. Four cameras are needed (one for each side): 4 * 8 = 32 Mbps From HV to remote driver (optional): Sensor data (interpreted objects) are also provided from the HV to the parking remote driver. Assuming 1 kB/object/100 ms and 50 objects, the result is 4 Mbps. From remote driver to HV: For the steering commands, assume torque values for brake/acceleration and steering. The command messages will be sent every 20 ms (maximum 50 messages per second).
Service Level Latency	[ms]	From HV to Remote driver: 100 From Remote driver to HV: 20	From remote driver to HV: Depends on the reaction time needed, which is directly related to the maximum driving speed allowed. For a speed of 20 km/h, the HV will move 0.14 m within 20 ms. Higher latency is not recommended for a parking area, where the distance between the vehicles and/or objects is short.

Service Level Reliability	%	From HV to Remote driver: 99 From Remote driver to HV: 99.999 (Very high)	From remote driver to HV: The transmission of commands or paths from the remote driver requires a very high level of reliability because this affects the safe and efficient operation of the AV. In addition, the video streams and/or sensor information should be sent with 'high reliability' to make sure that the remote driver has the correct (current) view of the surroundings.
Velocity	[m/s]	5.5	<20 km/h is considered the maximum speed in a parking area.
Vehicle Density	[vehicle/ km^2]	100	The number of vehicles that need to be remotely driven in the same area. Assumes 5%-10% of the parking spaces for the number of remote driving vehicles in large parking area (1000 vehicles) resulting in about 50-100 places.
Positioning	[m]	0.1 (3σ)	Positioning accuracy is needed to navigate around objects blocking parts of the driving lane and to navigate through small gaps between two or more objects.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No/Yes/No	Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc. Inter-operability and standardisation are also preferred since vehicles from different OEMs will be supported by the remote parking service.

4.24 Vehicle Collects Hazard and Road Event for AV

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	Scenario 1:300 m Scenario 2: N/A	Minimum range assuming the maximum speed in a highway and 4 seconds response time for AVs. Needs to reach an application server (AS).
Information Requested/ Generated	Quality of information/ Information needs	300 bytes/per message	The message sent from HVs to RVs or AS contains detected event types (barriers, road work, bad weather, etc.), location, priority, etc. And the message is sent by an event trigger. The maximum size of the message is assumed to be 300 bytes
Service Level Latency	[ms]	20	Low end-to-end latency is needed for AVs to get hazard information in time to maintain safety levels.
Service Level Reliability	%	99.9	High reliability is needed for AVs to take action based on the hazard and road event message for other vehicles.
Velocity	[m/s]	City: 19.4 Highway: 69.4	The maximum speed in a city is assumed to be 70km/h, and the maximum speed on highways is assumed to be 250 km/h. The maximum speed will match the traffic levels in different regions.

Vehicle Density	[vehicle/ km^2]	12,000	The maximum assumed density in urban situations.
Positioning	[m]	1.5 (3σ)	AVs need pinpoint accuracy to estimate event locations and avoid collisions. Typical positioning accuracy is needed to confirm the traffic lane.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Scenario 1: Yes/Yes/Yes Scenario 2: Yes/Yes/Yes	Interoperability between different OEMs' vehicles is needed (Scenario 1), as well as between the HD map provider and different vehicles (Scenario 2). Regulatory oversight for safety related issues is needed. Standardisation is required in the sense that the format for sensor data exchange should be commonly understood by all involved vehicles.

4.25 Vehicles Platooning in Steady State

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	MV - MV: 5-15 HV - MV: >175 HV - CA: Long	There are different range values for this use case, considering the different interactions among involved entities in this use case: • Member of a platoon (MV) - member of a platoon (MV): 5-15 m is the inter-vehicle gap. Note 1: depending on antenna(s) position(s), the maximum vehicle length of 20 m has to be added to this range. Note 2: In accordance with the main event flow, MV - MV is only expected between adjacent MVs. • Head of a platoon (HV) - member of a platoon (MV): Equal to the maximum length (in metres) of a platoon, which depends on the maximum length of a long vehicle (e.g. truck) and maximum inter-vehicle gap. Assuming that the maximum inter-vehicle gap is 15 m and the maximum vehicle length is 20 m, for a platoon that consists of 6 trucks (5 members and the head of the platoon) the range is: (5 * 15 m + 5 * 20) 175 m. Head of a platoon (HV) - coordination with cloud (CA) (optional): A cloud server that assists/supports a platoon could be placed anywhere that a cloud facility is located.

Information Requested/ Generated	Quality of information/ Information needs	MV - MV: 100 bytes HV - MV: 300 bytes (20 Hz) HV - CA: 1000 bytes (event based)	Different messages are sent in line with the different interactions among entities involved in this use case: • Member of a platoon (MV) - member of a platoon (MV): Maximum 100 bytes, since the MVs exchange speed, position and intentions such as braking, acceleration etc. The message periodicity depends on the inter-vehicle gap. Taking into account that the MVs have similar relevant speeds 10 Hz, periodicity is considered as adequate. • Head of a platoon (HV) - member of a platoon (MV): Reports are provided from the MV to the HV (e.g. speed, location information), while the HV provides configuration information (e.g. trajectory, speed and the intended acceleration of the HV). The maximum length of a HV - MV message that includes path/ trajectory information is 300 bytes. The messages from HV to MV are not periodic, but event-based. Head of a platoon (HV) - coordination with cloud assistance (CA) (optional): 1000 bytes of information about the road and weather conditions, if available, as well as traffic conditions according to the route that the platoon follows. This message is not periodic. It is sent during the initial establishment and when there is an update on any of the above parameters.
Service Level Latency	[ms]	MV - MV: 50 HV - MV: 100 HV - CA: >1000	• Member of a platoon (MV) - member of a platoon (MV): For short inter-vehicle gaps, a latency of 100 ms or less is needed. • Head of a platoon (HV) - member of a platoon (MV): 100 ms may be needed for notification of important/critical changes of the status of MVs or the configuration of the platoon by the HV (e.g. trajectory change). Other messages are not that critical. Head of a platoon (HV) - coordination with cloud assistance (CA) (optional): This is not a time-critical interaction.
Service Level Reliability	%	MV - MV: 99.9 HV - MV: 99.9 HV - CA: 99	• Member of a platoon (MV) - member of a platoon (MV): Reliability of 99.9% should be enough to allow a MV to keep a low inter-vehicle distance in a safe and efficient manner, and thus allow the maintenance of a high-density platoon. • Head of a platoon (HV) - member of a platoon (MV): Reliability of 99.9% will be needed for important/critical changes of the status of MVs or the configuration of the platoon by the HV that should be notified. Head of a platoon (HV) - coordination with cloud assistance (CA) (optional): This is not a time-critical interaction.
Velocity	[m/s]	227.8	The maximum speed of a platoon of trucks or other long vehicles is lower than 100 km/h for most countries.
Vehicle Density	[vehicle/ km^2]	4500 (Highway) 9000 (Rural) 12000 (Urban	The maximum vehicle density of the road that the platoon travels depends on the actual road environment. This parameter is useful, for example, to assess the performance of V2X communication when the load increases with traffic density. The maximum length of the platoon (in terms of involved vehicles) also depends on the type of vehicles participating in the platoon. For heavy vehicles, there are trials with six trucks involved. For other types of vehicle, the platoon could be larger.

Positioning	[m]	0.5 (3σ)	Higher than 'typical positioning accuracy to confirm traffic lane' is needed because control systems demand accuracy for lateral alignment of vehicles in platoon.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Vehicles of different OEMs need to be able to cooperate in a platoon. Regulation is needed because authorities may need to specify maximum speed, minimum accuracy, data formats, etc.

4.26 Bus Lane Sharing Request

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Applicable where bus lanes exist.
Information Requested/ Generated	Quality of information/ Information needs	500-1000 bytes UL and 500-1000 bytes DL	Depends on the protocol and coding used. Identifiers, authentication information, positioning information, Request and acknowledge/reject messages.
Service Level Latency	[ms]	200	The speed limit in these areas is normally not more 70 Km/h (most common speed limit would be 50 Km/h). 200 ms in 70 Km/h zone corresponds to the vehicle moving 4 m which should be sufficient for good UC execution.
Service Level Reliability	%	99	Not a critical service, just the procedure is repeated if a failure is detected.
Velocity	[m/s]	19.4	In urban areas, 70 km/h is considered the maximum speed.
Vehicle Density	[vehicle/ km^2]	10	Vehicle density reflects the number of vehicles with a bus sharing feature.
Positioning	[m]	1.5 (3σ)	Lane level accuracy.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No / Yes / Yes	Interoperability between OEMs would not be needed since the interaction is with the infrastructure. Regulation may be needed because authorities may need to specify usage, authorisation methods, logging information, etc. Standardisation would be needed since vehicles from different OEMs will potentially support the bus lane sharing feature, and to avoid different solutions emerging in different countries (or even per city).

4.27 Bus Lane Sharing Revocation

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Applicable where bus lanes exist.
Information Requested/ Generated	Quality of information/ Information needs	500-1000 bytes UL and 500-1000 bytes DL	Depending on the protocol and coding used. Identifiers, authentication information, positioning information, Revoke and acknowledge messages.
Service Level Latency	[ms]	200	The speed limit in these areas is normally not more 70 Km/h (most common speed limit would be 50 Km/h). 200 ms in 70 Km/h zone corresponds to the vehicle moving 4 m which should be sufficient for good UC execution.
Service Level Reliability	%	99	Not critical service, just the procedure is repeated if a failure is detected.
Velocity	[m/s]	19.4	In urban areas, 70 km/h is considered the maximum speed.
Vehicle Density	[vehicle/ km^2]	10	Vehicle density reflects the number of vehicles with a bus sharing feature.
Positioning	[m]	1.5 (3σ)	Lane level accuracy.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	No / Yes / Yes	Interoperability between OEMs would not be needed since the interaction is with the infrastructure. Regulation may be needed, since authorities may need to specify e.g. usage, authorization methods, logging information etc. Standardisation would be needed since vehicles from different OEMs will potentially support the bus lane sharing feature, and to avoid different solutions emerging in different countries (or even per city).

4.28 Continuous Traffic Flow via Green Lights Coordination

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	10000	Assuming V2N: Communication range within the coverage of a macro cell.
Information Requested/ Generated	Quality of information/ Information needs	From HV to traffic management server or a roadside infrastructure: 300 bytes (every 50 ms/20 Hz per participating vehicle) From traffic management server or a roadside infrastructure to HV: 300 bytes	From HV to a traffic management server or a roadside infrastructure, information such as HV location (including direction) and intended trajectory are included. Assumes the size of this message is similar to a basic safety message (300 bytes). Timing and/or speed recommendations are sent from a traffic management server or by a roadside infrastructure to the HV. Hence, considering that speed or timing information can be provided for a set of waypoints, then the maximum size of this message is 300 bytes. This is not a periodic message, but sent at the beginning of the service and if there is any update on the speed and/or timing recommendations. A maximum frequency of 1 Hz can be assumed for calculations.
Service Level Latency	[ms]	100	Depends on the reaction time needed to adjust the speed of the car at the current intersection. This is directly related to the maximum allowed driving speed. For instance, at a speed of 50 km/h, the car will move 1.38 m within 100 ms. 100 ms of latency for communication between the traffic management server or a roadside infrastructure and the HV is assumed.
Service Level Reliability	%	95	The transmission of timing and/or speed recommendations from the traffic management server or a roadside infrastructure to the HV requires a medium level of reliability, since this may affect the safe and efficient operation of the HV (especially if the speed setting needs to be modified due to an unexpected change in the sequence of traffics lights that should normally turn green. 95% reliability is assumed for the communication between the traffic management server or a roadside infrastructure and the HV.
Velocity	[m/s]	19.4	Maximum speed in urban areas is considered to be 70 km/h.
Vehicle Density	[vehicle/ km^2]	3200 vehicle / km^2	Assumes at one intersection that there are 80 vehicles (e.g. 8 lanes considering different directions and 10 vehicles in each lane). Further assuming that there are up to 40 intersections per km^2 (e.g. in Manhattan), it results in 3200 vehicles/km^2 as an upper bound.
Positioning	[m]	1.5 (3σ)	Positioning accuracy needed by the traffic management server or roadside infrastructure in order to know the HV's location (including direction) and lane.

Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability is needed between vehicles of different OEMs and the traffic management server or a roadside infrastructure. Regulatory oversight for safety related issues is needed. Standardisation on the application layer (message set and flow control) is desirable.

4.29 Group Start

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	150 1500	Assuming that a vehicle (including inter-vehicle) gap is 15 m, and 10 vehicles within the group, the result is 150 m between vehicles, and 300 m between vehicle and roadside Infrastructure. For a centralised solution and for correct location assignment, distances between vehicle and manoeuvre control unit needs to be larger
Information Requested/ Generated	Quality of information/ Information needs	300 bytes (every 50 ms/20 Hz per participating vehicle)	The majority of the packages are expected to be status update reports (e.g. position, acceleration, yaw rate, etc.). Hence, the size of the messages are expected to be similar to a basic safety message (about 300 bytes).
Service Level Latency	[ms]	10	10 ms of Service Level Latency for communications between the members of the group. This is based on the very low distances (e.g. inter-vehicle = 20 cm) between vehicles waiting at the red light during the start manoeuvre.
Service Level Reliability	%	99.999	Corresponds to the high probability of this use case being successfully applied. A tolerable packet error rate on the lower layers is considered to be 99%.
Velocity	[m/s]	70km/h, 19.4m/s	Assumes the usual speed in cities reached by the end of the manoeuvre.
Vehicle Density	[vehicle/ km^2]	3200	Assumes at one intersection that there are 80 vehicles (e.g. 8 lanes considering different directions and 10 vehicles in each lane). Further assuming that there are up to 40 intersections per km^2 (e.g. in Manhattan), it results in 3200 vehicles/km^2 as an upper bound.
Positioning	[m]	0.2 (3σ)	Required for low inter-vehicle distance.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Use case considered possible between different brands/makers. Regulatory oversight for safety related questions is needed. Standardisation on the application layer (message set and flow control) is desirable.

4.30 Accident Report

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Data centres can be anywhere in the network.
Information Requested/ Generated	Quality of information/ Information needs	1000-1500 byte packets Large files containing sensor data prior to and after the collision	30 seconds of BSM (CAN) - type data for each vehicle (~75KB/vehicle). 60 seconds of at least two cameras (8 Mbps/camera). In total 120 MB Video Data + 15 MB CAN Data i n 10 minutes result in a data rate of 1.8 Mbps. HD map of the street section prior to the crash.
Service Level Latency	[ms]	N/A	Data is not time critical.
Service Level Reliability	%	High / 99.99	Data needs to be transferred reliably.
Velocity	[m/s]	0	Both vehicles are at full stop.
Vehicle Density	[vehicle/ km^2]	12000	Maximum assumed density in urban environments.
Positioning	[m]	1.5 (3σ)	Required for the precise reconstruction of the accident.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability is needed between HV, RVs, traffic lights, surrounding video cameras and data centres. Regulation: Yes Standardisation: Yes

4.31 Patient Transport Monitoring

User Story #1

Service Level Requirement	SLR Unit	SLR Value	Explanations/Reasoning/Background
Range	[m]	N/A	Assumes that the emergency room could be arbitrarily far from the emergency vehicle (EV), which yields a N/A value. It should be noted that the EV might exchange information (e.g. patient's condition) with a virtual emergency room.
Information Requested/ Generated	Quality of information/ Information needs	Mix of video streaming, 2-way voice and data	8 Mbps video data rate. 64 Kbps voice data rate. 1 Mbps for monitoring of patient. (e.g. patient's vital signs are measured on-board the vehicle and sent to the hospital physicians for real-time monitoring and later review; such data may include 3, 5 and 12 lead ECG, SpO2, plethysmogram , respiration, skin temperature and continuous non-invasive blood pressure).
Service Level Latency	[ms]	150	Voice and video streaming, real-time data.

Service Level Reliability	%	99 video and voice 99.999 for data	Some errors in video and audio are acceptable.
Velocity	[m/s]	30	Assuming speeds up to 100 km/h.
Vehicle Density	[vehicle/ km^2]	12000	Maximum assumed density in urban situation.
Positioning	[m]	N/A	Positioning accuracy is not critical for this use case.
Interoperability/ Regulatory/ Standardisation Required	[yes/no]	Yes/Yes/Yes	Interoperability (from the ambulance to the application server): Yes Regulatory for data protection issues: Yes Standardisation: Yes

5. Conclusions

This White Paper describes 31 use cases for C-V2X, presented in a solution-agnostic way. It provides Service Level Requirements for the use cases, which include advanced applications with complex interactions in relation to self-driving (autonomous) vehicles. Together with the 12 use cases that have been presented in 5GAA's first White Paper, these new use cases allow the analysis of service flows and requirements that belong to different categories such as Safety, Vehicle Operations Management, Convenience, Autonomous Driving, Platooning, Traffic Efficiency and Environmental friendliness, Society and Community.

The use case descriptions, together with the Service Level Requirements, are used by other 5GAA Work Groups to develop solutions, create test procedures, demos and pilots, evaluate spectrum needs and business cases as well as potential deployment plans. The UC descriptions are also used for cooperating with standards development organisations.

A. Templates

A.1 Use Case Description Template

The following table presents the template for a detailed description of C-V2X use cases with the corresponding explanation of the different fields.

Template for Use Case Descriptions

Fields	Description
Use Case Name	Name and abbreviation of the use case if existing.
User Story/Use Case Scenario	Many user stories can be defined for a single use case. Additionally, different user stories could lead to the same requirements and the same system solution. It is not necessary, likely nor practical to define all user stories initially, and it is expected that more such stories can be added later.
Category	Safety, vehicle operations management, convenience, autonomous driving, platooning, traffic efficiency and environmental friendliness, society and community.
Road Environment	Intersection, urban, rural, highway, other
Short Description	Short description of the use case.
Actors	Drivers, vehicles, traffic lights, VRUs, remote operators, application servers, etc. including who the sending and receiving actor is (human, vehicle, or AV - automated vehicle - e.g. SAE Automation levels 1-5 considered for the specific use case and that may affect the performance requirements).
Vehicle Roles	Host vehicle, remote vehicles.
Road/Roadside Infrastructure Roles	Role of the road and traffic infrastructure (e.g. traffic signs, lights, ramps, etc.). Does not refer to the network infrastructure.
Other Actors' Roles	The role of other actors involved in this use case (e.g. VRU).
Goal	Goal of the use case.
Needs	The needs to be fulfilled in order to enable the use case.
Constraints/Presumptions	Basic requirements that all actors need to adhere to.
Geographic Scope	Geographic areas where the use case is applicable.
Illustrations	Pictorial information exemplifying the use case and showing the role of the different actors.
Pre-Conditions	Necessary capability of the different actors to ensure the realisation of the use case.
Main Event Flow	Flow of events from the moment the use case is triggered to the moment it closes, including the trigger point to enter and to exit the use case (i.e. who and what).
Alternative Event Flow	Alternative flow of events in case a different possibility exists. Alternative Event Flows in this document are not intended as replacements for the Main Event Flow. They are intended to represent different possible flows.

Post-Conditions	Description of the output/flow clarifies which data is provided to the HV. • Note 1: This data will trigger implementation-specific actions in the HV • Note 2: It is also contained in the field information requirements
Service Level Requirements	Requirements to provide the service.
Information Requirements	High-level description of information exchanged among involved actors (e.g. sensor data, kinematic data, etc.).

A.2 Service Level Requirements Description Template

The following table presents the template for detailed description of C-V2X use cases with the corresponding explanation of the different fields.

Definitions of C-V2X Service Level Requirements

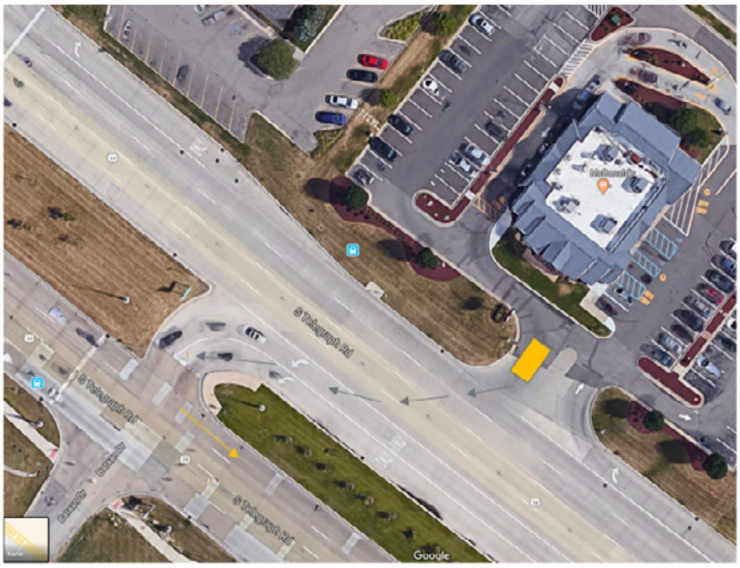
Service Level Requirement	Definition
Range	Expected distance from host vehicle to scenario application zone.
Information Requested/ Generated	Quality of information/information needs of the end-user (e.g. a driver, a passenger, robot in the car or remote, application program running in an ECU, etc.) In this description, the end result of the information delivery is important while the actual transfer is not a concern.
Service Level Latency	Measurements of time from the occurrence of the event in a scenario application zone to the beginning of the resulting actuation. Depending on implementation, this includes one or more of the following: • Processing of the event into information by the information generator • Communication of the information to end-user • Processing of the information by the end-user • Time to actuation driven by the result of processing of the information
Service Level Reliability	Based on an agreed QoS framework, the guaranteed and expected performance to start/initialise, perform and finalise (end-to-end) applications within use cases. Different agreed and provided QoS levels will result in different performances within the applications. Known or expected changes in Service Level Reliability before starting an application or during operation should be announced in a timely fashion to the relevant applications and entities involved.
Velocity	Describes the maximum absolute speed of a vehicle at which a defined QoS can be achieved (in km/h). Note: Describes the extent of mobility and the average speed of the vehicle involved in the use case. Note that there may be a need to capture the peak expected speed. This definition may also need to be split to describe the type of mobility from the speed. For instance, nomadic is a type of mobility.
Vehicle Density	Expected number of vehicles per given area (per km2) during the execution of the use case. Note: This provides an indication that multiple vehicles within the same area run the same (and potentially additional) use case(s) in parallel.

Positioning	Positioning accuracy, position accuracy, location accuracy when position information is delivered to end-user (HV), i.e. between the actual position and the position information: a) Location type: absolute/geographical or relative or N/A, b) KPI: accuracy level. Note: The confidence interval of position information is provided in units of sigma e.g. 1-sigma (1σ), 2-sigma (2σ), 3-sigma (3).
Interoperability/ Regulatory/ Standardisation Required	Yes/No, to indicate the need for inter-OEM interoperability, for example in cooperative safety use cases. Note: Some of the use cases are implemented in a physically distributed manner. If a use case realisation is not meant as a proprietary solution, the interactions and interfaces between such functions need to be standardised. Standardisations refers to the specification of the communication (protocol) between these distributed functions. The standard defines the messages and the information format exchanged between these functions. However, it does not define how these functions are implemented. Standards could also be commonly agreed de facto standards. The distributed functions need to interoperate, independent of who implemented the function.

B. Detailed Description of C-V2X Use Cases

Cooperative Traffic Gap

Use Case Name	Cooperative Traffic Gap
User Story #1	The host vehicle is about to make a manoeuvre which involves multiple space-time boxes (e.g. multiple lanes which have to be crossed). Most prominent examples are vehicles merging into a certain lane of a multi-lane road or a commercial truck making a U-turn. The vehicle, which can be automatically or manually driven, sends out a request to all vehicles in the traffic flow. • Due to the limited capabilities of the HV doing this, the vehicles in the traffic flow will cooperate to find if there is sufficient vehicles among them equipped and willing to cooperate by freeing up the space requested by the vehicle. This is a topic involving multiple use cases with complex interactions. • If there is sufficient vehicles available, communication with the host vehicle will be started, to inform the host vehicle about the upcoming traffic gap along with an estimated time. • The HV can, for example, pre-train its sensors or provide timing information to the driver requesting a 'cooperative gap', which is the space-time box the host vehicle uses and the remote vehicles then keep free. • The RVs confirm their awareness of the usage of the space-time boxes in the gap by the host vehicle. • The host vehicle starts to execute its manoeuvre, while potentially informing others about the execution status. • Each RV checks if the host vehicle has passed through the space-time boxes in which the RV controls the traffic behind it. If it is the case, the RV take no further part in the cooperative interaction, as it has no concrete contributions for the on-going manoeuvre. If not, the RV waits until the host vehicle passes through the lane where the RV is located. When the host vehicle receives a request to leave the cooperative interaction from an RV, it checks if it has passed the corresponding lane. If it has, it acknowledges the request.

Category	Convenience, safety.
Road Environment	Urban.
Short Description	• A vehicle tries to pull into a certain lane of a multi-lane road. To do so, it needs to cross multiple lanes. • It asks vehicles in the traffic flow to cooperate in forming a gap to support the host vehicle's manoeuvre. If enough vehicles are (opportunistically) found to support this, the host vehicle is informed by the supporting group.
Actors	Vehicle.
Vehicle Roles	Host vehicle and remote vehicles.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	Improve safety and convenience in a multi-lane driving manoeuvre.
Needs	Remote vehicles need to cooperate.
Constraints/ Presumptions	The manoeuvre needs to be called off if one of the vehicles/drivers decides it will no longer support the manoeuvre. The manoeuvre can only be called off if the host vehicle has not started any activity yet. If the host vehicle has started, a cooperative manoeuvre alignment is required to solve the situation.
Geographic Scope	Anywhere.
Illustrations	 The vehicle indicated by the orange box tries to merge onto the multi-lane road and go to the leftmost lane as it wishes to turn.
Pre-Conditions HV	• Host vehicle is ready to start a manoeuvre, but needs to wait for a traffic gap to open up in an ongoing traffic flow.
Pre-Conditions RVs	• All participating remote vehicles are in the traffic flow for which the host vehicle is expecting a gap to open up.

Main Event Flow	• Host vehicle sends information that it would like others to form a traffic gap • Receiving vehicles cooperate among each other to find out if there is sufficient and advantageously positioned vehicles to support the request by the host vehicle. This is a complex interaction requiring an efficient protocol. • Assuming there is not sufficient supporters, the host vehicle receives no reply. • Assuming there is sufficient supporters, (potentially a subset of)the supporting vehicles will communicate with the host vehicle and inform about the upcoming gap, its estimated size, and when the gap will become visible and usable to the host vehicle. If there is multiple gap offers from the supporters, the host vehicle will choose one and acknowledge to its communication partner from the group of supporting vehicles.
Alternative Event Flow	Not applicable.
Post-Conditions	None.
Information Requirements	Car sensor data.

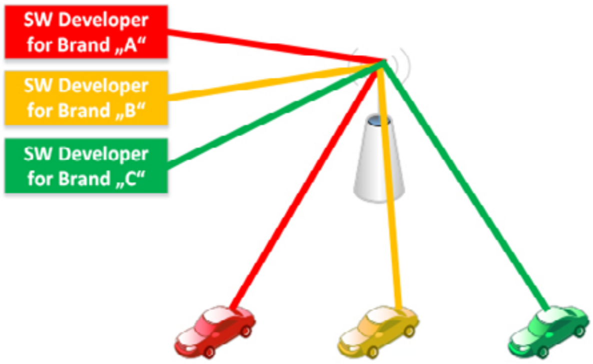
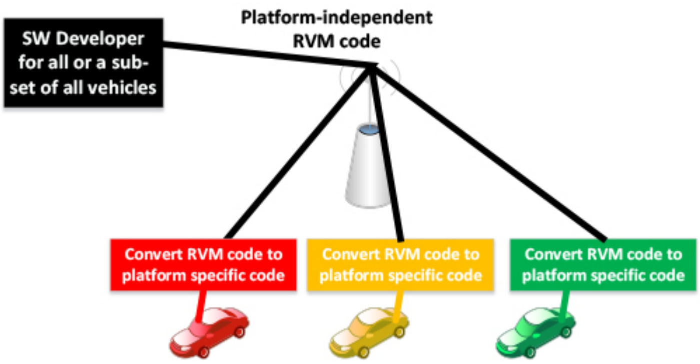
Interactive VRU Crossing

Use Case Name	Interactive VRU Crossing
User story #1	A VRU (e.g. pedestrian, cyclist) expresses intent to cross a road. Vehicles approaching the area in which the VRU intends to cross receive the message and send an acknowledgment when they have begun to slow down to allow the VRU to cross safely. Upon receiving this acknowledgment from the vehicles, the VRU may cross the street. Upon reaching the other side of the street, the VRU may send another message to the vehicles confirming that they have safely crossed.
Category	VRU safety.
Road Environment	Urban.
Short Description	• A VRU is preparing to cross the street • After signalling this intent, nearby vehicles acknowledge to reassure the VRU that it is safe to cross • As the VRU is crossing, communicating continues with stopped vehicles: - The VRU tells vehicles when it has cleared the zone in front of them so that they may continue driving The VRU double checks with vehicles just before moving in front of them that they are clear to move forward.
Actors	Vehicle(s), vulnerable road user.
Vehicle Roles	Vulnerable road user and remote vehicles.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	Improved safety for VRUs and awareness for vehicles.
Needs	Not applicable.
Constraints/ Presumptions	Not applicable.
Geographic Scope	Non-highway roads with pedestrian traffic.
Illustrations	Not applicable.

Pre-Conditions HV	Not applicable.
Pre-Conditions RVs	Not applicable.
Main Event Flow	• VRU approaches street • VRU expresses intent to cross • Approaching vehicle receives message and performs target classification • If the vehicle determines that it can accommodate the request, it acknowledges the VRU and notifies nearby vehicles that it is stopping • When the VRU receives sufficient evidence that it is safe to cross (may vary with number of lanes and vehicles present), crossing is initiated • While the VRU is crossing, his/her personal device sends information (e.g. PSMs) notifying stopped vehicles of its progress When vehicles are safe to proceed after the VRU crosses, they begin moving again.
Alternative Event Flow	After a vehicle has sent an acknowledgment, if they begin accelerating early again, a NACK should be sent to the pedestrian, cancelling the positive indication they previously received.
Post-Conditions	The VRU may send a session-closing message to vehicles notifying them of successful crossing.
Information Requirements	• Accurate positioning • VRU ID • Local map data (to determine how many vehicles need to stop, i.e. how many lanes are there)

Software Update of Reconfigurable Radio System

Use Case Name	Software Update of Reconfigurable Radio System
User Story	The HV's reconfigurable radio system has its software or firmware updated with a new feature set, new standard release, to comply with regional requirements, etc.
Category	Vehicle operations management.
Road Environment	Intersection, urban, rural, highway, other.
Short Description	• Vehicle OEM, equipment manufacturer or chipset vendor publishes software or firmware updates for one or more reconfigurable radio systems on targeted HVs • Or HV enters a geographic region with specific regulatory radio requirements and its equipment needs to be adjusted accordingly • Or a driver or passenger requests to install a feature or standard due to specific needs in a specific location • Updates can serve to increase radio feature sets, due to new releases of wireless communications standards or to comply with a specific (regional) regulation not available in the installed radio software version Updates can also mitigate vulnerabilities and implementation issues that were discovered after market deployment.
Actors	• Host vehicle • Vehicle OEM, equipment manufacturer or chipset vendor • Driver or passenger
Vehicle roles	HV represents the targeted vehicle for an intended reconfigurable radio software or firmware update.
Roadside Infrastructure Roles	Not applicable.

Other Actors' Roles	• Vehicle OEM, equipment manufacturer or chipset vendor publishes radio software or firmware updates or is requested by • The driver or passenger requests vehicle OEM, equipment manufacturer or chipset vendor to provide a specific radio software or firmware version An automated system in the HV passenger requests OEM, equipment manufacturer or chipset vendor to provide a specific radio software or firmware version.
Goal	Deliver radio software or firmware updates targeted HVs upon request from the vehicle OEM, equipment manufacturer, chipset vendor, driver, passenger or automated system in HV.
Needs	Driver and passengers in the HV need to be provided with reliable and high quality connectivity.
Constraints/ Presumptions	• Vehicle OEM, equipment manufacturer or chipset vendor targets an update for a list of vehicles • A software update may depend on a chain of previous versions • A radio software update may be mandatory or optional • A radio software update might be rolled back • HVs will retain one previous radio software version to facilitate rollbacks • Downloading radio software updates should not affect the performance of safety features
Geographic Scope	Global, national or regional
Illustrations	 **Figure 1: First Generation - each vehicle type receives dedicated SW package (platform specific executable code)**  **Figure 2: Second Generation - each vehicle type (of a predefined set of vehicles) receives identical, platform-independent SW package and converts it to platform specific code**

<table>
<tr>
<td>Illustrations</td>
<td>
It should be noted that this UC may apply to various types of reconfigurable radio systems, including

i) Software-defined radios (full reconfigurability)
ii) ASIC type components complemented by reconfigurable elements (such as FPGA, DSP, etc.)
iii) ASIC type components designed for firmware updates

It is expected that typical commercial implementations will not rely on the highest level of flexibility due to cost constraints, but rather apply a combination of ASIC type components and reconfigurable elements.
Figure 1 presents a typical example representation of a transmission chain which is comprised of components A, B, C, D, E, F.

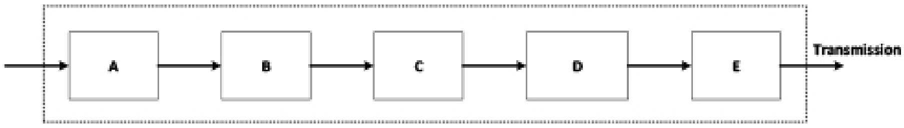


Figure 3: Example representation of components of a transmission chain

It is assumed that a manufacturer may choose to enable (third party) software developers to replace one or many of these components with novel software components. Figure 2 illustrates the replacement of component B through a novel implementation by (third party) software developers. This step may be motivated, for example, by an identification of security challenges in the corresponding component.

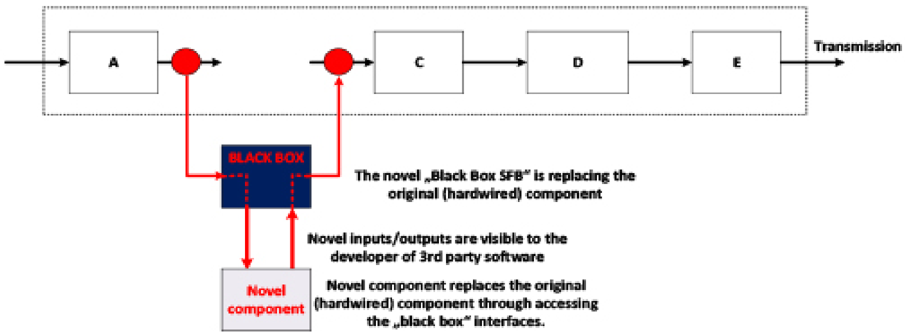


Figure 4: Example replacement of a component through interfacing with novel standard functional block (SFB) provided by a (third party) software provider

The upper examples illustrate how a limited set of reconfigurable elements can mitigate (security) vulnerabilities. Also, such reconfigurable elements may be employed in order to selectively add new functionalities of, for example, a new 3GPP release or IEEE amendment - instead of a full software-based implementation of the entire stack.
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<td>Pre-Conditions</td>
<td>
• Vehicle OEM, equipment manufacturer or chipset vendor publishes a software update for a target list of HVs
• Drivers, passengers or automated HV system discovers or decides that a radio software or firmware update should be requested
</td>
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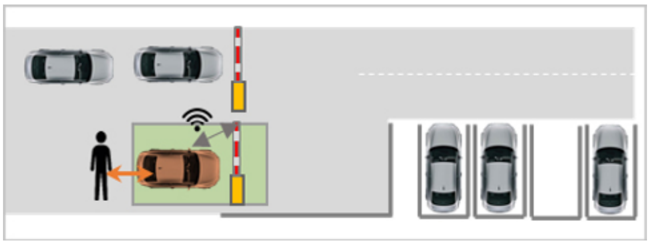
</table>

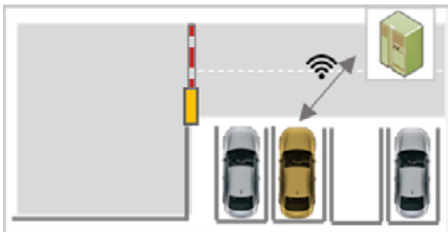
Main Event Flow	• Vehicle OEM, equipment manufacturer or chipset vendor posts a mandatory radio software or firmware update and notifies targeted HVs of the new version • HV receives notification and starts downloading the radio software or firmware update • HV downloads segments of the radio software update at opportune moments that do not affect the performance of safety features • If HV completes downloading the posted radio software update a. HV installs the downloaded radio software update at a convenient time b. HV self-tests if the radio software update allows reliable and high-quality radio communication operations c. Declaration of conformity is issued after the update has completed • HV notifies the vehicle OEM, equipment manufacturer or chipset vendor of the applied radio software update version
Alternative Event Flow	• Driver, passenger or automated HV system requests a radio software or firmware update • HV starts downloading the radio software or firmware update • HV downloads segments of the radio software update at opportune moments that do not affect the performance of safety features • If the HV completes downloading the requested radio software update - HV installs the downloaded radio software update at a convenient time - HV self-tests if the radio software update allows reliable and high-quality radio communication operations - Declaration of conformity is issued after the update has completed HV notifies the vehicle OEM, equipment manufacturer or chipset vendor of the applied radio software update version.
Post-Conditions	Mandatory or optional software update are deployed on targeted HVs.
Information Requirements	• HV's list of current radio software feature versions • Vehicle OEM, equipment manufacturer or chipset vendor list of radio features and standard releases • HV's radio software update download progress • Declaration of conformity issued after radio software has been updated

User Story	Detailed description, specifics and main differences to the user story in the main template
Upgrade of Feature-Set	Radio air interface evolves and new features are added. The required time for equipping all vehicles with the updated features may be up to one year.
Addressing Vulnerabilities	Identified vulnerabilities such as bad design choices, protocol weaknesses, etc. need to be addressed and the affected functionality needs to be modified. Depending on the criticality, the required time for equipping all vehicles with the updated features may be between one day and up to one year. In particular for critical security leaks, a one-day update time for the entire fleet may be required.

Automated Valet Parking - Joint Authentication and Proof of Localisation

Use Case Name	Automated Valet Parking - Joint Authentication and Proof of Localisation
User Story #1	• A manual driver drops off the vehicle in a designated transition zone for autonomous parking in a parking facility • The transition zone is separated from the parking area, for example by a barrier which should open for validated vehicles only After a successful authentication and proof of the vehicle's position, the vehicle is accepted for autonomous parking (i.e. the barrier opens for this vehicle).
Category	Convenience, autonomous driving, parking.
Road Environment	Parking areas.
Short Description	• The parking facility wants to ensure that only authorized vehicles get access to the (autonomous) parking area The infrastructure verifies a vehicle's position claim and gives the vehicle access to the parking facility in case of success.
Actors	Vehicle, parking infrastructure.
Vehicle Roles	Autonomous vehicle: autonomous parking in approved facilities.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Parking Infrastructure: Parking infrastructure that support driverless parking.
Goal	Access control to a parking facility for autonomous vehicles.
Needs	Not applicable.
Constraints/ Presumptions	Not applicable.
Geographic Scope	Parking areas validated for autonomous parking.
Illustrations	
Pre-Conditions	The vehicle is dropped off by a manual driver in the transition zone and ready for autonomous parking.
Main Event Flow	• After the vehicle is placed in the assigned transition zone by a manual driver, the vehicle asks for access to the parking facility on a communication connection • The infrastructure verifies the position of the vehicle • In the event of a successful check, the vehicle is admitted for autonomous parking
Alternative Event Flow	If the proof of localisation fails, the driver is informed and the access to the driverless parking function has to be denied.
Post-Conditions	The authenticity and position of the vehicle is verified.
Information Requirements	Not applicable.

Automated Valet Parking (Wake Up)

Use Case Name	Automated Valet Parking (Wake Up)
User Story #1	• A parked sleeping vehicle in a parking facility should be autonomously moved for (re)parking (e.g. charging) or pick-up • For this purpose, the vehicle receives a wake-up call upon which the autonomous drive is prepared
Category	Convenience.
Road Environment	Parking areas.
Short Description	• An application running on infrastructure sends a wake-up call to a specific vehicle. The wake-up call can be sent using the Uu interface on cellular networks or using the PC5 interface. Both options are required as it is assumed that not all underground parking garages will have cellular coverage form all operators. In case of PC5, we assume PC5 infrastructure components in the parking garage. • Upon receiving the wake-up call, the vehicle should start preparations for an autonomous movement • Other vehicles should ignore the wake-up call • The vehicle's 'listening to wake-up calls' process should consume as little energy as possible Integrity/availability/authenticity/confidentiality all have to be ensured.
Actors	Vehicle, parking application.
Vehicle Roles	Autonomous vehicle: autonomously parking in approved facilities.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Automated Valet Parking Infrastructure: local PC5 infrastructure to communicate with parking vehicles.
Goal	Wake up sleeping autonomously driving vehicles for the purpose of movement.
Needs	The autonomous vehicle needs to receive the wake-up message.
Constraints/ Presumptions	• C-V2X communication between vehicle and infrastructure • Possibility to address a specific vehicle • Possibility to verify the authenticity of the wake-up call • Minimum energy consumption, i.e. power efficiency on receiver side is crucial
Geographic Scope	Parking areas supporting autonomous parking, including parking areas with cellular coverage and those where sidelink communication to the local PC5 infrastructure is available.
Illustrations	
Pre-Conditions	• Sleeping/parked vehicle in parking area • Trigger for vehicle movement
Main Event Flow	• Upon a trigger for a vehicle movement, the parking application sends a wake-up call including an identifier for the addressed vehicle • This can be delivered over cellular Uu or local PC5 interface; in the latter case, local PC5 infrastructure is required • The addressed vehicle checks the authenticity of the wake-up call and starts with preparations for the autonomous movement • The vehicle confirms the receipt of the wake-up call

Alternative Event Flow	• The vehicle ignores wake-up calls which could not be authenticated • The parking application informs the driver if the wake-up is not confirmed
Post-Conditions	The parking application receives a confirmation of the wake-up call.
Information Requirements	Not applicable.

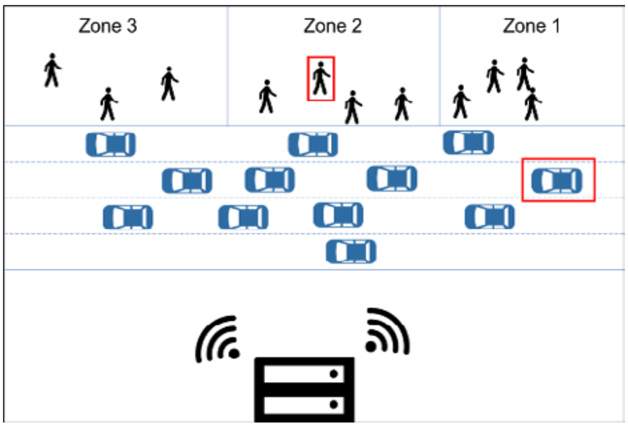
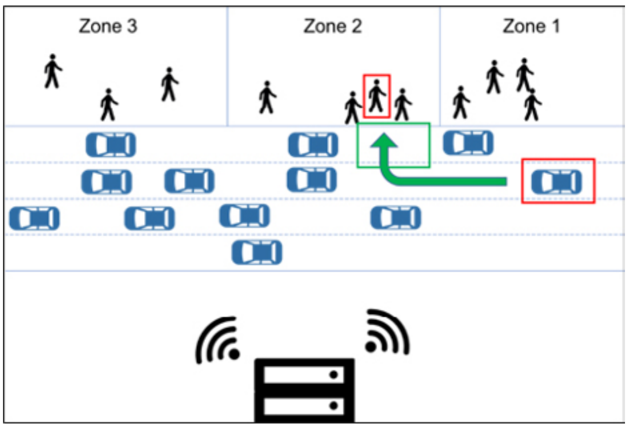
Awareness Confirmation

Use Case Name	Awareness Confirmation
User Story #1	The host vehicle is sending out messages. This can include basic safety messages and future, more evolved message types. Further, this use case is not limited to PC5 sidelink communication but also applicable in transmission over the Uu interface. The host vehicle indicates whether it would like to receive confirmation on its messages and sets properties accordingly, such as those described in detail below. The host vehicle receives confirmation information from the remote vehicles and uses this for one or more of the following purposes: • In a manually driven vehicle, indicate the general V2X penetration level of the current surroundings (e.g. low, medium, high) • In a manually driven vehicle, indicate which remote vehicles confirmed awareness of the host vehicle, or alternatively, those which have not. This can be shown visually to the driver using a heads-up display In an automatically driven vehicle, the host vehicle adapts its driving style according to the V2X penetration level it has received from the surrounding remote vehicles.
Category	Convenience.
Road Environment	Urban, highway.
Short Description	• A host vehicle sends out messages, e.g. with a regular cadence • It indicates for which of these messages it would like to receive confirmation and sets according properties It receives confirmations on the messages and processes these.
Actors	Vehicle.
Vehicle Roles	Host vehicle and remote vehicles.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	Host vehicle gains awareness of remote vehicles.
Needs	The host vehicle needs to receive confirmation messages from remote vehicles.
Constraints/ Presumptions	The host vehicle needs to implement or set properties (functionality) to send/receive confirmation messages. The remote vehicles need to implement functionality to send confirmation messages according to the requested properties.
Geographic Scope	Anywhere.
Illustrations	Not applicable.

Pre-Conditions	The host vehicle sets the following properties for confirmation messages: • Type of message: for which messages should confirmation be sent to the host vehicle, e.g. BSM. • Feedback rate control: for a given remote vehicle, specify the cadence of feedback, e.g. 'every second message'. • Maximum confirmation latency: delay between sending a message and receiving confirmation of it • Vehicle sampling: specify maximum distance, time offset or probabilistic feedback to reduce the number of remote vehicles sending confirmation to the remote vehicle • Reliable channel: assuming that there are reliable and unreliable logical channels, indicate whether feedback should be sent over a reliable or an unreliable logical channel • Transmission type: request confirmation for multicast, broadcast, and unicast messages. • Signalling reduction methods: use methods to reduce the channel load, e.g. by piggybacking the reply on the next payload • Validity period: statement on how long these properties would be deemed current The host vehicle sends out a confirmation property message, which informs its surroundings about these properties. • Note: it should not be possible to request confirmation messages in congested scenarios (i.e. when the channel load exceeds a certain threshold); a rejection message should be sent promptly
Main Event Flow	• The remote vehicles receive messages from the host vehicle, no confirmation is sent • Once the remote vehicles receive a confirmation property message from the host vehicle, they decide whether to send confirmations and, if affirmative, create and send confirmations according to the defined properties • The vehicle receives the confirmation messages and uses it for one or more of the following purposes: (a) In a manually driven vehicle, indicate the V2X safety level of the current surroundings, (b) In a manually driven vehicle, indicate which remote vehicles confirmed awareness of the host vehicle and which did not. This can be implemented using a heads-up display, (c) In an automatically driven vehicle, the host vehicle adapts its driving style according to the level of confirmation it has received from the surrounding remote vehicles Note: this use case does not foresee confirmation on confirmation messages (ACK of ACK).
Alternative Event Flow	Not applicable.
Post-Conditions	The HV stops sending messages (the payload messages, e.g. BSM). Remote vehicles stop sending confirmation messages as they do not receive any messages from the host vehicle.
Information Requirements	Car sensor data to match confirmations with surrounding situation.

Cooperative Curbside Management

Use Case Name	Cooperative Curbside Management
User Story #1	A pedestrian and a vehicle are planning a pick-up at a crowded curbside area. Before entering the area, they indicate to their respective devices (e.g. vehicle, smartphone, etc.) that they are looking for each other. The curbside area is managed by a certified and trusted traffic management entity (TME) infrastructure node that has knowledge of all active pick-up sessions. This TME transacts with the pedestrian and vehicle, and designates a specific pick-up zone along the curbside when it determines that they are both in the near vicinity and there is room for the pick-up to take place. When designating this dynamic pick-up zone, the TME takes into account all other groups whose transactions it is facilitating. This designated pick-up zone is communicated to both the vehicle and the pedestrian, which then both communicate with one another directly until pick-up is confirmed.
User Story #2	If applicable.

Category	Convenience.
Road Environment	Urban.
Short Description	• Vehicle and pedestrian are attempting to meet at crowded curbside area • Certified infrastructure node designates pick-up area based on other active pick-ups • Shares this information with vehicle and pedestrian to facilitate interaction • Vehicle and pedestrian meet in area, confirm pick-up to infrastructure node
Actors	Vehicles, pedestrians, infrastructure.
Vehicle Roles	Host vehicle - Autonomous or human-driven will follow pathing instructions from TME (time management entity) to complete curbside pick-up of pedestrian.
Road/Roadside Infrastructure Roles	Mediation of interaction between vehicle and pedestrian, designation of pick-up zones, dictation of traffic flow.
Other Actors' Roles	• Pedestrian must follow instructions to reach vehicle pick-up zone and load
Goal	• Improve efficiency and safety of densely populated curbside pick-up areas
Needs	• Certification of infrastructure, cooperation of vehicles
Constraints/ Presumptions	Not Applicable
Geographic Scope	Densely-populated areas with curbside pick-up area
Illustrations	
Pre-Conditions	HV and pedestrian know each other's identifiers, infrastructure node is certified and trusted.
Pre-Conditions RVs	Not applicable.

Main Event Flow	• Pedestrian and HV arrive at pick-up area • Pedestrian and HV individually inform the TME who they are looking for • TME determines there is a match • TME designates pick-up area along curbside based on positions of RVs and active pick-ups • TME communicates pick-up area to HV and pedestrian • HV and pedestrian communicate directly with one another until meeting • HV and pedestrian confirm to TME that pick-up has been completed
Alternative Event Flow	HV could be told to wait outside the pick-up area until pedestrian arrives or if traffic is too heavy to bring in other vehicles.
Post-Conditions	HV could be informed of a viable exit route from the pick-up area that does not conflict with active pick-up instructions for RVs.
Information Requirements	• Vehicle/pedestrian pick-up IDs • Data defining dynamic pick-up zones

Cooperative Lateral Parking

Use Case Name	Cooperative Lateral Parking
User Story #1	The host vehicle identifies a free parking space in a longitudinal parking scenario. It sends information to the vehicles in its vicinity to inform them of the planned parking action and asks them to 'make room' for this purpose. To this end, it includes sensor information which allows the parked vehicles to identify themselves and provides information on the expected duration of the manoeuvre, and detailed information on how much space is needed and the precise location. • In a manually driven vehicle, the driver can request additional parking space • In a vehicle with driver assistance systems, the parking assistant can assess whether a parking space becomes viable if additional space is provided by the surrounding vehicles In an automatically driven vehicle, the host vehicle decides which parking spot to take and whether additional space needs to be requested from the other vehicles.
Category	Convenience.
Road Environment	Urban.
Short Description	• A vehicle would like to perform longitudinal parking and needs more space • It asks surrounding vehicles to 'squeeze together' and thus make more space temporarily; this is a recursive scheme, if one vehicle cannot create sufficient space, it asks the next vehicle to move as well Once completed, all remote vehicles return to their original space, except for leaving space for the newly parked vehicle.
Actors	Vehicle.
Vehicle Roles	Host vehicle and remote vehicles.
Road & Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	Increase speed and convenience of parking manoeuvre.
Needs	Remote vehicles need to cooperate.
Constraints/ Presumptions	Remote vehicles need to wake up on the request message and need to be able to perform simple driving manoeuvres (driving closer to another vehicle).
Geographic Scope	Anywhere.

Illustrations	Not applicable.
Pre-Conditions HV	Host vehicle is arriving at a zone where it is planning to park.
Pre-Conditions RVs	All participating remote vehicles are parked, but are capable of receiving C-V2X messages and wake-up based on these messages.
Main Event Flow	• Host vehicle sends information that it would like to park at a given location • Receiving vehicles send awareness confirmation along with their willingness to participate • Host vehicle decides whether parking is possible • If possible, host vehicle sends sensor information such that vehicles in front and behind the parking space can identify themselves; and the host vehicle sends information on the duration and exact space requirements (front/rear) • Remote vehicles react accordingly: create the needed longitudinal space to the HV and inform the host vehicle that it can start the parking manoeuvre Host vehicle sends confirmation that parking action is complete.
Alternative Event Flow	• Host vehicle decides whether parking is possible • Host vehicle sends information that it would like to park at a given location • Receiving vehicles send awareness confirmation and willingness to participate • If possible, host vehicle sends sensor information such that vehicles in front and behind the parking space can identify themselves; and the host vehicle sends information on the duration and exact space requirements (front/rear) • RVs begin recursive scheme of determining the feasibility of requested manoeuvre • One of the RVs required for the manoeuvre declines the request • Option 1: Vehicles decide on a solution without involving the vehicle which declined the request • Option 2: Host vehicle sends acknowledgement and aborts the manoeuvre
Post-Conditions	Remote vehicles coordinate to return to a position close to original position.
Information Requirements	Car sensor data.

In-Vehicle Entertainment (IVE) - High-Definition Content Delivery, On-line Gaming and Virtual Reality

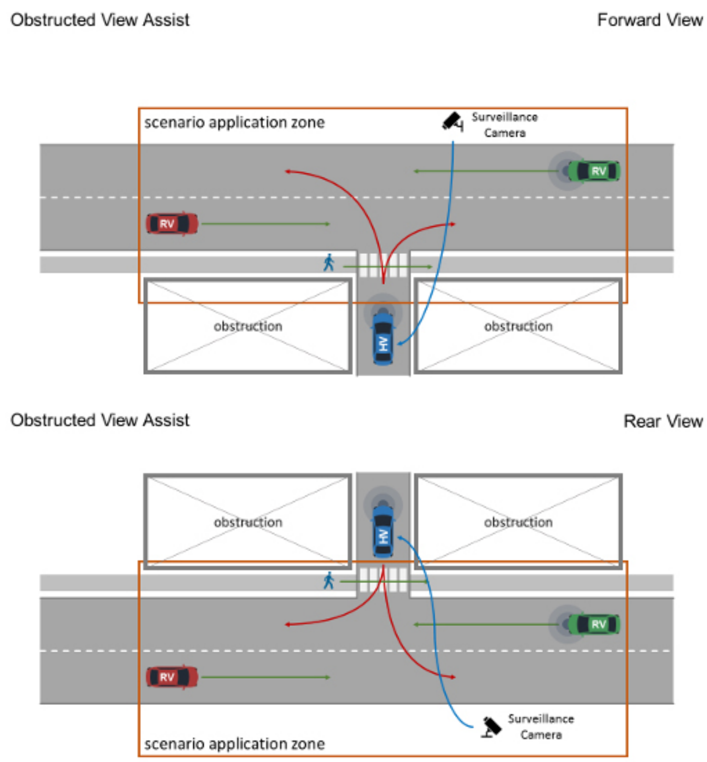
Use Case Name	In-Vehicle Entertainment (IVE)
User Story	High-definition (HD) Content Delivery, On-line Gaming and Virtual Reality
Category	Convenience
Road Environment	Intersection, urban, rural, highway, others.
Short Description	The use case concerns entertainment content delivery to the passengers of a moving or stationary vehicle. It is applicable to both automated and non-automated vehicles, where in the latter the driver is restricted in the content he or she is allowed to consume. For cars, up to four occupants can consume high-definition and immersive entertainment media content while the vehicle is stationary or moving. For buses and transporters up to 30 passengers can consume the same content under similar conditions. Each occupant may be interested in different content which may include video, gaming, virtual reality (VR), office work, online education, advertisement, etc. Contextual information can be embedded in the entertainment media depending on the location of the HV.
Actors	Host vehicle, HV owner, operator or manager, passengers, service providers (e.g. wireless network operators, road operators, streaming and gaming services, a combination of them, and others).
Vehicle Roles	Host vehicle is the vehicle where the passengers consume the content.
Roadside Infrastructure Roles	The roadside infrastructure does not necessarily play a direct role in this user story.

Other Actors' Roles	• The passengers are the consumers of the HD content and potentially possess a business relationship with the service provider and/or with the HV owner, operator or manager • Service providers are the originators of the content and/or wireless connectivity providers and possess a business relationship with the passenger and/or with the HV owner, operator or manager HV owner, operator or manager is an entity that has a business relationship with the service providers and/or with the passengers, or it is a passenger itself.
Goal	To supply and deliver on-demand HD entertainment content to the HV passengers.
Needs	Passengers want entertainment while commuting and travelling for long periods of time, but also while HV is parked or stopped in traffic.
Constraints/ Presumptions	• The operation of in-vehicle entertainment should not compromise safety • HV owner, operator, manager or passengers has established business relationships with other mobile wireless devices, but potentially needs to extend this relationship to encompass the employed HV to the multi-streaming of the HD content • HV owner, operator, manager or passengers and service providers already have established business relationships (subscription, contract, pay-per-view, on-demand, B2B, B2C, etc.) that support the multi-streaming of HD content • HV and service providers can establish a secure communication link • HV and service providers should be able to mutually authenticate
Geographic Scope	National or international, depending on the areas where the service provider has permission and is able to provide the service, e.g. due to IPR, copyright, censorship, law, etc.
Illustrations	Not applicable.
Pre-Conditions	• Service providers have access to the means allowing them to stream, store, transcode and distribute the HD content, including live transmissions of events • Service providers are able to adjust QoS and QoE according to the environment where the HV is located, even at high speeds • HV is equipped with on-board devices that provide the means to verify the existence of a business relationship with the service providers for wireless connectivity and HD content • HV is equipped with on-board devices that provide the means to each passenger individually accessing the HD content data • HV is equipped with on-board devices that provide the means to process and deliver the video and audio data of the HD content to each passenger individually • Alternatively, passengers can bring individual hand-held devices that provide the means to process and deliver the video and audio data of the HD content • Passengers are individually provided with the means to choose which HD content they are interested in • Service providers can fulfil IPR, copyright, censorship and other legal requirements to supply the requested content • HV owner, operator, manager or one of the passengers can select the service providers for wireless connectivity from a list (1 to N), and the service provider for HD content (1 to N) (e.g. 'customer choice')
Main Event Flow	• A communication link between the HV and wireless service provider is established • The new communication link for the HD content does not disrupt the communication link for other use cases involving safety and other mission-critical services • A business relationship with a HD content service provider is established or verified (Note: this does not preclude wireless and HD content service providers from being the same entity) • Each passenger individually chooses which HD content he/she is interested in before or after entering the car • Individual passengers request access to the chosen HD content each time they enter the car • Service providers identify each passenger's individual choices and the HV's location • Service providers check if the content is available and/or has permission to be accessed in the region where the HV is located and if the HV is authorised to receive the HD content • Service providers makes the HD content available to individual passengers • Each passenger individually accesses and plays the HD content at his or her own convenience • Each passenger stops or pauses the HD content at his or her own convenience

Alternative Event Flow	• A communication link between the future passengers' handheld and desktop devices and wireless service providers is established • A business relationship with a HD content service provider is established or verified (Note: this does not preclude wireless and HD content service provider from being the same entity) • Each future passenger individually chooses (on a handheld or desktop device) which HD content he/she is interested in before entering the car • Each future passenger individually requests (on a handheld or desktop device) access to the chosen HD content before entering the car • Each service provider identifies each future passenger's individual choices and location •• Each service provider checks if the content is available and/or has permission to be accessed in the region where the future passenger is located • Each service provider makes the HD content available to each individual future passenger • Passengers enter the HD and decide if they wish to continue accessing the HD content on handheld or on-board devices • A communication link between HV and wireless service provider is established • A business relationship with the HD content service provider is established or verified, now for the HV connection (Note: this does not precludes wireless and HD content service provider from being the same entity) • Each passenger individually accesses and plays the HD content at his or her own convenience before or after entering the HV • Each passenger individually stops or pauses the HD content at his or her own convenience before or after entering the HV
Post-Conditions	The HD content chosen and played (or not) by the passenger may be partially or temporarily stored in the HV
Information Requirements	HD content data, HV authentication and identification data, passengers' preferences, choices and identification data, HV location.

User Story	Detailed description, specifics and main differences to the user story in the main template.
High-End Service for Cars	The extreme case that includes up to four consumers of HD 8k video content, including gaming with higher latency constraints and interactive, immersive entertainment, such as VR data streaming.
Low-End Service for Cars	The relaxed case that includes two content consumers of HD 4k video streams and does not support low latency gaming services.
Bus Passenger Service	Another extreme case that includes up to 30 consumers of HD video content but no low latency services such as gaming and immersive entertainment.

Obstructed View Assist

Use Case Name	Obstructed View Assist
Category	Convenience.
Road Environment	Intersections, e.g. in rural and urban environments.
Short Description	HV is provided an alternate when faced with an obstructed view.
Actors	CCTV cameras (for User Story 1 only), host vehicle, remote vehicles (for User Story 2 only)
Vehicle Roles	HV represents the vehicle with an obstructed view. In User Story 2, remote vehicles provide a video stream to support HV.
Roadside Infrastructure Roles	Surveillance cameras provide alternate views where installed.
Other Actors' Roles	Not applicable.
Goal	Provide HV with an alternate view of the obstructed road segments.
Needs	HV needs an alternative view when an obstructed view prohibits the HV from proceeding safely. This view can be provided by CCTV (User Story 1) or other cars (User Story 2).
Constraints/ Presumptions	Surveillance cameras (and cars, for User Story 2) can share video.
Geographic Scope	Global.
Illustrations	
Pre-Conditions	• HV is stopping because of an obstructed view. • The 'forward view' scenario application zone is determined from: - HV's location - HV's intention to proceed forward - lane designations and geometry • The 'rear view' scenario application zone is determined from: - HV's location - HV's intention to proceed in reverse • Lane designations and geometry

Main Event Flow	• HV intends to proceed (forward or backwards) • HV queries video stream providing entities within the 'forward/rear view' scenario application zone • HV selects suitable entities and requests a video stream • An entity that is capable of providing a video stream sends it to the HV
Alternative Event Flow	Not applicable.
Post-Conditions	A video stream is provided to the HV, circumventing the obstructed view from the HV perspective.
Information Requirements	• HV's location • Surveillance camera's location and vector • Surveillance camera video stream

User Story	Detailed description and specifics
User Story #1	HV faces an obstacle obstructing its view while on a road, at an intersection, sidewalk, parking lot or driveway. It queries entities in its vicinity capable of providing a video stream that extends the HV's view, making it possible to see around/behind the obstacle. One or several CCTV cameras with communication abilities are installed and respond to the query (possibly along with other entities), providing their position, heading vector, available bandwidth, and potentially other values. HV requires a video stream from one or several CCTV cameras. The (one or more) CCTV cameras send their real-time video stream to the HV.
User Story #2	HV faces an obstacle obstructing its view while on a road, at an intersection, sidewalk, parking lot or driveway. It queries entities in its vicinity capable of providing a video stream that extends HV's view, making it possible to see around/behind the obstacle. No CCTV camera is available, but other vehicles respond to the query stating their position, heading angle, velocity, available bandwidth for video stream communication, and possibly other values. HV requires video stream from one or several vehicles. The vehicles send the video stream to the HV.

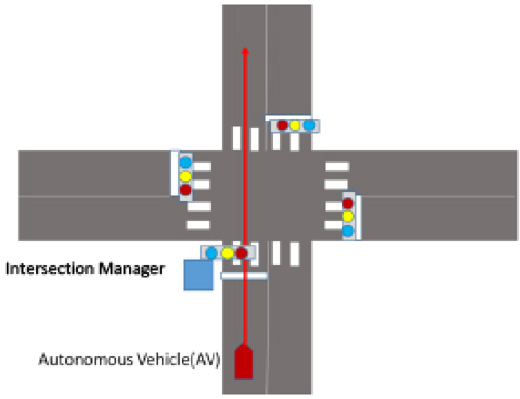
Vehicle Decision Assist

Use Case Name	Vehicle Decision Assist
Short Description	A host vehicle detects a stationary vehicle in front. It enquires whether this RV is only stopping for a short period of time or if it has broken down or similar, making it necessary to overtake the vehicle. In a more generalised form, a vehicle is able to request various information from a RV, which will then share such information with the HV.
1. RV Waiting for Short Period of Time	• HV approaches a RV on narrow rural road, realises it is stationary • Due to dense traffic in the opposite direction, it is not possible to overtake the RV easily, so the HV requests information about the RV's likely length of stay • RV reports that it will continue driving after a short while • HV receives feedback and decides not to initiate a cooperative overtaking manoeuvre, informing the RV on that decision After a short while, the RV continues driving, with the HV following behind.

2. RV Broken Down	• HV approaches a RV on narrow rural road, and perceives it as stationary • Due to dense traffic in the opposite direction, it is not possible to overtake the RV easily, so the HV requests information about the RV's likely length of stay • RV reports that it is broken down (i.e. mechanical failure) • HV receives feedback and decides to initiate a cooperative overtaking manoeuvre together with cars in the opposite direction (different use case), informing the RV of the decision
3. Bus Having to Wait	• Due to good traffic conditions, a bus arrived at a station ahead of schedule • The driver thus has to wait at that station before continue along the regular route • An HV approaches the bus, not sure how long it intends to wait • It sends an enquiry to the bus, asking for the expected duration of stay • The bus, knowing its schedule, reports the expected time of departure • The HV receives feedback and adjusts its driving strategy It may also further provide the information to oncoming traffic.
4. Slow Vehicle on Route	• HV approaches a slow vehicle on a one-lane road • HV enquires how long the RV will stay on the same route as the HV • RV shares this information with the HV • HV can base a decision on whether/where to overtake on the feedback received • HV informs the RV on the driving strategy • HV may inform oncoming traffic on the route of the event
Category	Safety, advanced driving assistance.
Road Environment	Urban, rural, highway.
Actors	Host vehicle, remote vehicle.
Vehicle Roles	Host vehicle, remote vehicle.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	Assist a vehicle in deciding whether it should overtake a stationary vehicle it detects in front, and enable vehicles to exchange arbitrary information.
Needs	Not applicable.
Constraints/ Presumptions	All participating vehicles need to be equipped with communication abilities.
Geographic Scope	Global.
Use case diagram	Not applicable.
Sequence diagram	Not applicable.
Further Illustrations	Not applicable.
Pre-Conditions	HV needs to be able to request information from other vehicles. • It might be necessary to consider privacy, depending on the information requested.
Pre-Conditions RVs	RV needs to be able to (roughly) predict how long it expects to remain stationary, or at least be able to interact with its driver to inform them about the expected length of stay. RV needs to be able to process the information requests received from the HV.
Main Event Flow	• HV detects a stationary vehicle in front, e.g. via sensors, communication, etc. • HV sends enquiry to the vehicle about its expected duration of stay • RV sends report to the HV on the expected duration, along with other potential information such as whether an accident happened, if help is needed, etc. • HV accommodates the answer in its driving strategy, e.g. in order to determine whether or not to perform an overtake HV potentially informs other vehicles about the RV and its expected duration of stay.

Alternative Event Flow	• HV detects a vehicle in front, e.g. via sensors, communication, etc. • HV sends an information enquiry to the RV • RV sends back the requested information - to the extent possible • HV accommodates the answer in its driving strategy HV potentially informs other vehicles about the RV.
Post-Conditions	• HV is informed about the RV's status Other vehicles are able to receive information about the RV.
Information Requirements	• RV's duration of stay/other information • Optionally, a vehicle status report from the RV (broken down vs. normal operation) Potentially other information (flexible approach).

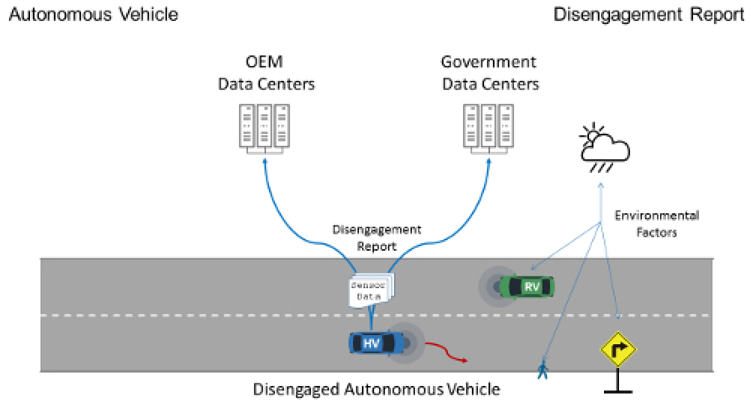
Automated Intersection Crossing

Use Case Name	Automated Intersection Crossing
User Story	An autonomous vehicle goes through the intersection while respecting the signal traffic signal.
Category	Autonomous driving.
Road Environment	Intersection.
Short Description	An autonomous vehicle goes through an intersection with a set of traffic lightsAV goes through or stops taking signal timing into account. When stopping at the intersection, the AV can readjust its position.
Actors	Host vehicle, traffic lights
Vehicle Roles	Host vehicle goes through the intersection automatically.
Roadside Infrastructure Roles	Traffic lights (intersection manager) control traffic flow at intersections.
Other Actors' Roles	Not applicable.
Goal	Go through an intersection in automatic driving mode.
Needs	Host vehicle needs to know the roads, lane designations and geometry. It also needs to know the phase and timing of the traffic lights at the intersection.
Constraints/ Presumptions	Host vehicle can drive automatically using the roads, lane designations, geometry and the phase and timing of traffic lights at the intersection.
Geographic Scope	Intersection.
Illustrations	 Note: In this scenario the intersection manager is locally placed, and can be centrally located as well.

Pre-Conditions	HV is in the scenario's application zone.
Main Event Flow	• The intersection manager sends to the HV the roads, lane designations, geometry and the phase and timing of traffic lights at the intersection • HV receives the roads, lane designations, geometry and the phase and timing of traffic lights at the intersection, and the HV creates its own driving scenario using the information received • HV goes through or stops taking signal timing into account; it can stop at the correct position using the roads, lane designations and geometry
Alternative Event Flow	Not applicable.
Post-Conditions	HV passes through the intersection and continues automated driving.
Information Requirements	• HV's location and dynamics • Lane designations and geometry of intersection • Road conditions • Phase and timing of traffic lights

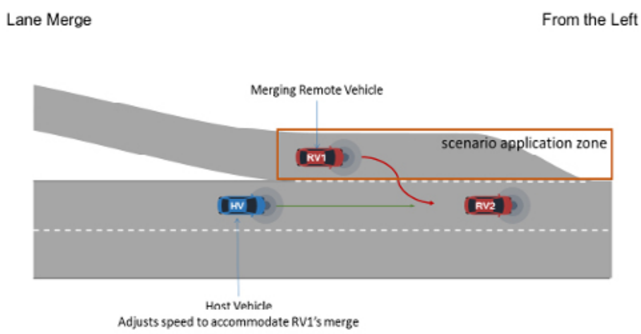
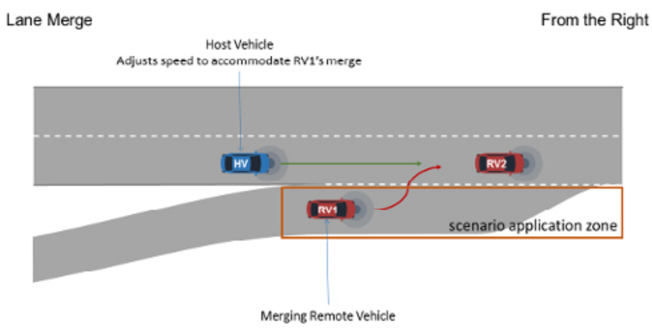
Autonomous Vehicle Disengagement Report

Use Case Name	Autonomous Vehicle Disengagement Report
User Story	When an autonomous HV virtual driver system disengages, it submits a disengagement report containing a time-windowed recording of vehicle systems data, rich sensory information and dynamic environmental conditions to OEM and government data centres.
Category	Autonomous driving
Road environment	Urban, rural, highway
Short Description	Host vehicle sends a disengagement report to OEM and government data centres.
Actors	Host vehicle and remote vehicle.
Vehicle Roles	• HV represents the autonomous vehicle that is sending the report • RVs provide dynamic environmental input to the autonomous vehicle
Roadside Infrastructure Roles	Signs and traffic signals provide dynamic environmental input to the autonomous vehicle.
Application Server Roles	Not applicable.
Other Actors' Roles	• OEM and government data centres are receiving the reports • Vulnerable road users provide dynamic environmental input to the autonomous vehicle
Goal	Send disengagement reports to OEM and government data centres.
Needs	HV needs to send a disengagement report containing a time-windowed recording of vehicle systems data, rich sensory information and dynamic environmental conditions to OEM and government data centres.
Constraints/ Presumptions	• Information from RVs and other actors includes typical data in support of other safety applications Any government reporting should follow recommended standards if mandated.
Geographic Scope	Global.

Illustrations	
Pre-Conditions	The 'disengagement report' scenario is enacted when the autonomous HV's virtual driver system is faced with an unmanageable situation and decides to disengage.
Main Event Flow	• If the 'disengagement report' scenario is enacted: - HV notifies nearby actors of the event and need to capture data - HV captures its own system data - HV captures its own sensory data - HV sends its own event data to OEM data centres and government data centres where required - Nearby actors capture relevant data and send it to the HV . Relevant surveillance cameras capture a time-windowed recording . RVs capture their location and dynamics . VRUs capture their location and dynamics . Traffic signals capture timing and phase information HV sends a disengagement report to OEM data centres and government data centres where required.
Post-Conditions	HV sent a disengagement to OEM data centres and government data centres where required.
Information Requirements	• HV's disengagement report including a captured time window of: - HV system data - HV sensory data including cameras, RADAR, LIDAR, etc. - Environmental data including: . Position and dynamics of RVs . Position and dynamics of vulnerable road users . Position, nature and state of traffic signals, signs, etc. . Surveillance cameras . Weather and road conditions • Connectivity status

User Story	**Detailed description and specifics**
User Story #1	An autonomous vehicle is stopped in the middle of a city street due to unanticipated roadworks blocking a lane ahead. Human driver assistance requested.

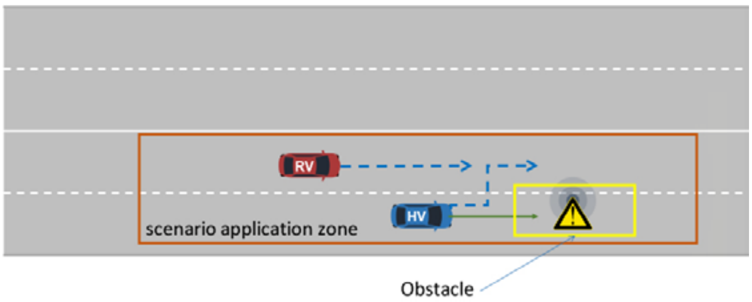
Cooperative Lane Merge

Use Case Name	Cooperative Lane Merge
User story	A host vehicle accommodates a remote vehicle that is merging into the HV's traffic lane.
Category	Autonomous driving.
Road Environment	Urban, rural, highway.
Short Description	A host vehicle accommodates a remote vehicle travelling ahead in an adjacent lane that is merging with the HV's traffic lane.
Actors	• Remote vehicle 1 (RV1) • Remote vehicle 2 (RV2) • Host vehicle (HV)
Vehicle Roles	• RV1 represents the vehicle merging into the HV's traffic lane • RV2 represents a lead vehicle in the HV's traffic lane • HV represents the vehicle accommodating RV1's manoeuvre
Road/Roadside Infrastructure	Roads are defined by their lane designations and geometry.
Other Actors' Roles	No other actors have been considered.
Goal	Enable safe cooperative lane-merge manoeuvres.
Needs	• HV needs to be aware of RV1's merge into HV's traffic lane • HV needs to know RV2's location and dynamics • HV needs to know the roads, lane designations and geometry • RV1 needs to know if the HV intends to accommodate RV1's manoeuvre
Constraints/ Presumptions	• The 'from the left' scenario application zone is defined by the geometry of an adjacent merging lane to the immediate left of the HV starting from the position of the HV and ending at the end of the merging lane • The 'from the left' scenario application zone is defined by the geometry of an adjacent merging lane to the immediate left of the HV starting from the position of the HV and ending at the end of the merging lane
Geographic Scope	Everywhere.
Illustrations	 

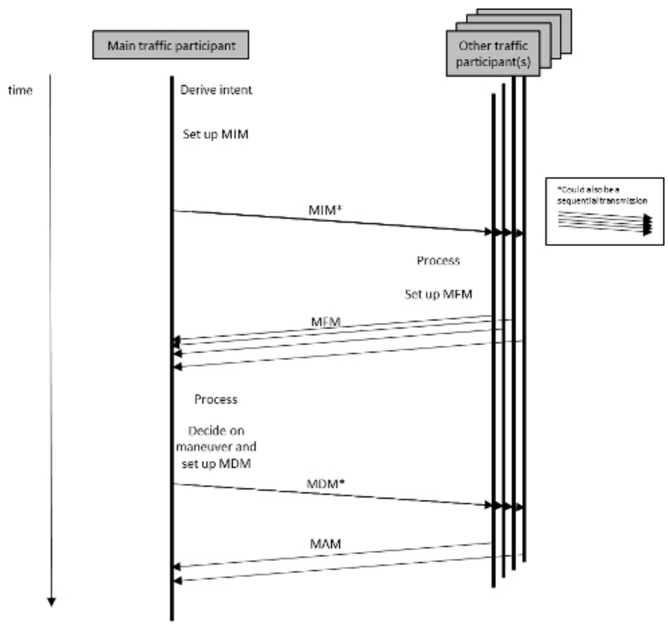
Pre-Conditions	RV1 is in the scenario's application zone.
Main Event Flow	• HV receives RV1's intention to apply a lane-merging manoeuvre, providing location, speed and manoeuvre information • If there is not a lead vehicle RV2 then: - HV uses RV1's location and dynamics and the length of the merge to adjust the speed of the HV, such that at the end of the manoeuvre, the HV is positioned in a safe following distance from RV1 - RV1 is made aware of the HV's intention to accommodate the manoeuvre. It adapts accordingly (if needed) its speed and notifies the HV for acceptance before initiating the manoeuvre • If there is a lead vehicle RV2 then: - HV uses RV1's location and dynamics, RV2's location and dynamics and the length of the merge to adjust the speed of the HV, such that at the end of the manoeuvre, the HV is positioned a safe following distance from RV1 and RV1 is positioned a safe following distance from RV2 • RV1 is made aware of HV's intention to accommodate the manoeuvre. It adapts accordingly (if needed) its speed and notifies the HV for acceptance before initiating the manoeuvre
Alternative Flow	• HV receives RV1's intention to apply a lane-merging manoeuvre, providing location, speed and manoeuvre information • HV uses RV1's location and dynamics, adjacent lane traffic conditions and decides (i.e. HV) to change lane, such that at the end of HV's manoeuvre, the HV allows RV1 to merge • RV1 is made aware of HV's intention to accommodate the manoeuvre, by changing its lane. RV1 notifies the HV for the acceptance (or not) and initiation of its manoeuvre
Post-Conditions	After the merge, the HV is positioned a safe following distance from RV1 and RV1 is positioned a safe following distance from any lead RV2.
Information Requirements	• RV1's location and dynamics • RV2's location and dynamics • HV's location and dynamics • Lane designations and geometry • Road conditions

Cooperative Manoeuvres of Autonomous Vehicles for Emergency Situations

Use Case Name	Cooperative Manoeuvres of Autonomous Vehicles for Emergency Situations
User Story	An autonomous vehicle identifies a dangerous situation (e.g. collision with a moving object) and undertakes to coordinate with neighbouring AVs in order to jointly decide and perform their manoeuvres.
Category	Autonomous driving
Road Environment	Intersection, urban, rural, highway.
Short Description	An obstacle is detected by an autonomous vehicle in its lane and a manoeuvre is needed to avoid a crash with the obstacle e.g. sudden lane change. However, this could result in an accident with a neighbouring or approaching AVs in the adjacent lane. The emergency manoeuvre, together with the actions (e.g. emergency braking, manoeuvre) of neighbouring vehicles are agreed and planned in a cooperative manner. The cooperation among AVs avoids the dangerous situation, reduces the risk of a collision with adjacent AVs in an emergency manoeuvre, and thus improves safety.
Actors	Vehicle.

Vehicle Roles	There are two roles of AVs involved in this use case: • Host vehicle • Remote vehicle
Road/Roadside Infrastructure	Not a necessary role for the specific user story.
Other Actors' Roles	No other necessary roles envisaged in this specific user story.
Goal	Eliminate accidents during unforeseen situations by enabling quick coordination between vehicles.
Needs	To enable vehicles to exchange information about intended manoeuvres and agree on planned trajectories in a cooperative manner.
Constraints/ Presumptions	The HV and RVs are AVs and equipped to share messages conveying precise location, speed, acceleration, trajectories and sensor data.
Geographic Scope	Everywhere.
Illustrations	
Pre-Conditions	RV is following the HV in the adjacent lane.
Main Event Flow	• The HV detects an obstacle, using information received by sensors or cameras on the HV and identifies the need to execute an emergency manoeuvre to avoid a collision • The HV, taking into account the distance from the obstacle, road conditions (if available) and the position of other RVs, shares its intention (e.g. trajectory) to avoid the collision with the detected obstacle. • The RV(s), based on current status and location and considering traffic and road conditions, checks if the HV's shared intention can be executed without creating any further risks/collisions between the corresponding RV and the HV due to the emergency manoeuvre: - If an adaptation of RV's driving behaviour is needed to allow the HV to apply its emergency manoeuvre in a safe manner, then the RV informs the HV about its updated intention and/or acceleration/braking, etc. - Or the RV replies to the HV by providing its own intentions • The HV checks whether it needs to adapt its original intention taking into account the RVs' response, and notifies the RV about any updated intentions • Lateral and longitudinal controls are applied simultaneously (based on agreed intentions) by the HV and RVs until the manoeuvres are completed
Alternative Event Flow	Not applicable.
Post-Conditions	After the completion of the agreed manoeuvres and the HV has avoided colliding with the detected obstacle, the AVs (HV, RV) drive safely towards their defined destination,
Information Requirements	• Vehicles' location, speed information • Vehicles' trajectory • Driving intention (brake, accelerate) • Traffic conditions • Road conditions

Coordinated, Cooperative Driving Manoeuvre

Use Case Name	Coordinated, Cooperative Driving Manoeuvre
Category	Safety, convenience, advanced driving assistance
Road Environment	Intersection, urban, rural, highway
Short Description	• A main traffic participant wants to perform a certain action (e.g. lane change, exit highway, U-turn, etc.) • Participant shares this intention with other traffic participants potentially involved in the manoeuvre • The traffic participants indicate to the main traffic participant whether they support or plan to decline the planned manoeuvre • The main traffic participant informs a superset of the traffic participants informed whether it plans to perform the manoeuvre NB: Assume that every vehicle, on average, might plan on performing a manoeuvre using this use case as a main traffic participant once every 1-10 seconds in urban scenarios. On highways with less traffic, an interval of approximately once every 1-20 seconds might be enough.
Actors	Vehicles.
Vehicle Roles	Host vehicle, remote vehicles might play the role of one or more traffic participants.
Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Vulnerable road users, such as cyclists, pedestrians, might play the role of one or more traffic participants.
Goal	The main traffic participant is able to evaluate whether a certain manoeuvre can be performed. Other traffic participants are informed about manoeuvres planned by the main traffic participant.
Needs	The main traffic participant needs to receive feedback messages from other traffic participants.
Constraints/ Presumptions	• The main traffic participant needs to be equipped with the means to inform other traffic participants about planned manoeuvres • Other traffic participants need to be able to signal confirmation/support/approval or denial/rejection of the planned manoeuvre • The main traffic participant needs to be able to process feedback received and needs to be able to inform surrounding traffic participants about the final decision regarding whether the manoeuvre will be performed or not.
Geographic Scope	Global.
Illustrations	

Pre-Conditions	The main traffic participant wants to perform a manoeuvre involving surrounding traffic participants.
Main Event Flow	• The main traffic participant evaluates at least the following aspects and sets up a MIM, accordingly: - Identifier: in order to be able to relate MIM to the car that sent it, e.g. based on position - Manoeuvre type: type of manoeuvre the main traffic participant wants to perform, e.g. lane change, driving around obstacle and thus into neighbouring lane without lane change, cross a road, performing a turn at an intersection, etc. - Urgency: desired time until main traffic participant wants to start the manoeuvre - Criticality: an indicator on the consequences of not performing the manoeuvre would have for the vehicle (e.g. missing a slip road when not changing a lane, etc.) - Feedback type: the type of feedback the main traffic participant is expecting (e.g. support/reject, which variant of a manoeuvre is preferred, additional information, etc.) - Message ID: a random number with enough digits to - combined with the manoeuvre type - provide a unique identifier for all manoeuvres performed at the same time with overlapping application region The main traffic participant sends the MIM to other traffic participants. • Other traffic participants receive the MIM and process information given within • After processing, they set up a MFM covering at least the following aspects: - Relevant message ID: the message ID received that the current response is referring to - Identifier: in order to be able to later relate MFM to the car that sent it, e.g. based on position - Manoeuvre type: the manoeuvre in question - Support/Rejection: general assessment of one's own involvement in the manoeuvre - Further feedback: relating to the feedback type requested by the main traffic participant - Time horizon: earliest and latest time within which the respective traffic participant would be willing to participate, in case of supporting the manoeuvre • The MFM is sent back to the main traffic participant, and possibly other traffic participants • The main traffic participant receives MFMs from surrounding traffic participants and processes them. Based on this, a MDM is set up, covering at least: - Relevant message ID: the message ID the current MFM is referring to - Identifier: the identifier also used in the MIM - Manoeuvre decision: whether or not main traffic participant plans to perform the manoeuvre - Starting time: when the main traffic participant plans to initiate the manoeuvre • The MDM is sent to other traffic participants to inform them • In the event the MDM contains the decision to perform the manoeuvre, the participating vehicles send a MAM in order to ensure that all involved parties have received and agreed on the manoeuvre to be taken. This MAM covers at least: - Relevant message ID: the message ID the current MAM is referring to - Identifier: the identifier used in MIM and MFM • ACK: field indicating decision to comply with the HV's decision

Post-Conditions	In the event of a decision to perform the manoeuvre, the main traffic participant initiates the manoeuvre at the time indicated in the MDM. Other vehicles take appropriate actions (possibly before the initiation time instant of the main traffic participant).[1] • In the event of a decision not to perform the manoeuvre, traffic flows as before, without performing the manoeuvre. Actors might decide to attempt similar/alternative manoeuvres
Information Requirements	None.[2]
Use Case Name	• Coordinated, Cooperative Driving Manoeuvre
Category	• Safety, Convenience, Advanced Driving Assistance
Road Environment	• Intersection, Urban, Rural, Highway

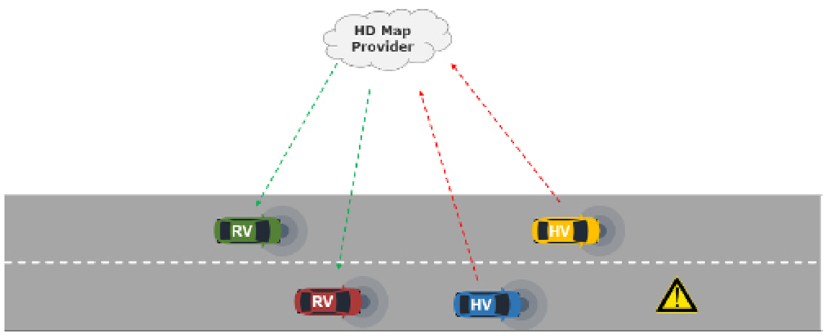
In the following, three different possible application scenarios are described where Coordinated Cooperative Driving Manoeuvres are enabled via the message exchanges outlined above.

User Story	Coordinated, Cooperative Driving Manoeuvre
Cooperative Lane Change	The main traffic participant is a host vehicle. It wants to perform a lane change, but there are remote vehicles in the lane that the HV wants to change into. Therefore, it issues a MIM supporting a lane change. RV1 right next to the HV and RV2 behind it both send MFMs containing rejections, but RV3 behind RV2 sends affirmative feedback. After processing the three feedback messages, the HV sends an MDM confirmation including a time instant far enough in the future to give RV1 and RV2 enough time to overtake HV. RV3, after sending a MAM, might already slow down to make room for the HV which then changes lane in front of RV3.
Pedestrian Crossing Road	A pedestrian wants to cross a road with broken traffic lights. His/her mobile device sends out a MIM indicating the intention to cross the road. A vehicle approaching the road sends a supportive MFM. After his/her phone sends an affirmative MDM and he/she receives the respective MAM, the pedestrian starts crossing the road, knowing that the vehicle will decelerate - if necessary - in order not to hit him/her.
Road Blockage	One lane of a rural road is blocked by a traffic accident. Traffic heading in the other direction prevents blocked vehicles from driving around the obstacle. An HV approaching the obstacle sends a MIM indicating it wants to drive around the blockage. While some vehicles reject this request (sending respective MFMs), a relatively small vehicle sends a supportive MFM. It drives to the outermost part of the lane or stops in front of the obstacle, making enough room for the blocked HV to drive around it. The HV sends a MDM indicating that it will drive around the obstacle when the small vehicle is near enough. The small vehicle sends a MAM to acknowledge participation.

[1] This use case assumes that appropriate measures are in place to identify and punish misbehaviour (never cooperating, performing manoeuvres without consent of other traffic participants, etc.), for example by revoking a traffic participant's ability to initiate manoeuvres. How such measures could look is not treated in this use case description.

[2] No information like car sensor data, positions, or the like is required. Of course, the information stated in the event flow is required to be exchanged.

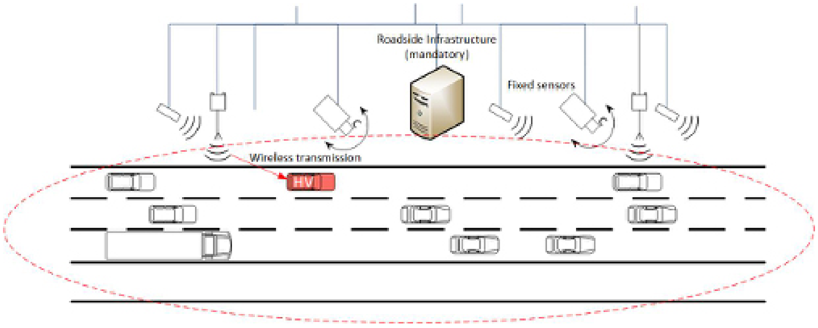
High-Definition Map Collecting and Sharing

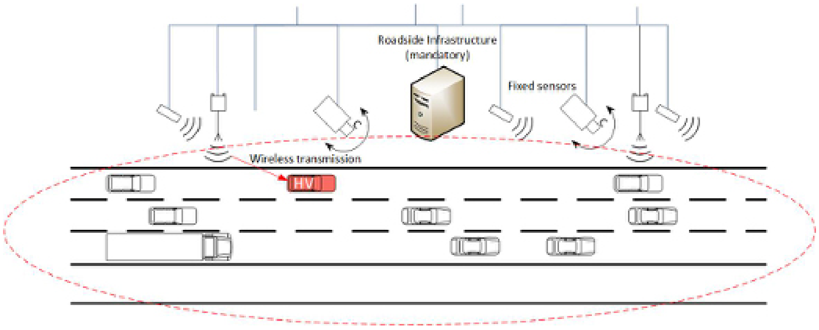
Use Case Name	HD Map Collecting and Sharing
User Story	For vehicles to acquire an accurate HD map updated in real-time.
Category	Autonomous driving.
Road Environment	Intersection, urban, rural, highway.
Short Description	Vehicles equipped with LIDAR or other HD sensors can collect environment data around themselves, and share the information with a HD map provider (e.g. cloud server). The HD map provider analyses the information collected and merges or combines it to build a regional HD map. This helps to build HD maps that are dynamically updated and more accurate.
Actors	Host vehicle, remote vehicle
Vehicle Roles	HVs collect information about their surroundings using their own sensor devices, and share the information with a HD map provider. • RV receives the HD map; each HV can also play the role as a RV
Road/Roadside Infrastructure Roles	Can provide sensor data or other information useful for the building of a HD map.
Other Actors' Roles	HD map provider collects sensor information from HVs and optionally also from road and roadside infrastructure in order to build the HD map.
Goal	The vehicles receive (or build) fresh map information in a timely fashion to complete a HD map.
Needs	To provide safety and optimal route selection for semi- and fully automated driving by exploiting the availability data gathered from sensor information shared by other vehicles.
Constraints/ Presumptions	The HV and RV can establish an authenticated and secure communication channel between each other or with the HD map provider.
Geographic Scope	Global.
Illustrations	
Pre-Conditions	The vehicles can make optimal driving decisions based on an up-to-date, precise, and reliable vision of the environment. The HVs are equipped with sensors and they can share sensor information. The HD map provider can collect (and merge) sensor information from different sources to build the HD map in a fast and reliable manner.
Main Event Flow	• HVs gather environment information from their own sensors • HVs provide sensor information to the HD map provider • The HD map provider analyses and merges/combines the sensor data to build a unified (more complete) HD map, and refreshes the map in real time. • The map provider provides the HD map • RVs receive the real-time HD map
Alternate Event Flow	Not applicable.

Post-Conditions	• RV can make an optimal driving decision based on an up-to-date, precise, and reliable vision of the environment using also the more accurate, real-time HD map.
Information Requirements	• Car sensor data (RADAR, LIDAR, etc,.) • Road conditions • Car status (e.g. location, dynamics, etc.) • Events detected by vehicles

Infrastructure Assisted Environment Perception

Use Case Name	Infrastructure Assisted Environment Perception: Data Distribution about Objects on the Road in the Form of Object Lists or Occupancy Grids
User Story	When an automated vehicle enters a section of the road covered by infrastructure sensors it enrols to receive information from the infrastructure containing environment data provided by dynamic and static objects on the road. This data is used to increase the trust level of the car's own sensor observations and extends its viewing range.
Category	Autonomous driving.
Road Environment	Urban, highway, intersection.
Short Description	An automated vehicle can subscribe to an infrastructure service that provides enhanced environment information regarding dynamic and static objects on the road. The vehicle is then authenticated and enabled to receive authorised information from the local road environment. The distributed data contain frequent (e.g. every 100 ms) updates of the local road segment. They also contain rolling ID's for each vehicle with information such as location, speed, direction and size. The ID allows each vehicle to identify itself quickly in the map and transform the data into a view from its ego-position. This data is then fused into the car's automated driving stack. This fulfils two purposes: 1) The trust level of the car's own sensor observations will be increased by adding an independent source. 2) The car's view of the road is enhanced at the front and back, enabling a smoother and more prescient driving experience.
Actors	Vehicle, road and roadside infrastructure.
Vehicle Roles	Host vehicle represents the vehicle consuming the environment data. Remote vehicles represents other neighbouring vehicles that are represented as mainly moving (or static) objects in the environment data.
Road/Roadside Infrastructure	• Mandatory) different types of sensors (RADAR, LIDAR, cameras) provide a complete picture of the dynamic road conditions • Roads are defined by their lane designations and geometry • Traffic signs provide laws, guidelines and timely information
Other Actors' Roles	Not applicable.
Goal	Increases trust in the HV's sensor perception data and enhances the viewing range which can sometimes be limited or obstructed by other vehicles, road bends or dips, intersections or limited sensor range.
Needs	The HV needs to receive and fuse received environment data received with its own sensor data to improve the reliability of the situation awareness.
Constraints/ Presumptions	• The road infrastructure provides the sensor infrastructure, data and processing capabilities to perform sensor data fusion and communicates the results in real time • The HV is authorised and can enrol in the service provided by the road infrastructure • HV and road infrastructure can establish a secure communication link • HV and road infrastructure are able to mutually authenticate • HV has implemented a flexible automated driving SW stack enabling the fusion of perception data from external sources with the HV's own perception data

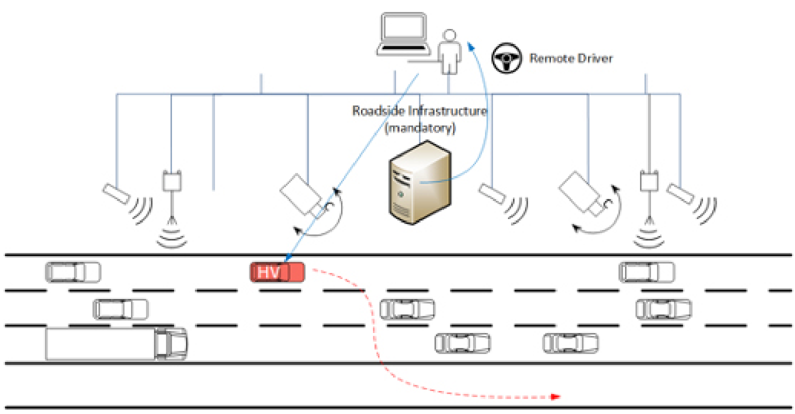
Geographic Scope	Locations with well-developed city, road and traffic infrastructure.
Illustrations	
Pre-Conditions	• The road infrastructure has access to means allowing it to capture sensor data, process and fuse this data, as well as store and send it to the HV and other vehicles in real-time • The HV is equipped with on-board devices that provide means to receive and process data from the infrastructure • The HV already has precise map data on the road layout
Main Event Flow	• On entering the zone with infrastructure coverage, the HV and infrastructure perform an initial handshake to establish a secured communication link • During the initial handshake the basic technical capabilities of the HV are communicated to the infrastructure to be used for different services that it provides • As basic functionality, the infrastructure's sensors track all moving vehicles including the HV so its location is known • The infrastructure and vehicle agree on a secure communication scheme; for example, encryption keys can be employed to check the integrity of the messages or to prevent hackers posing as infrastructure either by themselves or as a man-in-the-middle-attack • Infrastructure outlines the available services to the HV • HV picks the local dynamic map (LDM) data service • Infrastructure and vehicle agree on an ID for the vehicle that will be used as identification inside the broadcasted environment data (for privacy reasons a rolling ID scheme is agreed) • By participating, the vehicle starts to receive the environment data from the infrastructure • The HV merges external perception data with its own data and optimises its driving decisions
Post-Conditions	• The HV has left the area of infrastructure support • A sign-off is performed and the car continues using its own sensors only
Information Requirements	• Infrastructure sensor data including video streams • Road conditions • RVs' status (e.g. location, dynamics etc) • Lane designations and geometry • HV's status (location, speed, etc.)

Use Case Name	Infrastructure Assisted Environment Perception: Individual Data Transmission in the Form of Trajectories or Actuation Commands
User Story	As an extension to the first user story the vehicle can hand over more functionality to the infrastructure and receive driving trajectories directly from it. In this case, the vehicle retains emergency sensing and acting capabilities. We envision such a scenario for enclosed compounds like airports or industrial campuses or for vehicles that follow the same route regularly like buses or shuttles. Each vehicle needs to obtain individual trajectories. The purpose of this user story is to reduce redundancy in sensing and computing, and better coordinate traffic flow in well-structured environments like highways, where direction is the same and speed is very similar. Single lanes such as virtual bus lanes or platooning lanes can be equipped like this. It is even possible to combine the use case on data distribution about objects on the road and this use case on different lanes.
Category	Safety, Advanced driving assistance, convenience.
Road Environment	Highway, closed compounds.
Short Description	When the automated vehicle enters a section of the road covered by infrastructure sensors it enrols to receive trajectories from the infrastructure. This trajectory is updated in short time intervals (e.g. every 100 ms), thus invalidating the one before. The received trajectory is directly injected into the automated driving stack at the planning stage. The car follows the received trajectory unless it senses an obstacle using its remaining sensors which then leads to an emergency braking manoeuvres
Actors	Vehicle, road and roadside infrastructure.
Vehicle roles	Host vehicle represents the vehicle consuming the environment data. Remote vehicles represents other neighbouring vehicles. The received trajectories takes RVs into account by either adjusting their speed or avoiding them by steering manoeuvres.
Road/Roadside Infrastructure	• (Mandatory) different types of sensors (RADAR, LIDAR, cameras) provide a complete picture of the dynamic road conditions • Roads are defined by their lane designations and geometry • Traffic signs provide laws, guidelines and timely information
Other Actors' Roles	Not applicable.
Goal	Guides vehicles along a trajectory calculated by the infrastructure.
Needs	The HV needs to use the received trajectory as sole input for the planning stage in automated driving and then follow said trajectory.
Constraints/ Presumptions	The infrastructure provides the sensor infrastructure, data and processing capabilities to perform sensor data fusion, create an environment model - based on the calculated individual trajectories - and communicate the results in real time.
Geographic Scope	Locations with well-developed city and traffic infrastructure.
Illustrations	

Pre-Conditions	• The road infrastructure has access to the means allowing it to capture sensor data, process and fusion this data, calculate individual trajectories, and store and send data to the HV and other vehicles in real-time • The HV is equipped with on-board devices that provides the means to receive and process data from the infrastructure • The HV already has precise map data on the road layout • The HV enables the reception of peer-to-peer messages from the infrastructure
Main Event Flow	• On entering the zone with infrastructure coverage, the HV and infrastructure perform an initial handshake to establish a secured communication link • During the initial handshake basic technical capabilities of the HV are communicated to the infrastructure and used for different services that the infrastructure provides • As basic functionality, the infrastructure's sensors track all moving vehicles including the HV so its location is known • Infrastructure and vehicle agree on a secure communication scheme; for example, encryption keys can be employed to check the integrity of the messages or to prevent hackers posing as infrastructure either by themselves or as s man-in-the-middle-attack • The infrastructure outlines available services to the HV • The HV picks the trajectory data service • Infrastructure and vehicle agree on an ID for the vehicle that will be used as identification for the trajectories (for privacy reasons a rolling ID scheme is agreed) • Starting from the current location of the vehicle the infrastructure sends individual trajectories in regular intervals (e.g. 100 ms); a trajectory consists of a series of waypoints together with the velocities at each waypoint • Each new trajectory invalidates the previous one even if not all waypoints were passed by the vehicle • The HV follows the provided trajectory while retaining a minimum environment-sensing capability to enable emergency braking manoeuvres
Post-Conditions	The HV has left the area of infrastructure support. A sign-off is performed and the car continues using its own sensors only or a human driver takes over.
Information Requirements	• Infrastructure sensor data including video streams • Road conditions • RVs' status (e.g. location, dynamics, etc.) • Lane designations and geometry • HV's status (location, speed, etc.) • HV's trajectory

Infrastructure-Based Tele-Operated Driving

Use Case Name	Infrastructure-Based Tele-Operated Driving
User Story	When the automated vehicle detects a failure in a critical subsystem it prepares a status report and using its geo-position performs the necessary safety function (e.g. slow down or stop) and transmits all information to the tele-operator. Assuming the incident location is covered by infrastructure sensors the tele-operator retrieves a real-time picture of the road environment centred around the HV. Based on the perceived situation and the capabilities of the car, the remote driver can provide the appropriate trajectory and manoeuvre instructions to help the autonomous vehicle move to a safer location.
Category	Autonomous driving.
Road Environment	Urban, highway, intersection.

Short Description	An automated vehicle (e.g. passenger cars, shuttles or buses) may detect a failure in either computing or sensor components that are critical for the automated driving functionality. Without external support this may lead to a safety function (a full stop) being performed/implemented. Depending on where this happens (e.g. highway or in front of traffic lights) this can be a safety hazard or a mere inconvenience for the host vehicle's occupants or other vehicle's drivers. A human driver could be overwhelmed by this situation (e.g. if the HV stops at the left-most lane on a highway and asks for help from a tele-operator). A tele-operator supported by infrastructure sensors will be able to assess both the position of the HV and that of other vehicles and pedestrians in the vicinity. The tele-operator will then guide the HV either by remote-steering or remote-driving support to the nearest safe location (e.g. safety lane on the highway or parking spot in the city). This use case can be potentially extended by accessing other parts of the traffic infrastructure, such as traffic lights or warning and speed limit signs, in order to further support the safe driving of the HV.
Actors	Vehicle, remote driver, road and roadside infrastructure.
Vehicle roles	Host vehicle represents the remotely driven vehicle. Remote vehicles represents other neighbouring vehicles.
Road & Roadside Infrastructure	• (Mandatory) different types of sensors (RADAR, LIDAR, cameras) provide a complete picture of the dynamic road conditions • Roads are defined by their lane designations and geometry • Traffic signs provide laws, guidelines and timely information
Other Actors' roles	Remote driver (human or machine) takes over the HV for a short period of time to overcome a dangerous or complex situation en route.
Goal	Enables the remote driver to support the HV remotely in the absence of sensor data from the HV itself.
Needs	The HV needs to receive and apply the driving instructions sent by the remote driver.
Constraints/ Presumptions	The road infrastructure provides the sensor infrastructure, data and processing capabilities to enable remote driving functionality. • The HV is authorised and can enrol in the service provided by the road infrastructure • HV and road infrastructure can establish a secure communication link • HV and road infrastructure are able to mutually authenticate
Geographic Scope	Locations with well-developed city, road and traffic infrastructure.
Illustrations	
Pre-Conditions	• The road infrastructure has the means allowing it to capture sensor data, store, process and fuse this data, perform remote driving functions and send remote driving commands to the HV in real time • The HV is equipped with on-board devices that provide the means to receive and process data from the infrastructure • The HV has detected a situation that leads to the reduced functionality of sensors needed for automated driving • The HV has asked and established an authenticated and secure communication link with the remote driver/operator

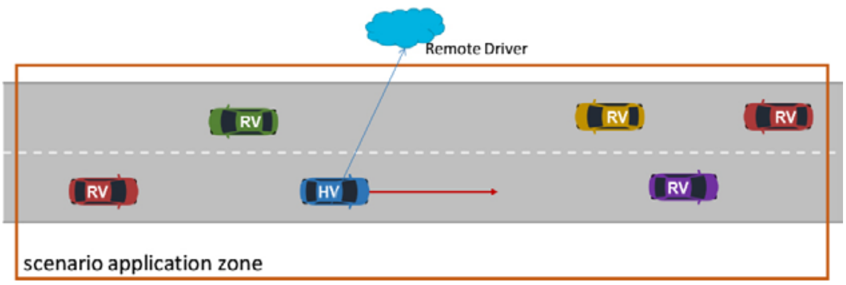
Main Event Flow	• On entering the zone with infrastructure coverage, the HV and infrastructure perform an initial handshake to establish a secured communication channel and speed up emergency communication • During the initial handshake, basic technical capabilities of the HV are communicated to the infrastructure used for different services that it provides, among others for the tele-operator or remote driving function • As basic functionality, the infrastructure's sensors track all moving vehicles including the HV so its location in case of emergency is known If the remote driver is a machine then: • The HV vehicle informs the remote driver about its emergency situation and sends an update regarding faulty subsystems. • A repair service is alerted in parallel • Because of the pre-established relationship between the HV and infrastructure a seamless handover between HV and remote driver is possible, potentially reducing the speed of the HV • The necessary information to build a model of the surrounding and the HV's own speed, direction and location is already available to the remote driver because it is continuously generated by infrastructure sensors • If the automated HV is capable of following complete trajectories the infrastructure provides one or several safe emergency trajectories to the HV • The HV selects the trajectory based on distance and comfort, and executes it • New trajectories are generated repeatedly until the HV is safely at its destination • If the HV cannot process trajectories then the remote driver takes over control of the car actions • If available, secondary information from other vehicles is accessed to obtain a more holistic view of the situation • Feedback is provided to the remote driver in parallel with the execution of the manoeuvre
Alternative Event Flow	If the remote driver is a human then: • The HV needs to stop before a human driver can take over • Based on infrastructure sensors including cameras, a virtual view of the environment is provided to the remote driver (similar to a video game), which can be augmented with raw video streams (real camera data from the infrastructure is added) • The infrastructure sensor data can be augmented by sensor data from other vehicles • The remote driver analyses the situation and selects the appropriate trajectory and/or the manoeuvre instructions that will help the HV to resolve the corresponding situation where uncertainty is high • The remote driver sends to the HV trajectory and/or the manoeuvre instructions and executes them, according to HV's on-board security checks • Simulated feedback and video data from an appropriate infrastructure camera is provided to the remote driver in parallel with the execution of the manoeuvre
Post-Conditions	The HV has left from the point where support was needed. The remote driving support session is de-activated and the HV can wait for the repair service at a safe location.
Information Requirements	• Infrastructure sensor data including video streams • Road conditions • RVs' status (e.g. location, dynamics, etc.) • Traffic signs • Traffic information • Lane designations and geometry • HV's status (location, speed, etc.) • HV's trajectory • HV's manoeuvre instructions (steering wheel, acceleration and brake pedal inputs)

Remote Automated Driving Cancellation (RADC)

Use Case Name	RADC
User Story	High automated/autonomous driving level of an AD vehicle has to be immediately cancelled for safety reasons. This can be triggered by a number of criteria, including lack of network coverage, insufficient KPIs and SLAs, unusual and/or unsafe driving conditions, etc.
Category	Autonomous driving.
Road Environment	Any type of road.
Short Description	High automated/autonomous level of an AD vehicle has to be immediately cancelled for safety reasons. Due to unexpected and unpredictable reasons the high automated/autonomous level of an AD vehicle has to be cancelled. As a result of cancelling AD, the control of the car has to be either given to: • A remote tele-control operator, or • To the driver of the vehicle - if there is one The remote control can be provided via another vehicle, a remote driver, a set of relays on roadside infrastructure, or by a remote operator in the cloud, etc.
Main Actors	AD vehicle/s.
Vehicle Roles	Host vehicle in AD mode.
Roadside Infrastructure Roles	For example, roadside units (RSU) communicating with the HV.
Other Actors' Roles	For example, other (remote) vehicles in the proximity of the HV communicating with the HV.
Goal	Dangerous traffic situations that could arise in AD mode have to be avoided immediately by cancelling the AD level remotely.
Needs	The AD HV needs to receive immediate information and sufficient instructions about the cancellation of the AD level in its vicinity (i.e. on its section of the road), and transfer the vehicle to a safe 'temporary' mode, where an alternate driving method can take over the HV.
Constraints/ Presumptions	• HV's initial network connection (e.g. AD mode started with...) is not available, or the available SLA (e.g. required QoS) is not sufficient to meet the needs of the HV's AD mode • Autonomous driving cancellation (ADC) message is supported in the network
Geographic Scope	Everywhere.
Pre-Conditions	• Capability of initial network (MNO) to detect that the AD HV is not reachable • Capability of initial network to trigger other networks (provided by other MNOs) with possible network coverage in the vicinity of the AD HV (i.e. through enhanced multi-operator interworking) • Capability of initial network to trigger an ADC message for an AD HV via other network connections (e.g. RSU, RV, sidelink or Uu)
Main Event Flow	• HV is in steady state mode in autonomous mode • HV in high (highest) AD level is approaching a road section where it is unsafe at that current level • ADC mechanism is triggered • ADC message is sent to the HV by a. Initial network (Uu) b. Other networks (provided by other MNOs) c. Other network connections (e.g. RSU, RV, sidelink) • HV receives an ADC notification to discontinue AD • HV applies an ADC and in self-control mode moves the vehicle to a safe location Note: Additional information is provided to the vehicle for the next steps - but this is a different use case (i.e. remote control).

Post-Conditions	• Acknowledgement of an ADC message is send by the HV and confirmation that AD has been exited or changed • A subsequent action can include remote control operation of the vehicle, as well as non-AD (autonomous/automated) driving mode engaged Implications on other use cases: • If HV is in platooning mode, the vehicle needs to first exit the platoon safely
Information Requirements	• ADC command needs to be successfully received • ADC subsequent action

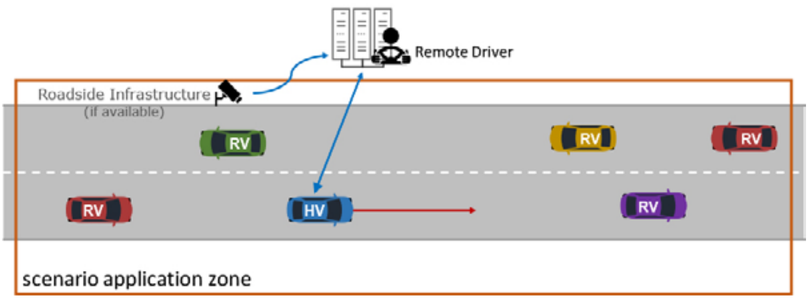
Tele-Operated Driving

Use Case Name	Tele-Operated Driving (TOD)
User Story	A temporary health issue (e.g. illness, headache) of a driver impairs his/her concentration, reactions and judgement, and consequently affects his/her ability to drive safely. The driver of the vehicle (with some autonomous capabilities) asks a remote driver to take control of the vehicle and drive the vehicle in an efficient and safe manner, from the current location to the destination
Category	Autonomous driving.
Road Environment	Urban, rural, highway, intersection, parking area.
Short Description	Based on the perceived environment, the remote driver provides to the vehicle that is remotely driven the appropriate trajectory and manoeuvre instructions to navigate to the destination efficiently and safely.
Actors	Vehicle, remote driver, road and roadside infrastructure.
Vehicle Roles	Host vehicle represents the remotely driven vehicle, and remote vehicles.
Road/Roadside Infrastructure	• Roads are defined by their lane designations and geometry • Traffic signs provide laws, guidelines and timely information
Other Actors' Roles	Remote driver (human or machine) undertakes to drive the HV remotely.
Goal	Enables the remote driver to control the HV remotely.
Needs	The HV need to receive and apply the driving instructions sent by the remote driver.
Constraints/ Presumptions	The HV provides the infrastructure and data to enable remote driving functionality.
Geographic Scope	Everywhere.
Illustrations	
Pre-Conditions	The remote driver has established an authenticated and secure communication channel with the HV.

Main Event Flow	If the remote driver is a machine then: • The remote driver receives road conditions (e.g. obstacles) and status information of neighbouring RVs (e.g. location, speed, dynamics, etc.) derived, for example, by the HV's sensors and status information (e.g. speed, location), and traffic conditions. • The remote driver, based on the received information, builds the model of its surroundings (i.e. awareness of the environment of the HV) and, taking into account the destination point, selects the trajectory and manoeuvre instructions • The HV receives from the remote driver trajectory and/or the manoeuvre instructions and executes them, according to the HV's on-board security checks • Feedback is provided to the remote driver in parallel with the execution of the manoeuvre
Alternative Event Flow	If the remote driver is a human then: • The remote driver receives video streams of high quality (e.g. to identify road conditions, neighbouring RVs) and the HV's status information (e.g. speed, location) • The remote driver, based on the received information, builds his/her situation awareness and, taking into account the destination point, selects the trajectory and manoeuvre instructions • The HV receives from the remote driver trajectory and/or the manoeuvre instructions and executes them, according to HV's on-board security checks Feedback is provided to the remote driver in parallel with the execution of the manoeuvre.
Alternative Event Flow	If the remote driver has to communicate with a passenger or any person outside of the vehicle (e.g. policeman) then: • An audio stream is also established between the remote driver and the vehicle (passenger or outside person) • The audio stream ends when the communication is no longer needed
Post-Conditions	The HV adjusts its trajectory, speed, acceleration, etc. based on received control information. When the vehicle has reached its destination then the remote driving process ends.
Information Requirements	• Video streams • Audio communication • Car sensor data (RADAR, LIDAR, etc.) • Road conditions • RVs' status (e.g. location, dynamics, etc.) • Traffic signs • Traffic information • Lane designations and geometry • HV's status (location, speed, etc.) • HV's trajectory • HV's manoeuvre instructions (steering wheel, acceleration and brake pedal inputs)

Tele-Operated Driving Support

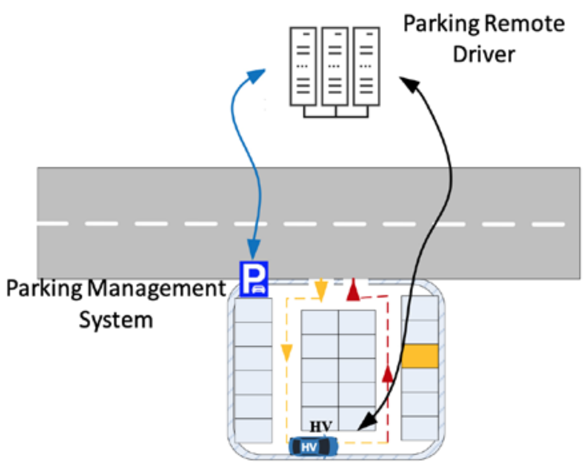
Use Case Name	Tele-Operated Driving Support
User Story #1	**Tele-Operated Driving Support: Remote Steering** An autonomous vehicle (e.g. passenger cars, or even a vehicle that performs dedicated tasks in very complex environments, e.g. snow ploughing, cleaning, loading and unloading) may detect a highly uncertain situation and cannot make the appropriate decision for a safe and efficient manoeuvre. In this case the autonomous vehicle can ask for the support of a remote driver in order to resolve the difficult situation and then switch back to the normal autonomous driving mode without the remote driving support.
Category	Autonomous driving.
Road Environment	Urban, rural, highway, intersection.

Short Description	When the autonomous vehicle detects the need for remote support, it starts sharing video and/or sensor data (e.g. from RADAR and LIDAR sensors in either raw or pre-processed form) and/or 'situation interpretation' data to communicate what is going on in the environment to the remote driver. Based on the perceived situation, the remote driver can provide the appropriate trajectory and manoeuvre instructions to help the autonomous vehicle resolve the highly uncertain situation.
Actors	Vehicle, remote driver, road and roadside infrastructure.
Vehicle roles	Host vehicle represents the remotely driven vehicle. Remote vehicles represents other neighbouring vehicles.
Road & Roadside Infrastructure	• Roads are defined by their lane designations and geometry • Traffic signs provide laws, guidelines and timely information • (Optional) video feed from traffic cameras
Other Actors' roles	Remote driver (human or machine) undertakes to drive the HV remotely for a short period of time to overcome a dangerous or complex situation en route.
Goal	Enable the remote driver to support the HV remotely.
Needs	The HV needs to receive and apply the driving instructions sent by the remote driver.
Constraints/ Presumptions	The HV provides the infrastructure and data to enable remote driving functionality.
Geographic Scope	Everywhere.
Illustrations	
Pre-Conditions	• The HV has detected a situation which is too uncertain to select a safe and efficient manoeuvre • The HV has asked and established an authenticated and secure communication channel with the remote driver/operator
Main Event Flow	If the remote driver is a machine then: • The HV vehicle provides to the remote driver information about the type of the HV, its destination and also information that will enable the remote driver to build the model of surroundings. This information may include road conditions derived, for example, by the HVs' sensors and cameras, status information of neighbouring RVs (e.g. location, speed, dynamics, etc.), and traffic conditions. • If available, secondary information from road infrastructure is accessed to obtain a more holistic view of the situation • The remote driver analyses the situation and selects the appropriate trajectory and/or manoeuvre instructions that will help the HV to resolve the corresponding situation where uncertainty is high • The remote driver sends to the HV trajectory and/or manoeuvre instructions and executes them, according to HV's on-board security checks • Feedback is provided to the remote driver in parallel with the execution of the manoeuvre

Alternative Event Flow	If the remote driver is a human then: • The HV vehicle provides high-quality video streams (e.g. to identify road conditions, neighbouring RVs) and its status information (e.g. speed, location, destination) • If available, secondary information from road infrastructure is accessed to obtain a more holistic view of the situation • The remote driver analyses the situation and selects the appropriate trajectory and/or the manoeuvre instructions that will help the HV to resolve the corresponding situation where the uncertainty is high • The remote driver sends to the HV trajectory and/or manoeuvre instructions and executes them, according to HV's on-board security checks Feedback (video, other sensors, HV status) is provided to the remote driver in parallel with the execution of the manoeuvre.
Post-Conditions	• The HV has left from the point where the support was needed. The remote driving support session is de-activated and the HV switches back to its normal autonomous driving mode to continue performing its planned task or the trip to its destination.
Information Requirements	• Video streams • Car sensor data (RADAR, LIDAR, etc.) • Road conditions • RVs' status (e.g. location, dynamics, etc.) • Traffic signs • Traffic information • Lane designations and geometry • HV's status (location, speed, etc.) • HV's trajectory • HV's manoeuvre instructions (steering wheel, acceleration and brake pedal inputs)

User Story	Detailed description, specifics and main differences to the user story in the main template	
User Story Title #2 **Tele-Operated Driving Support: Remote Driving Instructions**	User Story:	There are also situations where uncertainty is high due to detection problems from one of the sensors (e.g. unresolved objects). For instance, a road construction area has just been set up or changed and with that road direction and lane markings have changed or are confusing. Such situations might need the decision of a human (tele-operator) to be resolved. The difficult situation is resolved by a remote driver who advises the HV how to proceed with the autonomous driving task. The remote driver will provide instructions to the HV, which will then execute them in its autonomous driving mode. The remote driver does not take over control of steering and acceleration. However, it is possible for the remote driver to control the brakes.
	Other Actors' Roles:	Remote driver (human or machine) undertakes to send driving commands or instructions remotely (e.g. 'ignore lane marking', 'pass car blocking the road on the right/left') to the HV for a short period of time to overcome a dangerous or complex situation en route.

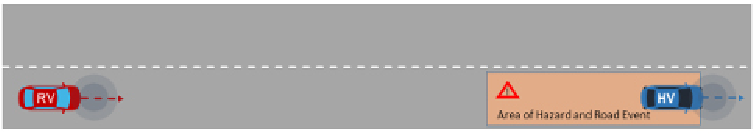
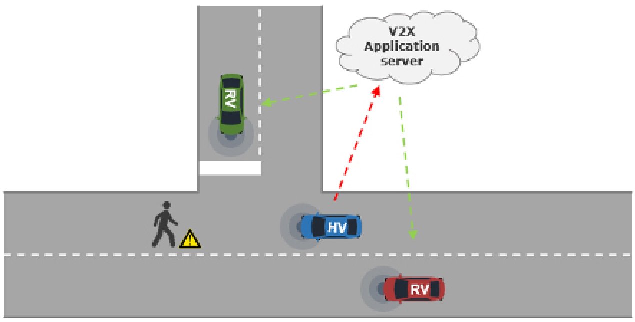
Tele-Operated Driving for Automated Parking

Use Case Name	Tele-Operated Driving for Automated Parking
User Story #1	**Tele-Operated Driving for Automated Parking: Remote Driving Paths** When a vehicle arrives at its destination parking area, the driver leaves the vehicle and it is parked by a remote driver located in a tele-operation centre.
Category	Autonomous driving.
Road Environment	Parking area (indoor or outdoor).
Short Description	• A vehicle arrives at its destination parking area • The vehicle is taken over by the parking remote driver • The vehicle is parked in the designated parking space by a remote driver
Actors	Vehicle, parking remote driver, parking management system.
Vehicle Roles	Host vehicle represents the parking vehicle that is remotely driven.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	• Parking remote driver constructs an accurate model of the HV's surrounding environment using information received from the parking management system and HV (e.g. vehicle sensors, video streams), and provides the driving paths and/or manoeuvre instructions for the HV • The parking management system provides high-definition mapping and sensor information inside the parking area
Goal	Enables HV parking using remote driving without the presence of the passengers.
Needs	The HV receives and applies the driving path from the parking remote driver and uses this for autonomously driving in the parking lot.
Constraints/ Presumptions	• The HV provides the infrastructure and data to enable remote driving functionality • The parking management system provides the data to identify free parking slots and their location
Geographic Scope	Anywhere.
Illustrations	
Pre-Conditions	• The parking remote driver can construct an accurate model of the surrounding environment based on information received from parking management system and HV • HV has high-accuracy positioning enabled • HV vehicle must be able to autonomously driver based on the provided path • Authenticated and secure communication is provided between HV, parking remote driver and parking management system

Main Event Flow	• The HV arrives in the 'pick-up/drop-off' area and requests an automated remote parking service from the parking remote driver • The parking remote driver constructs the surrounding environment model using information provided by the HV (e.g. sensor data, type of vehicle) and parking management system (e.g. sensors and3high-definition map inside the parking area), and identifies the appropriate parking spot • The parking remoter driver estimates the driving path to the available parking slot and sends the coordinates to the HV • The HV receives and executes the driving path instructions from the parking remote driver according to on-board security checks • The HV provides updated information (i.e. sensor data) about its location and status to the parking remote driver. The latter monitors the HV's route and adapts the path if needed, according to feedback from the vehicle or parking management system
Alternative Event Flow	Not applicable.
Post-Conditions	The HV has reached its destination and it is successfully parked in the destination parking place. The remote parking service ends.
Information Requirements	• High-definition map inside the parking area • Positioning information • HV information (e.g. type, size) • Video streams • HV's path • HV's manoeuvre instructions (steering wheel, acceleration and brake pedal inputs) • Car sensor data (RADAR, LIDAR, etc.)

User Story	**Detailed description, specifics and main differences to the user story in the main template**	
User Story Title #2 **Tele-Operated Driving for Automated Parking: Remote Steering**	User Story:	In this user story the parking remote driver (human or machine) undertakes full control of the HV. Based on the HV's sensor information (e.g. LIDAR, RADAR), status and video streaming, the parking remote driver builds a model of the surroundings, and manoeuvre instructions (e.g. steering wheel, speed, acceleration) are sent for the route to the destination parking position.
	Main Event Flow	• The HV arrives in the 'pick-up/drop-off' area and requests an automated remote parking service by the parking remote driver • The HV transmits to the parking remote driver the vehicles' sensor information, status and high-definition video streaming • The parking remote driver constructs the model of surroundings, using also the parking management system information, if available, to identify the appropriate parking spot. Taking into account the destination point, it selects the manoeuvre instructions • The parking remote drive transmits periodically to the HV the manoeuvre instructions (e.g. steering wheel, speed, acceleration) • The HV executes the driving commands received from the parking remote driver, according to the on-board security checks • Feedback is sent from the HV to the parking remote driver as the manoeuvre is executed

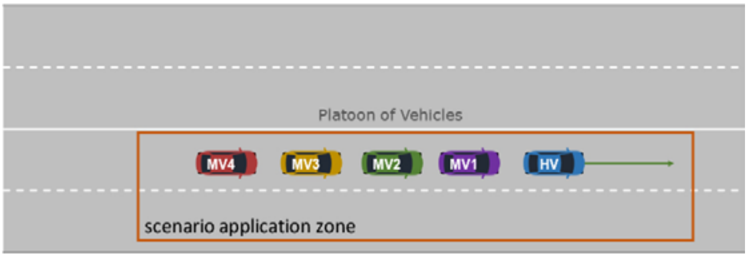
Vehicles Collects Hazard and Road Event for AV

Use Case Name	Vehicle Collects Hazard and Road Event for AV
User Story	Vehicles collect hazard and road event information based on vehicle sensor data for further use by autonomous vehicles and V2X application server.
Category	Safety.
Road Environment	Intersection, urban, rural, highway
Short Description	Whenever a vehicle detects a hazard or road event based on its own sensor data, the corresponding information will be collected together with the geographic location of the vehicle for the purpose of sharing with other vehicles, especially AVs and V2X AS.
Actors	Host vehicle, remote vehicle.
Vehicle roles	HV represents the vehicle that detects events based on its own sensor data during the driving; the RV, which is typically an AV, receives information collected by the HV.
Road/Roadside Infrastructure Roles	Optionally, a roadside infrastructure role may be involved in the use case for receiving information from the HV and broadcasting it to the RV.
Other Actors' Roles	Optionally, a V2X application server role may be involved in the use case for receiving information from HV and forwarding it to the RV.
Goal	Share road, traffic and weather event information detected by vehicles to AVs, so that the information horizon of the AVs is extended.
Needs	The AVs need prior information about the road, traffic and weather to improve their trajectory planning and motion control.
Constraints/ Presumptions	Assumptions will be required for the following information: • The HV is able to detect road, traffic and weather events based on its sensor data • The HV is able to communicate the detected events
Geographic Scope	Global.
Illustrations	Scenario 1 **Vehicle collects hazard event for AV**  Scenario 2 **Vehicle collects hazard event and send it to the V2X AS** 
Pre-Conditions	• HV is driving through the scenario application zone - Defined as the area in which a road, traffic or weather event occurred • The scenario application zone may be a point location, e.g. stationary car, or a trace of multiple points on the road (e.g. a slippery road segment)

Main Event Flow	• The HV detects a hazardous event (road, traffic, weather, etc.) • The HV sends out information of the detected event • The RV is approaching the scenario application zone and receives the information directly from the HV
Alternate Event Flow	• The HV detects a hazardous event (road, traffic, weather, etc.) • The HV sends out information of the detected event to the V2X application server • The application server gathers and analyses the hazard information to assess potential dangers involving RVs • The RV is approaching the scenario application zone and receives the warning information from the V2X application server
Post-Conditions	Information of the detected hazard and road events are available and used by the RV.
Information Requirements	• HV's sensor data • Road conditions • Car status (e.g. location, dynamics, etc.) • Events detected by vehicles

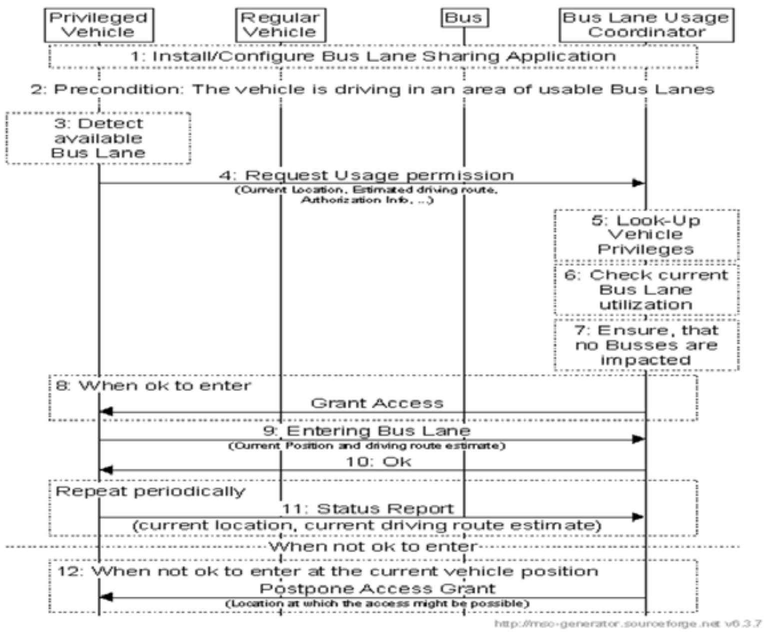
Vehicles Platooning in Steady State

Use Case Name	Vehicles Platoon in Steady State
User Story	A group of vehicles (e.g. trucks travelling from warehouse facilities to a transportation area e.g. rail, ship) drive closer - in a coordinated manner - to decrease fuel consumption, increase efficiency and reduce traffic congestion. There are also potential driver and logistics efficiencies possible.
Category	Platooning.
Environment	Urban, rural, highway.
Short Description	Platooning enables a group of vehicles of the same vehicle class (e.g. cars, trucks, buses etc) to drive in close proximity in a coordinated manner (e.g. high-density platooning). The head of the platoon (host vehicle) is responsible for coordinating other vehicles in the group (member vehicles) and, potentially, for coordinating with cloud assistance and overall support of the platoon. By sharing status information (such as speed, heading and intentions such as braking, acceleration etc) between the members, and with the support of the platoon head, the distances between vehicles can be reduced, the overall fuel consumption and emissions are also reduced, together with the overall cost. Moreover, platooning enhances safety and efficiency by reducing the influence of unanticipated driving behaviour, small speed variations, and road capacity issues.
Actors	Vehicle.
Vehicle roles	There are two vehicle roles involved in this use case: • Host vehicle: head of a platoon • Member vehicle: member of a platoon
Road/Roadside Infrastructure	Not applicable.
Other Actors' Roles	Not applicable.
Goal	A number of vehicles travelling closely together that are 'electronically' connected, to reduce fuel consumption and cost.
Needs	The group of vehicles, which are coordinated/controlled by a HV, need to share common mobility patterns, to maintain formation - typically inter-vehicle distances and speed alignment - and exchange information about intended manoeuvres.
Constraints/ Presumptions	The HV and each MV are equipped to share messages conveying precise location, speed, acceleration, direction and sensor data.

Geographic Scope	Everywhere.
Illustrations	
Pre-Conditions	• A group of MVs and the HV have formed a platoon and they have authenticated each other • The destination and the goal of the platoon are known and agreed (HV and MVs)
Main Event Flow	• The HV receives information about the road and weather conditions, if available, as well as traffic conditions according to the route that the platoon follows • The HV also receives information about the status of the MVs (e.g. speed, location) • Based on the information collected, the HV decides the behaviour and configuration of the platoon (e.g. inter-vehicle distance guidance, speed, location and direction and intentions such as acceleration etc.) • The MVs receive configuration information about the platoon from the HV (e.g. trajectory, speed and acceleration intention of the HV) • The MVs (e.g. MV2) receives speed, position and the intentions such as braking and acceleration of the respective front MV (e.g. MV1) • Each MV (e.g. MV2) based on the collected information, and considering its own dynamics and important parameters (e.g. tyre pressure), determines its driving behaviour (e.g. accelerate, brake or even to keep a stable distance with the front vehicle, i.e. MV1)
Alternative Event Flow	Not applicable.
Post-Conditions	Vehicles within the platoon maintain appropriate inter-vehicle distances, aligning their speed and driving towards the defined destination - the goal of the platoon.
Information Requirements	• Vehicles location, speed information • Platoon trajectory • Driving intention (brake, accelerate) • Traffic conditions • Road conditions • Weather conditions

Bus Lane Sharing Request

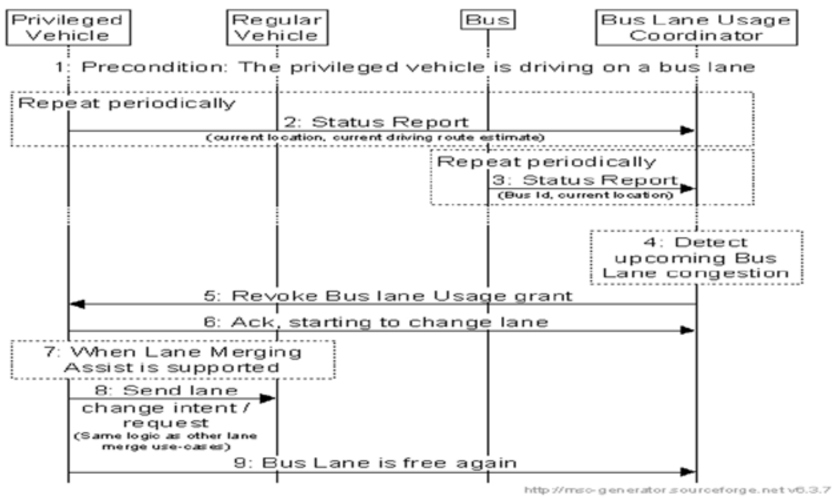
Use Case Name	Bus Lane Sharing request
User Story #1	In order to improve road usage and traffic efficiency a (temporary) access to bus lanes can be granted by the road authority/city. This access could be granted to certain vehicles, e.g. to create an incentive for electric and/or autonomous vehicles.
Category	Traffic efficiency and environmental friendliness, convenience, autonomous driving.
Road Environment	Urban.

<table>
<tr><td>Short Description</td><td>A vehicle which supports bus lane sharing features and is authorised to participate in this ‘community’, requests permission to use the bus lane. The Vehicles sends a bus lane sharing request to the relevant application, providing the vehicle identity, its current position (e.g. where it desires to enter the bus lane) and an approximate route/trajectory (i.e. which track to follow and where the intention is to exit the bus lane). The bus lane usage application accepts the request, depending on whether the vehicle is authorised to use bus lanes and on the current traffic volume (i.e. other vehicles already granted permission to use them), as well as the position and arrival of next bus and potentially other policies.</td></tr>
<tr><td>Actors</td><td>Vehicle, bus lane usage application.</td></tr>
<tr><td>Vehicle Roles</td><td>Vehicle applying the bus lane usage application.</td></tr>
<tr><td>Road/Roadside Infrastructure Roles</td><td>Not applicable.</td></tr>
<tr><td>Other Actors’ Roles</td><td>Not applicable.</td></tr>
<tr><td>Goal</td><td>Increase usage in particular of urban bus lanes without impacting public transport.
Promoting environmentally friendly vehicles/transport.</td></tr>
<tr><td>Needs</td><td>The vehicle needs to support interaction with the bus lane usage application.</td></tr>
<tr><td>Constraints/ Presumptions</td><td>The city may need to have the means to monitor the bus lanes strictly to prevent misuse. This could, for example, be handled by cameras on buses taking photos of licence plates and checking them against the bus lane usage application (i.e. if vehicles in bus lanes are authorised to use them).</td></tr>
<tr><td>Geographic Scope</td><td>Anywhere.</td></tr>
<tr><td>Illustrations</td><td>
</td></tr>
<tr><td>Pre-Conditions</td><td>A vehicle is enrolled in the bus-lane-sharing community
Law enforcement is aware that the vehicle is allowed to use bus lanes
This can be done in several ways, for example:
- Statically - information known by law enforcement confirming the vehicle can use the bus lanes
- Dynamically - by informing law enforcement at the bus lane entry point
- Law enforcement query - direct from law enforcement vehicle, or via law enforcement back-end system, to the bus lane usage application
- Vehicle information - sent out from vehicle actually in the bus lane (e.g. a valid token)</td></tr>
</table>

Main Event Flow	• Vehicle approaching an area with bus lanes • Vehicle connects to bus lane usage application • Vehicle requests access to the bus lane and provides the required information (vehicle identity, its current position or where it desires to enter the bus lane - a route estimate) • Bus lane usage application checks the request • If accepted, the bus lane usage application sends an 'accept' message with instructions when and where to access the bus lane • Vehicle informs when it is entering the bus lane • Vehicle periodically reports its position to the bus lane usage application to control how the bus lane is used
Alternative Event Flow	• A vehicle is enrolled in the bus-lane-sharing community • Vehicle approaches an area with bus lanes • Vehicle connects to bus lane usage application • Vehicle requests access to the bus lane and provides the required information • Bus lane usage application checks the request If not accepted, the bus lane usage application sends a 'reject' message.
Post-Conditions	Vehicle enters/uses the bus lane.
Information Requirements	• Vehicle identifier • Authentication information • Positioning information

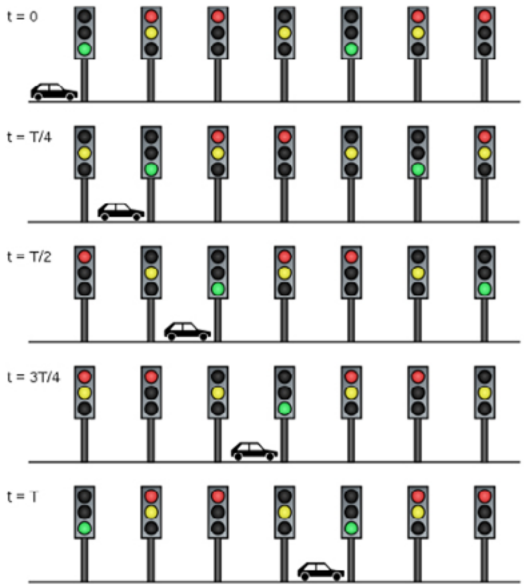
Bus Lane Sharing Revocation

Use Case Name	Bus Lane Sharing Revocation
User Story #1	A set of vehicles is given permission for bus lane usage, but a bus is approaching faster than initially anticipated. In order to free up the bus lane so the bus can pass without delay. The bus Lane sharing usage application detects that a set of vehicles are likely to interrupt the bus, so it sends a message to 'revoke' the usage granted to relevant vehicles.
Category	Traffic efficiency and environmental friendliness, convenience, autonomous driving.
Road Environment	Urban.
Short Description	• A bus lane usage application detects an upcoming interruption of a public transport by authorised vehicles on the bus lane • The bus usage application revokes the usage granted and instructs the relevant vehicle(s) to free up the bus lane The vehicle acknowledges the instruction (e.g. to be used for legal reasons).
Actors	Vehicle, bus lane usage application.
Vehicle Roles	Vehicle applying the bus lane usage application.
Road/Roadside Infrastructure Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	Increase usage in particular of urban bus lanes without impacting public transport.
Needs	The vehicle needs to support interaction with the bus lane usage application.
Constraints/ Presumptions	The city may need to have the means to monitor the bus lanes strictly to prevent misuse.
Geographic Scope	Anywhere.

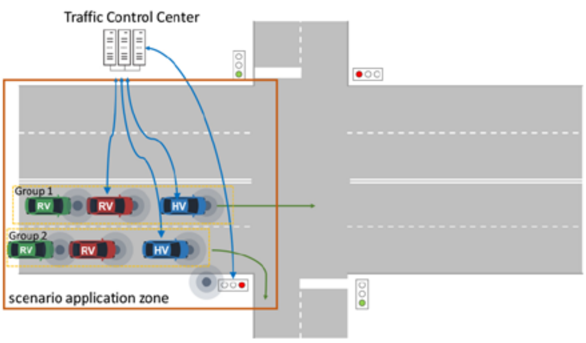
Illustrations	
Pre-Conditions	• Vehicle has been granted permission to use the bus lane usage application • Vehicle is connected to the bus lane usage application • The bus lane usage application monitors the vehicles position
Main Event Flow	• The bus lane usage application detects that a vehicle will interrupt the buses • The bus lane usage application instructs the vehicle to leave the bus lane • Vehicle confirms the instruction and leaves the bus lane (e.g. to be used for legal reasons)
Alternative Event Flow	Not applicable.
Post-Conditions	Not applicable.
Information Requirements	• Vehicle identifier • Authentication information • Positioning information

Continuous Traffic Flow via Green Lights Coordination

Use Case Name	Continuous Traffic Flow via Green Lights Coordination
User Story	Any vehicle travelling along with the 'green wave' will see a progressive cascade of green lights, and will not have to stop at the intersections.
Category	Traffic efficiency and environmental friendliness.
Road Environment	Intersection.
Short Description	A series of traffic lights (usually three or more) are dynamically coordinated to allow continuous traffic flow over several intersections in one main direction. The benefits of traffic flow optimisation via dynamic traffic signal and phase changes are: reduction of CO_2 emissions, reduction of fuel consumption, reduction of cars' waiting time at side roads, pedestrians receive more time to cross (and help to cross streets with vehicles travelling in platoons), and increased traffic efficiency in urban areas.
Actors	Vehicle, road and roadside infrastructure.
Vehicle Roles	Host vehicle represents the vehicle that approaches intersections.
Road/Roadside Infrastructure	• Roads are defined by their lane designations and geometry • Intersections are defined by their crossing designations and geometry • Traffic lights control right of way traffic flow through an intersection • Local traffic laws and rules control right of way through three-way stops, four-way stops and unsigned intersections

Goal	Helps drivers/autonomous vehicles to select the right speed setting to avoid having to stop at a series of intersections.
Needs	HV needs to know the timing of traffic lights for a progressive cascade of green lights (i.e. green wave), when approaching a series of intersections and where the HV can adapt its speed according to the timing parameter.
Constraints/ Presumptions	• HV's intended direction through the intersection is known • HV's intended trajectory could be provided if available or assumed
Geographic Scope	Global.
Illustrations	
Pre-Conditions	Traffic lights are dynamically coordinated to turn green in sequence, taking into account the traffic conditions and/or information from different sources if available e.g. cameras, sensors on the roads.
Main Event Flow	• The HV reports location, direction and/or intended trajectory to a traffic management server or to roadside infrastructure (this information is periodically updated) • HV is approaching a series of intersections • HV receives timing and/or speed recommendations either by a traffic management server or by roadside infrastructure in order to follow the cascade of green lights (the timing and/or speed recommendations could be updated, while the HV passes through intersections e.g. due to change of traffic conditions) • HV displays the recommended timing and/or speed or automatically adjusts its speed
Alternative Event Flow	Not applicable.
Post-Conditions	HV passes a series of intersections without a stop.
Information Requirements	• HV's location (including direction) • HV's intended trajectory (if available) • Lane designations and geometry • Intersection geometry • Traffic light signal phase and timing • Traffic rules and laws for three-way stops, four-way stops and unsigned intersections

Group Start

Use Case Name	Group Start
User Story	Self-driving or semi-automated vehicles form a group to start jointly at traffic lights. In a centralised implementation of this use case, a traffic control centre provides tactical and strategic information to coordinate the activity.
Category	Traffic efficiency and environmental friendliness.
Road Environment	Intersection, urban.
Short Description	A traffic control centre or HV identifies several vehicles which intend to cross an intersection on a similar path at a similar time. The candidate vehicles are placed into groups following the same paths, guided through the intersection by their corresponding 'group lead' vehicle. After the manoeuvre is executed the groups are dissolved. The lead vehicle reports the manoeuvre to the traffic control centre.
Actors	• Host vehicle • One or more remote vehicles • Traffic control centre • Traffic lights
Vehicle Roles	• HV represents the lead vehicle for a given group • RV represents the other group members
Roadside Infrastructure Roles	• Traffic light sends signal phase and timing information to the traffic control centre and/or to all vehicles in the vicinity
Other Actors' Roles	The traffic control centre provides tactical and strategic information to facilitate the group start activity. This happens while the vehicles are approaching the intersection and while vehicles are waiting at the red light.
Goal	Allows more efficient use of a green phase at an intersection. Reduces noise and pollution in cities. Increases convenience for drivers thanks to shorter waiting times.
Needs	• A HV detects the benefit of the use case and its potential implementation at an intersection, and initiates the use case • The traffic control centre identifies that multiple vehicles are approaching an intersection and intend to cross it on the same path and at a similar predicted time
Constraints / Presumptions	• There is a mixture of vehicles which are capable and vehicles which are not capable of participating in the group start use case waiting at or approaching the traffic light. Vehicles without such capabilities are regarded as the group 'delimiter'. The next group, which is independent of the 'non-capable' one, is expected to start independently of the first group. • The vehicles waiting at or approaching the traffic light have different capabilities (e.g. in terms of achievable acceleration, sensor equipment) • There are more vehicles at the light than can pass during one phase • All vehicles potentially participating in the group can securely communicate to each other • Centralised: All vehicles potentially participating in the group can establish a secure connection with the appropriate traffic control centre • Centralised: There is one dedicated traffic control centre for the given intersection
Geographic Scope	Regional.
Illustrations	

Pre-Conditions	• Intersections benefiting from the use case need to be known to the initiating HVs (e.g. through prior communication or updates) • The traffic control centre provides advice to the vehicles on how to approach the intersection and which path to take there (lane, relative position or absolute position) • The vehicles arrive at the intersection and wait at a red light

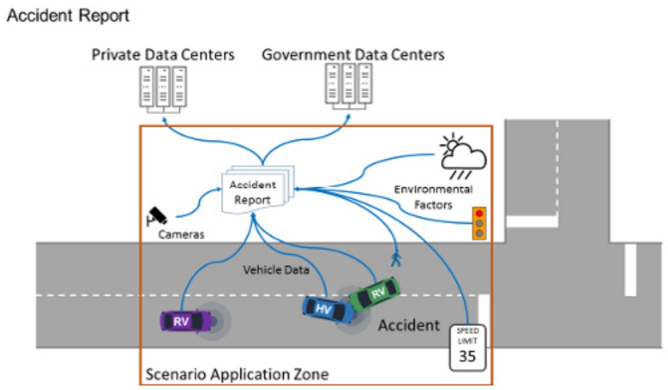
Main Event Flow	Centralised solution, use case driven by the traffic control centre:
	
	Phase 1 (group formation by the traffic control centre with communication channelled through it alone):
	• The traffic control centre announces the formation of a group of vehicles to perform a group start
	• The traffic control centre assigns the leadership role to leading vehicles in the group
	• The traffic control centre announces the final group properties (e.g. planned manoeuvre and trajectory, including acceleration, yaw rate, etc.) and requests an acknowledgement from each vehicle which has the ability to opt out of the formed group
	• If needed, the traffic control centre updates the group according to the final acknowledgements
	
	Phase 2 (manoeuvre selection and initiation):
	• The lead vehicle performs additional double checks to verify that the traffic light information is correct (e.g. cross-checking locally available information with that from the traffic control centre) and the environment is ready for the group start the manoeuvre
	• The lead vehicle initiates the manoeuvre through a message to all group participants
	• From this point on the group is considered as 'closed' and communicates within the group only (communication within the group is confidential/encrypted) - there is no communication between different groups
	• To the outside world, the lead vehicle announces the intent, position, and progress of the platoon (e.g. similar to a CAM type message)
	• All vehicles send updates and additional information (e.g. detour or delay due to pedestrians) to the lead vehicle
	• To the infrastructure and the traffic control centre, the lead vehicle stays in contact to report the platoon's progress
	
	Phase 3 (manoeuvre monitoring and update):
	• While executing the manoeuvre, the vehicles constantly monitor the environment; the lead vehicle takes a special role by monitoring ahead for any obstacles - all manoeuvre changes are announced by the lead vehicle
	
	Phase 4 (group release):
	• The lead vehicle terminates the group start manoeuvre
	  - Successful: All vehicles have completed the intended path of the 'group start' platoon
	  - Unsuccessful: At least one vehicle has not yet completed the intended path within a given time
	    . The lead vehicle communicates that the group is dissolved unsuccessfully
	    . The lead vehicle also includes the most recent signal phase and timing information in that message
	• The lead vehicle provides a report of the group start manoeuvre to the traffic control centre

Alternative Event Flow	Decentralised solution, use case driven by the HV:
	
	Phase 1 (group formation by the HV):
	• The HV announces the formation of a group of vehicles to perform a group start
	• The RVs decide, depending on their route, if partaking in the group is of benefit to them and accept/decline
	• The lead vehicle performs checks to verify that the traffic light information is correct (e.g. cross-checking locally available information with that from RVs) and updates the RVs
	
	Phase 2 (final group and manoeuvre selection and initiation):
	• The HV announces group leads and the trajectory (e.g. planned manoeuvre and trajectory, including acceleration, yaw rate, etc.) - leads are selected based on the information gathered in Phase 1 by the HV
	• From this point on, the different groups are considered as closed and communicate within the group only (communication within the group will be confidential (encrypted) - there is no communication between different groups
	• The group lead initiates the manoeuvre through a message to all group participants and the environment is ready for the group start manoeuvre
	• To the outside world, the group lead announces the intent, position, and progress of the platoon (e.g. similar to a CAM type message)
	• All vehicles send updates and additional information (e.g. detour or delay due to pedestrians) to the group lead
	
	Phase 3 (manoeuvre monitoring and update):
	• While executing the manoeuvre, the vehicles constantly monitor the environment; the group lead takes a special role by monitoring ahead for any obstacles - all manoeuvre changes are announced by the lead vehicle
	
	Phase 4 (group release):
	• The group lead terminates the group start manoeuvre
	  - Successful: All vehicles have completed the intended path of the ‘group start’ platoon
	  - Unsuccessful: At least one vehicle has not yet completed the intended path within a given time
	    . The lead vehicle communicates that the group is dissolved unsuccessfully
	    . The lead vehicle also includes the most recent signal phase and timing information in that message

Post-Conditions	All vehicles have completed the manoeuvre or the green phase ends.
Information Requirements	• Signal phase and timing information • Properties of the group • Position • Speed • Acceleration • Yaw rate • Planned path • Timeout after which the manoeuvre is considered as unsuccessful

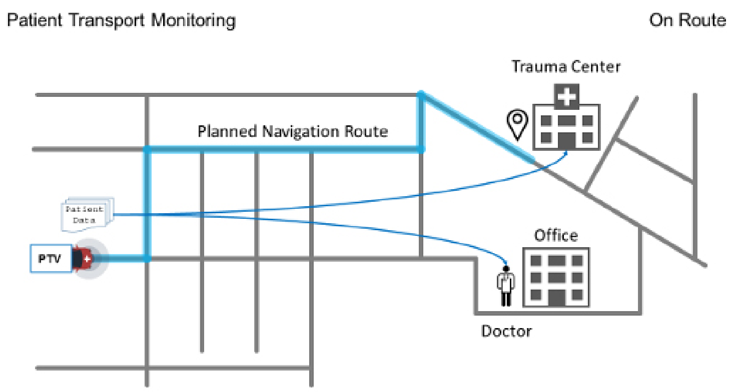
Accident Report

Use Case Name	Accident Report
User Story	When host vehicles are involved in an incident, an accident report containing a time-windowed recording of vehicle systems data, rich sensory information, environmental conditions and any available camera views is sent to government and private data centres.
Category	Society and community.
Road Environment	Urban, rural, highway
Short Description	Host vehicles send an accident report to government and private data centres.

Actors	Host vehicles, remote vehicles.
Vehicle Roles	HVs represents vehicles involved in the accident. RVs represent neighbouring vehicles.
Roadside Infrastructure Roles	Signs and traffic signals provide dynamic environmental input to the accident report.
Application Server Roles	Not applicable.
Other Actors' Roles	• OEM and government data centres are receiving the reports • Vulnerable road users provide dynamic environmental input to the report • Weather and road conditions provide environmental input to the report • Surveillance cameras provide a capture video recording of the accident
Goal	Sends accident reports to OEMs, government and insurance data centres.
Needs	HV needs to send an accident report containing a time-windowed recording of vehicle systems data, rich sensory information and dynamic environmental conditions to OEM and government/insurance data centres.
Constraints/Presumptions	• Assumptions will be required for the following information: - Extent of scenario application zone • Parties involved have agreed to sharing information and reporting in the event of a collision • Capturing data recordings needs to adhere to regulatory rules where applicable
Geographic Scope	Global.
Illustrations	
Pre-Conditions	The 'accident report' scenario is enacted when one or more HV's are involved in an accident.
Main Event Flow	If the 'accident report' scenario is enacted when: • Locations and dynamics are collected from HVs • Vehicle system data recordings are collected from HVs • Locations and dynamics are collected from RVs in the scenario application zone • Dynamic environmental data is collected from sources in the scenario application zone • Video recording are collected from cameras in the scenario application zone An accident report is sent to appropriate data centres.
Post-Conditions	Accident report is sent to appropriate data centres.
Information Requirements	• Accident report includes a captured time window of: - Position and dynamics of HVs - Vehicle system data of HVs - Video from nearby cameras • Environmental data including: - Position and dynamics of RVs - Position and dynamics of vulnerable road users - Position, nature and state of traffic signals, signs, etc. • Weather and road conditions

User Story	Detailed description and specifics
User Story #1	A host vehicle rear-ended a remote vehicle while another HV was pulling out of a parking spot on a crowded downtown street.

Patient Transport Monitoring

Use Case Name	Patient Transport Monitoring
User Story	Paramedics, patient monitoring equipment, trauma centres and doctors share vital patient telemetry data, images, voice and video during patient transport.
Category	Society and community.
Road Environment	Urban, rural, highway.
Short Description	Patient transport vehicle (PTV) shares patient telemetry data, images, voice and video between paramedics, hospitals and doctors.
Actors	Patient transport vehicle.
Vehicle Roles	PTV represents the vehicle that is transporting a patient.
Roadside Infrastructure Roles	Not applicable.
Application Server Roles	Not applicable.
Other Actors' Roles	Not applicable.
Goal	Shares patient telemetry data, images, voice and video with paramedics, trauma centres and doctors during patient transport.
Needs	Paramedics, trauma centres and doctors need to share patient telemetry data, images, voice and video during patient transport.
Constraints/ Presumptions	Not applicable.
Geographic Scope	Global.
Illustrations	
Pre-Conditions	• The 'en route' scenario is enacted when: - The patient is in the PTV - The patient is being monitored - The destination trauma centre is identified • The assigned doctor(s) are identified

Main Event Flow	• If the 'en route' scenario is enacted: - PTV streams patient telemetry data to the trauma centre and doctor(s) - If requested, PTV sends images to trauma centre and doctor(s) - If requested, PTV establishes an audio call between paramedics, trauma centre and doctor(s) If requested, PTV establishes a video call between paramedics, trauma centre and doctor(s).
Post-Conditions	PTV is sharing patient telemetry data, images, voice and video between paramedics, hospitals and doctors while en route.
Information Requirements	• PTV's location and dynamics • Patient information • Destination trauma centre • Assigned doctor(s) • Navigation route • Patient telemetry data (health monitoring) • Voice call • Video call • Images

User Story	Detailed description and specifics
User Story #1	Patient transport vehicle is moving at 100 km/h on a crowded downtown street towards an emergency room.

C. Correspondence of C-V2X Use Cases Listed and 5GAA Roadmap White Paper

‘5GAA Roadmap White Paper’ refers to 5GAA White Paper: A Visionary Roadmap for Advanced Driving Use Cases, Connectivity Technologies, and Radio Spectrum Needs.

Traffic Efficiency (Safety Related)

Use Case listed in 5GAA roadmap white paper	Corresponding to Use Case listed in
Local Hazard and Traffic Information	Derived from Traffic Jam Warning and Route Information in WP C-V2X Use Cases, Methodology, Examples, Service Level Requirements (ch. 4.4)
Hazard Information Collection & Sharing for Avs	Derived from Vehicle collects hazard and road event for AV in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.24)
HD Maps Collection & Sharing for AVs	Derived from High definition map collecting & sharing in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.17 Case 1)
Informative sensor sharing	Derived from High definition map collecting & sharing in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.17 Case 2)

Safety (Traffic Efficiency)

Use Case listed in 5GAA roadmap white paper	Corresponding to Use Case listed in
Emergency-Electronic-Brake-Light	Derived from Emergency Brake Warning in WP C-V2X Use Cases, Methodology, Examples, Service Level Requirements (ch. 4.3)
Left-Turn-Assist	Derived from Cross-Traffic Left-TurnAssist in WP C-V2X Use Cases, Methodology, Examples, Service Level Requirements (ch. 4.1)
VRU: Collective awareness	Derived from Vulnerable Road User in WP C-V2X Use Cases, Methodology, Examples, Service Level Requirements (ch. 4.12)
Group Start	Derived from High definition map collecting & sharing in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.29)

Advanced Safety + Automated Driving (Step I)

Use Case listed in 5GAA roadmap white paper	Corresponding to Use Case listed in
Automated Valet Parking for AVs	Derived from Automated Valet Parking - Joint Authentication and Proof of Localization, Automated Valet Parking (Wake Up), Tele-operated Driving for Automated Parking in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.4, 4.5, 4.23)
TeleOperated Driving	Derived from Tele-Operated Driving in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.21)
VRU: Complex interactions	Derived from Interactive VRU Crossing in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (cap 4.2) Interactive VRU Crossing (T-190133) from xWI on Complex interactions 40 kbps derived from UC Awareness Confirmation (both UCs can also be found in white paper which is currently prepared by WG1)
Cooperative Manoeuvres	Derived from Coordinated, Cooperative Driving Manoeuvre, in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.16)
Sensor Sharing for AVs	Derived from See-Through for Pass Manoeuver in WP C-V2X Use Cases, Methodology, Examples, Service Level Requirements (cap 4.10)

Advanced Safety + Automated Driving (Step II)

Use Case listed in 5GAA roadmap white paper	Corresponding to Use Case listed in
Dynamic Cooperative Traffic Flow (see Cooperative Manoeuvers)	Derived from Cooperative Manoeuvers of Autonomous Vehicles for Emergency Situations (incl. Coordinated, Cooperative Driving Manoeuvre) in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.15), from connectivity perspective similar requirements as Coop. Manoeuvers
Dynamic Intersection management (only advanced user story addressed)	Derived from Automated intersection crossing in WP C-V2X Use Cases Volume II: Examples and Service Level Requirements (ch. 4.12)
HD Sensor Sharing for AVs	Derived from High Definition Sensor Sharing in WP C-V2X Use Cases, Methodology, Examples, Service Level Requirements (ch. 4.9). Not mentioned in the use case. We deem 10 Hz more sensible since 100 Hz would generate 100 kB/veh and would mean e.g. 100 fps for camera data (100 Hz may be a typo in the Master List).

5GAA is a multi-industry association to develop, test and promote communications solutions, initiate their standardisation and accelerate their commercial availability and global market penetration to address societal need. For more information such as a complete mission statement and a list of members please see https://5gaa.org

5GAA Automotive Association