White Paper Connected and Cooperative Automated Driving (CCAD)

CAR 2 CAR Communication Consortium

About the C2C-CC

Enhancing road safety and traffic efficiency by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is the dedicated goal of the CAR 2 CAR Communication Consortium. The industrial driven, non-commercial association was founded in 2002 by vehicle manufacturers affiliated with the idea of cooperative road traffic based on Vehicle-to-Vehicle Communications (V2V) and supported by Vehicle-to-Infrastructure Communications (V2I). The Consortium members represent worldwide major vehicle manufactures, equipment suppliers and research organisations.

Over the years, the CAR 2 CAR Communication Consortium has evolved to be one of the key players in preparing the initial deployment of C-ITS in Europe and the subsequent innovation phases. CAR 2 CAR members focus on wireless V2V communication applications based on ITS-G5 and concentrate all efforts on creating standards to ensure the interoperability of cooperative systems, spanning all vehicle classes across borders and brands. As a key contributor, the CAR 2 CAR Communication Consortium and its members work in close cooperation with the European and international standardisation organisations.

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1 Introduction

The fields of connected driving and automated driving have in the past years often been handled as separate technologies, often divided into driving assistance and telematics functions. This reflects in the current Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication (V2X) standard ITS G5 in messages and applications, which are designed for the assistance of human drivers in automation level 0. With recent advances in automation both in production vehicles and in R&D comes a new demand for V2X between manual vehicles and automated vehicles, between automated vehicles and roadside infrastructure, and of course within a set of automated vehicles.

Vehicular communication has evolved over the last years and is available in series production cars. Mainly the Day-1 use cases are available, e.g. Green Light Optimized Speed Advisory (GLOSA) at traffic light intersections or In-Vehicle Signage (IVS), even though technically many more use cases are possible. A challenge is still the number of cars and installed infrastructure to support more use cases.

At the same time, automated driving up to automation level three has reached the mass market. For further development of automated vehicles, V2X can be a key technology. Many more operational fields or manoeuvres can hardly be realized with in-vehicle sensors only. V2X can be a key technology for automated driving, when it comes to cooperative manoeuvres, e.g. overtaking or merging. A lot of research results from different projects on ‘Connected and Cooperative Automated Driving’ (CCAD) already exist, looking at different aspects of CCAD.

This whitepaper is created by the Working Group ‘Connected and Cooperative Automated Driving’ (CCAD) in the Car-2-Car Communication Consortium (C2C-CC). The working group has the aim of collecting and analysing progress in the field of connected automated driving functions, particularly in the European domain. Thereby it assists the C2C-CC in decision making for the next generation of wireless communication standards for the automotive field, especially in the light of automated and autonomous driving functions.

The whitepaper is a culmination of discussions inside the working group and questionnaires kindly provided by thirteen research and development projects. It consists of an overview of current research and development in connected automated driving, a list of analysed projects, an overview of identified common key functionalities in these projects, and a summary.

2 Overview of projects of Cooperative Automated Driving in Europe

2.1 Number of projects

In total, thirteen research projects on cooperative and connected and cooperative automated driving have been examined. These projects differ in a range of aspects. Not all of them use test vehicles, but some of them evaluate results in simulation only. While this seems to be a disadvantage, actually in simulation, more scenarios and parameters can be evaluated. The projects that have been investigated are:

- 5G NETMOBIL[1]
- ADAS&ME[2]
- AdaptIVe[3]
- AutoNet2030[4]
- Fraunhofer FOKUS CMP[5]
- ICT4CART[6]
- iKoPA[7]
- IMAGinE[8]
- MAVEN[9]
- MEC-View[10]
- PRoPART[11]
- SecForCARs[12]
- TransAID[13]

While the goal of all projects is to improve automated driving performance by communication and automation, not all projects use automated vehicles. As legal aspects make automated driving still difficult on public roads, communication and cooperation can well be tested in manually driven cars. In this case, V2X messages are exchanged as well and even cooperative driving manoeuvres can be planned based on the messages. However, the execution of the manoeuvres is left to the driver, who might be informed about the driving options through an onboard HMI.

Different automation levels according to SAE J3016 have been tackled by the different projects. Even though cooperation and communication have a high impact on automated driving, they can be applied at each automation level. Out of the 13 projects, all but two addressed automated driving directly. Most of the projects use different automation levels,

1 https://5g-netmobil.de/

2 https://www.adasandme.com/

3 http://www.adaptive-ip.eu/

4 http://www.autonet2030.eu/

5 https://ieeexplore.ieee.org/abstract/document/8375118

6 https://www.ict4cart.eu/

7 https://ikopa.de

8 https://imagine-online.de/en/home/

9 http://maven-its.eu/

10 http://www.mec-view.de/

11 http://propart-project.eu/about/

12 https://www.secforcars.de

13 https://www.transaid.eu/

ranging over all of the SAE automation levels 0-5. An overview of the different automation levels of the project can be seen in Table 3. While in most projects actual driving is performed, PRoPART and 5G NetMobile use simulation for evaluation.

Project	ADAS& ME	AdaptIVe	PRoPART	iKoPA	5G NetMobile	AutoNet 2030	IMAGinE	MAVEN	TransAID	CMP	ICT4CART	MEC-View	SecForCARs
Automation level	3-5	3-4	n/a	2-3	n/a	0-5	0-3	0-5	2-5	3-5	3-4	0-3	0-5

Table 3: Automation level of projects

Communication is a wide field of research. While most projects use Dedicated Short Range Communication (DSRC), some of the projects have also chosen other communication technologies. For example, in some of the projects instead of DSRC, 5G prototype hardware is used. Furthermore, not all projects use direct communication between vehicles, but rather use backend services or connections over the cellular phone network.

Most of the projects belong to the automotive sector. However, some of the projects, while still having major aspects of automotive usage, also have a focus on specific other technologies. ProPart addresses mainly GNSS correction for automated vehicles. Furthermore, 5GNetMobil aims mainly on a 5G network architecture for connected automated driving. The major aspect of MEC-View is increasing the perception of vehicles through cooperation.

3 Project details

3.1 5G NetMobil

5G NetMobil is a research project funded by the German Federal Ministry of Education and Research (BMBF). The main objective of the 5G NetMobil project was to develop a comprehensive communication infrastructure for tactile connected driving and to demonstrate the advantages of tactile connected driving in terms of traffic safety, traffic efficiency, and environmental impact compared to autonomous driving based solely on local sensor data.

While autonomous driving already promises more comfort and safety, tactile networked driving enables new driving strategies that further increases road traffic safety, significantly reduce carbon dioxide emissions, and significantly improve road traffic efficiency through better capacity utilization and reduced risk of traffic jams and accidents.

Additional networking possibilities will eliminate the fundamental limitations of today's autonomous system approaches, which use only the information obtained by locally installed onboard sensors for vehicle control. The decision horizon is thus extremely restricted since the ‘visibility of the vehicle’ is limited by the sensor technologies used, in particular radar and camera sensors. The sensors of all vehicles, as well as the environment or the existing infrastructure (e.g., surveillance cameras at intersections or on motorways, local weather sensors, etc.), can be combined virtually in the network, which contributes to better decision-making and in particular provides information about regions and scenarios that are still far away from the vehicle but are relevant for guidance. Direct communication between vehicles also expands their field of vision and enables new applications leading to increased efficiency and comfort. The information obtained in this way can be supplied to all vehicles by a central decision-making authority and can thus be used to control and regulate the local actuators. For the resulting control loops, transmission latency times in real-time, which means a few milliseconds, are necessary.

3.2 ADAS&ME

ADAS&ME is the acronym for ‘Adaptive ADAS to support incapacitated drivers Mitigate Effectively risks through tailor-made HMI under automation’.

The project developed ADAS that incorporated driver/rider state, situational/environmental context, and adaptive HMI to automatically hand over different levels of automation and thus ensure safer and more efficient road usage for all vehicle types (conventional and electric car, truck, bus, motorcycle).

The ADAS&ME project used cooperative awareness and collective perception to obtain a ‘situational context’ for the driver to assess the driving difficulty at any point. Standardized CAMs and CPM (CPM is currently under standardization in ETSI) were used to achieve this. Additionally, for its passenger vehicle use cases, ADAS&ME used very basic manoeuvre coordination using a basic MCM.

The message types CAM, CPM, and MCM were exchanged over standard ITS G5 technology. Additionally, cellular communication was used to obtain information (such as driving difficulty from a road-layout point of view) from a cloud-based entity.

The main passenger vehicle use case of ADAS&ME was ‘Non-Reacting Driver Emergency Manoeuvre’. Due to hindrance/road works, a vehicle must give the control back to the driver, but when the driver is incapacitated or inattentive, the vehicle needs to perform an emergency manoeuvre, e.g.

- Coordinated safe stop: the vehicle makes a safe stop by coordinating with neighbouring vehicles to make space
- e-towing: the vehicle agrees with a neighbouring vehicle and drives behind it as if being towed

3.3 AutoNet2030

AutoNet2030 shall develop and test a cooperative automated driving technology, based on a decentralized decision-making strategy, which is enabled by mutual information sharing among nearby vehicles. The project is aiming for a 2020-2030 deployment time horizon, taking into account the expected preceding introduction of co-operative communication systems and sensor-based lane-keeping/cruise-control technologies. By taking this approach, a strategy can be worked out for the gradual introduction of fully automated driving systems, which makes the best use of the widespread existence of cooperative systems in the near term and makes the deployment of fully automated driving systems beneficial for all drivers already from its initial stages.

The inter-vehicle co-operation is not only intended among automated vehicles but extends also to manually driven vehicles. Drivers shall receive manoeuvring instructions on their HMI; the ergonomics and non-distraction of this new user interface shall be validated. This system is to make safe, predictable, and efficient manoeuvring decisions.

The technology developed in AutoNet2030 is validated through drive-testing and simulation tools. The results have been showcased in October 2016.

3.4 CMP – Collaborative Manoeuvre Protocol

CMP is a manoeuvre protocol for robust negotiation between automated vehicles. It uses a distributed state machine for role-based collaboration. Vehicles can negotiate a common distributed state through request-response messages in voting rounds. CMP is fully peer-to-peer, each station observes vote rounds.

Vehicles can join a session for cooperative driving manoeuvres. Agreement on the planned manoeuvre, the so-called session nature, is determined with specific messages of CMP. The vehicles keep in sync through the distributed state machine. The protocol is designed for DSRC, which usually does not support bidirectional stateful communication. Thus, session identifiers are introduced to cluster broadcast messages into sessions.

The content of a state determines vehicle behaviour in a defined function, e.g. the state of a platoon can be ‘forming’, ‘disband’, or ‘lane change’. Each transition to follow-up states passes through another vote round. Thereby it is assured that all members of a session are within the same state of the state machine. A new state is only reached when all members of the session have voted for the state change. This is achieved with a three-stage voting mechanism. In the first round, a vote about a proposed state change is performed. In the second round, the negotiation is fixed through sync messages. Finally, heartbeat messages are continuously transmitted to keep all session partners in sync.

CMP uses heartbeat messages to determine the synchronicity and health of all cooperating stations. Thereby lost vehicles, e.g. which have left the session without notification or are no longer within communication range, can be detected. Furthermore, each transition is synchronized with the Turquoise algorithm.

CMP aims to form a robust cooperation protocol specifically designed for adverse network conditions [1].

3.5 ICT4CART

ICT4CART, in alignment with the EU vision, is providing an ICT infrastructure to enable the transition towards road transport automation. To meet this high-level objective ICT4CART is bringing together, adapting, and improving technological advances from different industries, mainly telecom, automotive, and IT. It adopts a hybrid communication approach where all the major wireless technologies, i.e. cellular and ITS G5, are integrated under a flexible network architecture. This architecture will ensure performance and resilience for different groups of applications according to the needs of higher levels of automation (L3 & L4). On top of that, a distributed IT environment for data aggregation and analytics is implemented. This offers seamless integration and exchange of data and services between all the different actors, allowing third parties to develop, deliver and provide innovative services, thus creating new business opportunities. Cyber-security and data privacy aspects are considered thoroughly throughout the whole ICT infrastructure. In addition, a novel accurate localization services, exploiting the cellular network and information from other sources, such as onboard sensors, especially in complex areas (e.g. urban), are addressed. To achieve its objectives, ICT4CART, instead of working in generic solutions with questionable impact, builds on four specific high-value use cases (urban and highway) which are demonstrated and validated under real-life conditions at the test sites in Austria, Germany, Italy, and across the Italian-Austrian borders.

3.6 iKoPA

In the iKoPA project, an integrated cooperation platform for automated electric vehicles is developed. The innovative concept of iKoPA integrates three different communication technologies, ITS-G5, Digital Audio Broadcast+ (DAB+), and mobile internet via cellular networks.

In iKoPA, automated driving is addressed as well as Advanced Driver Assistance Systems (ADAS) with a highly flexible architecture that integrates both the different communication technologies and different automation levels. An important aspect of the iKoPA project is the assistance of electric automated vehicles through communication. Electric automated vehicles can receive information about available charging spots in their environment, along a planned route, or at the destination area. Once automated vehicles have reached the charging spot, authorization, authentication, and billing is performed with vehicular communications. Apart from charging infrastructure, also traffic light systems are integrated into the iKoPA platform. Therefore, with ADAS such as Green Light Optimized Speed Advisory (GLOSA) the energy consumption of electric vehicles can be improved.

A major aspect of iKoPA is secure communication and authentication in vehicular networks. Therefore, a set of messages is developed that allow for secure authentication at parking garages or charging infrastructure [2]. One outcome of iKoPA is a system that allows automated vehicles to charge in a fully automated manner, in which all aspects of the charging process are considered. The iKoPA platform allows an automated electric vehicle to access a parking area with charging infrastructure, drive to a free charging spot and perform the charging process including the billing process.

3.7 IMAGinE

The IMAGinE (Intelligent Maneuver Automation – cooperative hazard avoidance in real-time) project develops innovative driver assistance systems for cooperative driving, i.e. road traffic behaviour in which road users cooperatively plan and execute driving manoeuvres. Individual driving behaviour is coordinated with other road users and the overall traffic situation based on automatic information exchange between vehicles and infrastructure. Critical situations can be avoided or mitigated, thereby making driving safer and more efficient.

Communication technologies enable vehicles to exchange information with other vehicles about objects detected by onboard sensors in real-time, thus providing the technological basis for collective environmental perception. Intuitive human-machine interaction concepts ensure high user acceptance of these technologies. IMAGinE employs advanced simulation systems to analyse to what extent cooperative driving manoeuvres increase traffic efficiency.

The IMAGinE project consortium consists of twelve German partners and brings together leading companies from the automotive industry, small- and medium-sized businesses focusing on simulation, an academic institution, and a public road management company. IMAGinE is funded by Germany's Federal Ministry for Economic Affairs and Energy.

3.8 MAVEN

The objective of MAVEN (Managing Automated Vehicles Enhances Network) is to deliver C-ITS-assisted solutions for managing Cooperative Automated Vehicles (CAVs) at signalized intersections and intersection corridors to increase traffic efficiency and safety. MAVEN develops infrastructure-assisted platoon organization and negotiation algorithms. These help in the management of automated vehicles at signalized intersections and corridors. Thereby, vehicle systems for trajectory and manoeuvre planning and infrastructure systems for adaptive traffic light optimization are extended and connected.

In MAVEN, traffic lights that adapt their signal timing are investigated. These traffic lights facilitate the movement of organized platoons and allow for better utilization of infrastructure capacity. Thereby the vehicle delay and emission are reduced. MAVEN develops a prototype for field tests and extensive modelling for impact assessment. It contributes to the development of enablers, e.g. standards and high precision maps. MAVEN also provides ADAS techniques for vulnerable road users (VRU). The goal of MAVEN is the development of a roadmap for the introduction of vehicle-road automation to support road authorities in the changes of their role and the tasks of traffic management systems. [3]

3.9 MECView

Automated driving in complex urban environments is limited due to occlusions of relevant road users or obstacles – in these situations, the performance of onboard surround sensor systems is limited as a matter of principle, which cannot be compensated by car-2-car connectivity in scenarios of incomplete sensing capability or incomplete connectivity of the overall vehicle fleet.

To tackle this problem, the publicly funded project MEC-View focuses on the evaluation of a complementary roadside sensor system and a high-precision digital map of the driving environment in addition to the sensor systems and processing capability of an automated vehicle. Based on the roadside sensor objects, a mobile edge computing (MEC) server frontend delivers a local environment model via a prototype 5G mobile network to the automated vehicle.

The overall system is implemented and verified in a test area at the city of Ulm in unrestricted urban traffic through a dedicated use case: an automated vehicle, relying on the local MEC environment model, seamlessly enters a priority road at an urban road junction. To meet these requirements novel approaches for the prediction of dynamic objects and intention planning using machine learning concepts are essential.

The MEC-View project strives for a safe and efficient automated driving in complex and challenging urban situations. Moreover, the system provides an improved perception of vulnerable road users, e.g. pedestrians, cyclists, and motor bikers.

3.10 SecForCARs

SecForCARs is a cooperation project funded by the German Federal Ministry of Education and Research (BMBF) and consists of partners from the automotive industry, medium-sized companies, and research institutions. Within the framework of the project, the cooperation partners are jointly researching aspects of information security and autonomous driving.

As with all information processing systems, security is also not to be neglected in the vehicular domain. Particularly with regard to driver assistance systems, and in the future also for automated driving, the intervention in the driving control system creates an interdependency of security and safety.

Within the framework of SecForCARs, the partners are jointly investigating the weaknesses and vulnerabilities of modern vehicles. To this end, they develop a security architecture as well as tools and test methodologies to incorporate both safety and security into the future development process. In addition, security mechanisms are developed based on a vulnerability assessment to detect and prevent attacks against the vehicle from inside and outside.

3.11 TransAID

As the introduction of automated vehicles becomes feasible it is necessary to investigate their impacts on traffic safety and efficiency. This is particularly important during the early stages of market introduction, where automated vehicles of all SAE levels, connected vehicles (able to communicate via V2X), and conventional vehicles share the same roads with varying penetration rates. There will be areas and situations on the roads where high automation can be granted, and others where it is not allowed or not possible due to missing sensor inputs, high complexity situations, etc. In these areas many automated vehicles will change their level of automation. TransAID refer to these areas as 'Transition Areas'. The project develops and demonstrates traffic management procedures and protocols to enable the smooth coexistence of automated, connected, and conventional vehicles, especially in Transition Areas. A hierarchical approach is followed where control actions are implemented at different layers including centralized traffic management, infrastructure, and vehicles.

TransAID defines traffic management procedures assisted by Cooperative Intelligent Transport Systems (C-ITS) to mitigate the negative effects of automated vehicles‘ Transition of control (ToCs) in critical areas (‚Transition Areas‘ like roadworks, bottlenecks, motorway mergings, etc.) in future mixed traffic scenarios where automated, cooperative, and conventional vehicles will coexist. In this context, V2X is used by the C-ITS road infrastructure to inform about warnings (presence of a non-AD area) and suggest manoeuvres (preventive transitions of control or lane changes, etc.). When implemented by the addressed CAVs, these suggestions address traffic situations associated with possible ToCs.

4 Identified key functionalities (basic technologies, to be grouped)

4.1 Collective Perception

Collective perception enables connected traffic participants and infrastructure to share information about other road users and obstacles that were detected by local perception sensors such as radars, cameras, and alike. In that sense, it aims at increasing the awareness of traffic participants by mutually contributing information about their perceived objects to their environment model. The Collective Perception Message (CPM) consists of information about the disseminating station, its sensory capabilities, and its detected objects. For this purpose, the message provides generic data elements to describe detected objects in the sender reference frame.

4.1.1 ICT4CART

In ICT4CART, collective perception is used to provide a 360 degrees virtual mirror to the driver. At intersection crossings in urban areas and lane merging spots on highways, infrastructure via hybrid connectivity and MEC provides collective perception information to create awareness of the entire situation. Cooperative perception is also shared in ICT4CART at all times between vehicles to increase the awareness of vehicles.

4.1.2 ADAS&ME

ADAS&ME project uses collective perception to obtain a 'situational context' for the driver to assess the driving complexity at any point. This information is complemented with route information (such as driving difficulty from a road-layout point of view) from the cloud.

4.1.3 AutoNet2030

In AutoNet2030, the Cooperative Sensing Service is a facilities-layer component that disseminates and receives information about perceived external dynamic objects (e.g. other vehicles, pedestrians, and motorcyclists) to/from neighboring C-ITS stations. Sharing (semi-)static data is out of the scope of this component. The shared moving data includes, among others, the position, speed, heading of the detected objects in addition to their respective confidence values. These data may be measured using onboard sensors (e.g. radar, Lidar, camera) or indirectly, utilizing V2X.

The exchange of information is based on the periodic broadcast of Cooperative Sensing Messages (CSM) with a fixed frequency of 1 Hz from the C-ITS stations. The CSM message body contains a sequence of DetectedObjects, which describe the attributes of detected, external objects such as their type, position, and speed. Such objects may be ITS stations or other moving objects without any C-ITS technologies. For each DetectedObject, a field DetectionSource describes what sensor type (e.g. local, remote) is used to measure the object.

Further information about the Cooperative Sensing Service can be found in the [4]of the AutoNet2030 project.

4.1.4 IMAGinE

In the IMAGinE system, cooperative vehicles use the Collective Perception Service (CPS) to exchange information about their environment perceived by the onboard sensors (e.g. detected objects and free space areas). To enable this service, the Collective Perception Message (CPM) in standardization by ETSI is used. The service receives an object list provided by the IMAGinE environmental model and fills the CPM accordingly for transmission. After decoding a received CPM, the contained objects are included into the IMAGinE environmental model on the receiver side.

4.1.5 MAVEN

MAVEN deals with I2V-assisted automated driving solutions at C-ITS-equipped signalized intersections and corridors. Therefore, it applies CPS for the protection of VRUs and drivers in such scenarios. Figure 1 represents an example of CPS usage for this purpose.

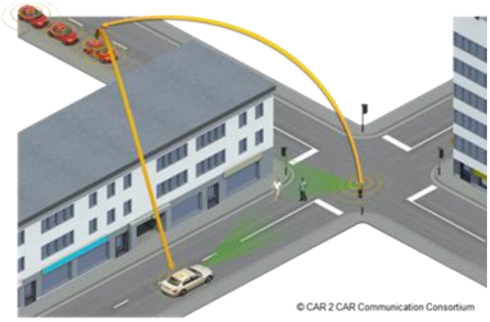


Figure 1: MAVEN application of CPS at intersection scenarios

Isolated cooperative automated vehicles (CAVs) and/or CAVs organized in a Cooperative Adaptive Cruise Control (CACC) string (in red) are heading towards the same intersection equipped with C-ITS and detection capabilities. Conventional traffic or VRU in dangerous positions can be detected only by a subset of the approaching CAVs and by the intersection sensors. On the contrary, other CAVs cannot detect the risk (e.g. in Figure 1, the string of red CAVs is not capable to detect pedestrians since they are hidden around the corner). Knowing about the presence of hidden obstacles would give CAVs more information for planning paths in a safer way (e.g., in Figure 1, if the platoon needs to turn right). In fact, with this additional information, CAVs might decide to slow down preventively before getting in the proximity of the stop line and checking with onboard sensors if the obstacle still represents a risk. In order to let CAVs aware of VRUs and other unequipped vehicles that cannot be locally detected at road intersections, collective perception is used at both vehicles and the infrastructure side. For this purpose, MAVEN contributed to CPS pre-standardization at ETSI TC ITS by proposing an adaptation of the CPM message format to convey information suitable for describing and handling object detections performed by the road infrastructure (e.g. different sensing capabilities, distinct coordinate systems, etc.) [5]. The above-mentioned CPS application scenario has been tested by MAVEN with proving ground tests using a Hyundai CAV prototype as explained in Appendix 8.3.

4.1.6 MECView

Data from infrastructure sensors can significantly improve the field of view for intelligent vehicles, both in terms of range and completeness. The MECView project investigates how automated driving can benefit from incorporating such data in the perception processing chain. On the infrastructure side, a central computational node, called MEC-Server, is connected to a base station and receives objects from multiple roadside sensors. Those are used to create a fused environmental model, which is distributed to vehicles close by via a managed cellular network.

Vehicles use tracks received from the MEC-Server in their perception system by fusing local onboard sensor data with estimations by the MEC-Server. For this, multiple approaches to track-level fusion and data association, including their application in the vehicle perception system, are evaluated.

4.1.7 TransAID

To optimally calculate traffic management decisions, the C-ITS infrastructure needs to achieve a more precise and real-time assessment of traffic demands and stream (e.g. how many vehicles, and of what categories are heading the transition areas). The estimation of traffic demands is achieved by the TransAID road infrastructure through analysis or received CAMs and CPM messages. In particular, receiving CPMs is of special relevance in a mixed traffic scenario where conventional and cooperative (automated) vehicles coexist. This information can be employed to detect conventional vehicles that cannot share their presence due to lack of connectivity. As a result, the road infrastructure can employ this information, together with the information about the ego vehicle (CAMs), to estimate the status and composition of the traffic stream (see Figure 2).

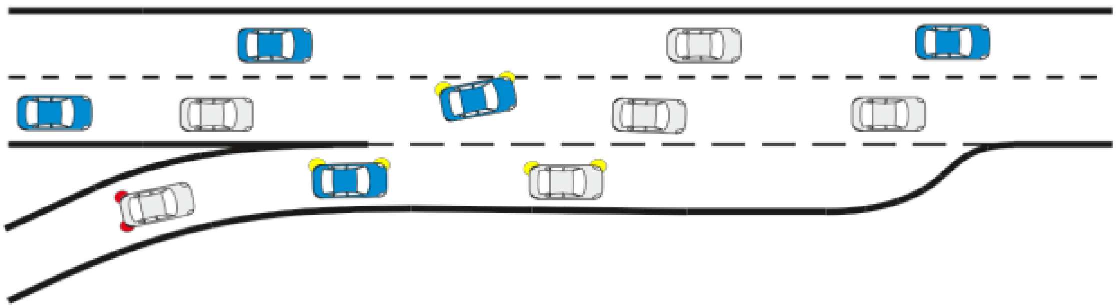


Figure 2: Typical example of CPS application in TransAID: cooperative (automated) vehicles supporting CPS (in blue) inform the road infrastructure about the presence of non-connected vehicles [6]

The main contributions of TransAID to the CPS service are a proposal for a dynamic generation rule aimed at reducing the channel load, and a proposal of an object redundancy mitigation scheme. For reducing the overall number of generated CPM messages TransAID proposes predicting the triggering conditions for objects included in the next messages ('Dynamic Look-Ahead' method). Following these predictions, all objects that would be included in the next CPM, are already selected for inclusion in the currently generated CPM. As a redundancy mitigation scheme, TransAID proposes a Dynamics-based mitigation rule according to which inclusion of a detected object in the own CPM is subject to analysis of CPMs previously received by other neighbours. In particular, a detected object is omitted for transmission in the next own CPM if the currently estimated position and speed of the object do not vary from the one retrieved from reception of one of the previously received CPMs in a given time window [7]. A more detailed description of these contributions can be found in Appendix 8.14.

4.1.8 SecForCARs

SecForCARs investigates security implications of Collective Perception as standardized by the ETSI [7]. Specifically, Misbehavior Detection in that context is considered because relying on potentially false perception data from untrusted sources can lead to severe safety risks.

4.2 Intention sharing

Intention sharing refers to the transmission of an abstract representation of the current driving state which does not require negotiation or 2-way communication. This approach can be applied in situations ranging from a short-term time horizon to long-term manoeuvres. Example use cases for intention sharing are emergency braking, the transition of control (from automated to manual driving or vice versa), minimum risk manoeuvre, and in-out manoeuvre at an intersection.

4.2.1 MAVEN

MAVEN deals with I2V-assisted automated driving solutions at C-ITS-equipped signalized intersections and corridors including platoon driving through those intersections and corridors. For this, MAVEN supports CAVs' interactions in an efficient and backward compatible way by defining ETSI ITS CAM extensions: MAVEN CAVs and cooperative intersections will be able to process the whole extended message, pre-MAVEN cooperative vehicles and infrastructure will discard the extensions yet process the rest of the received message. As indicated in Figure 3, two separate extended CAMs are defined (the MAVEN extensions are highlighted in light grey). Some of the content of these extensions can be seen as information related to intention sharing, because the content of those extensions does not necessarily imply the establishment of negotiation sessions with other vehicles or infrastructure units. In particular, the Extended CAM on SCH0 carries, besides other information, CAV and/or platoon features (planned route, platoon ID, participants, etc.) usable by cooperative intersections to perform traffic light signal timing optimization. As indicated in Figure 3, this information is contained in an optional special vehicle container called MAVENAutomatedVehicleContainer, better detailed in Table 4.

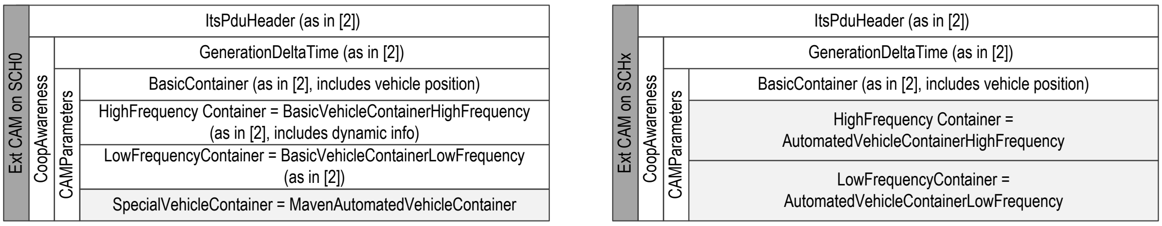


Figure 3: MAVEN CAM extensions

	Data Field/Element	Description
MAVEN Automated Vehicle Container	*RouteAtIntersection*	Planned route at next intersection (in/out lane)
	IntersectionRoute	Planned route in terms of next intersections to cross
	DesiredSpeedRange	Desired min and max speed for driving in a platoon
	AccelerationCapability	Supported max positive and negative accelerations
	PlatoonId	Id of the platoon that the vehicle is currently in
	PlatoonParticipants	List of following vehicle IDs (tx by platoon leader only when approaching a cooperative intersection)
	desiredPlatoonSpeed	Speed the platoon desires to adopt (txd by platoon leader only when approaching a cooperative intersection)

Table 4: Content of the MAVEN Automated Vehicle container

4.3 Trajectory sharing

Trajectory sharing refers to sharing a short-term planned trajectory implying one-way communication with just one trajectory type to represent the planned manoeuvre by the vehicle. Receiving traffic participants may then use this received planned trajectory to improve the sender vehicle's prediction in its environmental model. However, cooperation between several traffic participants requires a more complex mechanism.

4.3.1 MAVEN

MAVEN addresses urban platooning in a very different way compared to other developments targeting highways. Based on a common distributed algorithm and V2V exchanged information, individual CAVs shall form platoons, manage their operation (joining, leaving, etc.), and control their motion. In this sense, MAVEN platooning can be seen as an extended Cooperative ACC [8]. The C-ACC-like vehicle control and platoon management is executed independently at each vehicle following a common distributed protocol. Adopting dedicated messages instead of small extensions of already deployed messages would imply additional channel load (due to the overhead of lower layers' protocol headers). A complete description of the ASN1 definitions for the different data elements of the MAVEN extended CAMs (including the representation of the planned trajectory) is provided in [5].

	Data Field/Element	Description
Automated Vehicle Container HighFreq	*Heading*	Vehicle heading
	Speed	Vehicle speed
	LongitudinalAcceleration	Vehicle longitudinal acceleration
	LanePosition	Lane the vehicle is currently driving
	PlannedPath	Planned vehicle trajectory in terms of future positions and headings
	PlannedLane	Lane the vehicle plans to drive to
	EmergencyFlag	Indicates that an emergency situation is locally ongoing
Automated Vehicle Container LowFreq	*PlatoonId*	Id of the Platoon that the vehicle is currently in
	PlatoonFollowers	List of following vehicle IDs
	PlatoonVehicleState	State of the platoon that the vehicle is currently in
	PlatoonFormingState	Forming state of the platoon that the vehicle is currently in
	PlatoonDistanceState	Distance state of the platoon that the vehicle is currently in
	PlannedPath	Planned vehicle trajectory in terms of future positions and headings

Table 5: Content of the Automated Vehicle containers in the MAVEN extended CAM on the SCHx

4.4 Cooperative trajectory planning

Cooperative trajectory planning refers to the short-term local coordination of vehicle manoeuvres via V2X communication including the transmission of at least two types of trajectory (e.g., planned and desired trajectory). Vehicles have thereby the possibility to adapt their trajectory to enable another vehicle's desired trajectory.

4.4.1 IMAGinE

In the IMAGinE-System, the Manoeuvre Coordination Service realizes the exchange and negotiation of prospective trajectories between neighbouring vehicles. This allows a group of vehicles to find a common joint manoeuvre that optimizes their global benefit. Since currently there is no standardized V2X message type for the exchange of prospective trajectories, a new message type called 'Manoeuvre Coordination Messages (MCM)' is specified and implemented in IMAGinE. The MCM essentially contains a list of attributed trajectories of the ego vehicle which are generated in the system module 'manoeuvre planning and coordination'.

4.5 Cooperative manoeuvre planning

The cooperative manoeuvre planning pursues the short-term local coordination of vehicle manoeuvres, the same objective as the cooperative trajectory planning (Section 4.1.4). However, in this case traffic participants transmit abstract manoeuvre representations (e.g., lane change) instead of trajectories.

4.5.1 AutoNet2030

In AutoNet2030, the Cooperative Lane Change Service (CLCS) supports the planning and execution of a lane change of a single vehicle or a group of vehicles (e.g. platoon) in collaboration with surrounding cooperative vehicles. Figure 4 illustrates a situation where two subject vehicles intend to perform a cooperative lane change.

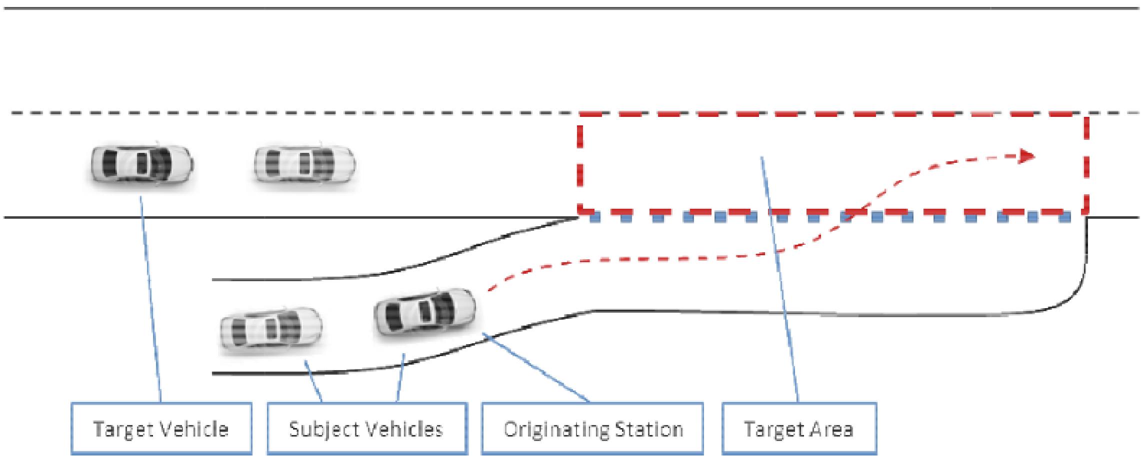


Figure 4: Planned lane-change manoeuvre

Vehicles plan a lane change by selecting a target geographical area to which they intend to drive. This relative area in front of another vehicle is negotiated with the vehicles, which will be driving in the target area during the lane change.

The CLCS component splits a cooperative lane change into three phases:

- Search Phase: during the search phase, potential target vehicles during the search phase. This phase is optional and only executed when the originating station cannot select a target vehicle. During the search phase, zero, one, or multiple potential target vehicles may be found and the originating station should select one to start the preparation phase.
- Preparation Phase: the originating station requests a target vehicle to open the required space to facilitate the lane change. This phase ends when the target vehicle has confirmed the opened space or the preparation has been aborted by either the target or subject vehicle(s). During the preparation phase, the subject vehicles will physically align to the space opened by the target vehicle to execute lane change.
- Execution Phase: The lane change is executed. Subject vehicle(s) and target vehicle should use perception sensors and C2X communication to ensure safe execution. When safety cannot be guaranteed, both subject and target vehicles can abort the cooperative lane change.

The CLCS is executed by exchanging Cooperative Lane Change Messages (CLCM). There are four types of CLCM: laneChangeRequest, laneChangeResponse, laneChangeAbort and laneChangePrepared. Each of these message types contains the relevant information that is exchanged by the involved vehicles for every manoeuvre phase. *Further information about the* Cooperative Lane Change Service *can be found in [4].*

4.5.2 ADAS&ME

For its passenger vehicle use cases, the ADAS&ME project uses very basic manoeuvre coordination. In case the host vehicle can't drive automated, for example, due to a construction site, and the driver is not taking over the control, the vehicle sends out a coordinated manoeuvre request for 'e-towing' (aka 'follow-me') or cooperative safe stop. The remote vehicle accepts or rejects the request with a simple yes or no.

4.6 Cooperative routing

Cooperative routing is the adaptation of long-term routes based on the information exchanged via V2X communication. A long-term route can reach from the start point of a journey to the destination and usually is of coarse detail.

4.6.1 iKoPA

The project iKoPA uses cooperative routing for electric vehicles to optimize the usage of charging infrastructure in public car parks. The information is transmitted over TPEG-EMI or cellular communication. Car park operators provide information about free charging spots in their car parks. Vehicles can optimize their route based on free parking spots with charging infrastructure.

4.7 Manoeuvre negotiation

As opposed to cooperative manoeuvre planning, manoeuvre negotiation comprises a longer-term coordination process among several neighbouring connected traffic participants. Examples of such approaches include collective voting concepts, peer-2-peer coordination, or master-slave schemes.

4.7.1 AutoNet2030

In AutoNet2030, the Convoy Control Communication Service: component provides an advanced communication mechanism that enhances the functionality of cooperative automated cruise control (C-ACC), allowing the control and maintenance of multi-lane vehicle formations. Cooperative vehicles are able to plan automated adjustments of their speed and heading according to a decentralized mechanism, or to plan needed lane-change manoeuvres. This service supports continuous control over the vehicle’s longitudinal dynamics and lane change manoeuvring, supporting inherently safe multi-lane driving on highways.

The functionalities offered by the convoy driving service in AutoNet2030 are the following: longitudinal manoeuvre negotiation, cooperative lane change transaction, and joining and leaving of convoys.

During convoy driving mode, neighbouring automated vehicles periodically exchange manoeuvre negotiation messages to adjust their speed and heading for mutually safe distance keeping and formation maintenance. The convoy control mechanism facilitates the safe execution of merging-in lane changes. Convoy driving mode is applicable to highly automated vehicles (with automated lateral and longitudinal control) or vehicles with at least cooperative ACC functionality.

The convoy management is handled by transmitting Convoy Management Messages (CMM), of which the following types exist: joinRequest, joinAccept, laneChange, leave, response, modifyGraph, and modifyGroupSpeed. Each message contains the required information to perform the corresponding action. *Further information about the* Convoy Control Communication Service can be found in [4].

4.7.2 MAVEN

Negotiation of manoeuvre is applied by MAVEN in the context of its urban platooning concept [9]. The platooning action is based on C-ACC. Therefore all control actions (gap size, speed…) inside the platoon are performed on their responsibility for each vehicle. In MAVEN, this platooning approach has been prototypically implemented and tested, first in simulation, and later on by using DLR and Hyundai test vehicles [8]. The basis for the logic behind the urban platooning is a set of state machines, each serving a specific aspect of the platooning logic. In order to have a stable platoon at the end, these state machines must be implemented in all vehicles being part of the platoon in the same way. This is also true for the conditions used for state transitions, which need to be defined globally in order to reach a stable behaviour. The state machines implemented are explained in detail in [10] and graphically represented in appendix 8.15 in Figure 14. Each of them has the following tasks: The basis for all actions is done in the main platooning state machine which shows the current platooning state of the vehicle. Besides, there is a platoon forming state machine, which is only active during platooning (i.e. when the platooning state machine is in the state 'in a platoon'). Furthermore, there is the message state machine which is responsible for the frequencies, in which each part of the platoon-related V2X information is sent in the MAVEN extended CAM messages. Finally, there is the distance state machine which is responsible for managing the distance to the vehicle ahead or opening up a gap. All of the state machines are briefly explained in appendix 8.15.

4.8 Manoeuvre advisory

Manoeuvre advisory refers to roadside infrastructure providing manoeuvre advices to connected traffic participants via V2X communication. Since the infrastructure may have better sensor equipment and is typically located in a high position with a larger field of view than individual vehicles, it may calculate manoeuvre advices to optimize the traffic safety and efficiency for all nearby vehicles. The recipients of the manoeuvre advices are not obliged to respect the suggestion, but they take it into account in their manoeuvre planning.

4.8.1 iKoPA

In the project iKoPA SPaT and MAP messages are used at designated traffic lights in the cities of Merzig in Berlin. Automated vehicles in this project control their speed based on the GLOSA information calculated from the SPaTs. This is used to enhance the traffic flow at these intersections.

4.8.2 ICT4CART

The Project ICT4CART uses dynamic data about the road infrastructure for manoeuvre planning. Infrastructure-related information, such as traffic density or road works, allows the vehicle to adapt its manoeuvres before reaching the location and hence avoiding critical situations. Handing over to the driver as an emergency manoeuvre is also considered as manoeuvre advice.

4.8.3 AutoNet2030

In AutoNet2030, *the* Cooperative Intersection Control Service manages the information exchange between vehicle and intersection controller for priority-based coordination of autonomous and manually driven vehicles at intersections. *Priority-based coordination is heavily dependent on V2I and I2V communication. Autonomous vehicles are using V2I communication to request entry to an intersection and thereby specifying the ingress and egress lanes, the predicted time to enter the intersection, and vehicle parameters like position, speed, and heading of the approaching vehicle. The cooperative intersection controller is using this information to calculate the relative priorities between vehicles and uses I2V communication to inform these vehicles about these priorities.* Then vehicles are able to cross the intersection efficiently following the order of their assigned priority.

The information exchange in the Cooperative Intersection Control Service happens in form of Intersection Entry Messages (IEM). The IEM consists of an active request, cancellation request, or status update. The 'active request' is used by a vehicle to request entry or update a previous entry request. The 'status update' is used by the cooperative intersection controller to announce the assigned intersection entry priorities. *Further information about the* Cooperative Intersection Control Service can be found in [4].

In AutoNet2030, a Cooperative Speed Advising Service allows vehicles to broadcast speed recommendations for a given road segment. In addition, each vehicle reports events when it is unable to maintain the advised speed, e.g. due to traffic congestion. The speed recommendations are polled periodically from a speed-advising server via cellular communications.

The server maintains a 'group speed map' database based on semi-permanent data such as speed limits, roadwork restrictions, weather restrictions, etc. This data is modified by reported driving speed deviations; i.e. if a convoy member reports that it can only achieve 60 km/h group speed instead of the 100 km/h value in the speed map, and then the speed map is adjusted accordingly to 60 km/h. These dynamic adjustments have a lifetime and a geographic gradient (in the upstream direction). As the lifetime goes to zero, the speed value continuously changes back to the semi-permanent data through linear or exponential decay. The goal of the speed advising server application is to adjust properly the parameters for the lifetime and geographic gradient size.

The message exchange is based on Cooperative Speed Advising Messages (CSAM)*, which* consists of a speed request message, a speed advice message, or a speed report message. *Further information about the* Cooperative Speed Advising Service can be found in [4].

4.8.4 MAVEN

MAVEN defines I2V interactions for enabling negotiations between cooperative intersections (CIs) and CAVs. In the first negotiation phase (Figure 5a), an isolated CAV and/or a platoon continuously transmit information describing intentions (e.g. planned route at the intersection) or vehicle/platoon characteristics (e.g. desired speed, platoon size, etc.). As this information is collected, the CI continuously updates its queue model and re-optimizes its traffic light signal timing, which results in transmitting I2V advisories for CAVs or platoons to adapt speed and/or change lanes (Figure 5b). As the last negotiation phase, CAVs and/or platoons communicate if the advisories can be executed (Figure 5c). This feedback on CAV compliance with the provided advisory is used by the CI to put priority on its validity and ‘freeze’ the signal timing re-optimization (e.g. ensuring that the traffic light stays green until the platoon has passed at the suggested speed). Speed advisories at CIs can be disseminated using standard Signal Phase and Timing (SPAT) messages. A definition of the intersection topology transmitted in standard MAP messages is also needed. Through this, CAVs compute the relevance of the received advices taking into account their position and distance to the stop line. If the advice is relevant, they decide whether adapting the speed or preparing to stop by also considering the local environmental situation (e.g. presence of other vehicles in front). In general, SPATs contain speed advices applying to a group of parallel ingress (i.e. input) lanes. Since a more granular intersection control is wanted in MAVEN, implementation solutions for lane-specific speed advices are needed. With regard to lane change advices, it has been found that simply instructing CAVs to change on the lane with the highest speed advice would result in traffic light timing oscillations. For this reason, a specific I2V message able to influence CAVs individually is needed. All the mentioned V2I and I2V messages shall be transmitted at least every second and broadcasted so that traffic light planning and current CAV intentions are known to everyone. Although CAVs are centrally coordinated by the CI in a way preventing conflicting situations, sharing CAV intentions and feedbacks to advisory compliance leaves the possibility open for additional V2V coordination, if needed.

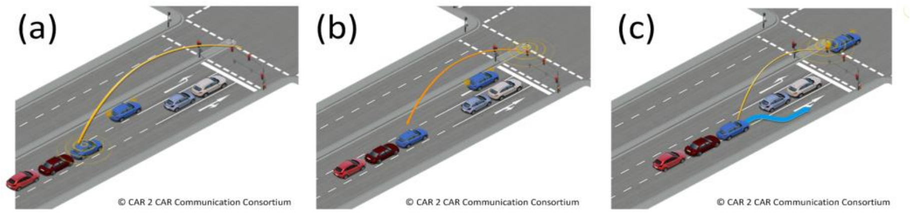


Figure 5: MAVEN interactions for I2V manoeuvre advisory

MAVEN supports I2V interactions in an efficient and backward compatible way by defining ETSI ITS CAM extensions (Figure 3 and Table 4). The Extended CAM on SCH0 carries CAV and/or platoon features (planned route, platoon ID, participants, etc.) usable by CIs to perform traffic light signal timing optimization. Moreover, MAVEN defines a brand-new lane change advisory service to assist CAVs in selecting optimal ingress lanes when approaching an intersection. This permits CIs to more evenly distribute and more rapidly serve incoming traffic demands. For this purpose, it was considered using SPAT-based lane-specific speed advices and letting CAVs automatically change to the lane with the highest speed. However, this would imply lane advice oscillations when too many vehicles follow the same advice. Therefore, a new Lane change Advice Message (LAM) was introduced to provide individualized advices. To foster interoperability, the LAM was designed in a way to reuse many elements of current SAE J2735 [11] and ETSI ITS dictionaries [12]. Intersection topology information is referenced from MAP messages, which prevents sending it twice.

4.9 Match making

The match-making approach is based on information sharing via V2X communication to identify common goals, features, possibilities, and abilities to implement cooperative functions (e.g., platooning or misbehaviour detection) in a safe way.

4.9.1 SecForCARs

SecForCARs considers a global Misbehaviour Detection Authority collecting misbehaviour reports from vehicles. Before forming a platoon, potential members can query that authority and decide whether they deem potential partners trustworthy enough to form a platoon with them.

4.9.2 MAVEN

MAVEN addresses urban platooning in a very different way compared to other developments targeting highways. While platoon vehicles on highways share the same route for many kilometers, vehicles on urban roads only share the same route for a very limited time, e.g. passing a few intersections before separating again. As shown in [9], flexibility for dynamically changing the platoon configuration is a key requirement in urban scenarios. Based on a common distributed algorithm and V2V exchanged information, individual CAVs shall form platoons, manage their operation (joining, leaving, etc.), and control their motion. In this sense, MAVEN platooning can be seen as an extended Cooperative ACC [8], where every CAV closely follows its preceding one by still controlling its speed, distance, and possible emergency reactions. Yet, the platoon leader has the central role of communicating platoon properties to the cooperative intersections. In terms of V2X requirements, CAVs need to broadcast local information (e.g. planned route, desired speeds, acceleration/braking capabilities, etc.) to detect platoon initialization opportunities with other CAVs (match-making process). This information is included in the already mentioned CAM extension MAVEN Automated vehicle container described in Table1. A detailed description of the real road tests to verify the establishment of a little platoon based on the exchanged match-making information can be found in [13].

4.10 VRU consideration/inclusion in V2X

A key functionality of V2X communication is to create awareness of Vulnerable Road Users (VRU), such as pedestrians or cyclists, to all connected traffic participants. This can be achieved either by active advertising of connected VRUs and by collective perception of VRUs detected by another connected traffic participant.

4.10.1 5GNetMobil

The 5GNetMobil project defines a city crossing assistance for vulnerable road user protection (CC VRU), which aims at increasing the safety of pedestrians and cyclists. See details in use case 'Intersection assistant'.

4.11 Current Driving status sharing

With the proliferation of vehicles with different degrees of automated driving, it is useful for some use cases to share the current driving status including manual and various levels of automation (e.g., longitudinal or lateral automated control). This information may be used by receiving traffic participants to adapt their manoeuvre planning accordingly and by roadside infrastructure to initiate a transition of control procedure, for example.

4.11.1 5GNetMobil

In 5GNetMobil, vehicles in a platoon broadcast periodically their status in Platoon Control Messages (see sections 5.5 'PCM' and 6.4 'Platooning') to other platoon members.

4.11.2 AutoNet2030

AutoNet2030 extends the standardized CAM in an Extended Cooperative Awareness Basic Service with new high and low-frequency containers to support the cooperative automated driving application. This application handles traffic situations like driving in a convoy, a platoon, and cooperative lane changes. The AutomatedVehicleContainerHighFrequency includes only the minimal dynamic information of a vehicle such as its heading, speed, acceleration, and distance to a preceding vehicle. Such a compact container shortens the CAM length and consumes fewer network resources while transmitted at high frequencies of 10 Hz or higher. The AutomatedVehicleContainerLowFrequency introduces new data elements for automated driving which are sent at a lower frequency (e.g. 2 Hz), including the vehicle driving mode (manual or automated), engaged automated control systems, target speed and acceleration, brake capacity, target distance to the preceding and following vehicles, predicted trajectory and convoy/platoon identifier in which the vehicle is driving.

Furthermore, AutoNet2030 considers traffic situations in which awareness is paramount and requires that CAMs are transmitted with 10Hz in several situations, e.g. when driving in a platoon or convoy. For this reason, additional generation rules are introduced that transmit CAMs at high frequency in such situations, also exploiting more than one transmission channel to divide the load. Further information about the *Extended Cooperative Awareness Basic Service* can be found in [4].

4.11.3 SecForCARs

SecForCARs assumes some kind of beaconing mechanism (e.g. CAM or BSM) to be in place for platooning. However, no specific message format is required.

5 Usage of network technologies and messages

5.1 CAM

5.1.1 AutoNet2030

AutoNet2030 extends the standardized CAM with new high and low-frequency containers to support the cooperative automated driving application, including driving in a convoy, platoon, and cooperative lane changes.

5.1.2 MAVEN

Precise control of platooning CAVs requires receiving more detailed information (e.g. planned trajectory of preceding vehicles) than what Day1 CAMs included, and with a higher frequency. As such information is useless for pre-MAVEN systems, it can be transmitted on another ITS G5 channel to save bandwidth on the SCH0. For this purpose, besides the MAVEN automated vehicle container extension on the SCH0 (see Table 4), MAVEN defines an Extended CAM on SCHx (see Figure 3 and Table 5). This CAM carries needed information to manage and control platoons of MAVEN CAVs in a distributed manner. It is transmitted at a fixed higher frequency [10-30Hz] and using a separate ITS G5 channel not to overload Day1 systems on the SCH0. The same approach is suggested in other R&D projects [4] and pre-standardization studies [8]. Moreover, transmitting this CAM at a fixed frequency naturally prevents the negative effect of CAM synchronization in platooning scenarios as highlighted in [14]. The transmission of this CAM is triggered during the platoon initialization phase. Then, the message is populated following the distributed platoon logic running at individual vehicles [9]. An AutomatedVehicleContainerHighFrequency is always transmitted to carry important information that CAVs consider for controlling and executing close-following driving. The AutomatedVehicleContainerLowFrequency is included every n messages, mostly with information reflecting the platooning state machine running at each vehicle and used for distributed platoon management [9]. The suitable generation rate for these CAMs has been validated in MAVEN to be adequate when set to 10Hz, with the above-mentioned parameter n set to 10 for inclusion of the AutomatedVehicleContainerLowFrequency. From a communication point of view, the selection of CAM as a periodic broadcast message (instead of for example request/reply unicast messages) makes sense for MAVEN platooning.

5.1.3 Other projects

IMAGinE, ADAS&ME and SecForCARs use standardized CAMs.

5.2 CPM[14]

IMAGinE, MECView, 5GNetMobil, ADAS&ME, and SecForCARs use the CPM in standardization in ETSI TS 103 324 [15].

5.3 MCM [15]

5.3.1 ADAS&ME

ADAS&ME defines a very basic MCM format in its manoeuvre coordination use-cases.

[14] Collective Perception Message

[15] Maneuver Coordination Message

5.3.2 IMAGinE

IMAGinE defines an MCM format to implement its Maneuver Coordination Service (see Section 'Cooperative trajectory planning').

5.4 CMP[16]

IMAGinE defines a Driving Strategy Service (based on CMP), which enables long-term cooperation among vehicles by means of synchronization of distributed state machines.

5.5 PCM[17]

5.5.1 5GNetMobil

5GNetMobil defines the PCM, used by platoon members to exchange regularly information about their current kinematics status and data collected from their local onboard sensors. PCMs contain the lateral and longitudinal information necessary for the platoon motion controller and have a size of around 90 bytes. PCMs are periodically transmitted and used locally by the platooning application to generate suitable control parameters, which optimize the manoeuvre of the truck and maintain target distance to the preceding vehicle. 5GNetMobil considers for truck platooning that the local platoon controller expects a PCM every 50ms. A PCM packet needs to be transmitted within 9ms to allow for internal processing before providing the control parameters to the local controller.

In addition, 5GNetMobil uses Platoon Management Messages (PMM) to exchange platooning management information (join request, join accept, split request, etc.) PMMs are broadcasted by platoon members and are event-triggered.

5.6 ROP[18]

The remote operation protocol (ROP) is developed alongside CMP at Fraunhofer FOKUS. It contains different sets of messages, namely control messages and sensor messages. The sensor messages transmit LIDAR point clouds and possibly other sensors. The challenge is in encoding the sensor information in a way that it can be transmitted also at low bandwidth. Therefore, not the whole sensor information is transmitted, but only relevant parts and the encoding makes use of domain knowledge to reduce the message size. The control messages transmit the signals to steer the vehicles and also to enable or disable remote-operated driving.

5.7 ITS-G5

5.7.1 AutoNet2030

In AutoNet2030, a Reliable Basic Transport Protocol (RBTP) provides a reliable end-to-end, connectionless transfer of data on top of GeoUnicast. The reliability is achieved by a combination of packet retransmissions and acknowledgments. The RBTP is a lightweight protocol for the reliable transmission of datagrams. The RBTP packet header includes mainly a sequence number, source, and destination ports and adds between 3 and 9 bytes to the packet length. Unlike the well-known transmission control protocol (TCP), RBTP does not provide advanced features like flow control, congestion control, or re-ordering of packets.

An Extended GeoNetworking (EGN) module provides the functionality to route packets among cooperative entities within AutoNet2030. GeoNetworking is based on geographical routing, which makes use of the geographical positions of the cooperative entities to find forwarding

[16] Collaborative Maneuver Protocol

[17] Platoon Control Message

[18] Remote Operation Protocol

paths from source to destination. EGN extends the ETSI GeoNetworking routing protocol with two new forwarding algorithms: Greedy Broadcast Forwarding and Greedy Multicast Forwarding, designed to allow fast and reliable information dissemination within vehicle groups, such as platoons and convoys.

Further information about the Reliable Basic Transport Protocol and Extended GeoNetworking can be found in [4].

IMAGinE, ADAS&ME and SecForCARs use a standardized ITS-G5 system.

5.8 5GNetMobil

The current V2X technologies, which are intended for existing ITS safety and efficiency services, are neither flexible nor reliable enough to meet and ensure the diverse communications requirements of the 5GNetMobil use cases in terms of reliability, latency, and throughput. The approach of hybrid V2X communications aims to overcome these performance limitations by enabling wireless connectivity using multiple communications technologies in a combined and coordinated fashion. Depending on the driving situation and availability of communications resources, the most suitable radio access technology (RAT), its best-fitting configuration, or even a suitable combination of several RATs (e.g. IEEE 802.11p on 5.9 GHz, LTE/5G-sidelink on licensed band) is selected in order to adapt quickly, purposefully and efficiently to the requirements.

5.8.1 MECView

To meet the positioning requirements of the road users in a local environment model, the sensor data need to be transferred in real-time operation. The MEC-View team uses a low-latency prototype LTE/5G mobile radio network and a mobile edge computing (MEC)-server to satisfy the timing demands. The MEC-server hosts an algorithm for the data fusion and tracking of the roadside sensor data and associates these data on a precise digital map. Based on the LTE/5G network, the server provides the local environment information to the automated vehicle as quickly as a flash.

In the future, traffic control and information systems of urban administrations could be equipped with MEC-servers to provide this local environment model information. A precondition for the automated driving on the MEC-View approach is the area-wide coverage of the LTE/5G mobile radio network.

5.9 V2V vs. V2I vs. V2X

5.9.1 5GNetMobil

5GNetMobil considers a hybrid communication approach including LTE, IEEE 802.11p, and 5G, as well as a Mobile Edge Cloud and network slicing. The aim of the project is not only to develop further the individual technological advantages but also to develop solutions that can use a mix of different technologies. The individual adaptation to different applications allows an optimal use of all existing technical potentials.

The achievement of the necessary quality of service between the end-user devices is made possible by agile edge computing. This brings data processing closer to the end-user equipment. The necessary latency times can thus be achieved and the data loss rate is reduced. Especially for tactile networked driving, network slicing can be used to ensure the security and stability of different applications. For example, for safety-critical applications, a dedicated virtual network is reserved that is completely self-sufficient and individually configured from other layers. This ensures that safety-relevant communication between vehicles can be guaranteed at all times.

5.9.2 Other projects

In iKoPA besides ITS-G5 also TPEG-TEC and TPEG-EMI are used, both via DAB+-Broadcast and HTTP requests.

ICT4CART uses both ITS-G5 and cellular communication, besides Mobile Edge Computing (MEC) is applied.

MECView uses a mobile edge computing server for the calculation of the local environment model (sensor data fusion, georeferencing, and object tracking).

5GNetMobil considers a hybrid communication approach including LTE, IEEE 802.11p, and 5G, as well as a Mobile Edge Cloud and network slicing.

6 Identified key use cases

6.1 Cooperative intersections

6.1.1 5GNetMobil

The 5GNetMobil project defines a city crossing assistance for vulnerable road user protection. This use case considers an inner-city intersection where different road users share the traffic space. The core idea is based on a fusion of sensor data in which the data from infrastructural sensors (e.g. cameras) is combined with the data from vehicle sensors on board. The goal of this sensor fusion is to reliably recognize other road users who, due to other objects or optical effects (e.g. dead angle when turning right, buildings, other vehicles, glare effects, etc.) may not be recognizable or only with difficulty and possibly cross the path of the vehicle. The information is used to evaluate collision probabilities and thus to trigger appropriate collision avoidance measures, e.g. to warn drivers early or to trigger an active automatic intervention in the vehicle.

The main goal of this use case is the development of a video-based driver assistance system, with which critical driving situations of unprotected road users (e.g. pedestrians or cyclists) can be detected early. The aim is to warn the driver or to influence automatically the control of the vehicle (e.g. automated braking or steering). Such systems are particularly useful in complex traffic environments with poor visibility for the driver, such as road junctions, confusing turns, at night, or in poor weather conditions.

6.1.2 AutoNet2030

The AutoNet2030 project realized an intersection crossing use case (i.e., merging of vehicles into the same road). Two vehicles are coordinated to merge into the main road. A roadside unit coordinates the merging order through the intersection by assigning relative priorities to incoming vehicles in real-time. Then vehicles are able to cross the intersection efficiently following the order of their assigned priority. The vehicle having no priority decelerates to provide sufficient merging space. The merging operation is successfully performed (i.e., no collision occurs) and then the relation of two vehicles becomes normal car following. Using cooperative manoeuvring, the merging can be performed safely and efficiently. The reliability and benefits of Cooperative communication and cooperative sensing are also demonstrated by AutoNet2030.

6.1.3 ICT4CART

The project ICT4CART investigates an intersection assistant with hybrid computing and MEC.

6.1.4 IMAGinE

In IMAGinE, cooperative driving on highway crossings is facilitated through V2X communication: from transmitting turning intentions to other vehicles on the highway, thus increasing the signalling range, to collectively coordinated turning manoeuvres.

6.2 Cooperative merging

6.2.1 AutoNet2030

The AutoNet2030 demonstrated a highway merge use case, where two cooperative automated vehicles drive in convoy along the highway-like road. A manually driven vehicle approaches and intents to merge into the same lane as the two convoy vehicles. The convoy vehicles increase their in-between gap and the car safely joins the convoy relying on HMI projections. All three vehicles are driving in cooperative mode, in the same lane at a speed of 70 km/h. The manually driven car uses HMI projections to advise the driver on how to drive safely in the cooperative cluster staying for some time in the lane and keeping a constant speed. By employing cooperative decision-making and manoeuvring, the merging is performed safely and efficiently. Then, the manually-driven vehicle decides to leave the cooperative cluster and performs this manoeuvre by changing lanes and pulling away from the two vehicles. The latter ones recognize the leaving and close the gap. In this case, the cooperative ITS communication system, the cooperative control, and HMI features are demonstrated.

6.2.2 IMAGinE

IMAGinE enables the cooperative turning at highway junctions by the V2X exchange of merging cars' planned manoeuvres and the coordination of cooperative manoeuvres, for example by opening a gap in traffic for the merging car.

6.2.3 MECView

In MECView, a seamless merge of a connected automated vehicle (CAV) onto a priority road without stopping is showcased at a test area in Ulm. The CAV approaches a crossway on a side road and synchronizes on a gap between adjacent vehicles on the priority road.

6.3 Cooperative overtaking

6.3.1 IMAGinE

IMAGinE develops technical solutions that allow vehicles to exchange information about their trajectory and speed and objects in the environment as well so that drivers can be warned about oncoming traffic during overtaking manoeuvres.

A further IMAGinE use case helps in finding the right timing for truck overtaking manoeuvres on motorways, enabling the exchange of information between the vehicles involved in the passing manoeuvre about current and the planned target speeds in the near future or the weight of the heavy-goods vehicle.

6.4 Platooning

6.4.1 5GNetMobil

The 'High Density Platooning System' considered in the 5GNetMobil project is based on cooperative wireless control of the dynamics and kinematics of trucks. The relationship between the latency time (time elapsing between the signal and its processing capability between transmitter and receiver) of the overall system, reliability, and energy efficiency is examined in detail. These studies show that reducing latency between trucks is essential for safe and energy-efficient platooning systems. This fact increases the necessity to evaluate current V2X and V2V technologies (Vehicle-to-Everything / Vehicle-to-Vehicle) for their performance for 'High Density Platooning Systems'. The purpose of the investigations is to illustrate the effects of existing and new communication systems on latency reduction, robustness, and stability as well as energy-efficiency of Platoons.

5G NetMobil aims to optimize the stability, energy efficiency, and road efficiency of platooning systems at a very close distance, with the focus of the investigations on heavy commercial vehicles.

The distance between vehicles should be as small as possible (e.g. less than 10 m) in order to achieve the objectives of increasing road efficiency and reducing energy consumption. The targeted energy savings are between 10% and 16% for subsequent train members and up to 5% for the first truck. Increased road efficiency and lower energy consumption are conflict-free and interlocking goals. For cars, it is assumed that an average throughput increase of 200% can be achieved.

Increased safety is another goal of the High Density Platooning System. This aspect represents a compelling optimization criterion in that the communication system fulfills the necessary reaction times and fail-safety. This can be achieved by optimizing and making the distances between the Platoon vehicles more flexible, depending on the situation and the latency times that can be achieved in end-to-end communication.

Another use case considered in 5GNetMobil is ‘Parallel Platooning’. In several field operations, two (or more) agricultural vehicles must drive side by side in a relative position. In particular, this includes work in which the harvested crop is overloaded and transported from the combine harvester to the transport vehicle. One challenge of this application is the often low network coverage in rural areas. A number of specific features must also be taken into account. Among other things, the behaviour of the systems at field edges, the starting, and stopping of transport vehicles as well as the consideration of the entire logistics chain.

The main objective of the ‘Parallel Platooning’ use case is to relieve the operating personnel during the parallel run in the forage harvesting process. The operating personnel should be able to concentrate fully on monitoring and optimizing the harvesting machine, i.e. control of the machine fleet can be completely relinquished in the optimum case.

The system allows several degrees of autonomy, related to the capabilities of the machines in relation to the assistance systems installed and currently usable. The most suitable combination of assistance systems is automatically negotiated between the machines to achieve the best possible process result. Communication must be manufacturer-independent, i.e. it must follow standardized protocols.

6.5 Cooperative Adaptive Cruise Control (CACC)

6.5.1 AutoNet2030

AutoNet2030 defines the convoy driving use case. In a multi-lane convoy, a master, centralized controller, or supervisor does not exist. Instead, the vehicle control, in both lateral and longitudinal directions, is distributed over all members of the convoy. The result of this approach is that vehicle disturbances, such as a braking vehicle, affect all members of the convoy to a greater or lesser extent, resulting in a stable formation. In order to maintain small inter-vehicle distances, convoy members rely on the high-frequency exchange of up-to-date and high-quality vehicle dynamics data among vehicles in the convoy. The proposed convoy control algorithm requires just the vehicle dynamics information of neighbour vehicles, instead of the information of all convoy members. As such, the algorithm scales well to large convoys and converges easily to the desired formation when vehicles join and leave the convoy.

6.5.2 IMAGinE

IMAGinE develops an approach that extends ACC in vehicles by integrating additional information about following and adjacent vehicles as well as the traffic infrastructure. Vehicles can adapt their speed to the driving situation predictively and avoid unnecessary acceleration processes, mitigating critical situations or even preventing them in advance.

6.5.3 SecForCARs

SecForCARs investigates the impact of misbehaving members on CACC strings. Potential attacks are analysed and detection as well as mitigation strategies are developed.

6.6 Blind spot assistant

6.6.1 MECView

MECView defines a ‘Virtual Mirror’ use case, where automated vehicles receive object data information of road users that cannot be detected by the onboard sensor system.

6.7 Automated Parking

The use case automated parking allows users to leave their vehicle when arriving at their destination and let the vehicle park itself. It is often related to as eValet or automated valet parking.

6.7.1 iKoPA

In the project iKoPA, automated parking is realized in an indoor parking garage. The vehicle's position is determined by external cameras and communicated to the vehicle via ITS-G5 RSU deployed in the indoor parking.

6.8 Cooperative Routing

In the cooperative routing use case, several vehicles negotiate their routes or base their route calculation on information received from the infrastructure via V2X.

6.8.1 iKoPA

The iKoPA project uses parking and charging spot information that is made available by the car park infrastructure provider to plan the route to a free charging spot.

6.8.2 IMAGinE

IMAGinE is developing an approach that aims at optimizing traffic distribution in the available road network considering the given capacities. Using V2X, vehicles send information about traffic volume on main and side routes to a traffic center. The traffic center integrates data from vehicles and infrastructure and calculates an optimized traffic flow distribution before sending traffic distribution recommendations back to vehicles.

6.8.3 SecForCARs

One use case in SecForCARs considers vehicles forming local, trusted communities over time where they share information on free parking spots in the respective areas via geo-cast queries/replies.

6.9 Non-Reacting Driver Emergency Maneuver

6.9.1 ADAS&ME

Due to hindrance/road works, an ADAS&ME vehicle must give the control back to the driver but the driver is incapacitated or inattentive. Vehicles are able to perform an emergency manoeuvre, e.g.

- Coordinated safe stop: the vehicle makes a safe stop by coordinating with neighbouring vehicles to make space
- e-towing: the vehicle agrees with a neighbouring vehicle and drives behind it as if being towed

7 Conclusion and Outlook

Through the efforts in different research projects, a lot of material is available on CCAD. The projects have a focus on different aspects, therefore the results are very heterogeneous. This white paper gives an overview of the various research approaches.

The paper analyses eleven different research projects which were conducted in Europe. Most of these projects use IEEE 802.11p DSRC, even though some of them, like 5G NetMobile also rely on 5G networks. The investigated research projects not only include projects from the vehicular communication or automated driving domain, but also from other fields, such as the SecForCars project mainly focusing on security.

CCAD is built on a number of key technologies. For different use cases, several of those key technologies are applied. As the use cases are different for each project, also the key technologies applied are not the same in every project. There are various levels of abstractions regarding the key technologies. Common technologies are cooperative perception, trajectory sharing, or intention sharing.

Another important aspect are network technologies. Also, here different levels must be regarded. There are various transport protocols, but also different message formats for V2X. Common messages are the original Day-1 use case messages, i.e. CAM and DENM, but also messages which are recently undergoing standardization, e.g. CPM. Various projects define their custom set of messages for aspects that are not covered by existing message types. Examples of this are the Manoeuvre Coordination Message (MCM) or the Platoon Control Message (PCM).

The research projects realize a great number of use cases with these technologies. These use cases not only address different levels of automation, but also different levels of cooperation. While platooning requires high interaction between traffic participants, for example, a blind spot assistant uses implicit cooperation. However, these use cases show the high potential of CCAD for the introduction of higher levels of automated driving in series cars.

8 Appendix A: Collected templates

8.1 CMP protocol

8.1.1 Project details

Field	Input	Remarks
Editor	Oliver Sawade, oliver.sawade@fokus.fraunhofer.de	
Project title	Collaborative Maneuver Protocol	
Project lead	Oliver Sawade	
Consortium	Fraunhofer, DCAITI	
Abstract	CMP is a manoeuvre protocol for robust negotiation between automated vehicles. It uses a distributed state machine for role-based collaboration. Vehicles can negotiate a common distributed state through request-response messages in voting rounds. CMP is fully peer-to-peer, each station observes vote rounds. The content of a state determines vehicle behavior in a defined function. E.g. the state of a platoon can be ‘forming’, ‘disband’, or ‘lane change’. Each transition to follow-up states passes through another vote round. CMP uses heartbeat messages to determine the synchronicity and health of all cooperating stations. Furthermore, each transition is synchronized with the Turquiose algorithm. CMP aims to form a robust cooperation protocol specifically designed for adverse network conditions.	
Framework	Own research	
Duration	Since about 2011.	

8.1.2 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	Platooning between passenger cars including advanced manoeuvres such as common state change, split-merge, etc. The focus of CMP is on communication (_not_ on the underlying function layers such as longitudinal control)	
Use-Case 2	Considered use-cases https://ieeexplore.ieee.org/iel7/7389774/7390768/07391161.pdf	

Field	Input	Remarks
Facility 1	CMP Director, which abstracts underlying protocol handling from functions. It automatically handles negotiation, transitions, and session health monitoring	
Facility 2	CMM message set (request-response-heartbeat, sync)	

8.1.3 Addressed challenges

Field	Input	Remarks
Challenge 1	The main challenge addressed is robust fail-safe cooperation under byzantine network conditions. CMP is designed to allow voting rounds under adverse network conditions (packet loss, altered packets, malicious attacks such as replay or DOS). If conditions deteriorate beyond acceptable limits, CMP ensures fail-safety through session health monitoring.	

8.1.4 Communication

Field	Input UC1	Remarks
Scope of communication	The scope of communication in CMP is negotiation and execution of cooperative driving manoeuvres. This includes negotiation of addressed function, role to be taken by each vehicle, and common distributed state. Furthermore, monitoring of session health and synchronous transitions are in scope.	
Used technology	Ad-hoc networking (ITS-G5, LTE-V2X)	
Used standards	Day1 message set	
Additional messages	CMM message set: Request (asking for a common state change) Response (acknowledgement, denying) Heartbeat (periodic information) Sync (synchronization using Turquoise algorithm)	
Additional protocols	CMP and Sync protocol	

8.1.5 Working assumptions

Field	Input UC1	Remarks
Automation in sending vehicle	Level 3+	
Automation in receiving vehicle	Level 3+	
Used/necessary roadside infrastructure		
Used/necessary central infrastructure		

8.1.6 Results

Field	Expected	Measured	Remarks
Stable session under average packet loss of	About 10% pl	Up to 20% pl in complex functions	A session is defined as stable, if a synchronous update has been received by all stations in a given timeframe.

Impact of CMP on tolerance to packet loss on function parameters.	The direct impact of guaranteed fail-safety in communication on safe longitudinal distance in platoons.	The more lost messages are tolerated before a session is cancelled, the more robust it becomes to packet loss. However, the also increases the time until failed communication is noticed and thus the guaranteed time for fail-safety.

8.1.7 Additional details

Session stability over packet loss is given in this diagram:

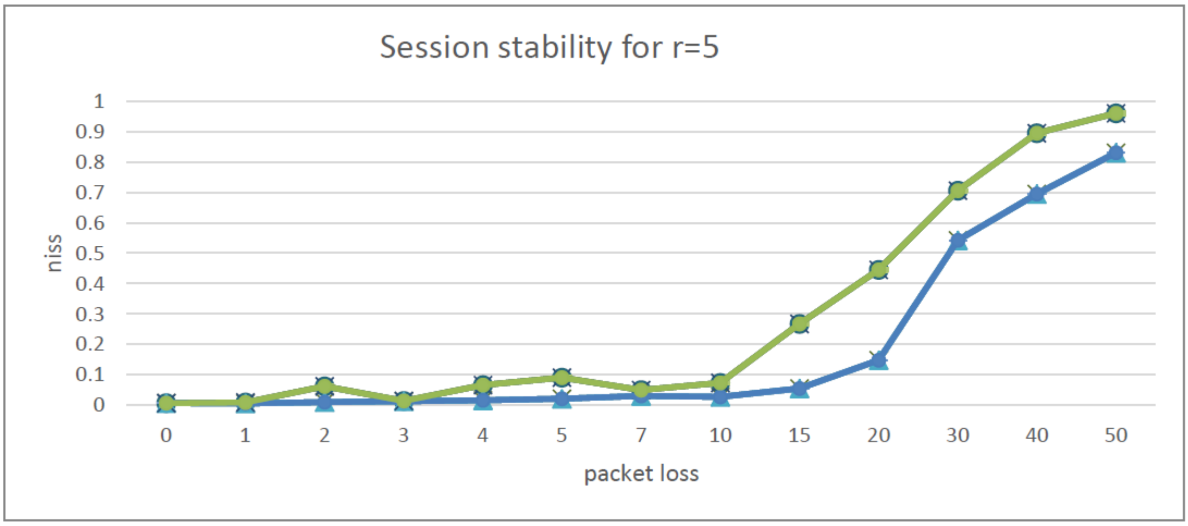


Figure 6: CMP session stability

The normalized inverse session stability index indicates session health, we consider niss < 0.1 as acceptable. The diagram shows stability with single messages (green) and with repeat messages for requests and responses (blue). The tolerated timeframe until the session is terminated fail-safe is 500ms (or 5 * sending frequency).

The impact of fail-safe time on function behaviour (in this case minimum safe longitudinal distance in a platoon driving at 30m/s) is indicated in Figure 7.

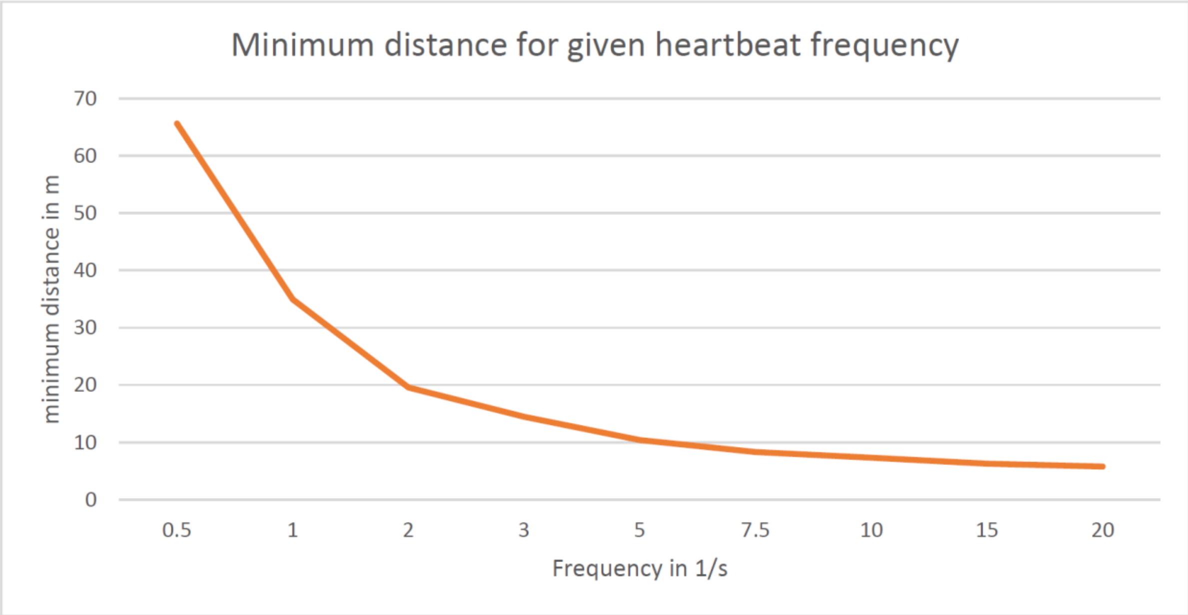


Figure 7: Evaluation of CMP

All results were simulated in the PHABMACS simulation suite.

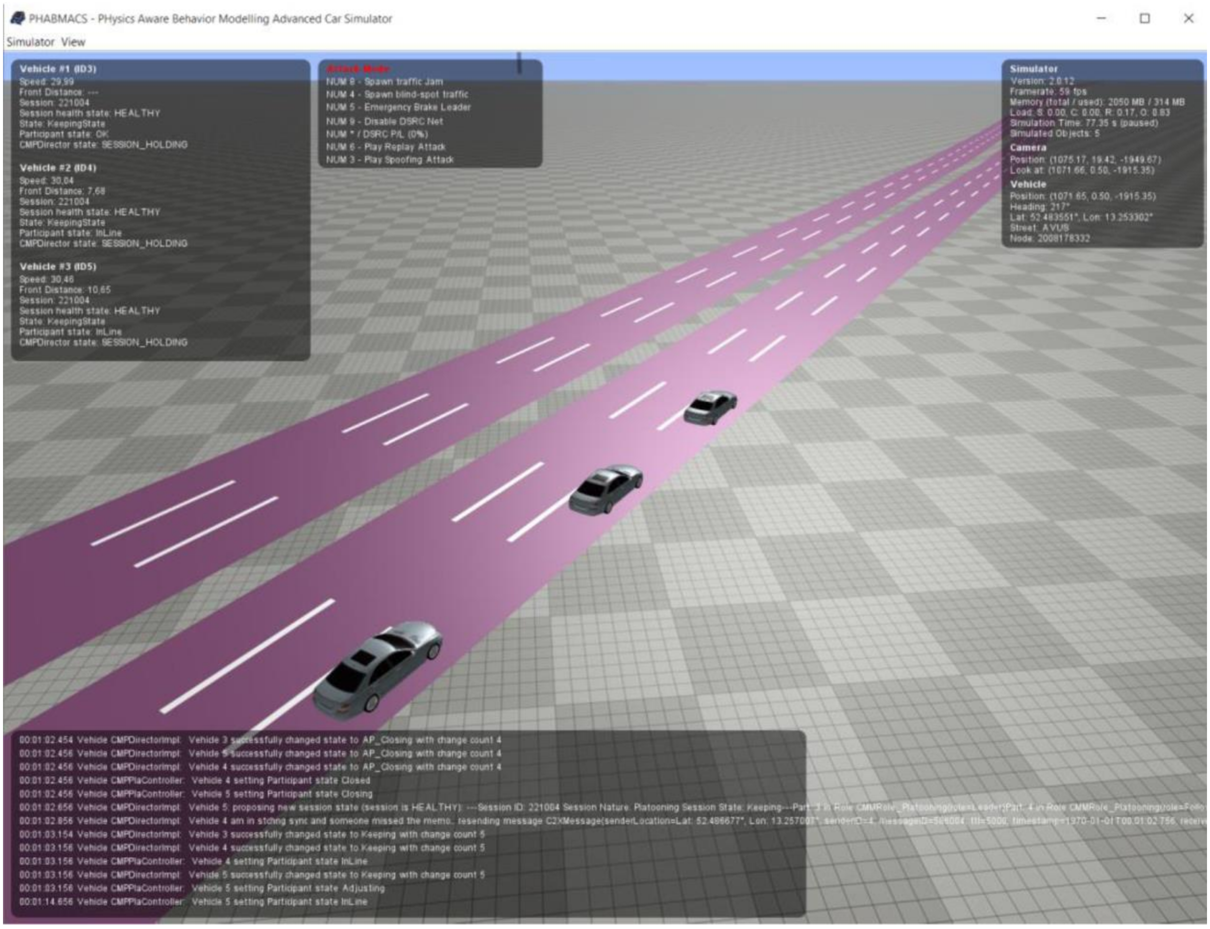


Figure 8: PHABMACS simulation framework

Further information on CMP can be found in [1], [16]–[18].

8.2 Security For Connected Automated caRs (SecForCARs)

8.2.1 Project details

Field	Input	Remarks
Editor	Keno Garlichs (TU Braunschweig), email: garlichs@ibr.cs.tu-bs.de	
Project title	Security For Connected Automated caRs (SecForCARs)	
Project lead	• Jochen Koszescha (Infineon Techologies AG), Jochen.Koszescha@infineon.com • Frank Kargl (Universtität Ulm) , frank.kargl@uni-ulm.de	
Consortium	• Infineon Technologies AG (Koordinator) • AUDI AG • Fraunhofer AISEC, Garching bei München • Fraunhofer IEM, Paderborn • Freie Universität Berlin • Robert Bosch GmbH • Technische Universität Braunschweig • ESCRYPT GmbH Embedded Security • itemis AG • Hochschule Karlsruhe - Technik und Wirtschaft • Mixed Mode GmbH • SCHUTZWERK GmbH • Technische Universität München • Universität Ulm	
Abstract	The main goal of the project is the development of methods and tools to secure critical vehicular communication and control in automated driving. We focus on information flows ranging from sensors like RADAR or cameras through ECUs to actuators like engine or brakes and also includes information communicated through inter-vehicle (V2X) communication. The functional architecture is augmented by security mechanisms that will hinder attackers from manipulating the behaviour of a self-driving car. Development, analysis, and test methods are developed to identify vulnerabilities enabling adversaries to gain control over the vehicle and are supported by according tools to make such methods applicable in practice. All investigations also consider the relations between functional safety and security.	
Framework	Funded by the German Federal Ministry of Education and Research	
Duration	01.04.2018 – 31.03.2021	

8.2.2 Use-cases & Facilities

Field	Input	Remarks

Use-Case 1	CACC/Platooning on highways	Focus on security
Use-Case 2	Cooperative search for parking spaces Vehicles can detect free parking spaces with their sensors and share that information with others when being queried.	Focus on security
Use-Case 3	Collision Warning based on CPMs Information received via CPMs can be used to extend CAM-based collision warning systems	Focus on security

Field	Input	Remarks
Facility 1	Collective Perception Service	For UC3
Facility 2	Cooperative Awareness Service For communication of dynamic status between CACC/Platoon members.	For UC1,3
Facility 3	LDM Necessary for the CP Service	For UC3
Facility 4	Security Architecture This includes all necessary components of the ETSI security architecture to establish authenticated, integrity-protected communication, extended security architecture for specific requirements of automated driving	For all UCs
Facility 5	Unicast/Multicast Communication Facilities To form, maintain and manage a platoon, directed communication means are required between the (potential) members. This could either be done locally or via back end communication	For UC1
Facility 6	Geonetworking To query vehicles in the designated parking area, geo-broadcast facilities are necessary	For UC2

8.2.3 Addressed challenges

Field	Input	Remarks
Challenge 1	Definition of an integrated methodology and tools for security and safety analysis and testing in different connected automated cars	
Challenge 2	Development of an automotive responsible disclosure framework	
Challenge 3	Protection against different attacks on local and distributed sensor systems (context: CACC, CPM, …)	
Challenge 4	Investigation of attacks focusing on specifics of automated driving, e.g. blinding or ghosting attacks against radars and other sensors. Investigate and develop security and pen-testing tools	
Challenge 5	Design of in-vehicle security architectures for connected, automated cars, based on secure platforms with	Usage of HSM for key storage and

	authenticated, integrity-protected communication between ECUs. Investigate architecture principles and building blocks	for cryptographic operations
Challenge 6	Development of methods to establish trust in (especially safety-relevant) data received from unknown participants of a network. Adaptation of misbehaviour detection framework to specifics of automated driving.	
Challenge 7	Detect intentional as well as unintentional misbehaviour in intra-vehicle and inter-vehicle networks. Investigate the relationship between sensor data fusion and misbehaviour detection.	IDS and Firewall on Gateway units (intra-vehicle network)
Challenge 8	Design components to be reusable	

8.2.4 Communication

Field	Input UC1	Input UC2	Input UC3	Remarks
Scope of communication	- Transmission of ego dynamic state and capabilities (i.e. CACC/Platooning-enabled)	- Query parking space situation in the designated parking area - Reply to those queries - Create ParkingCommunities	- Communicate dynamic state of and other relevant information about locally perceived objects to neighbouring vehicles	
Used technology	ETSI ITS-G5	ETSI ITS-G5	ETSI ITS-G5	
Used standards	- ETSI CAM	- GeoNetworking - BTP	- ETSI CPM	
Additional messages	- Potentially CAMs sent with transmitting rate > 10Hz - Potentially dedicated communication channel for beacons			
Additional protocols	- Platoon management protocol (establish, join, merge, leave, …) - Misbehaviour detection via IDS and protection via firewall (intra-vehicle networks) - Misbehaviour reporting protocol	- ParkingCommunities protocol (own development)	- Misbehaviour detection via IDS and protection via firewall (intra-vehicle networks) - Misbehaviour reporting protocol	

8.2.5 Working assumptions

Field	Input UC1	Input UC2	Input UC3	Remarks

Automation in sending vehicle	Level 1-5	Level 0-5	Level 0-5
Automation in receiving vehicle	Level 1-5	Level 0-5	Level 0-5
Used/necessary roadside infrastructure	Might be useful	Can be beneficial because it is more trustworthy than other vehicles	Can be very useful
Used/necessary central infrastructure	Useful as a central authority to report detected misbehaviour to and to query reputation of a vehicle in doubt from	Not required	Useful as a central authority to report detected misbehaviour to and to query reputation of a vehicle in doubt from

8.2.6 Additional details

More detailed information and results can be found in [19]–[21].

8.3 ADAS&ME

8.3.1 Project details

Field	Input	Remarks
Editor	Prachi Mittal p.mittal@denso-auto.de	
Project title	ADAS&ME (www.adasandme.com)	
Project lead	Anna Anund, VTI, Sweden anna.anund@vti.se	
Consortium	VTI, Ford, Scania, Ducati, Denso, Continental, Autoliv, Dianese, TomTom, Valeo, Vedecom, Applus IDIADA, SmartEye, DLR, Fraunhofer IAO, CERTH / HIT, TU Chemnitz, EPFA, RWTH Aachen, Stockholm University, …	
Abstract	ADAS&ME is acronym for “Adaptive ADAS to support incapacitated drivers Mitigate Effectively risks through tailor made HMI under automation”. The project will develop ADAS that incorporate driver / rider state, situational / environmental context and adaptive HMI to automatically hand over different levels of automation and thus ensure safer and more efficient road usage for all vehicle types (conventional and electric car, truck, bus, motorcycle).	
Framework	Horizon 2020 (Grant agreement no. 688900)	
Duration	42 months (Started 01/09/2016)	

8.3.2 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	**Driver state-based smooth & safe automation transitions** The vehicle driver automated when it detects that the driver is fatigued. Vehicle detects hindrance/road works ahead and prepares the driver to take over the control. Vehicle then verifies that the driver is able to drive manually.	
Use-Case 2	**Non-Reacting Driver Emergency Manoeuvre** Due to hindrance/road works, vehicle must give the control back to the driver but the driver is incapacitated or inattentive. Vehicle performs an emergency manoeuvre, e.g. • *Coordinated safe stop*: the vehicle makes a safe stop by coordinating with neighbouring vehicles to make space • *e-towing* : the vehicle agrees with a neighbouring vehicle and drives behind it as if being towed	

Field	Input	Remarks
Facility 1	**Cooperative perception** Perception using V2V/V2I/V2N communication, e.g. CAM for detecting a vehicle, DENM for detecting road works, information from a cloud-based service provider for receiving information on road traffic data	
Facility 2	**Collective perception / sensor sharing** The vehicles exchange information about their sensors' capabilities and detected objects. With this, the collective awareness of all vehicle improves.	
Facility 3	**Negotiation Module** Enables the vehicle to negotiate manoeuvres with neighbouring vehicles, e.g. agreement on e-towing	
Facility 4	**Coordination Module** Enables the vehicle to coordinate manoeuvres, e.g. coordinated safe stop, with neighbouring vehicles	
Facility 5	**Cloud data module** Enables the vehicle to exchange data (e.g. receiving 'driving difficulty' information for a road segment) with a cloud based service provider	

8.3.3 Addressed challenges.

Field	Input	Remarks
Challenge 1	**Message formats** Many communication messages used do not have a standard format. Project develops a suitable message format to serve the required functions.	
Challenge 2	**Protocols**	

	Many protocols used, e.g. for negotiation and coordination between vehicles, are not standardized. Project employs basic implementation of these protocols.	
Challenge 3	**Cloud services** To contribute to the assessment of driver state monitoring, the project employs a specific cloud service (which provides 'driving difficulty' factor for a requested road segment). There exists little or no prior art on this concept.	

8.3.4 Communication

Field	Input	Remarks
Scope of communication	• Transmission of ego motion • Collective perception messages (ego vehicle on-board sensing capabilities and detected objects) • Negotiation and coordination messages • Data exchange with cloud-based service provider	
Used technology	• ETSI ITS-G5 for direct communication • Cellular for cloud communication	
Used standards	• ETSI EN 302 637 (Cooperative Awareness Basic Service)	
Additional messages	• Collective Perception Message (CPM) • Coordinated Manoeuvre Message • Negotiation Messages • Cloud Data Exchange Messages (including both request and response)	
Additional protocols	• Coordination protocols • Negotiation protocols • Protocols for data exchange between vehicle and cloud-based service provider	

8.3.5 Prerequisites

Field	Input	Remarks
Automation in sending vehicle	Level 3-5	
Automation in receiving vehicle	Level 3-5	
Used/necessary roadside infrastructure	Roadside infrastructure capable of sending out event information, e.g. road works	
Used/necessary central infrastructure	Cloud infrastructure / service provider capable of sending relevant information, e.g. 'difficulty of driving'	

8.4 PRoPART

8.4.1 Project details

Field	Input	Remarks
Editor	Andras Varadi (andras.varadi@commsignia.com)	
Project title	PRoPART	
Project lead	RISE, Stefan Nord	
Consortium	AstaZero, Baselabs, CEIT-IK4, Commsignia, Fraunhofer IIS, RISE, Scania, Waysure	
Abstract	The main idea behind the PRoPART project is to develop and enhance an RTK (Real Time Kinematic) software solution by both exploiting the distinguished features of Galileo signals as well as combining it with other positioning and sensor technologies. The two main components developed within the project is a highly reliable positioning manager and an environmental perception layer for automated driving.	
Framework	This project has received funding from the European GNSS Agency under the European Union's Horizon 2020 innovation programme under grant agreement No 776307.	
Duration	2017 12 01 – 2019 11 30	

8.4.2 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	Automated lane change by a truck on the highway	

Field	Input	Remarks
Facility 1	Novel positioning manager with multiple external sources for position as well as augmentation services	
Facility 2	Perception layer for free space estimation combining onboard and external sensors	
	RTCM GNSS correction data service from Commsignia RSU to Scania vehicle	
	UWB ranging from RSU to vehicle	
	CPM service from RSU sensors to vehicle (on the environment around the vehicle)	
	Secure GNSS using latest features of Gallileo	

8.4.3 Addressed challenges

Field	Input	Remarks
Challenge 1	cm level positioning	

Challenge 2	multi anchor positioning, highly reliable positioning manager in locations with low GNSS coverage sensor fusion for free space estimation	

8.4.4 Communication

This WI is focused on cooperative automated driving, thus a form of communication is implied for projects. Here, specifics to the communication can be listed.

Field	Input	Remarks
Scope of communication	Transmission of RTCM correction, UWB node status, perceived object detected by roadside units	
Used technology	ETSI G5, UWB, Galileo	
Used standards	RTCM service over V2X (ETSI 103 301) CPM various versions CAM according to delegated act	
Additional messages	prototype CPM experimental UWB Status over V2X UWB ranging (non V2X)	
Additional protocols		

8.4.5 Prerequisites

Field	Input	Remarks
Automation in sending vehicle	n/a (roadside unit)	
Automation in receiving vehicle	TBD	
Used/necessary roadside infrastructure	Commsignia RSU with RTK, Radar, UWB nodes	
Used/necessary central infrastructure	none	

8.5 iKoPA

8.5.1 Project details

Field	Input	Remarks
Editor	Jonas Vogt	
Project title	iKoPA (germen abbreviation)	
Project lead	htw saar - University of Applied Sciences	
Consortium	• Bayerische Medien Technik GmbH • Daimler Center for Automotive Information Technology Innovations (DCAITI) • Fraunhofer-Institut für Offene Kommunikationssysteme FOKUS (FOKUS) • Fraunhofer-Institut für Sichere Informationstechnologie SIT (SIT) • Hochschule für Technik und Wirtschaft des Saarlandes (htw saar) • MyOmega System Technologies GmbH (MyOmega) • NXP Semiconductors Germany GmbH (NXP) • SWARCO TRAFFIC SYSTEMS GmbH (Swarco) • Unabhängiges Landeszentrum für Datenschutz Schleswig-Holstein (ULD)	
Abstract	CCAD in the context of a privacy friendly and secure communication architecture and electric mobility. Automated driving in parking garage	
Framework	Public funded research project (German Federal Ministry of Education and Research)	
Duration	2015-11—2018-12	

8.5.2 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	Automated driving in car park with von GPS or cellular coverage	
Use-Case 2	Hybrid communication (W-LAN; cellular, DAB, RFID)	

8.5.3 Addressed challenges

Field	Input	Remarks
Challenge 1	Secure and privacy friendly communication	
Challenge 2	Positioning in car parks	

8.5.4 Communication

Field	Input UC1		Remarks
Scope of communication			
Used technology			
Used standards			
Additional messages	Authetication	Cooperative Perception	
Additional protocols			

8.5.5 Working assumptions

Field	Input UC1	Remarks
Automation in sending vehicle		
Automation in receiving vehicle		
Used/necessary roadside infrastructure		
Used/necessary central infrastructure		

8.6 5GNetMobil

8.6.1 Project details

Field	Input	Remarks
Editor	Nadia Brahmi, nadia.brahmi@de.bosch.com	
Project title	5G NETMOBIL - 5G SOLUTIONS FOR FUTURE CONNECTED MOBILITY	
Project lead	Frank Hofmann, Frank.Hofmann2@de.bosch.com	
Consortium	Robert Bosch GmbH	
Abstract	5G NetMobil is a research project funded by the German Federal Ministry of Education and Research (BMBF). The overall objective of the project is the development of a holistic communication architecture for tactile connected driving and highlighting the new capabilities enabled by the next mobile network generation for bringing automated driving forward and improving traffic safety and efficiency. This includes the development of technical solutions and concepts for fifth generation 5 G) mobile radio networks fulfilling requirements of connected driving and the validation of the developed solutions and concepts by means of simulations and demonstrations in realistic scenarios.	
Framework	5G Tactile Internet within the German research program „IKT 2020 Research for Innovation“	
Duration	01.03.2017 29.02.2020	

8.6.2 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	High Density Platooning: The goal is to maintain a short distances between vehicles by forming a stable vehicle group while satisfying the road safety requirements. In order to ensure the driving safety, such short time gap (typically less than 0.5s) could not be realized by manual and would require the automatic driving functions, including longitudinal and/or lateral control.	
Use-Case 2	City crossing assistance for vulnerable road user protection (CC VRU): aims at increasing the safety of pedestrians and cyclists. The idea is based on cooperative sensor data fusion, combining data gathered from infrastructure-mounted sensors (e.g. cameras) with data collected from on-board vehicle sensors in order to detect other traffic participants that might be invisible due to occlusions (e.g. blind spot while turning right, buildings, other vehicles, etc.) and potentially crossing the vehicle’s path. The information is used for the evaluation of collision probabilities and accordingly, triggering the appropriate actions for collision avoidance, e.g. warning	

	the drivers early enough or triggering an active automatic intervention on the vehicle	

Field	Input	Remarks
Facility 1	PCM (Platoon Control Message) is used by platoon members to regularly exchange information about their current kinematics status and data collected from their local on-board sensors. This information. PCMs are periodically transmitted and used locally by the platooning application to generate suitable control parameters, which optimize the maneuver of the truck and maintain target distance to its preceding. In 5GNetMobil, we consider for truck platooning that the local platoon controller expects a PCM every 50ms. A PCM packet needs to be transmitted within 9ms to allow for internal processing before providing the control parameters to the local controller.	
Facility 2	CPM (Cooperative Perception Message) is used for transmitting the information about detected objects from infrastructure-based-sensors (e.g. camera) to all vehicles in the vicinity of a road intersection.	

8.6.3 Addressed challenges

Field	Input	Remarks
Challenge 1	One of the biggest challenges in platooning is string instability, which is the oscillation phenomena that can occur when multiple controllers are chained.	
Challenge 2	The challenge in the CC-VRU use case is the prediction of the pedestrian movement and its intension which impacts the reliability of the collision prediction and the probability of the false alarms.	

8.7 AutoNet2030

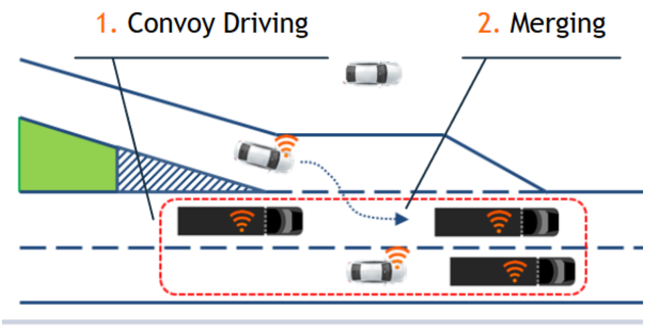
Project details

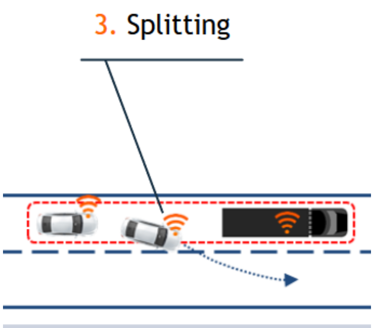
Field	Input	Remarks
Editor	Ignacio Llatser, Robert Bosch GmbH, Hildesheim (Germany), ignacio.llatser@de.bosch.com	
Project title	AutoNet2030 "Co-operative Systems in Support of Networked Automated Driving by 2030", http://www.autonet2030.eu/	
Project lead	Angelos Amditis, Institute of Communication and Computer Systems, a.amditis@iccs.gr	
Consortium	Broadbit, Baselabs, Centro Ricerche Fiat, Armines – MINES Paristech, Scania, Hitachi Europe, Ecole Polytechnique Federale de Lausanne, Institute of Communication and Computer Systems, Technische Universität Dresden	
Abstract	AutoNet2030 shall develop and test a co-operative automated driving technology, based on a decentralised decision-making strategy which is enabled by mutual information sharing among nearby vehicles. The project is aiming for a 2020-2030 deployment time horizon, taking into account the expected preceding introduction of co-operative communication systems and sensor based lane-keeping/cruise-control technologies. By taking this approach, a strategy can be worked out for the gradual introduction of fully automated driving systems, which makes the best use of the widespread existence of co-operative systems in the near-term and makes the deployment of fully automated driving systems beneficial for all drivers already from its initial stages.	
Framework	FP7 EU programme	
Duration	36 Months (November 2013 – October 2016)	

8.7.1 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	**Convoy driving:** In a multi-lane convoy use case, a master, centralized controller, or supervisor does not exist. Instead, the vehicle control, in both lateral and longitudinal directions, is distributed over all members of the convoy. The result of this approach is that vehicle disturbances, such as a braking vehicle, affect all members of the convoy to a greater or lesser extent, resulting in a stable formation. In order to maintain small inter-vehicle distances, convoy members rely on the high-frequency exchange of up-to-date and high-quality vehicle dynamics data among vehicles in the convoy. The proposed convoy control algorithm requires just the vehicle dynamics information of neighbor vehicles, instead of the information of all convoy	

members. As such, the algorithm scales well to large convoys and converges easily to a desired formation when vehicles join and leave the convoy.

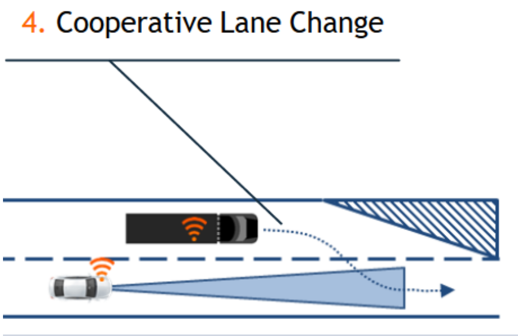




Use case 2

Cooperative Lane Change:

In the cooperative lane change use case, cooperative vehicles (both autonomous and manually driven) collaborate to perform a lane change of one or a group of cooperative vehicles (e.g., a convoy) in a safe and efficient manner. Unlike in a traditional lane change situation, cooperative vehicles share their planned trajectories in order to negotiate and align their maneuvers.

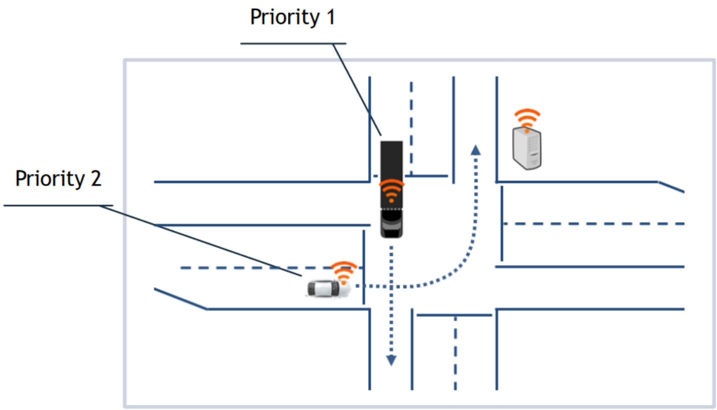


Use Case 3

Cooperative Intersection Control:

A cooperative intersection allows cooperative vehicles to traverse an intersection without the need for traffic lights.

This scenario requires a coordination mechanism in case their planned trajectories overlap. A possible solution is shown in the figure below, where a roadside unit coordinates the traffic flow through the intersection by assigning relative priorities to incoming vehicles in real time. Then vehicles are able to cross the intersection efficiently following the order of their assigned priority.



Field	Input	Remarks
Facilities 1	GCA Information Sharing: component providing a service to distribute information (e.g. traffic status) within a wide geographical area known as Global Cooperation Area (GCA), supervised by a dedicated application server.	
Facility 2	Cooperative Speed Advising Service: component enabling a traffic server to advise an appropriate driving speed to all vehicles within a given road segment.	
Facility 3	Cooperative Enhanced GNSS Message Service: a component which manages the transmission and reception of real-time kinematic corrections to data for enhanced geo-positioning, through a scalable broadcast-based approach.	
Facility 4	Cooperative Sensing Service: component to disseminate and receive information about perceived external dynamic objects (e.g. other vehicles, pedestrians, motorcyclists, etc.)	
Facility 5	Cooperative Lane Change Service: component that supports the planning and execution of a lane change in collaboration with surrounding cooperative vehicles.	
Facility 6	Convoy Control Communication Service: component providing an advanced communication mechanism which enhances the functionality of cooperative automated cruise control (C-ACC), allowing the control and maintenance of multi-lane vehicle formations.	

Facility 7	Cooperative Intersection Control Service: component that manages the information exchange between vehicle and intersection controller for priority-based coordination of autonomous and manually driven vehicles at intersections.	
Facility 8	Extended Cooperative Awareness Basic Service: extension of the standard component CABS as standardized in ETSI EN 302 637-2, in order to support the automated driving use-cases in AutoNet2030.	
Facility 10	SPAT/MAP: component managing the exchange of intersection topology information and traffic light signal phase and timing information.	
Facility 11	Local Dynamic Map: database which combines lane-level map information with sensed objects using local sensors and communication.	

8.7.2 Addressed challenges

Field	Input	Remarks
Challenge 1	The perception module must integrate on-board perception sensors as well as communication sensors, provide a coverage of 360 degrees around the host vehicle and be easily adaptable to different vehicle configurations.	
Challenge 2	A multi-level iterative prototyping and validation strategy is needed to close the gap between the theoretical design of suitable control laws and real vehicle experiments.	
Challenge 3	Cooperative control is highly dependent on the perception and communication components. Therefore, good initial assumptions on these two components are crucial for the successful integration at the end.	
Challenge 4	Having a highly accurate and reliable vehicle positioning technology is of prime importance for the reliable execution of automated driving maneuvers. The main requirement on the positioning accuracy is to be able to distinguish reliably the current lane, so that GNSS positioning may work as a complementary and redundant sensor to camera based lane sensing.	
Challenge 5	The V2X communication system needs to be compatible with existing V2X standards. For this, the Autonet2030 system was based on the implementation that was developed in previous projects on cooperative ITS for the first generation of V2X.	
Challenge 6	The system integration in AutoNet2030, where several partners contribute different modules to a complete system, proved to be a challenge. Within AutoNet2030 a tool-chain was used involving LCM for middleware and decoupling of modules, and Docker for isolation and orchestration of modules. This proved to be especially successful as the	

AutoNet2030 team was able to work independently from each other and a very stable system integration was reached.

8.7.3 Communication

Field	Input UC1	Input UC2	Input UC3	Remarks
Scope of communication	- Transmission of vehicle ego motion - Transmission of automated driving information (see Facility 8). - Negotiation of convoy join/leave maneuvers	- Transmission of vehicle ego motion - Transmission of automated driving information (see Facility 8). - Negotiation of lane change maneuvers	- Transmission of vehicle ego motion - Coordination of vehicle crossing by infrastructure	
Used technology	ETSI ITS-G5	ETSI ITS-G5	ETSI ITS-G5	
Used standards	ETSI CAM, CCD, CPM	ETSI CAM, CCD, CPM	ETSI CAM, CCD, CPM	
Additional messages	Extended CAM, Convoy Management Message, Cooperative Lane Change Message	Extended CAM, Cooperative Lane Change Message	Cooperative Intersection Control Message	
Additional protocols	Extended GeoNetworking, Reliable Basic Transport Protocol, Cooperative EGNSS Message Service	Extended GeoNetworking, Reliable Basic Transport Protocol, Cooperative EGNSS Message Service	Extended GeoNetworking, Reliable Basic Transport Protocol, Cooperative EGNSS Message Service	

8.7.4 Working assumptions

Field	Input UC1	Input UC2	Input UC3	Remarks
Automation in sending vehicle	Level 2-5	Level 0-5	Level 3-5	

Automation in receiving vehicle	Level 2-5	Level 0-5	-
Used/necessary central infrastructure	Might be used for high level optimization (e.g., distribution of traffic density information)	Might be used for high level optimization (e.g., distribution of traffic density information)	Might be used for high level optimization (e.g., distribution of traffic density information)

8.7.5 Results

Field	Expected	Measured	Remarks
Result 1	Design, development and demonstration of cooperative maneuver controller for vehicles.	Development of two maneuver controllers: a distributed graph-based controller tailored for the convoy motion of vehicles and a semi-distributed hierarchical control framework demonstrated in the intersection management use case.	
Result 2	Build up reliable and accurate knowledge of the environment of autonomous vehicles by means of an environmental model or perception layer.	Configurable multi-vehicle/multi-sensor perception developed in a prototypical way in combination with probabilistic data fusion algorithm. Information received via V2V communication is used as an addition sensor source. The range of the surveillance area around the host vehicle could be improved for a horizon of up to 300m under demonstration conditions.	
Result 3	Implementation of innovative communication services for the actual demonstrated system and performance evaluation of relevant algorithms by simulation.	Extension of CAM with additional fields to support the UC 1 and 2. Design of Convoy Control Communication Service, Cooperative Lane Change Service and Cooperative Sensing Service. Design of smart forwarding algorithms for cooperative automated driving.	
Result 4	HMI system to leverage information beyond the scope of the ego-vehicle perception system and provide it to the driver with the maximum possible clarity.	Designed user interface considering both driver comfort and easiness of use, suitable for different automation levels and with convoy driving as target scenario.	

8.7.6 Additional details

Please find more information on the AutoNet2030 deliverables available at http://www.autonet2030.eu/?page_id=14

8.8 IMAGinE

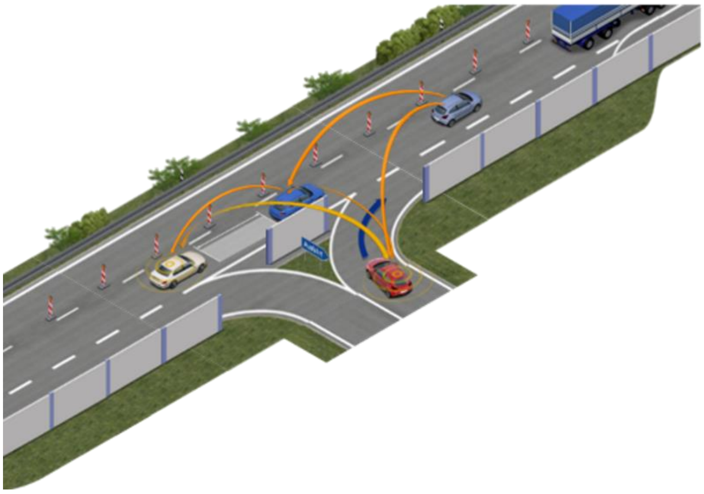
8.8.1 Project details

Field	Input	Remarks
Editor	Ignacio Llatser, Robert Bosch GmbH, Hildesheim (Germany), ignacio.llatser@de.bosch.com	
Project title	IMAGinE (Intelligent Maneuver Automation – cooperative hazard avoidance in realtime), https://imagine-online.de/en/	
Project lead	Dr.-Ing Steffen Knapp, Opel Automobile GmbH, steffen.knapp@opel.com	

Consortium	Opel Automobile GmbH, BMW AG, Daimler AG, Volkswagen AG, Continental Teves AG & Co. ohG, Robert Bosch GmbH, IPG Automotive GmbH, Nordsys GmbH, WIVW GmbH, Technische Universität München
Abstract	The IMAGinE (Intelligent Maneuver Automation – cooperative hazard avoidance in realtime) project is developing innovative driving assistance systems for cooperative driving. Cooperative driving refers to road traffic behaviour in which road users cooperatively plan and execute driving maneuvers. Individual driving behaviour is coordinated with other road users and the overall traffic situation based on automatic information exchange between vehicles and infrastructure. Critical situations can be avoided or mitigated, thereby making driving safer and more efficient.
Framework	Funding program from the German Federal Ministry for Economic Affairs and Energy
Duration	48 Months (01/09/2016 – 31/08/2020)

8.8.2 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	**Cooperative merging on highways** In areas where lanes end or merge, drivers must change lanes under spatial and time constraints. Different tasks such as looking for a suitable gap in traffic or signalling the wish to change lanes are accomplished simultaneously in part. The high complexity of this driving task often leads to accidents at these junctions. Based on V2X communication, IMAGinE enables the exchange of information about merging cars' planned maneuvers and the coordination of cooperative maneuvers, for example by opening a gap in traffic for the merging car. Misinterpretations of cooperative intentions can be prevented and critical situations avoided. The range of the on-board environmental sensors is increased using V2X communication. This results in longer timespans for decision-making and coordination with other vehicles for the merging car.	

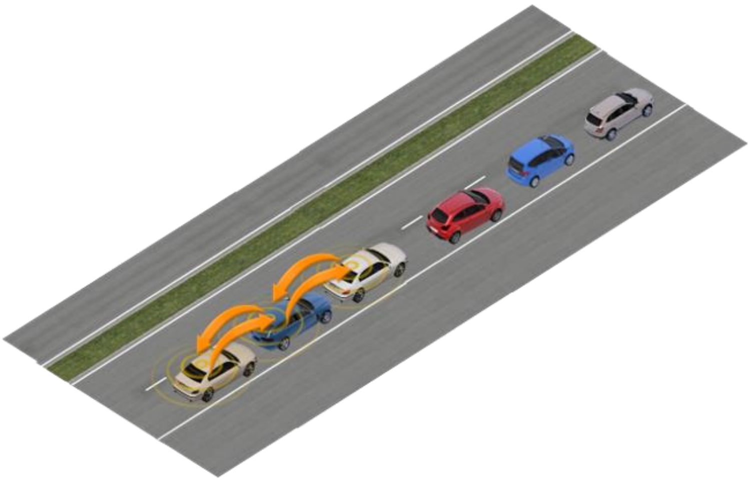


Use case 2

Cooperative longitudinal control on motorways

Current longitudinal control systems, such as Adaptive Cruise Control (ACC), use on-board sensors for detecting leading vehicles and control the distance through acceleration and deceleration. These systems are limited by their detection precision, range and latency of the deployed sensor technology.

IMAGinE is developing an approach that extends ACC in vehicles by integrating additional information about following and adjacent vehicles as well as the traffic infrastructure. For instance, situation-based traffic information can be included for setting the cruise control's target speed limit. Vehicles can adapt their speed to the driving situation predictively and avoid unnecessary acceleration processes, mitigating critical situations or even preventing them in advance. Cooperative longitudinal control on motorways via mutual coordination between vehicles additionally enables convoys to be formed in traffic jams, whereby vehicles drive in close distance at synchronized speeds.

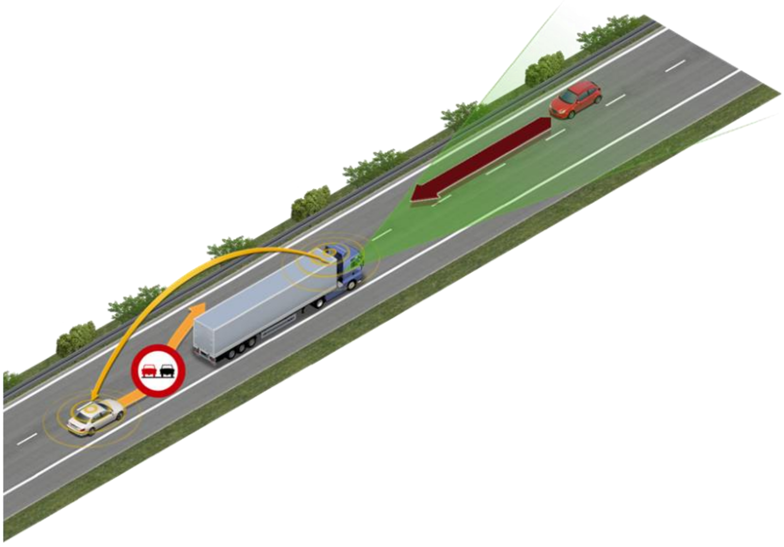


Use Case 3

Cooperative overtaking on rural roads

Serious collisions with oncoming traffic occur frequently on rural roads. These result from failed overtakings and evasive maneuvers, among other things. It is often impossible or insufficiently possible to recognise dangerous situations in a timely manner and evaluate the behaviour of other road users due to limited fields of view.

IMAGinE is developing technical solutions that allow vehicles to exchange information about their own trajectory and speed and about objects in the environment as well so that drivers can be warned about oncoming traffic during overtaking maneuvers. In case of a sudden danger, both the overtaking and oncoming cars contribute to accident prevention by cooperatively planning and coordinating their driving maneuvers.

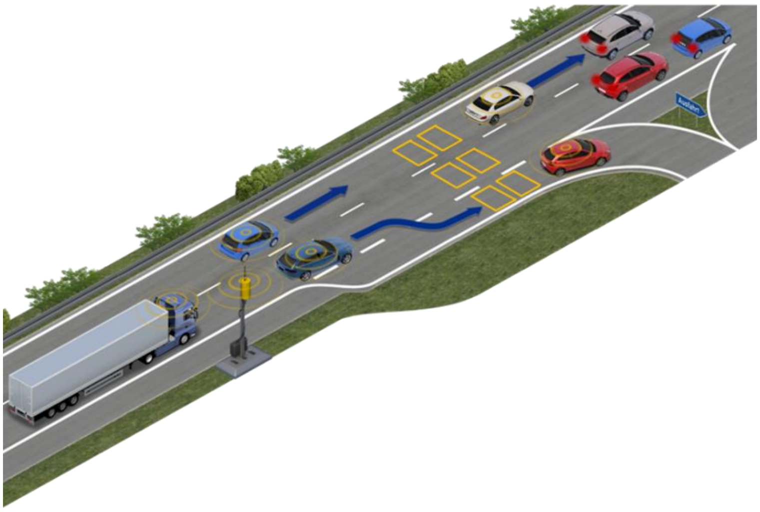


Use Case 4 **Cooperative strategic traffic distribution**

Individual route planning and recommendations, by navigation systems for example, usually work based on available information about distances and travel time. Local traffic infrastructure operators provide additional strategic routing recommendations. Integration of this additional information is not always possible, and sometimes the additional information is contradictory.

IMAGinE is developing an approach that aims at optimising traffic distribution in the available road network considering the given capacities. Using V2X communication, vehicles send information about traffic volume on main and side routes to a traffic centre. The traffic centre integrates data from vehicles and infrastructure and calculates an optimised traffic flow distribution before sending traffic distribution recommendations back to vehicles.

Vehicles receive the information, coordinate their intentions regarding their destinations and other routing criteria before their respective decision points, and then each vehicle calculates its own optimised route using the collective information.

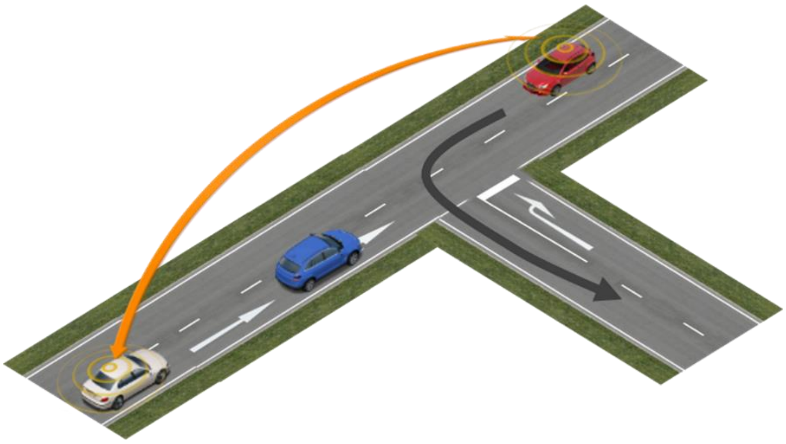


Use Case 5

Cooperative turning at junctions

Leaving a highway by a left turn and turning onto a highway are two critical and demanding driving situations where drivers need to watch for traffic coming from different directions. Current advanced driver assistant systems that support drivers in perceiving the traffic situation and executing turning maneuvers are restricted in their effectiveness by the sensor technology's limited range. Routes with vehicles travelling at high velocities, junctions with curves and heavy fog in particular are all demanding operational scenarios.

Cooperative driving on highways is made possible through V2X communication: from transmitting turning intentions to other vehicles on the highway, thus increasing the signalling range, to collectively coordinated turning maneuvers.

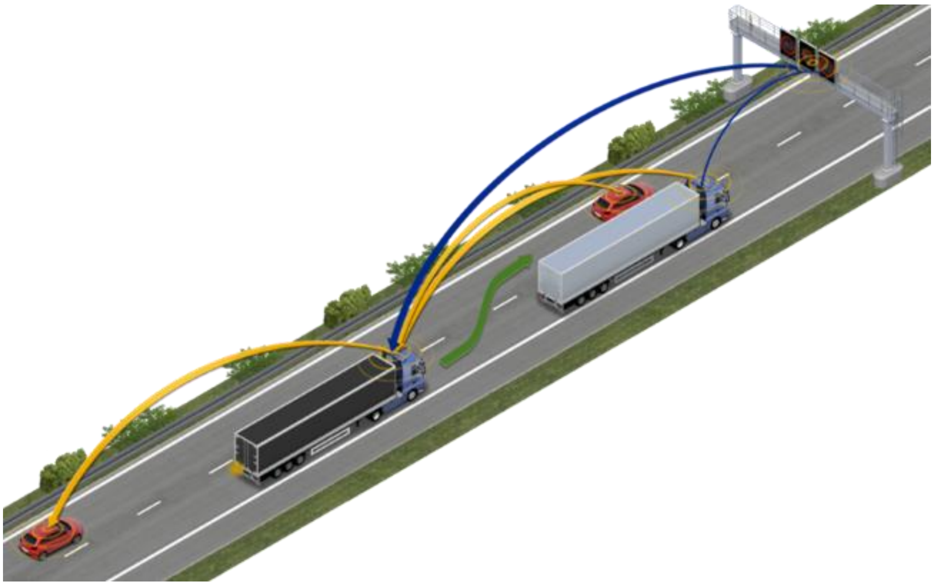


Use Case 6

Cooperative overtaking by heavy-goods vehicles on motorways

Choosing the right time to pass a slow-driving vehicle is a challenging task. This is especially true for heavy-goods vehicles passing other heavy-goods vehicles on motorways. The best timing for overtaking a truck depends on the lead vehicle's driving strategy, the ratio between its engine power and total weight, and the slope of the road.

The technological solutions IMAGinE is developing will help in finding the right timing, enabling the exchange of information between the vehicles involved in the passing maneuver about current and the planned target speeds in the near future or the weight of the heavy-goods vehicle. In heavy traffic, data about the position and velocity of adjacent traffic can also be integrated. Based on the available information, vehicles can coordinate amongst each other and make passing maneuvers more efficient and safer for following traffic.



Field	Input	Remarks
Facility 1	Cooperative Awareness (CA) Service, as standardized by ETSI EN 302 637-2.	For all UCs.
Facility 2	Decentralized Environmental Notification (DEN) Service, as standardized by ETSI.	For all UCs.
Facility 3	In-Vehicle Information (IVI) Service, as standardized by ETSI.	For all UCs.
Facility 4	Collective Perception (CP) Service: component to disseminate and receive information about perceived external dynamic objects (e.g. other vehicles, pedestrians, motorcyclists, etc.)	For all UCs.
Facility 5	Maneuver Coordination (MC) Service: enables the coordination of maneuver plans among neighbor vehicles by periodically exchanging their future trajectories.	For all UCs.
Facility 6	IMAGinE Driving Strategy (IDS) Service: enables long-term cooperation among vehicles by means of synchronization of distributed state machines (see Project CMP).	For UC 2 and 6.
Facility 7	IMAGinE Traffic Distribution (ITD) Service: route recommendations from road infrastructure to vehicles in order to optimize the global traffic flow.	For UC 4.
Facility 8	IMAGinE Debug (ID) Service: allows remote diagnostics to assist the system development via V2X debug messages.	For all UCs.

8.8.3 Addressed challenges

Projects often focus on specific challenges, advancing state of the art in them. Thus, a project developing CACC might focus on string-stability, on UI or on transmission methods. If possible, list here specific issues, which are in focus of the project.

Field	Input	Remarks
Challenge 1	Develop a generic cooperative driving system, independent of the use case.	
Challenge 2	Cooperative driving system adapts to mixed-traffic scenarios: vehicles with automation level 0 to 5 in the same scenario.	
Challenge 3	Cooperative driving system adapts to mixed-traffic scenarios: vehicles equipped with V2X communication and non-equipped vehicles in the same scenario.	
Challenge 4	Cooperative maneuver coordination by means of direct V2V communication without infrastructure support.	
Challenge 5	Tolerance with respect to different environmental models in the cooperating vehicles.	
Challenge 6	Tolerance with respect to different accuracies for the ego-data (e.g. position) and sensor measurements in the cooperating vehicles.	

8.8.4 Communication

Field	Input UC1	Input UC2	Input UC3	Input UC4	Input UC5	Input UC6	Remarks
Scope of communication	- Transmission of vehicle ego motion - Transmission of sensor data - Transmission of vehicle trajectories - Transmission of debug messages	- Transmission of vehicle ego motion - Transmission of sensor data - Transmission of vehicle trajectories - Coordination of distributed state machines - Transmission of debug messages	- Transmission of vehicle ego motion - Transmission of sensor data - Transmission of vehicle trajectories - Transmission of debug messages	- Transmission of vehicle ego motion - Transmission of sensor data - Transmission of vehicle trajectories - Transmission of route recommendations - Transmission of debug messages	- Transmission of vehicle ego motion - Transmission of sensor data - Transmission of vehicle trajectories - Transmission of debug messages	- Transmission of vehicle ego motion - Transmission of sensor data - Transmission of vehicle trajectories - Coordination of distributed state machines - Transmission of debug messages	
Used technology	ETSI ITS-G5						
Used standards	ETSI CAM, DENM, IVIM, CDD, CPM	ETSI CAM, DENM, IVIM, CDD, CPM	ETSI CAM, DENM, IVIM, CDD, CPM	ETSI CAM, DENM, IVIM, CDD, CPM	ETSI CAM, DENM, IVIM, CDD, CPM	ETSI CAM, DENM, IVIM, CDD, CPM	
Additional messages	MCM, IDM	MCM, IDSM, IDM	MCM, IDM	MCM, ITDM, IDM	MCM, IDM	MCM, IDSM, IDM	
Additional protocols							

8.8.5 Working assumptions

Field	Input UC1	Input UC2	Input UC3	Input UC4	Input UC5	Input UC6	Remarks
Automation in sending vehicle	Level 0-2						

Automation in receiving vehicle	Level 0-2		
Used/necessary central infrastructure	Might be used for high level optimization (e.g., distribution of traffic density information)	Infrastructure required to broadcast traffic route recommendations	Might be used for high level optimization (e.g., distribution of traffic density information)

8.8.6 Results

Field	Expected	Measured	Remarks
Result 1	Analysis, representation and requirements of cooperative scenarios		
Result 2	Specification and architecture of cooperative driving system		
Result 3	HMI studies of public acceptance		
Result 4	Concept for collective perception and cooperative maneuvering		
Result 5	System integration in test vehicles and joint demonstration in test track		
Result 6	System evaluation via co-simulation of vehicle, traffic and V2X communication		

8.9 MAVEN

8.9.1 Project details

Field	Input	Remarks
Editor	Michele Rondinone, Hyundai Motor Europe Technical Center - HMETC (Germany), mrondinone@hyundai-europe.com	
Project title	H2020 MAVEN (Managing Automated Vehicles Enhances Network), http://maven-its.eu/	
Project lead	Robbin Blokpoel, Dynniq (NL), robbin.blokpoel@DYNNIQ.COM	
Consortium	DLR (DE), Dynniq (NL), Hyundai Motor Europe Technical Center (DE), Czech technical University Prague (CZ), TomTom (DE), Polis (BE), Helmont city (NL), Greenwich borough (UK), Map Traffic Management (NL)	
Abstract	The objective of MAVEN is to deliver C-ITS-assisted solutions for managing Cooperative Automated Vehicles (CAVs) at signalized intersections and intersection corridors with the aim of increasing traffic efficiency and safety.	
Framework	H2020 EU programme	
Duration	36 Months (Sept 2016 – August 2019)	

8.9.2 Use-cases & Facilities

Field	Input	Remarks

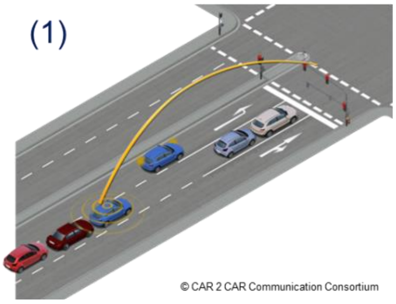
Use-Case 1

Traffic light info optimization via V2I:

In proximity of urban signalized intersections, isolated CAVs and/or CAVs organized in CACC strings continuously transmits information describing intentions (like planned route at intersection) or vehicle/string characteristics (like desired speed, string size, etc.). By collecting this explicit probing V2I information, the traffic light controller updates its queue models and calculates more efficient traffic light phases and durations.

CAV: Cooperative Automated Vehicle

CACC: Cooperative Adaptive Cruise Control

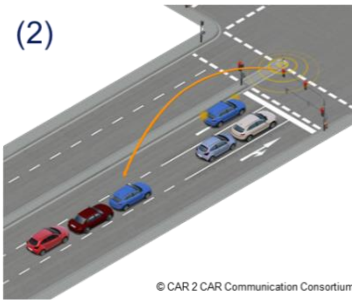


Use-Case 2

Automated adaptation to GLOSA and Lane change advices:

Thanks to the collected V2I information, the traffic light controller can compute lane-specific GLOSA and lane change advices that CAVs can apply to pass the intersection more efficiently

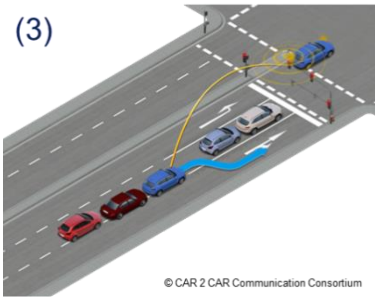
GLOSA: Green Light Optimal Speed Advice



Use-Case 3

Automated adaptation to GLOSA and Lane change advices with I2V negotiation:

CAVs and/or CAVs strings communicate if the GLOSA and Lane change advices can be executed by updating their own transmitted messages. This feedback can be used by the traffic light controller to further refine the traffic light phase and time algorithms (e.g. to put priority at the phases whose GLOSA advices that can be applied, e.g. ensure a long enough and stable time to green for a big string of CAVs to pass the stop line before the next red starts.



Use case 4

Urban CACC string (MAVEN urban platooning):

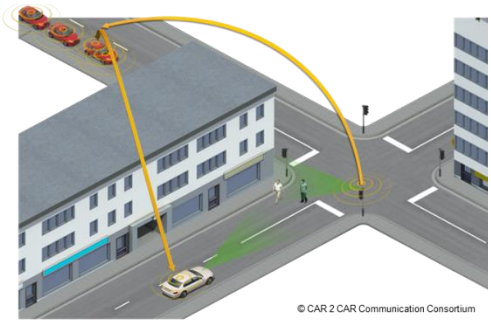
CAVs form and drive in small and flexible platoon formations, where flexible means implementing cooperative methods for forming, joining, travelling in, leaving, and breaking a platoon. MAVEN platooning is a mix between a distributed and centralized scheme (Figure 3). Based on common distributed algorithms and V2V exchanged information, individual CAVs form platoons, manage their operation (joining, leaving, etc., see Figure 3 (1)), and control their motion (both longitudinal and lateral). In this sense, the MAVEN platooning approach can be seen as an extended Cooperative ACC (CACC strings), where every vehicle closely follows its preceding vehicle by still controlling its speed, distance, and possible emergency reactions. Yet, the platoon leader has the central role of communicating platoon properties/features to the infrastructure according to the above mentioned I2V negotiation process, see figure below.

Use Case 5

Cooperative detection of-/reaction to conventional traffic and VRUs:

VRU: Vulnerable road user

Isolated CAVs and/or CAVs in CACC string (in red) are heading towards the same intersection equipped with C-ITS and detection capabilities. Conventional traffic or VRU in dangerous positions can be detected only by a subset of the approaching CAVs and by the intersection. On the contrary, other CAVs cannot detect the risk (e.g. in the figure, the platoon of red CAVs is not capable to detect the pedestrians since they are hidden around the corner). Knowing about the presence of hidden obstacles would give CAVs more information for planning paths in a safer way (e.g., in the figure, if the platoon needs to turn right). In fact, with this additional information, CAVs might decide to slow down if, once in proximity of the stop line, the hidden obstacle would still represent a risk. In order to let CAVs aware of VRUs and other unequipped vehicles that cannot be locally detected, collective perception is used at both vehicles and infrastructure side.



Field	Input	Remarks
Facilities 1	At the vehicle side: extensions of the standard ETSI ITS Cooperative Awareness Message (CAM) service allowing CAVs to explicitly communicate the planned intentions to the infrastructure and provide feedbacks on the compliance to advised speeds or lane changes (explicit probing). CAM extensions reuse CCD and SAE J2735 semantics and are backward compatible	For UC1/UC3 in such a way that CAVs can indicate the planned route and compliance to infra advices using C-ITS semantics
Facility 2	At the infrastructure side: I2V standard SPAT/MAP services profiled for enabling lane-specific glosa	For UC2
Facility 3	At the infrastructure side: a brand new Lane Change advice service enabling lane change advices for individual CAVs reusing CCD and SAE J2735 semantics	For UC2
Facility 4	At the vehicle side: other specific extensions of the standard ETSI ITS Cooperative Awareness Message (CAM) supporting MAVEN platooning. CAM extensions for detecting platoon initialization opportunities are appended to Day1 CAMs (CCH). CAM extensions for managing platoon management (form, join, leave, break-up, etc.) and controlling car-following functionalities are transmitted in separate CAMs on one of the SCHs. CAM extensions reuse CCD and SAE J2735 semantics and are backward compatible	For UC4

Facility 5	At the vehicle and infrastructure side: Collective perception service	For UC5
Facility 6	At the vehicle side and infra side: Extended LDM including an underlying HD map representation of the intersection where HD map features (lane groups) can be associated C-ITS features (SAE SPAT/MAP intersectionID, LaneID, SignalGroup, etc)	For UC1/UC3 in such a way that CAVs can indicate the planned route and compliance to advices using C-ITS semantics; For UC4 in such a way that the position of a detected obstacle at the intersection can be associated to a C-ITS representation (e.g. LaneID, distance to stop line, etc.)
Facility 7	At the vehicle side and infra side: Extended LDM capability to properly fuse and track information received via C-ITS (CAMs, CPMs) with information detected via local sensors	For UC4 and UC5

8.9.3 Addressed challenges

Field	Input	Remarks
Challenge 1	Fusion and tracking of C-ITS info combined with local sensor detected info. If not done properly negatively affects the performance of platooning and cooperative detection/reaction applications	
Challenge 2	Definition of object quality/confidence for its inclusion in CPM message. If not harmonized, can lead to misuse at receiving side	

8.9.4 Communication

Field	Input UC1	Input UC2	Input UC3	Input UC4	Input UC5	Remarks
Scope of communication	- Transmission of ego motion - Transmission of ego-plans (route at intersection) - Transmission of ego features (desired speed, platoon size, etc)	- Transmission of GLOSA and lane change advices	- Transmission of ego compliance to infra advices	- Transmission of ego motion - Transmission of ego-plans (route at intersection for identifying platoon initialization opportunities; planned trajectory for vehicle lateral and longitudinal following) - Transmission of ego features (states of platoon state machines to manage joining, leaving, break-up, etc.	Transmission of detected object (both cars and infra)	
Used technology	ETSI ITS-G5 cch	ETSI ITS-G5 cch	ETSI ITS-G5 cch	ETSI ITS-G5 cch + sch	ETSI ITS-G5 cch OR sch	
Used standards	ETSI CAM, CDD	ETSI TS 103301 + SAE 2735	ETSI CAM, CDD	ETSI CAM, CDD	ETSI CPM	
Additional messages	MAVEN extensions (backwards compatible)	MAVEN LAM	MAVEN extensions (backwards compatible)	MAVEN extensions (backwards compatible)		
Additional protocols						

8.9.5 Working assumptions

Field	Input UC1	Input UC2	Input UC3	Input UC4	Input UC5	Remarks
Automation in sending vehicle	Level 3-5	-	Level 3-5	Level 3-5	Level 2-5	
Automation in receiving vehicle	-	Level 3-5	-	Level 3-5	Level 3-5	
Used/necessary roadside infrastructure	necessary	necessary	necessary	Not used, but infra advices can indirectly induce platoon forming or splitting	Used, not necessary	
Used/necessary central infrastructure	Might be used for high level optimization (green wave + GLOSA at corridor)	Might be used for high level optimization (green wave + GLOSA at corridor)	Might be used for high level optimization (green wave + GLOSA at corridor)	-	-	

8.9.6 Results

Field	Expected	Measured	Remarks
Result UC1	Explicit probing improves TLC planning efficiency	Demonstrated in simulation (SUMO) on large scale, demonstrated on small scale with real CAV and infra on real roads	TLC= traffic light controller
Result UC2	GLOSA and lane advice better serve traffic demands at intersections	To be demonstrated in large scale simulations (SUMO). Proof of concept demonstrated with real CAVs on test tracks and real infra on real roads	
Result UC3	I2V negotiation further increase TLC planning for better traffic demands serving at intersections	To be demonstrated in large scale simulations (SUMO). Proof of concept demonstrated with real CAV and infra on real roads	
Result UC4	Platooning application allows better traffic demands serving at intersections	To be demonstrated in large scale simulations (SUMO). Platooning functionalities demonstrated in AD Simulation environments. Proof of concept demonstrated with real CAVs and infra on test track and on real roads. Real road tests demonstrate the high dependency from sensor fusion performance	AD: Automated Driving
Result UC5	Cooperative detection allows safer planning at road intersection to take into account hidden obstacles	Platooning functionalities demonstrated in AD Simulation environments. Proof of concept demonstrated with real CAVs on test track. Real road tests will be performed to test against real infrastructure.	

Additional details

Please find more information on the current and future MAVEN deliverables available at http://maven-its.eu/

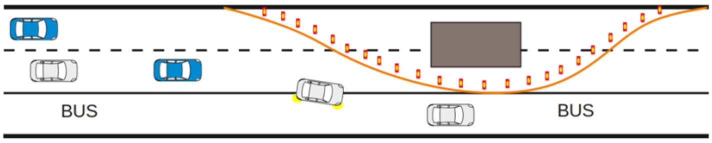
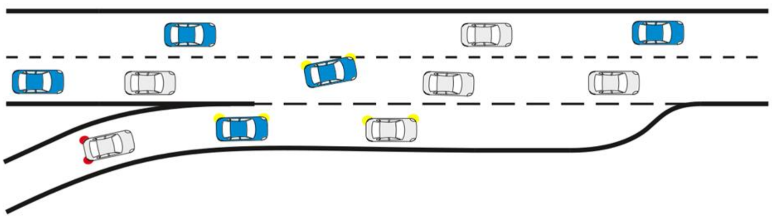
8.10 TransAID

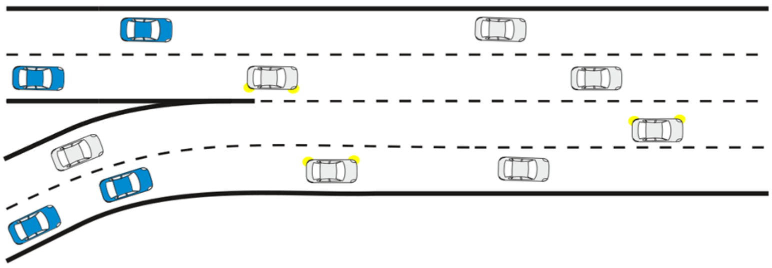
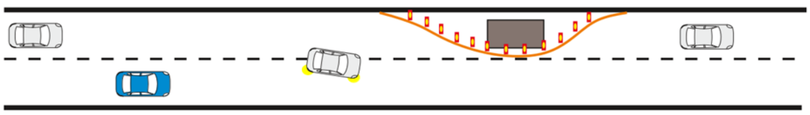
8.10.1 Project details

Field	Input	Remarks
Editor	Michele Rondinone, Hyundai Motor Europe Technical Center - HMETC (Germany), mrondinone@hyundai-europe.com	Please give your name and email
Project title	H2020 TransAID (Transition Areas for Infrastructure–assisted driving), https://www.transaid.eu/	Project title
Project lead	Julian Schindler, DLR (DE), Julian.Schindler@dlr.de	Please give name and email
Consortium	DLR (DE), Dynniq (NL), Hyundai Motor Europe Technical Center (DE), University Miguel Hernandez of Elche (ES), Centre for Research and Technology Hellas (GR), Transport & Mobility Leuven (BE), Map Traffic Management (NL)	Please list additional involved entities
Abstract	As the introduction of automated vehicles becomes feasible it is necessary to investigate their impacts on traffic safety and efficiency. This is particularly true during the early stages of market introduction, where automated vehicles of all SAE levels, connected vehicles (able to communicate via V2X), and conventional vehicles share the same roads with varying penetration rates. There will be areas and situations on the roads where high automation can be granted, and others where it is not allowed or not possible due to missing sensor inputs, high complexity situations, … At these areas many automated vehicles will change their level of automation. We refer to these areas as “Transition Areas”. TransAID develops and demonstrates traffic management procedures and protocols to enable smooth coexistence of automated, connected, and conventional vehicles, especially at Transition Areas. A hierarchical approach is followed where control actions are implemented at different layers including centralised traffic management, infrastructure, and vehicles.	Short project description
Framework	H2020 EU programme	Please list framework for publicly funded projects or mention “company activity” or “own research”
Duration	36 Months (Sept 2017 – August 2020)	Please list project duration for temporary activities

8.10.2 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	**Prevent TOC/MRM by Providing path around the road works via bus lane:** In case road works block the main road and the alternative route is provided via the bus lane, a path must be provided to CAVs. CAVs need	ToC: Transition of Control

	to know that the normal lanes are blocked and that the bus lane is allowed for driving. If this information was not provided, the CAVs would detect the lane blockages at last moment and would need to perform a MRM (come to a stop), because no alternative route can be calculated. By receiving by the Infra a drivable path around the road works, CAVs have information about the blockage in time and can circumvent the road works using the path. In this way, CAVs can maintain their AD mode and ToCs and/or MRMs are prevented 	to manual mode CAV: Cooperative Automated Vehicle MRM: Minimum risk maneuver
Use-Case 2	**Prevent ToC/MRM by providing speed, headway and/or lane advice:** This UC focusses on motorway onramp merging sections as is illustrated in the figure below. The lateral perception of automated vehicles is usually limited to the immediate area around the vehicle required for changing lanes at that moment. However, at the on-ramp it is more important to oversee a larger section of the motorway. On the main road automated vehicles may not break up platoons or create extra space for vehicles on the onramp when they have no space to merge. The infrastructure can assist in both cases using its sensors that measure the traffic situation at both the onramp and the motorway itself and broadcast advice messages to assist the merging process. Without infrastructure assistance, situations would occur where the automated vehicles cannot solve the situation and have to initiate a ToC or MRM to mitigate potentially dangerous situations. 	
Use-Case 3	**Apply traffic separation before motorway merging/diverging:** This UC aims at reducing the interactions between automated and non-automated vehicles and consequently the number of potential ToCs on automated vehicles by separating these vehicle classes over different sectors of the road. In the below figure the traffic management measure is applied to two two-lanes motorways merging in a four-lane motorway. In this scenario, the RSI disseminates a traffic separation measure where the automated vehicles are advised to move to the outermost-lanes and the non-automated vehicles are advised to move to the inner lanes. As a result, the above mentioned interactions are minimized in the middle lanes, where dangerous human-initiated manoeuvres can occur (e.g. sudden/delayed merging, cut-offs, quick take overs, etc.).	RSI: Roadside Inftastructure

		
Use case 4	**Manage minimum risk maneuvers by providing info about Safe spot in lane of blockage** This UC is basically an additional measure to the other services and is employed when the ToC is about to fail. This situation is depicted in the next figure, where road works are blocking one proceeding lane of the motorway road. The deployed RSI holds information about the construction area and its vicinity and shares this information to the approaching CAVs. Some CAVs are not able to pass the construction site without any additional guidance and in such case they need to perform a ToC. In case the ToC is not successful, the respective CAV must perform a MRM. Without additional measures, the CAV would simply brake and stop on the lane it is driving. This might disrupt the traffic flow when happening on the right lane as shown in the figure. To avoid this situation, the RSI continuously monitors the area just in front of the construction site and offers a place on the road as a safe spot to the vehicle, if available. This safe spot may e.g. be placed in front of the construction site on the closed lane. The CAVs will use this shared safe spot information to plan and execute the MRM in a less critical way. 	
Use Case 5	**Schedule ToCs before no AD zone:** After a transition of control (ToC) from automated to manual mode, the driving characteristics are different (e.g. different headway, different lateral movement variation, different overtaking behavior, etc.). Consequently, the traffic flow and safety are disturbed at Transition Areas, where multiple transitions of control occur. To prevent these negative effects ToCs are distributed in time and space upstream of the Transition Area. As a result, the ToCs are extended to a large area and thus the negative effects of ToC in the traffic flow and safety are reduced. Next figure shows the use case where multiple CAVs are approaching an area where the automated driving is not possible. This can occur because the automated driving mode reaches its system limits, due to the complexity of the situation, or due to a particular traffic regulation that forbids the automated mode in this area. The RSI collects information about the traffic stream and determines the optimal location and time for	VRU: Vulnerable road user

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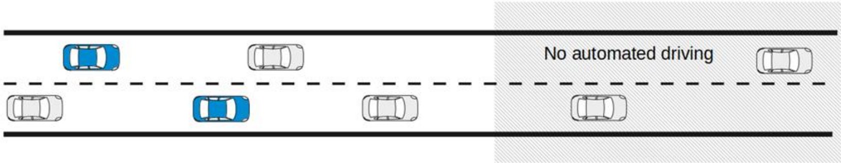
<tr>
<td></td>
<td>the CAVs to perform a downward ToC. CAVs approaching the no AD zone receive the ToC advises and execute the ToC before entering the area. As a result, the ToCs are extended to a large area and thus the negative effects of ToC in the traffic flow and safety are reduced

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Field	Input	Remarks
Facilities 1	At the vehicle side: extensions of the standard ETSI ITS Cooperative Awareness Message (CAM) service allowing CAVs to explicitly communicate the current automation level as well as its distance from the preceding and following vehicle	For all UCs
Facility 2	At the vehicle side: extensions of the standard ETSI ITS DENM service allowing CAVs and infra to explicitly communicate the occurrence of ToC, MRM At the infra side: extensions of the standard ETSI ITS DENM service allowing infra to explicitly communicate the presence of a non-AD suitable road section	For all UCs
Facility 3	At the vehicle side: Collective perception service to let the RSI be aware about non-cooperative vehicles, hence allowing to better estimate the traffic flow as well as the traffic composition	For all UCs
	At the infra side: the ETSI IVIM service based on the ISO IVI format is used by the RSI to transmit static as well as dynamic road sign and message sign information on highways. Applying this approach to TransAID allows RSI to fulfil the generic requirement of sharing information about traffic rules to be respected. Furthermore, the IVIM can also be employed to transmit generic advices (i.e. speed advices) to cooperative vehicles that are not able to decode Day 2 and beyond messages such as the MCM.	For all UCs IVI: In-vehicle Information MCM: Maneuver coordination message
Facility 4	At the infrastructure side: I2V standard SPAT/MAP services profiled or extended for indicating the availability of safe spots to stop	For UC4
Facility 5	At the vehicle side: proposal for MCS service indicating planned and desired trajectory, target automation level, occurrence and characteristics of ToC and MRM, as well as feedback on compliance to Infra advices At the infra side: proposal for MCS service extension allowing the RSI to participate in the MCS service. The	For all UCs

	TransAID MCS proposes an MCM format differentiating between MCM containers sent by a vehicle and containers sent by the infrastructure. The RSI container will include information to coordinate the traffic from a global perspective in order to increase the traffic flow and safety. The infrastructure will transmit in this container a generic vehicle advice data field to individual CAVs. This generic advice will in turn include different specific advice types. There are three different specific advice types, the lane advice, the car following advice (speed or gap) and the ToC advice	
Facility 4	At the vehicle side and infra side: Extended LDM including an underlying HD map representation of the intersection where HD map features (lane groups) can be associated C-ITS features (SAE SPAT/MAP intersectionID, LaneID, SignalGroup, etc)	For all UCs
Facility 7	At the vehicle side and infra side: Extended LDM capability to properly fuse and track information received via C-ITS (CAMs, CPMs) with information detected via local sensors	For all UCs

8.10.3 Addressed challenges

Field	Input	Remarks
Challenge 1	Fusion and tracking of C-ITS info combined with local sensor detected info. If not done properly negatively affects the performance cooperative detection/reaction applications	Add a short description
Challenge 2	Definition of object quality/confidence for its inclusion in CPM message. If not harmonized, can lead to misuse at receiving side	

8.10.4 Communication

Field	Input UC1	Input UC2	Input UC3	Input UC4	Input UC5	Remarks
Scope of communication	- Transmission of vehicle ego motion, and currently supported AD level - Transmission of vehicle detected objects - Transmission of infra lane change advices	- Transmission of vehicle ego motion and currently supported AD level - Transmission of vehicle detected objects - Transmission of infra lane change advices, speed, headway advices	- Transmission of vehicle ego motion and currently supported AD level - Transmission of vehicle detected objects - Transmission of infra lane change advices	- Transmission of vehicle ego motion and currently supported AD level - Transmission of vehicle detected objects - transmission of MRM occurrence - Transmission of infra lane change advices - transmission of infra safe spot availability	- Transmission of vehicle ego motion and currently supported AD level - Transmission of vehicle detected objects - Transmission of infra ToC advices	Please list the main scope of communication here (e.g. transmission of ego motion, negotiation, ..)
Used technology	ETSI ITS-G5	ETSI ITS-G5	ETSI ITS-G5	ETSI ITS-G5	ETSI ITS-G5	E.g. ETSI ITS-G5
Used standards	ETSI CAM, CDD, ETSI TS 103301, ISO IVI, ETSI CPM	ETSI CAM, CDD, ETSI TS 103301, ISO IVI, ETSI CPM	ETSI CAM, CDD, ETSI TS 103301, ISO IVI, ETSI CPM	ETSI CAM, ETSI DENM, CDD, ETSI TS 103301, ISO IVI, ETSI CPM, SAE J2735	ETSI CAM, ETSI DENM, CDD, ETSI TS 103301, ISO IVI, ETSI CPM	Please list standard and version, if applicable
Additional messages	TransAID CAM extensions (backwards compatible), TransAID MCS proposal for infra participation in maneuver coordination	TransAID CAM extensions (backwards compatible), TransAID MCS proposal for infra participation in maneuver coordination	TransAID CAM extensions (backwards compatible), TransAID MCS proposal for infra participation in maneuver coordination	TransAID CAM extensions (backwards compatible), TransAID MCS proposal for infra participation in maneuver coordination	TransAID CAM extensions (backwards compatible), TransAID MCS proposal for infra participation in maneuver coordination	Please describe shortly messages used if deviating/extending from standard (e.g. CPM)

Additional protocols	Please list used protocols if deviating/extending from standard (e.g. negotiation protocols)

8.10.5 Working assumptions

Field	Input UC1	Input UC2	Input UC3	Input UC4	Input UC5	Remarks
Automation in sending vehicle	Level 2-5	Level 2-5	Level 2-5	Level 2-5	Level 2-5	Which SAE level is addressed
Automation in receiving vehicle	Level 2-5	Level 2-5	Level 2-5	Level 2-5	Level 2-5	Which SAE level is addressed
Used/necessary roadside infrastructure	necessary	necessary	necessary	necessary	necessary	Please describe, if roadside infrastructure (sensors, communication, …) is used or necessary
Used/necessary central infrastructure	Might be useful	Might be useful	Might be useful	Might be useful	Might be useful	Please describe, if central / cloud infrastructure is used or necessary

Results

Field	Expected	Measured	Remarks
Result UC1			
Result UC2			
Result UC3			
Result UC4			
Result UC5			

8.10.6 Additional details

Please find more information on the current and future MAVEN deliverables available at https://www.transaid.eu/

8.11 ICT4CART

8.11.1 Project details

Field	Input	Remarks
Editor	Dr. Angelos Amditis a.amditis@iccs.gr	
Project title	ICT4CART: ICT Infrastructure for Connected and Automated Road Transport	
Project lead	Dr. Angelos Amditis a.amditis@iccs.gr	
Consortium	• INSTITUTE OF COMMUNICATION AND COMPUTER SYSTEMS (ICCS), Greece • IBM IRELAND LIMITED (IBM-IE), Ireland • IBM RESEARCH GMBH (IBM-Z), Switzerland • CENTRO RICERCHE FIAT SCPA (CRF), Italy • BAYERISCHE MOTOREN WERKE AKTIENGESELLSCHAFT (BMW), Germany • NOKIA SOLUTIONS AND NETWORKS GMBH &CO KG (NOKIA), Germany • WIND TRE SPA (WIND), Italy • T-Mobile Austria (T-MOB), Austria • ROBERT BOSCH GMBH (BOSCH), Germany • SWARCO MIZAR SRL (SWM), Italy • CASSIDIAN CYBERSECURITY SAS (AIRBUS), France • AUTOBAHNEN- UND SCHNELLSTRASSEN-FINANZIERUNGS- AKTIENGESELLSCHAFT (ASFINAG), Austria • AUSTRIATECH - GESELLSCHAFT DES BUNDES FUR TECHNOLOGIEPOLITISCHE MASSNAHMEN GMBH (ATE), Austria • UNIVERSITAET ULM (UULM), Germany • NAYTILIAKES METAFORIKES KAI EPIKOINONIAKES EPIXEIRISEIS SEABILITY EPE (SEAB), Greece	

	• LINKS FOUNDATION – LEADING INNOVATION & KNOWLEDGE FOR SOCIETY (LINKS), Italy • EUROPEAN ROAD TRANSPORT TELEMATICSIMPLEMENTATION COORDINATION ORGANISATION - INTELLIGENT TRANRANSPORT SYSTEMS & SERVICES EUROPE (ERTICO), Belgium • Stadt Ulm (COU), Germany • COMUNE DI VERONA (CDV), Italy • SOCIETA PER AZIONI AUTOSTRADA DEL BRENNERO (BRENNER-AUTOBAHN) (BRE), Italy • Urban Foresight Limited (UFL), UK	
Abstract	ICT4CART, totally aligned with the EU vision, is providing an ICT infrastructure to enable the transition towards road transport automation. To meet this high level objective ICT4CART is bringing together, adapting and improving technological advances from different industries, mainly telecom, automotive and IT. It adopts a hybrid communication approach where all the major wireless technologies, i.e. cellular and ITS G5, are integrated under a flexible network architecture. This architecture will ensure performance and resilience for different groups of applications according to the needs of higher levels of automation (L3 & L4). On top of that, a distributed IT environment for data aggregation and analytics will be implemented. This offers seamless integration and exchange of data and services between all the different actors, allowing 3rd parties to develop, deliver and provide innovative services, thus creating new business opportunities. Cyber-security and data privacy aspects will be duly considered throughout the whole ICT infrastructure. In addition, novel accurate localization services, exploiting the cellular network and information from other sources, such as on-board sensors, especially in complex areas (e.g. urban), will be addressed. To achieve its objectives ICT4CART, instead of working in generic solutions with questionable impact, it builds on four specific high-value use cases (urban and highway) which will be demonstrated and validated under real-life conditions at the test sites in Austria, Germany, Italy and across the Italian-Austrian borders.	Short project description
Framework	EU Horizon 2020 ART-01-2017 Innovation Action (IA) call (Automated Road Transport)	
Duration	September 2019 – August 2021 (36 months)	

8.11.2 Use-cases & Facilities

Field	Input	Remarks
UC1:	**Smart Parking & IoT services** According to the European strategy for connected and automated mobility, parking services (belonging to Day 1.5 list) are a priority in the next period. ICT4CART is dealing with parking services in cases with and without coverage (i.e., with/without cellular coverage and GNSS availability). Park & Ride information in order to establish a proper connection with Public Transport means will be also investigated in this use case.	

UC2: **Dynamic adaptation of vehicle automation level based on infrastructure information**

The main goal of this UC is to enable a comfortable and safe automated driving for SAE Level 3/4 vehicles. In principle we extend the sensor range of a highly automated vehicle with real-time information from the road infrastructure (e.g. traffic density, roadworks) using cellular and/or ad-hoc communications. This enables the automated vehicle to take decisions before reaching a potential critical situation and handover the control to the driver or come to a safe stop if needed.

UC3: **Intersection crossing (urban) & lane merging (highway) – "virtual mirror"**

Intersection crossing and lane merging is one of the most challenging use cases and of significant importance, considering that several traffic accidents occur in such situations. The intention here is to exploit hybrid connectivity and MEC to create a 360o awareness around the vehicle with very low latency, creating a kind of "virtual mirror" to support the automated vehicle while crossing an intersection or merging into a lane. The goal of ICT4CART in this use case is to enable the crossing of the intersection and/or the lane merging in an automated way involving mixed traffic.

UC4: **Cross Border Interoperability**

The target of this use case is to test and demonstrate the cross-border interoperability and functionality of the developed ICT4CART infrastructure. In one country an automated driving function may be using information received from the ITS G5 network, while in the neighbouring country may be using information from the cellular network. The purpose is to show that while crossing the border the operation of this function is kept uninterrupted, due to the ICT4CART infrastructure capabilities.

Field	Input	Remarks
Core ICT4CART Services/ Functions	***C-ITS Services*** C-ITS services such as Common Awareness, Decentralized Environmental Notification, Traffic Light Manoeuvre or Infrastructure-to-Vehicle Information are used to manage the generation, transmission and reception of C-ITS messages. ***Environment Perception Model Building and Fusion*** Data from vehicles and/or infrastructure are received and then processed in the Environment Perception Model (EPM) Building and Fusion function. This way, an EPM of the surveyed area is created, which is then provided to the road users. ***Service Provider Gateway*** The Service Provider Gateway (SPG) collects the data from various different vendors and provides a single downstream interface to the communication infrastructure. Based on historic data, the SPG makes predictions for parking space availability in a specific area and time frame. ***Geo Service*** The Geo Service determines the relevance radius for ITS messages, the group of wireless stations that transmit these ITS messages and the	

Connected and Automated Vehicles (CAVs) that are in the relevance radius.

Location Correction Data

To allow precise positioning of the CAV, the Location Correction Data function provides correction data for Global Navigation Satellite Systems (GNSS) data by using either physical reference stations or network-based ones.

Message Broker

The Message Broker is part of the hybrid C-ITS approach and will be used by CAVs to subscribe for messages of interest based on geographical location. There will be at least one Message Broker per country.

Analytics Services

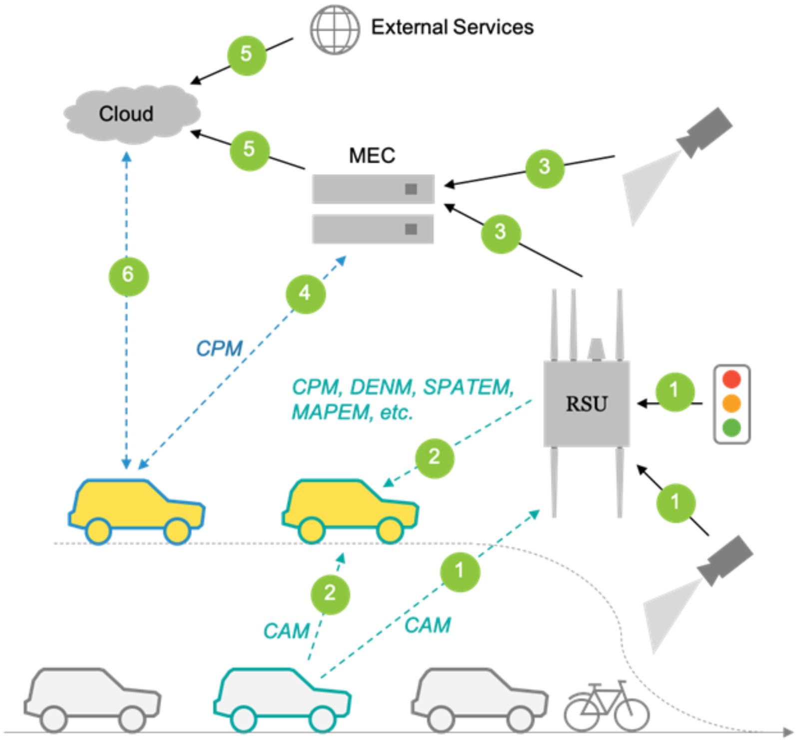
Analytics Services refine data by using algorithms in order to prepare them for other services. The SPG for example will make use of Analytic Services to make predictions of service availability for the future.

8.11.3 Addressed challenges

Field	Input	Remarks
Challenges	• Short range communications (e.g., 802.11p) have a limited availability due to all kind of physical effects such as shielding by hills, buildings, trucks or others, jammers, channel congestion, breakdowns, etc. Knowing that automated driving needs to rely more and more on connectivity, this low availability is not sufficient. • In high crowded environments, where many hundreds of vehicles can be present, the network could be quite overloaded by the exchange of CAM and DENM messages. • Lack of hybrid connectivity developments integrating smoothly the latest advances in both commercial and ad-hoc telecom networks. • Lack of cross-border testing activities in EU; currently limited to specification of common communication profiles among countries and interoperability testing (using the same vehicles in different countries). • Automated vehicles generate their Environmental Perception Model (EPM), based on embedded sensor data, short range messages and sensor data shared between vehicles. There will be a long phase where sensor data sharing will not be possible because of a lack of standards. • Data related services are highly dependent on the underlying network, data are not exchanged in an interoperable and standard way, while the semantics of the data exchanged may not be "understandable". • Fragmented and partial solutions related to cyber-security mechanisms for connected and automated driving. • Current data privacy mechanisms are insufficient for automated driving purposes. • Scarce availability of monetary resources and land use limitations for upgrading the civil infrastructure (roads construction, dedicated equipment e.g. RSUs, etc.).	

8.11.4 Communication

Field	UC1-UC4 (actual plan TBD per UC)	Remarks
Scope of communication	1. Road users (e.g., vehicles) or sensors may submit data to a road-side unit (RSU) about the current “driving environment”, e.g., cooperative awareness message (CAM) from vehicles, positions, speeds and directions of road users detected by sensors, information about obstacles, traffic signs, parking availability, etc.). 2. Consumer vehicles equipped with communication modules may receive data directly from an RSU or a MEC server, e.g., collective perception message (CPM), decentralized environmental notification message (DENM), signal phase and timing extended message (SPATEM), map extended message (MAPEM). They may also receive data directly from other vehicles, e.g., CAM, CPM. These may be used for short-term decisions and control. 3. One or multiple RSUs and road sensors may push their data to a multi-access edge computing (MEC) server in their vicinity. 4. A vehicle may exchange collective perception messages with a MEC server in its vicinity. 5. A cloud platform receives data from MEC servers, RSUs or ITS stations, and external services (e.g., third-party parking service, traffic service, etc.) to create large-scale maps and predictions (e.g., parking availability predictions, traffic jam analysis, etc.). 6. Vehicles may receive data from the cloud platform about traffic jams in their vicinities, parking availability predictions, etc. These may be used for long-term (strategic) decisions and for automation level adaptation.	



Used technology	ETSI ITS-G5 LTE 5G

Used standards

	Data Type	Relevant Standards
Provided by the IT Environment	Environment perception models (EPMs) for use by the automated driving (AD) vehicles	CPM as will be specified in ETSI TS 103 324 [15]
	Intersection map and topology	MAPEM as specified by ETSI TS 103 301 [22]
	Traffic light data	SPATEM as specified by ETSI TS 103 301 [22]
	Situations and events (e.g., accident, road closure, etc.)	DENM [23], DATEX II [24]
	Real-time parking spot and charging station availability	DATEX II [24], Open Mobility Vocabulary (MobiVoc) [25]
	Extracted or aggregated information and predictions, such as parking predictions, traffic jams, etc.	To be defined depending on the type of output data
	Correction data for GNSS-based localisation	ETSI TS 103 301 [22]
	HD Maps	To be defined
Consumed by the IT Environment	EPMs, or data required to build EPMs, from RSUs and road signs and sensors	CPM, CAM as specified by ETSI EN 302 672-2 [23]
	Data directly received from road signs and sensors in the absence of RSUs	CPM, DENM
	Data received from traffic and parking services	DATEX II
	Data received from vehicles either directly or indirectly through RSUs	CPM, CAM

Additional messages SEE ABOVE

Additional protocols

8.11.5 Working assumptions

Field	UC1-UC4	Remarks
Automation in sending vehicle	L3-L4	
Automation in receiving vehicle	L3-L4	
Used/necessary roadside infrastructure	**Traffic Sensors** Traffic sensors provide the Traffic Control Center with vital sensor information regarding the current traffic in the surveyed area. These sensors include observation sensors like video cameras, vehicle detectors like magnetic coils, and depth sensors like LiDAR sensors. **Traffic Lights** Connected traffic lights are used to adaptively control the traffic. They can both display the information and provide it digitally. In addition to the traffic light status, the remaining time to the next signal change may be shared. **Toll Stations** Toll Stations provide data regarding operational lanes, their occupancy rate, and available payment methods.	
Used/necessary central infrastructure	**Parking Service Provider (SP)** Parking Service Providers supply information regarding currently available parking spots to the Service Provider Gateway (SPG). In addition to the number of vacant parking spaces, their location is provided for navigation purposes. The providers may also make historic data available for prediction purposes. **Charging Service Provider (SP)** Charging Service Providers supply data regarding currently available charging stations to the SPG. The locations and the technical characteristics, like available charging plug types and charging modes, are shared. The providers may also make historic data available for prediction purposes. **Traffic Control Centre**	

	The Traffic Control Centre (TCC) provides the relevant data from the road infrastructure operator. This includes information like the maximum speed limit, the location of road works zones, or the current weather situation.

8.11.6 Results

The project is on its M10 out of the 36 months of duration and has not achieved any technical results so far. It is in its architectural specification and roll out phase.

8.12 MEC-View

8.12.1 Project details

Field	Input	Remarks
Editor	Dr. Rüdiger Walter Henn, Robert Bosch GmbH Ruediger.henn@de.bosch.com	
Project title	MEC-View Mobile Edge Computing basierte Objekterkennung für hoch- und vollautomatisiertes Fahren	
Project lead	Robert Bosch GmbH (Projektkoordinator) Ruediger.henn@de.bosch.com	
Consortium	The project consortium incorporates partners of various industries, academia, and public (associated): Daimler AG, IT-Designers GmbH, Nokia Solutions and Networks GmbH & Co.KG, OSRAM GmbH, Robert Bosch GmbH (coordination) and Robert Bosch Car Multimedia GmbH, TomTom Development Germany GmbH, University of Duisburg-Essen, University of Ulm, City of Ulm (associated).	
Abstract	Automated driving in complex urban environments is limited due to occlusions of relevant road users or obstacles – in these situations the performance of vehicle bound surround sensor systems is limited as a matter of principle, which either cannot be compensated by car-2-car connectivity in scenarios of incomplete sensing capability and/or connectivity of the overall vehicle fleet. To tackle this problem, the publicly funded project MEC-View focusses on the evaluation of a complementary road side sensor system and a high-precision digital map of the driving environment in addition to the sensor systems and processing capability of an automated vehicle. Based on the roadside sensor objects, a mobile edge computing (MEC) server frontend delivers a local environment model via a prototype 5G mobile network to the automated vehicle. The overall system will be implemented and verified in a test area at the city of Ulm in unrestricted urban traffic by means of a dedicated use case: an automated vehicle, relying on the local MEC environment model, shall seamlessly enter a priority road at an urban road junction. In order to meet these requirements novel approaches for the prediction of dynamic	

	objects and the intention planning by means of machine learning concepts will be essential. The MEC-View project strives for a save and efficient automated driving in complex and challenging urban situations. Moreover, the system provides an improved perception of vulnerable road users, e.g. pedestrians, cyclists and motor bikers.	
Framework	The MEC-View project is funded by the Federal Ministry of Economic Affairs and Energy (BMWi) on behalf of the German Bundestag.	
Duration	11.2016 – 05.2020	

8.12.2 Use-cases & Facilities

Field	Input	Remarks
Use-Case 1	“Virtual Mirror”: Automated vehicles receive object data information of road users that cannot be detected by the onboard sensor system.	
Use-Case 2	The operational use case, which is showcased at a test area in Ulm, is a seamless merge of a connected automated vehicle (CAV) on to a priority road without stopping. The CAV approaches a crossway on a side road and synchronizes on a gap between adjacent vehicles on the priority road.	

Field	Input	Remarks
Facility 1	Infrastructure sensor system (Lidar and Video)on street lights	
Facility 2	LTE/5G prototype network for the low latency data transmission	
Facility 3	Mobile edge computing server for the calculation of the local environment model (sensor data fusion, georeferencing and object tracking)	

8.12.3 Addressed challenges

Field	Input	Remarks
Challenge 1	Robust and reliable detection and classification of the road users of a local environment by road side sensors.	
Challenge 2	Low latency and delay in the overall system: - Data capturing and image processing, detection and classification at the road side - Data transmission from the road side units to the MEC-server and from the MEC-server to the CAV - Data processing and reaction of the CAV	

8.12.4 Communication

Field	Input UC1	Remarks
Scope of communication	Transmission of object state data. Transmission of free spaces	
Used technology	LTE, 5G	
Used standards	Prototype implementation	
Additional messages	Message content and format is optimized for the MEC-View use case	
Additional protocols	ANS.1	

8.12.5 Working assumptions

Field	Input UC1	Remarks
Automation in sending vehicle	Not applicable	
Automation in receiving vehicle	L3	
Used/necessary roadside infrastructure	Video and Lidar Sensors mounted on streetlights at the test area. Data pre-processing and LTE/5G communication modules in road side units.	
Used/necessary central infrastructure	Mobile edge computing server for the calculation of the environment model	

8.12.6 Results

Field	Expected	Measured	Remarks
Total system delay	< 200 ms	270 ms (05.2019)	

8.12.7 Additional details

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- Gabb, M.; Maier, M.; Müller, T.; Henn, R.-W.; Müller, J. & Buchholz, M. Urban Automated Driving using Environment Perception as a Service, ITS World Congress, 2018

- Müller, J.; Gabb, M. & Buchholz, M. A Subjective-Logic-based Reliability Estimation Mechanism for Cooperative Information with Application to IV's Safety, IEEE Intelligent Vehicles Symposium 2019

- Gabb, M.; Digel, H.; Müller, T. & Henn. R.W. Infrastructure-Supported Perception and Track-Level Fusion Using Edge Computing, IEEE Intelligent Vehicles Symposium 2019

8.12.7.1 Attachments / Links

www.mec-view.de

8.13 MAVEN CPS testing results

The above mentioned CPS application (see section 4.1.5) scenario has been tested by MAVEN with proving ground tests using Hyundai CAV prototypes with limited sensing capabilities (1 front LiDAR, 2 front short-range corner radar, one front medium-range radar, one front mono camera) to highlight the complementary benefits of CPS. A pedestrian dummy is used to cross at a configurable distance d_{int} from the intersection centre (see Figure 9). The CAV has to drive automated along a route having a conflicting right turn with the VRU and is programmed to stop as soon as an object is detected, tracked and assessed as a threat.

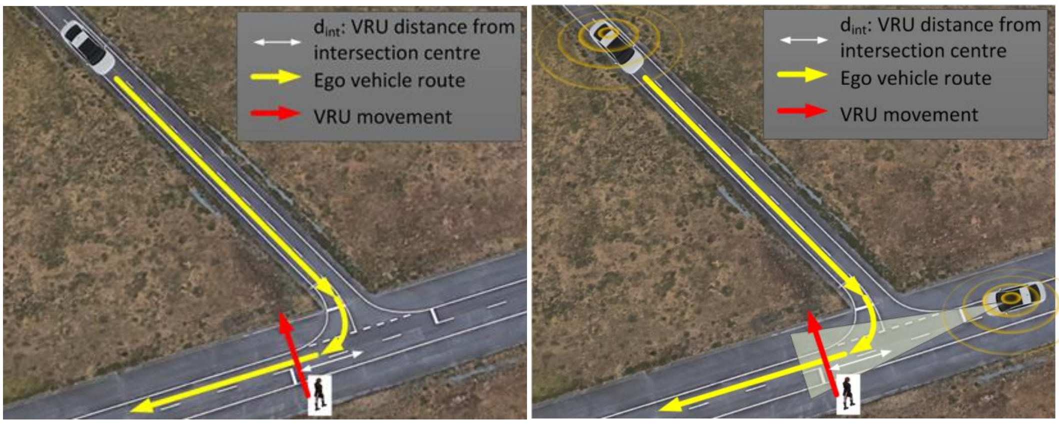


Figure 9: Evaluation setup for VRU/obstacle consideration based on on-board sensors (left) and with additional CPS (right) (visualized on GoogleMaps)

As demonstrated in [26], without the adoption of CPS, the CAV does not have enough time to correctly detect the VRU crossing at $d_{int} <= 16m$ as a threat when speeding up after turning right and has to be manually braked to avoid a collision. To overcome this limitation, the CAV is extended with functionality to take CPM information into account when operating threat assessments, manoeuvring decisions, and path and motion planning. The advantage here is that the AD logic decision modules are informed about the presence of objects along the route much before they enter the field of view of the onboard sensors, hence permitting more conservative and context-aware decisions and plans like slowing down and eventually stop before the VRU. This functionality has also been tested using the scenario depicted in the right part of Figure 9Bibliography

. By listening to the CPMs received from the other CAV, the CAV under test is constantly informed about the pedestrian crossing at d_{int}=16m. As it can be seen in Figure 10, the CAVs slow down to reach the stop line at a relatively low speed (10Kmph after covering 150m). When turning, the ego vehicle does not speed up. Instead, it further slows down as a result of taking the VRU presence into account. The ego vehicle then stops in front of the dummy, which is now correctly detected with the ego-sensors too. The CAV then waits for it to move out of the driven lane before speeding up to follow its route.

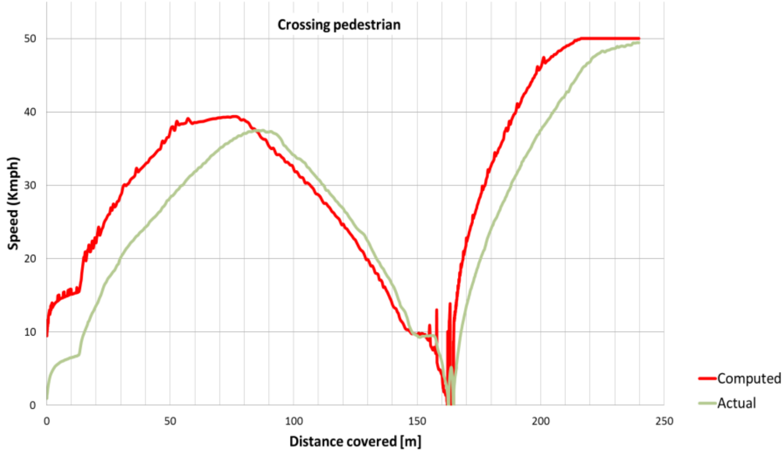


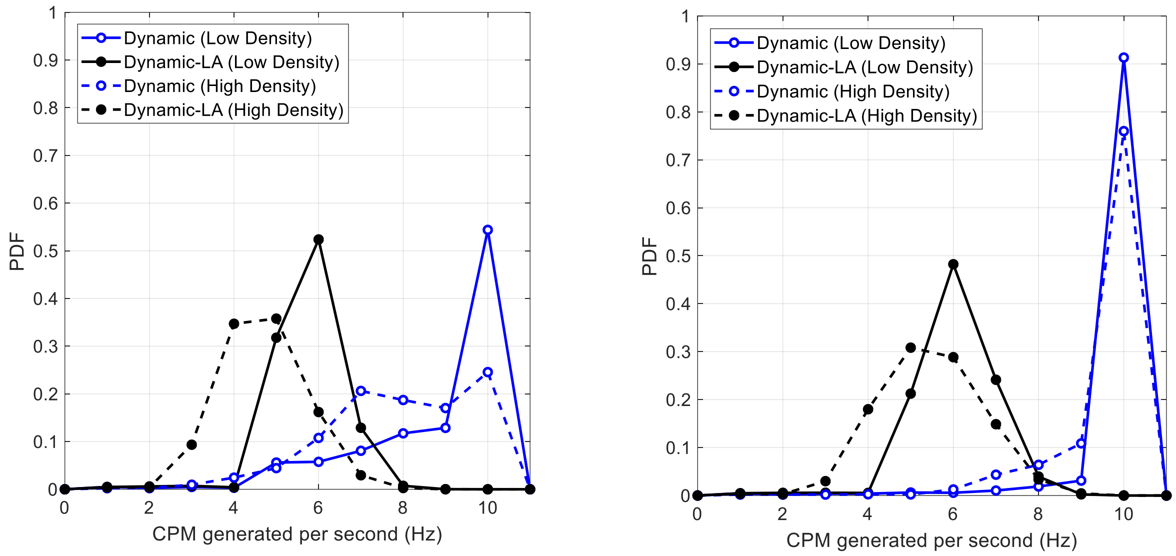
Figure 10: AD vehicle motion profile in case a collision with crossing pedestrian has been prevented via CPM information consideration

8.14 TransAID CPS contributions

Different rules are being considered at ETSI to generate CPM messages. These rules define, among others, which objects should be transmitted in a CPM, and how often they should be transmitted [7]. In general, CPM generation policies that improve the perception capabilities generate higher channel load and hence have a higher risk to saturate the communications channel. While some transmission redundancy could benefit the detection of nearby objects, unnecessary redundancy could severely impact the performance of vehicular networks. However, it is yet an open discussion whether the observed levels of redundancy are necessary to any C-ITS application or whether they could be further optimized to reduce any potential negative impact on the stability and scalability of future V2X networks. The ETSI 'Dynamic' policy for CPM generation achieves an interesting balance between perception capabilities and communications performance by looking at the dynamic properties of the detected objects to trigger their inclusion in CPMs. Instead of including all the detected objects in all the subsequent CPMs, objects are included if their dynamics have changed more than pre-defined thresholds from the last CPM transmission or if a threshold timeout has expired from their last inclusion. Beyond these generation rule definitions, TransAID developed a method for reducing the overall number of generated CPM messages by predicting the triggering conditions for objects included in the next messages ('Dynamic Look-Ahead' or

'Dynamic-LA' method). Following these predictions, all objects that would be included in the next CPM, are already selected for inclusion in the currently generated CPM. As demonstrated in [7] and indicated in Figure 11, this Dynamic-LA mechanism is able to significantly reduce the number of CPMs generated per second, independently of the traffic density (number of detectable objects) and the type of sensors considered on the ego-vehicle (forward or 360º sensors, in this case). As a result, the average number of CPMs generated per second is reduced between 34% and 43% with *Dynamic-LA*.

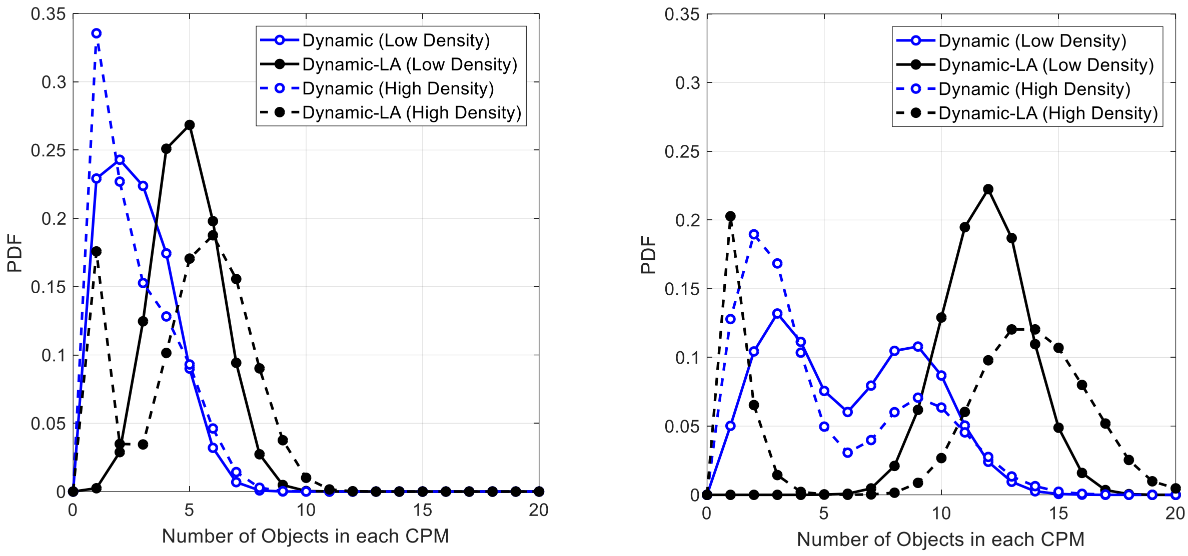
Figure 11: PDF (Probability Density Function) of the number of CPMs generated per second and per vehicle [ETSI CPS TR]



(a) Forward sensors

(b) 360º sensors

By adopting prediction of triggering conditions for objects inclusion in the CPMs, the Dynamic-LA mechanism reduces the number of CPMs transmitted with a small number of objects. On the contrary, more objects are jointly transmitted in fewer CPMs, which increases the efficiency in the channel usage. This can be observed in Figure 12 comparing the number of objects included in each CPM with and without the Dynamic-LA method. The results obtained show that the reduction of the CPM frequency with Dynamic-LA augments the number of objects per CPM.

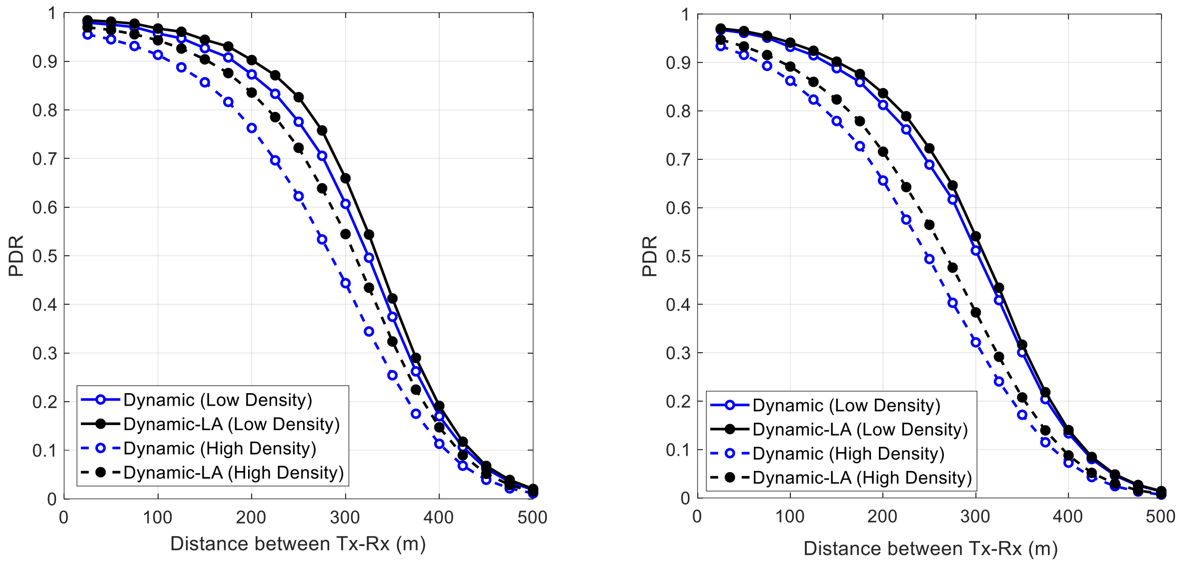


(a) Forward sensors

(b) 360º sensors

Figure 12: PDF (Probability Density Function) of the number of objects included CPMs [ETSI CPS TR]

In [7] it is shown that reducing the message frequency with the Dynamic-LA mechanism can decrease the Channel Busy Ration (CBR) between 10 % and 23 % approximately (depending on the evaluated traffic density and sensor configuration). This decrease is mainly due to the reduction of the transmission of headers (at different layers of the protocol stack) and containers related to the transmitting vehicle. Reducing the CBR has a positive impact on the PDR (Packet Delivery Ratio), defined as the probability of successfully receiving a CPM as a function of the distance between the transmitting and receiving vehicles. This improvement is due to a consequent reduction of the number of packet collisions. Figure 13 shows how the PDR can be improved with the Dynamic-LA method independently of the traffic density and type of sensor. The improvement of the PDR is especially higher for higher traffic densities, given the higher CBR gain achieved with this mechanism in these scenarios.



(a) Forward sensors (b) 360º sensors

Figure 13: PDR (Packet Delivery Ratio) as a function of the distance between transmitter and receiver for dynamic policies (S2)

The above described TransAID analysis on CPM generation rules identified that high object awareness ratios can be achieved while managing the channel load levels. Nevertheless, a deeper analysis of the detected object redundancy (number of updates received per second about the same object through the reception of CPMs from different transmitters) revealed that the dynamic generation policies can produce values of up to 25-30 updates per second. This indicates that further improvements in channel utilization can be achieved by adopting techniques for redundancy control without necessarily negatively affecting the object awareness levels. In this context, TransAID proposed a Dynamics-based mitigation rule according to which inclusion of a detected object in the own CPM is subject to analysis of CPMs previously received by other neighbours. In particular, a detected object is omitted for transmission in the next own CPM the currently estimated position and speed of the object do not vary from the one retried from reception of one of the previously received CPMs in a given time window [7].

8.15 MAVEN State machines

8.15.1 Platooning State Machine

The platooning state machine represents the overall state of the vehicle, so it describes whether the automated vehicle is currently not able to drive in a platoon, has the wish to create or join a platoon, is currently driving in a platoon, or currently leaving one. Normally, the vehicle should plan to drive in a platoon to gain the benefits of this kind of driving, like fewer waiting times on upcoming intersections. Nevertheless, the vehicle might not be able to join a platoon (state: 'Not able') due to various reasons: the needed subsystems may not be working or not getting the clearance for being active, or the driver has disengaged the platooning option. Whenever this is not the case and the system starts running, the state 'Want to form' is active. In this state, the vehicle announces that it is available for platooning by transmitting, via V2X, desired acceptable platoon characteristics, like the planned route on the upcoming intersections or the desired speed (Details can be found in Table 1). Nevertheless, it is not related to any specific situation on the road. Instead, it is more a local general plan of the vehicle's automation.

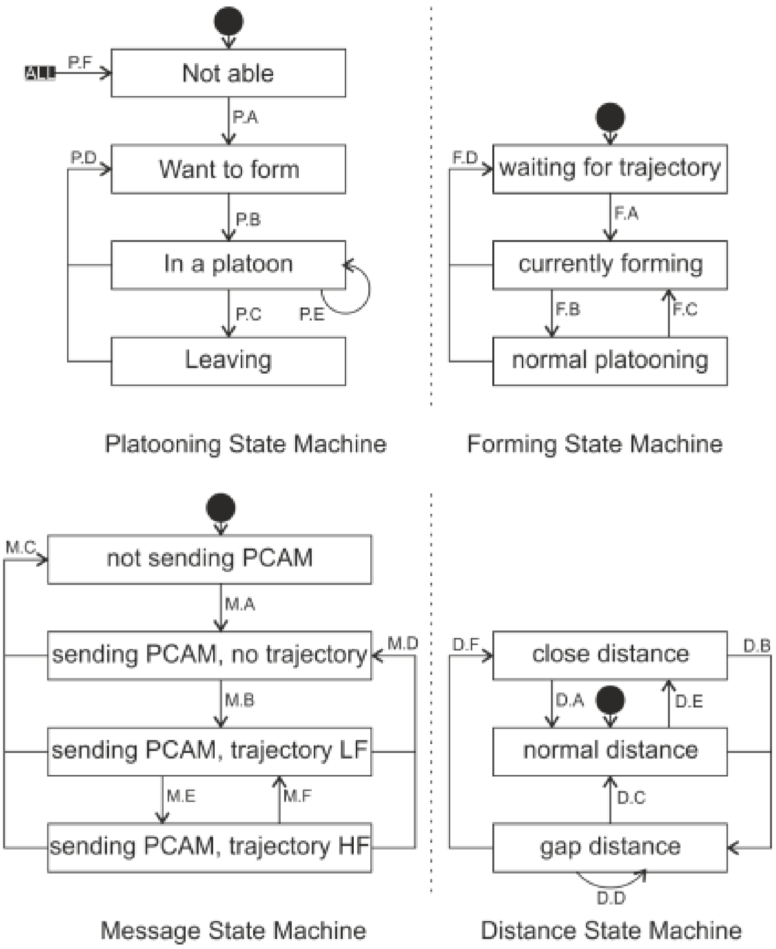


Figure 14: The four different state machines used for platooning

The platoon state machine stays in this state until a vehicle in front is detected to be close enough, transmitting matching acceptable platoon characteristics (i.e. which wants to drive the same route and with similar speed), and informing about the intention to form a platoon, which makes this vehicle a potential follower. When this is the case, the follower directly switches to 'in a platoon'. Further details of the procedure of forming a platoon are available in the forming state machine, which is activated at the moment of getting into the state 'in a platoon' and described in [10]. A predecessor (and therefore potential leader of the platoon) is switching to this state when a follower indicates the desire to follow. When the vehicle is in the state 'in a platoon' it still advertises the acceptable platoon characteristics like in the state 'Want to form', but truncated by the boundaries of the platoon participants, in order to acquire further members. The implementation does not foresee any limitation of the number of platoon members of a single platoon, as each follower is in control of the driving task on its own. Nevertheless, practically the number of followers will be limited in urban areas, as traffic lights may not guarantee green lights for all members of very long platoons, which in praxis will lead to a splitting up of the platoon into parts. Whenever a vehicle wants to or needs to leave a platoon, it will switch to the state 'Leaving' which indicates that it is not available for platooning anymore and therefore temporarily not able to form another platoon.

8.15.2 Forming State Machine

As said, the forming state machine is only active when the vehicle is in the state 'in a platoon', and therefore is kind of a sub-state machine of this. It describes the current state of the platoon forming procedure and consists of the states 'waiting for trajectory', 'currently forming' and ‘normal platooning’. The state machine is initialized in the first state, where it waits for more detailed trajectory data of the leading vehicle via V2X in the MAVEN CAM transmitted on the SCHx. As long as this data is not received, the following vehicle is not able to drive at a closer distance. Whenever this data is received, the forming process is started and the gap is reduced until the desired following distance is reached.

Message State Machine

As explained in section 4.1.7, V2X communications for MAVEN platooning rely on two Cooperative Awareness Message (CAM) extensions: the Extended CAMs on the SCH0 (Table 1, in this section, referred to as ECAMs), and the Platooning CAMs on the SCHx (Table 2, here referred to as PCAMs). In this context, the message state machine rules the inclusion of specific data elements in PCAMs and the frequency of this inclusion. It consists of four states and is running all the time. In normal driving outside of platoons and far away from other platoon forming candidates, the vehicle continuously broadcasts only ECAMs and hence is in the state ‘not sending PCAM’. Whenever it is detected that there is another vehicle, which matches its own desired platoon properties, approaching from behind and close more than a given threshold the vehicle is changing state to ‘sending PCAM, no trajectory’. By doing this, the vehicle starts transmitting basic platoon information needed by the follower to understand the predecessor’s platoon forming an intention. Whenever a vehicle behind informs about being ‘in a platoon’ state, trajectory information needs to be included at low frequency (LF), resulting in a change to ‘sending PCAM, trajectory LF’. This state is the normal state while forming a platoon or driving in a platoon with followers. Nevertheless, in some cases, it may be essential to receive trajectory data at a higher frequency (HF), e.g. when an emergency situation appears or when a fast reaction is required. To cope with such situations, the state ‘sending PCAM, trajectory HF’ has been introduced.

8.15.3 Distance State Machine

The distance state machine describes the proposed distance to the vehicle in front and is active all the time. During normal driving outside of a platoon, the state ‘normal distance’ is active. Whenever there is a situation requiring the opening of a gap in front (independent of driving in a platoon or not) the state changes to ‘gap distance’. The criteria for opening a gap are shown in Figure 15. The transition is triggered whenever there is a vehicle on an adjacent lane

- With its tail within a given range from own tail to preceding tail (blue area in Figure 15) or its front within a given range from own front to preceding front (orange area in Figure 15),
- Which is driving in the range +/-10% of own velocity,
- Which is intending to change the lane, e.g. by a set indicator, by a known lane closure ahead, or by other more sophisticated means which are currently under research.

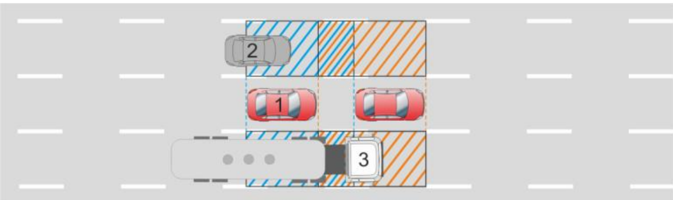


Figure 15: Ranges around vehicle 1 in which another vehicle is considered as a candidate for a lane change to V1’s lane. As the range is in relation to the tail of the other vehicle, V2 is not a candidate. The truck 3 is a candidate, because its front is in the ora

When the vehicle is currently starting to drive in a platoon with a forming state of ‘currently forming’, the distance state machine changes to ‘close distance’ in order to claim the goal of close following.

A complete description of how the MAVEN platooning state machine operates for handling several platooning use cases (i.e. Platoon initialization, Joining a platoon, Travelling in a platoon, Leaving a platoon, Platoon break-up, and Platoon termination) can be found in [10]. This description highlights the different conditions, including the exchanged V2X platooning information, that influence transitions among the different states of the state machines to effectively run the target use cases.

8.16 Maven manoeuvre advisory sample application

A sample application scenario is shown in Figure 16, where the CI wants to instruct the CAV with StationID 2 to merge to lane 1. If both vehicles before and after the gap are CAVs, the LAM can optionally provide information about them. In this way, the interested CAVs can initiate V2V manoeuvring coordination. Optimal time and space information for CAVs to start the lane change manoeuvre can be also optionally included in LAMs. However, it is provided only when the CI has sufficiently precise situational awareness. For situations where lane 1 is already full, the CI can simply advise the target lane: it will be up to the CAV to try to find a gap and eventually comply with the advice. The LAM structure is shown in Figure 17. Optional fields are marked in grey, mandatory ones in white. A lane advice list containing up to 256 vehicle- or platoon-specific advices is used. For every single advice, the target vehicle, lane, and intersection are mandatory to eliminate any ambiguity of advisory relevance. The reason for the advice is also mandatory so that CAVs can assess the criticality of the situation. The advice reason shall be chosen among several options. In this way, and given that the LAM is broadcasted, non-targeted CAVs get aware of currently active lane advices and can anticipate reactions or establish cooperative manoeuvring.

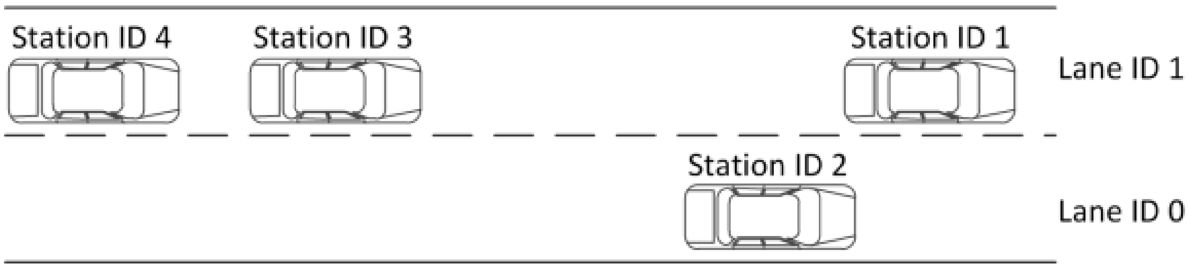


Figure 16: MAVEN lane change advisory scenario

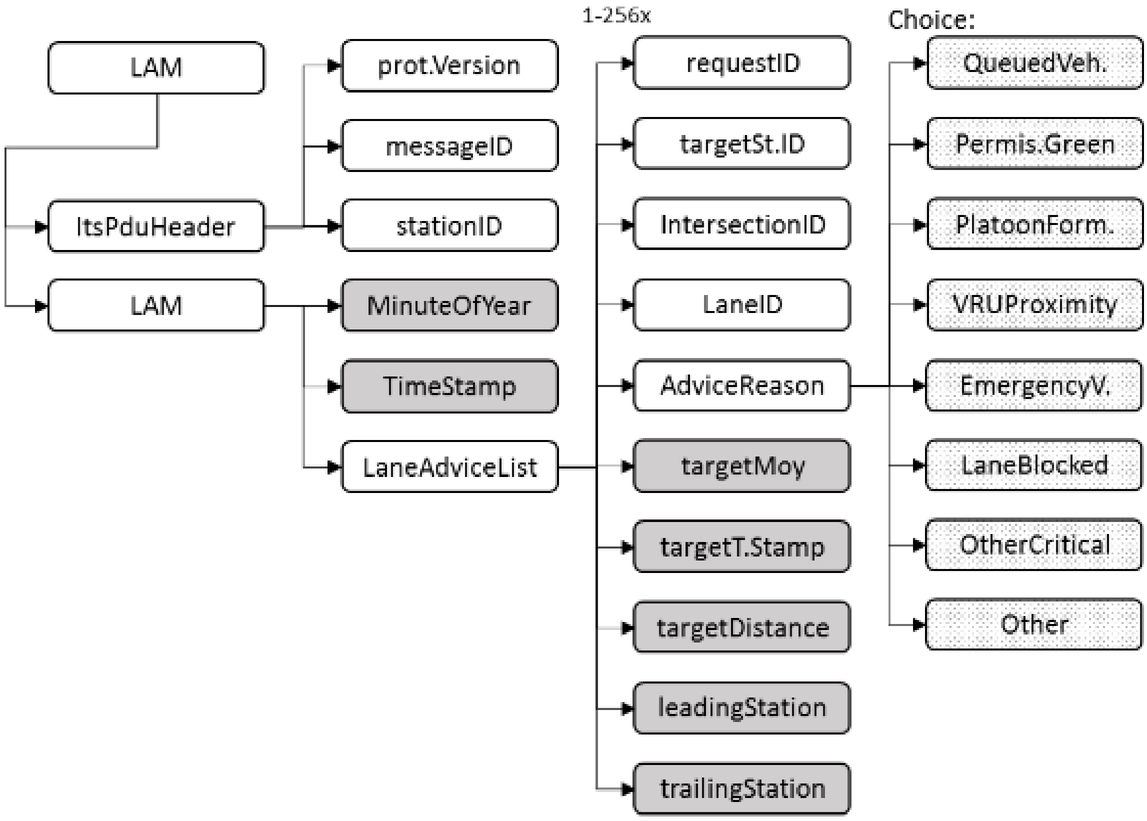


Figure 17: MAVEN Lane Change Advice Message structure

Although benefiting from the lane change advisory service, CIs will not completely balance traffic at ingressing lanes. Routing and/or vehicle class restrictions can still cause imbalances. To mitigate this effect, and let incoming CAVs pass without stopping on lanes with different occupancy levels (e.g. Figure 5a), lane-specific speed advices are needed. At signalized intersections, traffic on parallel ingressing lanes is often subject to the same traffic light signals (referred to as signal groups - SGs). In general, the MAP message indicates the SG associated with these lanes. The SPAT refers to this SG to provide a lane group-applicable speed advice. With current SPAT/MAP profiling [27] it is impossible to signalize distinct speed advices to such lanes. Current SPAT specifications only allow indicating queue length information on parallel lanes with the same SG. To overcome this limitation, MAVEN decided not to propose SPAT/MAP standards modifications, but instead a new profiling. Extra SGs are introduced and used for SPAT/MAP signalling at parallel ingressing lanes that would initially be associated with the same SG. The concept is illustrated in Figure 18. The two central lanes are subject to the same traffic light SG2. However, for SPAT/MAP signalling, SG2 is referred to with two distinct identifiers: SG1 for the rightmost lane and SG2 for the leftmost. The SPAT can now use these identifiers to provide lane-specific speed advisories on the lanes. In this way, a simple approach for CI-CAVs interoperability is achieved, which facilitates real-world implementation. This approach is not in contrast with current profiling definitions [27] and can be easily deployed.

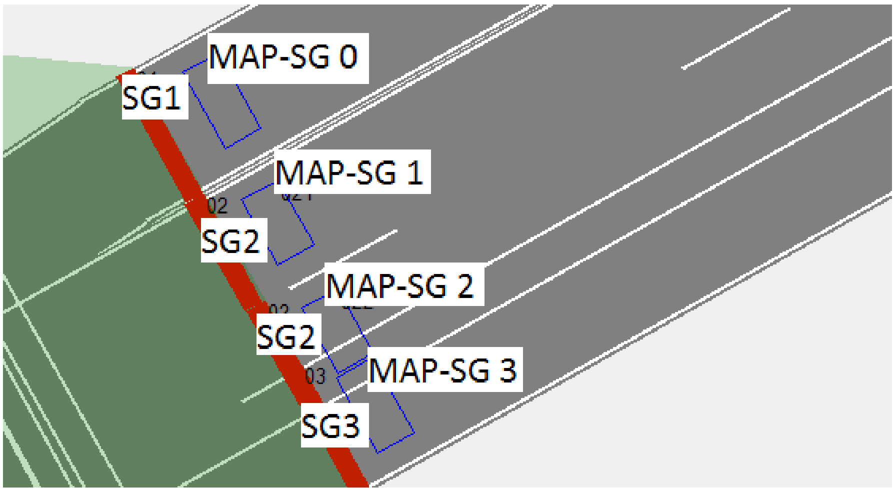


Figure 18: SG assignation for lane-specific speed advisory

MAVEN I2V interactions were successfully tested in real road traffic environments at the city of Helmond and demonstrated during the 2019 European ITS congress using a CAV from Hyundai and a traffic light controller from Dynniq (Figure 19)

Figure 19: Demonstration of MAVEN I2V interactions

9 Appendix B: Bibliography

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