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Executive Summary

The objective of the MAVEN project (Managing Automated Vehicles Enhances Network) is to deliver C-ITS-assisted solutions for managing Cooperative Automated Vehicles (CAVs) at signalised intersections and intersection corridors with the aim of increasing traffic efficiency and safety. These solutions include, among others, Infrastructure-to-Vehicle (I2V) interactions for optimal coordination of vehicle transit at intersections, consideration of small vehicle platoons and application of collective perception mechanisms.

In this context, it is key to identify and develop suitable V2X communication schemes and message sets to be concurrently adopted by CAVs and the C-ITS infrastructure deployed at signalized road intersections. In this deliverable, the MAVEN developed approaches and practical implementation solutions in this regard will be described in detail. Three major classes of communications schemes have been addressed, namely:

- I2V and V2I communications for intersection/corridor management enabling coordination/scheduling (I2V) and probing (V2I) of CAVs. For the first purpose, MAVEN has introduced a new profiling of the Signal Phase and Time (SPaT) service supporting lane-specific speed advices, and developed a novel I2V service for lane change advisory. For the second purpose, extensions of the standard ETSI ITS Cooperative Awareness Message (CAM) have been provided. These allow CAVs to explicitly communicate the planned intentions to the infrastructure and provide feedbacks on the compliance of the advised speeds or lane changes (explicit probing).
- V2V communications for platoon coordination. With the objective of supporting a common distributed platooning algorithm in which individual CAVs form platoons, manage their operation (joining, leaving, etc.), and control their motion in highly variable urban scenarios, other specific extensions of the standard ETSI ITS Cooperative Awareness Message (CAM) have been developed.
- V2X communications for collective perception. These communications enable CAVs and C-ITS infrastructure to share detected objects (pedestrian, non-cooperative vehicles, obstacles, etc.) in the observable surroundings in order to allow any receiver to increase its environmental awareness. For this purpose, the MAVEN partners have strictly collaborated within a dedicated ETSI ITS standardization group to jointly generate a V2X collective perception service suitable to the MAVEN project's vision and aim.

The deliverable will also highlight how the developed communication schemes address important aspects like backward compatibility with pre-existing systems and real-world interoperability in already deployed scenarios. Consideration of these aspects is necessary to ensure the future transfer of the MAVEN solutions into next-generation real-world deployments.

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List of Acronyms and Terms

Acronym / term	Full name / description
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
ASN.1	Abstract Syntax Notation One
BTP	Basic Transport Protocol
C2C-CC	Car2Car Communication Consortium
CA	Cooperative Awareness
CACC	Cooperative Adaptive Cruise Control
CAM	Cooperative Awareness Message
CAV	Cooperative Automated Vehicle
CDD	ETSI ITS Common Data Dictionary
CEN	European Committee for Standardization
CI	Cooperative Intersection
C-ITS	Cooperative Intelligent Transport Systems
CP	Collective Perception
CPM	Collective Perception Service
DENM	Decentralized Environmental Notification Message
DSRC	Direct Short Range Communications
EC	European Commission
ECC	Electronic Communications Committee
ETSI	European Telecommunications Standards Institute
EU	European Union
FoV	Field of View
GLOSA	Green Light Optimal Speed Advice
GPS	Global Positioning System
JSON	JavaScript Object Notation
HMI	Human Machine Interface
I2V	Vehicle to Infrastructure

IPR	Intellectual Property Rights
ISO	International Organization for Standardization
ITS	Intelligent Transport Systems
IVI	In-Vehicle Information
LAM	Lane Change Advisory Message
LAN	Local Area Network
LDM	Local Dynamic Map
MAVEN	Managing Automated Vehicles Enhances Network
OBU	On-Board Unit
OEM	Original Equipment Manufacturer
PC	Personal Computer
PER	Packed Encoding Rules
R&D	Research and Development
RSU	Roadside Unit
SCH	Service Channel
SAE	Society of Automotive Engineers
SDK	Software Development Kit
SG	Signal Group
SPaT	Signal Phase and Timing
SW	Software
TLC	Traffic Light Controller
TMC	Traffic Management Center
TransAID	Transition Areas for Infrastructure-Assisted Driving
TTC	Time To Change
UDP	User Datagram Protocol
UPER	Unaligned Packed Encoding Rules
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VRU	Vulnerable Road User
XER	XML Encoding Rules

XML	Extensible Markup Language
WP	Work Package

1 Introduction

Highly and fully automated vehicles, especially when connected to the C-ITS infrastructure, can significantly contribute to meeting the EU objective of effectively accommodating growing mobility demands while still ensuring lower environmental impacts and increased road safety. An increase of driving automation functions in newly released car models is already a visible trend. Moreover, the deployment of C-ITS technology is about to start in 2019 [1]. The combination of automated driving and C-ITS is expected to be a key enabler for distributed coordination of highly automated vehicles [2], and will eventually permit the road infrastructure to monitor, support and orchestrate their movements.

In this context, the MAVEN project (Managing Automated Vehicles Enhances Network) will deliver C-ITS-assisted solutions for managing Cooperative Automated Vehicles (CAVs) at signalised intersections and intersection corridors with the aim of increasing traffic efficiency and safety. For this purpose, traffic management algorithms for the inclusion and control of automated vehicles are developed at the infrastructure side. Thanks to V2X communications, these algorithms exchange information with automated vehicle systems that are in turn extended to include the V2X received information into the logic of their environmental perception and trajectory/manoeuvre planning modules. The MAVEN C-ITS assisted solutions include, among others, Infrastructure-to-Vehicle (I2V) interactions for optimal coordination of vehicle transit at intersection, consideration of small vehicle platoons and application of collective perception mechanisms.

In order to ensure the correct operation of the MAVEN solutions, it is key to identify and develop suitable V2X communication schemes and message sets to be concurrently adopted by CAVs and the C-ITS infrastructure deployed at signalized road intersections.

1.1 Purpose of this document

The purpose of this document is to describe in detail the communication schemes and message sets developed by the MAVEN project. Three major classes of communications schemes have been addressed, namely:

- I2V and V2I communications for intersection/corridor management enabling coordination/scheduling (I2V) and probing (V2I) of vehicles. For the first purpose, MAVEN has introduced a new profiling of the Signal Phase and Time (SPaT) service supporting lane-specific speed advices, and developed a novel I2V service for lane change advisory to CAVs. For the second purpose, extensions of the standard ETSI ITS Cooperative Awareness Message (CAM) have been provided. These allow CAVs to explicitly communicate the planned driving intentions to the infrastructure and provide a feedback on the compliance of the advised speeds or lane changes (explicit probing).
- V2V communications for platoon coordination. With the objective of supporting a common distributed platooning algorithm in which individual CAVs form platoons, manage their operation (joining, leaving, etc.), and control their motion in highly variable urban scenarios, other specific extensions of the standard ETSI ITS Cooperative Awareness Message (CAM) have been developed.
- V2X communications for collective perception. These communications enable CAVs and C-ITS infrastructure to share detected objects (pedestrian, non-cooperative vehicles, obstacles, etc.) in the observable surroundings in order to allow any receiver increasing its environmental awareness. For this purpose the MAVEN partners have strictly collaborated within a dedicated ETSI ITS standardization group to jointly generate a V2X collective perception service suitable to the MAVEN project’s vision and aim.

The deliverable also will highlight how the developed communication schemes address important aspects like backward compatibility with pre-existing systems and real-world interoperability in already deployed scenarios. Consideration of these aspects is necessary to ensure the future transfer of the MAVEN solutions into next-generation real-world deployments.

1.2 Document structure

The rest of this document is organized as follows:

Section 2 describes the main MAVEN use cases dealing with C-ITS and identifies the requirements for the generation of new communications schemes and message sets.

Section 3 highlights the communication architectures at both CAVs and Cooperative Intersections (CIs), which helps understanding the implementation of the developed communication services.

Section 4 presents the MAVEN communication services handling the schemes and message sets required by the MAVEN use cases in compliance with the CAVs and CI architectures.

Section 5 describes a sample of test bench and simulation setup used for the verification of the developed communication schemes.

Section 6 concludes the deliverable with some considerations on the future use of the developed schemes in the MAVEN integration and testing activities.

ANNEX A contains a detailed definition of the various data fields and elements of the MAVEN messages.

ANNEX B reports the ASN.1 definitions of the MAVEN messages that can be used for implementing them in real V2X hardware platforms.

ANNEX C lists MAVEN project contributions provided to relevant V2X standardization and specification activities till the time of writing this document.

2 MAVEN use cases and communication requirements

This section gives an overview of the most relevant MAVEN use cases from a V2X communication perspective and describes the associated communication requirements. These use cases can be grouped in three main classes:

1) I2V interactions
2) Platooning management
3) Inclusion of conventional traffic and VRUs

While an initial description of the MAVEN use cases can be found in the deliverable D2.1 [3], in the following sections these three main use case classes are described in order to identify the implementation solutions resulting from the co-work performed in WP3, WP4 and WP5. Based on these implementation solutions the communication requirements of each use case class are identified, which justifies the design of the communication protocols and message sets described in Section 4.

2.1 I2V interactions

For this category, CAVs and CIs interact by executing a negotiation process in which speed change advisory and lane change advisory are provided following the approach depicted in Figure 1.

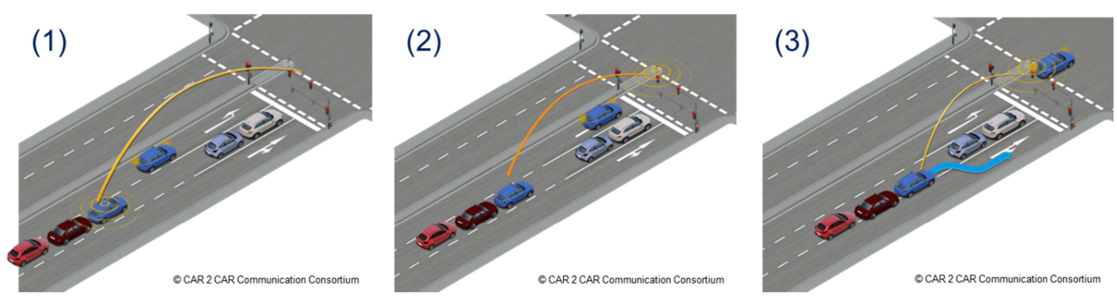


Figure 1 – MAVEN I2V interactions

As first phase of the negotiation (1), an isolated (non-platoon) CAV and/or a platoon continuously transmits information describing intentions (like expected route at intersection) or vehicle/platoon characteristics (like desired speed, platoon size, etc.). Accordingly, the CI updates its queue model and calculates new infrastructure advisories that result in transmitted suggestions for CAVs or platoons to adapt speed and/or change lane (2). As last stage of the negotiation, CAVs and/or platoons communicate if the suggestions can be executed by updating their own transmitted messages (3). This feedback can be used by the CI to put priority at the validity of the advice, e.g. ensure a stable time to green prediction. If this would not be prioritized, the traffic light controller can recalculate the timing schedule every second, resulting in constant acceleration and deceleration for the addressed vehicles.

The aforementioned interaction scenario covers several use cases previously defined in the MAVEN deliverable D2.1 [3]. These are UC7 Speed change advisory, UC8 Lane change advisory and UC15 Negotiation. These use cases require the extended CAM message described in this document to enable the vehicles to share essential information with the infrastructure. This includes expected route, desired speed, platooning status and whether the vehicle will comply with the speed advice. Without this information only the current state-of-the-art solutions are possible. All involved I2V and V2I messages should be transmitted at least every second and broadcasted so every involved actor knows about the intentions of the vehicles and traffic light planning.

Speed change advisory is also known as Green Light Optimal Speed Advice (GLOSA). It requires a definition of the intersection topology (including ingressing and egressing lanes' geographic coordinates) that is transmitted as a V2X I2V MAP message. This is used by receiving vehicles to compute the relevance of the received information with respect to their position. The dynamic information is disseminated using the Signal Phase and Timing (SPaT) V2X I2V message and contains the traffic lights' time to change and speed advice information that apply to group of ingressing lanes. The MAP and SPaT messages are already standardized [15] and profiled [19]. However, the interpretation of their content at the receiving side (cooperative vehicles), and the relation between this content and the actual current status of the traffic light controller can still lead to confusion. Knowing how to interpret the SPaT content at the receiving side is particularly critical in the case of CAVs. In fact, the automated behaviour of CAVs when approaching a CI will strongly depend on the information communicated in this message. Based on the correct interpretation of the SPaT content, and together with other environmental information achieved via on board sensors, CAVs will decide whether adapting the speed to the suggested one or prepare for stopping. The Table 1 below details the situations that occur in reality and the respective values for Time To Change (TTC) and speed advice in the SPaT:

Table 1: SPaT information content according to traffic situation

Situation	TTC prediction	Speed advice	Correct CAV behavior
Traffic light switched off	Not present	Not present	Switch to manual mode
No demand nor approaching vehicles on signal group.	Not present	Not present	Not applicable
Light is red, high time to green, speed advice would be lower than 30 km/h	Present	Not present	Prepare to stop at stop line
Light is green, but unknown time to change (no conflicting traffic approaching)	Not present	Not present	Current speed allows passing with green
Light is red, short time to green	Present	Present	Process SPaT data to determine if vehicle needs to adapt speed (Table 2)
Light is Green, short time to red	Present	Present	Process SPaT data to determine if vehicle needs to adapt speed (Table 2)

When the speed advice is present during the green phase, it indicates a speed advice equal to the speed limit at the farthest distance a vehicle can still pass the stop line before the red phase starts. Amber is therefore considered equal to red, which is in line with the guideline that a vehicle should stop for amber if this is safely possible. During the red phase, the first entry that can appear in the list of speed advices is a “180” up to a given distance, indicating a GLOSA not possible, since the advised speed would be too low in this zone. If a speed advice is possible, it starts at a distance where the vehicle should drive 35 km/h to make the green light. This is followed by a zone every 5 km/h until the speed limit, or until the end of the intersection approach is reached. The resulting expected CAV behaviour in presence of SPaT speed advices is summarized in Table 2.

Table 2: CAV behaviour in presence of speed advices

Situation	Speed advice list example (distances in m, speeds in 0.1m/s)		Correct CAV behavior
Green phase with provision of speed advice (the traffic light is going to become red)	Distance1=125	Speed1=139	If the vehicle is at a distance closer than 125m and drives 50km/h, then it will pass with green. Presence of other slower vehicles in front might cause the vehicle to fall behind the distance indicated in the SPaT. If this happens, then the vehicle will prepare the slow down to stop at the intersection
Red phase with provision of speed advice (the traffic light is going to become green)	Distance1=204 Distance2=233 Distance3=262 Distance4=286	Speed1=180[1] Speed2=97 Speed3=111 Speed4=125	If the vehicle is at a distance closer than 204m, then it will prepare the slow down to stop at the intersection. Excessive slowdown or other slower vehicles in front might cause the vehicle to fall behind into the speed advice zones. If this happens, by following the speed advice, the vehicle passes with green

The zoning concept for the speed advice is further illustrated in Figure 2. The advice is given in a series of points and it is important to consider that the closest speed advice behind the vehicle is the one that should be followed.

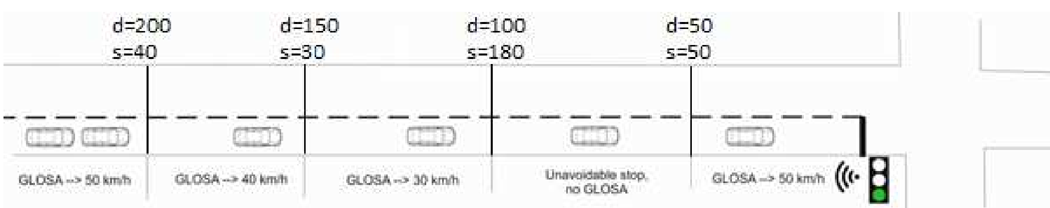


Figure 2 – Zoning concept for SPaT speed advice

For I2V lane change advisory it was observed that the currently available standard message sets are insufficient to cover MAVEN use cases with CAVs. There is no possibility to include lane change advice for urban intersection topologies in any of the standard I2V messages. The only possibility was to include different speed advices on different lanes and instruct vehicles to choose the lane with the highest speed advice. However, in that case oscillations may occur because too many vehicles could respond to the advice causing the advice to change again. To mitigate this problem individualized advices should be given, which is missing in the current message sets. Therefore, the Lane Advice Message (LAM) was designed to fill this gap. The message also enables the infrastructure to give specific instructions for the vehicle that should change lanes by giving optimal time and location to switch lanes. As already stated before, all messages are broadcasted, for LAM this sounds counter-intuitive because it is an individualized message.

[1] The Speed 180 is used in the SPaT standard to indicate that a speed advice is not possible. This can be used in all cases of "not present" except for the traffic light that is switched off.

However, other vehicles around can benefit from receiving the lane advice as they will know about the possible movements of neighbouring vehicles.
The requirements posed by MAVEN I2V interactions to V2X communication services are summarized in the following table:

Table 3: Requirements for I2V interactions

Requirement	Reason
Transmission of CAV intentions (e.g. expected route at next intersection, etc.)	Providing CI with necessary information for updating queue models and calculation of speed and lane advisories
Transmission of CAV/platoon characteristics (e.g. desired speed, platoon size, etc.)	Providing CI with necessary information for updating queue models and calculation of speed and lane advisories
Transmission of CAV feedbacks about advisories applicability	Enabling CI to put priority at the validity of the advisories
Transmission of lane specific GLOSA	Enabling CAVs to apply different speeds on distinct lanes
Clarifications on GLOSA advisory interpretation depending on SPAT content	Solving ambiguities and enabling CAVs to apply correct automation behavior
Transmission of individualized lane change advisory in a separate message with respect to SPAT	Preventing speed advisories recalculations caused by reactions to non-individualized speed advisories at CAVs
Transmission of time/space instructions for lane change advisory	Enabling optimal lane change at CAVs from a traffic management point of view
Transmission of CAVs' intentions, CAV/platoon characteristics, and feedbacks in broadcast fashion	Enabling both CIs and other CAVs to use this information at the receiving side (see also platoon management requirements in Table 4.
Transmission of CIs' speed and lane change advisories in a broadcast fashion	Enabling CAVs to know about advisories for other vehicles and consider them for own manoeuvre planning
Transmission of CAVs' feedbacks to advisories in broadcast fashion	Enabling both CIs and other CAVs to use this information at the receiving side. In case of CAVs, enabling the receiver to know about reactions on other vehicles and consider them for own manoeuvre planning

2.2 Platoon management

In MAVEN, CAVs will be able to form and drive in small platoons implementing cooperative methods for forming, joining, travelling in, leaving, and breaking a platoon.

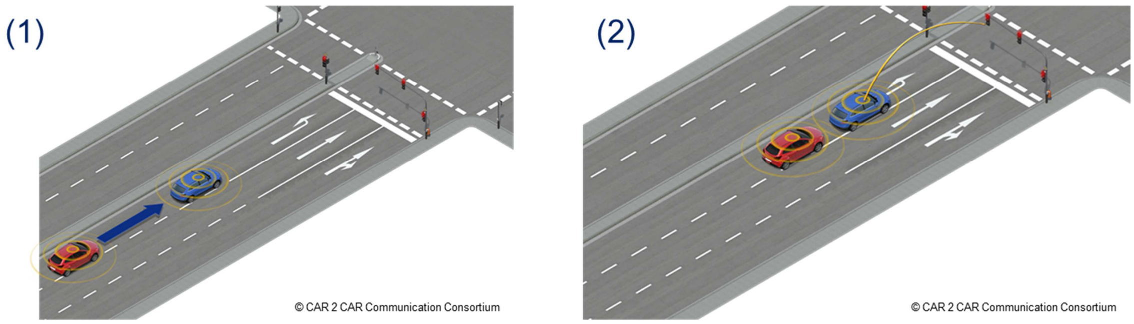


Figure 3 – MAVEN platooning

As MAVEN focusses on arterial roads in urban areas, the platooning approach is different compared to other platooning developments targeting highway driving. This is reasoned by the more complex environment: lanes need to be changed and are changed by others very often. Obstacles like parked vehicles or trucks stopped for loading appear on the road requiring reactions. Traffic lights induce stops and vulnerable road users can always be present. Therefore, flexibility is one of the key requirements for urban platooning, allowing vehicles to individually participate at platoons or leaving them quickly without complex sign in and sign off procedures. On the contrary, having a dedicated platoon leader being able to represent the whole platoon in negotiations with other entities like C-ITS infrastructure or other road users is also very useful as this can positively influence efficiency. For example, CIs can take whole platoons into account when negotiating speed and lane change advices as shown in Section 2.1.

As a result, the MAVEN platoon approach [4] 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. In this sense, the MAVEN platooning approach can be seen as an extended Cooperative ACC, 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 to the infrastructure according to the above mentioned negotiation process, see Figure 3 (2).

While the details of the platoon logic are presented in D3.1, the corresponding requirements on communication set by the MAVEN project are briefly described here. First of all, vehicles that want to initiate a platoon with other vehicles or to join an already existing platoon need to "advertise" some of their local characteristics such as planned route, desired speed, acceleration/braking capabilities, etc. By overhearing this information, a receiving vehicle can identify the opportunity and convenience to form a platoon with that vehicle, or to accept it in an already existing platoon. At the same time, vehicles already driving in a platoon need to perform the same advertisement, so that receiving isolated vehicles can evaluate the opportunity and convenience to join the platoon. As platoon candidates can be encountered anytime and anywhere, the first requirement that MAVEN dynamic platooning sets on communication is to perform this advertisement in a broadcast and periodic fashion.

A second very important requirement for MAVEN communication is backward compatibility: vehicles able to perform platooning in MAVEN are requested to be still "overheard" by other pre-existing cooperative vehicles and infrastructure not supporting the MAVEN approach. In fact, these pre-existing vehicles and infrastructure will expect receiving broadcast CAM messages [5] on the ITS G5 channel SCH0 [14], designated by the car industry (C2C-CC) to support the first C-ITS deployment phase on vehicles (i.e. the so-called "Day1" deployment) [20]. Taking into account these two requirements, the most efficient solution for MAVEN platooning is to be also based on the periodic exchange of standard broadcast CAM messages [5], especially considering that the period to exchange the platooning advertisement information will be similar to that required by Day1 CAMs transmissions. In MAVEN, CAMs on the SCH0 will be then enhanced with an optional container covering platooning details, as described in detail in Section 4.1.

However, a third requirement is posed by MAVEN platooning. Precise control and management of platooning vehicles will require receiving a lot of more detailed information (e.g. planned trajectory of preceding vehicles, platoon management information) than what is included in Day1 CAMs, and with a higher frequency of reception. As this information is useless for pre-existing cooperative vehicles and infrastructure, it has been decided to save bandwidth on the standard SCH0 channel and to use another ITS G5 channel (SCHx)[2] for this purpose instead. Following this approach, platoon vehicles can exchange the needed control information without wasting bandwidth on the standard SCH0 channel.

The requirements posed by MAVEN platoon management to V2X communication services are summarized in the following table:

Table 4: Requirements for platoon management

Requirement	Reason
V2V transmission of CAVs' intentions and CAV/platoon characteristics	Enabling other CAVs to use this information at the receiving side to detect possibilities for platoon initialization or joining
Centralized V2I transmission of platoon characteristics to be considered by the infrastructure	Providing CI with necessary information for updating queue models and calculation of speed and lane advisories. This can be done by the platoon leader only to save communication resources
More frequent and detailed V2V transmission of CAVs' dynamics, trajectory, and platoon management information on a separate ITS G5 channel	Enabling precise control and management of CAVs when driving in a platoon. As this additional information is required more frequently, a parallel channel is required, not to overload pre-existing systems on the currently used channel
Lightweight and flexible V2V broadcast and periodic transmissions for platoon initialization and management	CAVs use V2V communications as additional coordination information source for executing a decentralized platooning algorithm in very variable urban environments. As vehicle control and platooning decisions are totally decentralized and take into account also information from local sensors, there is no need for establishment of more complex communication sessions (like for example unicast request/replies)
Ensuring backward-compatibility with pre-existing systems	Making sure that pre-existing cooperative vehicles (non-automated) and infrastructure still receive the V2V broadcast information they expect to run their applications

[2] At the moment, in the frequency band 5875MHz to 5905MHz, three 10MHz channels for C-ITS Traffic Safety applications (SCH0, SCH1 and SCH2, respectively) are allocated and harmonized based on the ECC decision [21] and an EC decision [22]. Two more 10 MHz channels (SCH5 and SCH6) in the band 5905MHz to 5925MHz are identified for future extension for C-ITS traffic safety applications [21].

2.3 Conventional traffic and VRUs

The behaviour of MAVEN CAVs and CIs can be highly influenced by the presence of traffic participants (e.g. VRUs, other vehicles) that cannot initially cooperatively participate to the functions envisioned by the MAVEN framework.

In fact, MAVEN CAVs are requested to cope with situations like for example pedestrians suddenly crossing the road or conventional vehicles leaving a parking in front of them. Having those traffic participants able to “advertise” their presence and dynamic properties by using retrofit V2X solutions (e.g. via handheld devices) would be already beneficial for improving the CAV awareness of their surrounding environment. This would be especially the case when CAVs cannot detect those traffic participants with their local sensors: pedestrians and other vehicles might be hidden by other objects or buildings, and hence their presence/behaviour would be unknown till the last moment. Retrofit communications capabilities on those traffic participants could give CAVs some time advance for detection. However, retrofitting conventional traffic and VRUs with standard V2X communications capabilities would not be a reliable solution at the time of MAVEN experimentations due to the technical limitations of the available handheld devices. In fact, even if some standard V2X-capable handheld devices are commercially available at the moment, none of them is capable of providing positioning information precise enough to be safely considered by MAVEN CAVs. Let us assume that a pedestrian would carry such a handheld device to broadcast his position information before crossing the road. As the positioning accuracy normally supported by those devices at the moment would be around 5 meters (similar to that of positioning module integrated in current smartphones [26]), the transmitted position would not allow receiving CAVs to determine with enough confidence whether the pedestrian is still on the sidewalk or already on the carriageway[3].

Due to the limitations of the above mentioned retrofitting solutions, identified at an early stage of the MAVEN project, the MAVEN consortium decided to include VRUs and conventional vehicles in the MAVEN framework by adopting solutions relying on CAVs’ or CI’ local sensors detection capabilities or on collective perception. This approach is depicted in Figure 4. An isolated CAV (white car) and a platoon of CAVs (in red) are heading towards the same intersection equipped with C-ITS and detection capabilities (both an RSU and a camera are in place and connected to the TLC/TMC). The isolated CAV and the CI can detect some pedestrians temporarily occupying the carriageway (e.g. while crossing). These pedestrians do not currently represent a risk for the isolated CAV because their estimated movement does not interfere with the planned trajectory. Anyway, the CAV is continuously monitoring them with its local sensors to understand if some reaction needs to be taken at a given point (e.g. some automatic ADAS like automated braking). On the contrary, the platoon of CAVs is not capable to detect the pedestrians since they are hidden around the corner. Knowing about the presence of these pedestrians would give the platoon more information for planning its path in a safe way, especially if the platoon needs to turn right at the intersection. In fact, with this additional information, the platoon would decide to slow down if, once in proximity of the stop line, the pedestrian would still represent an obstacle to its planned trajectory. Then, after performing the right turn manoeuvre, the first platoon vehicle would start detecting the pedestrian with its own sensors, and hence decide to apply an automated ADAS reaction (e.g. automated braking). In order to let CAVs aware of VRUs and other unequipped vehicles that cannot be locally detected, collective perception is used. In Figure 4, both the white CAV and the CI will transmit Collective Perception Messages (CPMs) containing standardized abstract representations of objects detected by their local sensors.

[3] Similar problems due to GPS inaccuracies have been experienced on other use cases tested by the EU FP7 VRUITS project [27].

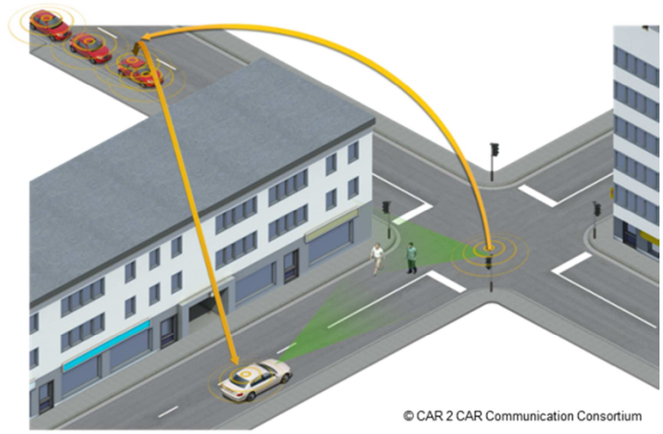


Figure 4 – MAVEN inclusion of traffic and VRUs

From a functional perspective, the requirements posed by MAVEN to collective perception is to have CPMs including, besides a commonly acknowledged description of the detected objects, also dynamic information about the detecting station (its position, speed, heading, etc.) as well as information about its detecting capabilities (sensors' field of view, ranges). This will in fact permit to implement the needed calculations and predictions about the shared detected objects when processing the information at the receiving side.

In [30], the potential of collective perception is studied in a simulation environment extended with a model for local perception sensors on vehicles. The findings of this work unveil that by complementing CAM self-announcements with collective perception messages, cars dramatically improve their awareness about presence of other vehicles in the surrounding already at moderate V2X penetration rates (i.e. 20%). However, this work assumes that only vehicles have the capability of implementing the CP service. Consequently, an important requirement set by MAVEN to CP is to implement a message format suitable to also allow RSUs at CIs to transmit information about detected object. This requirement is not trivial, as it involves extending the CPM with definitions to accommodate important differences between vehicles and RSU characteristics and capabilities. In fact, while vehicles are moving entities with somehow restricted sensing capabilities (limited sensor ranges, often obstructed obstacles encountered along the way), RSUs are stationary but have much better detection properties (they can be attached to sensors placed at strategic positions like hemispheric cameras monitoring an intersection from the top). Vehicle and RSUs need therefore to represent their sensing capabilities and detecting objects using two distinct coordinate systems. CAVs adopt a vehicle-centric system in which the x and y axes are parallel to the vehicle's longitudinal and lateral dimensions, respectively: as the vehicle moves, the system will also move. Instead, RSUs adopt an intersection-centric system where x and y are parallel to the east and north, respectively: as RSUs do not move, this system will stay static. All this requires defining new CPM message elements (specific for RSUs), or adapting/better specifying the elements to be valid for both vehicle and RSU coordinate systems.

From a communication point of view, the requirements for CPMs are very similar to those of CAM messages. Since the objective is to inform as much vehicles as possible about situations of locally detected objects, broadcast messages are needed. Moreover, since those situations are likely to change very dynamically according to the movements of both the detecting stations and the objects themselves, CPMs need to be periodically updated and retransmitted with a frequency not lower than that of standard Day1 CAMs.

The specification of the CP service is undergoing at ETSI ITS and its adoption has already been considered by the car industry (C2C-CC) to happen in a Day2 deployment phase to pave the way towards cooperative automated driving [2]. As indicated in Annex C, the MAVEN project has actively contributed to the ETSI ITS standardization work of the CPM. The MAVEN CPM implementation is described in Section 4.3. The requirements posed by MAVEN inclusion of conventional traffic and VRU to V2X communication services are summarized in the following table:

Table 5: Requirements for inclusion of conventional traffic and VRUs

Requirement	Reason
V2X transmission for collective perception (CP)	Enabling other CAVs and CIs to be informed about the presence of non-cooperative road users to detect risky situations and cope with them
Inclusion of dynamic information of detecting station in CP messages	Allowing necessary calculations and predictions about detected objects at the receiving side
Inclusion of detecting capabilities of detecting station in CP messages	Allowing necessary calculations and predictions about detected objects at the receiving side
Definition of message format suitable for RSUs at CIs to share detected objects	Enabling CIs to actively participate in the CP mechanisms
Transmission of CP messages in a broadcast and periodic fashion	Enabling all CAVs and CIs to be continuously updated about environmental situations changes in terms of detected objects

3 Communications architectures

This section describes the communication architectures implemented at both MAVEN CAVs and CIs sides. These descriptions permit identifying the subsystems involved for running the communication services described in Section 4 as well as the interfaces connecting them and the exchanged information.

3.1 CAV communication architecture

In the following Figure 5, the MAVEN CAV communication architecture is depicted. The overall automated driving software implementation is indicated by "AD_SW". The internal implementation of the AD_SW is better specified in the MAVEN deliverable D3.1 [17]. This implementation differs at the DLR and Hyundai CAVs in terms of adopted algorithms, which partially depends on the fact of using different local sensor setups. However, in the different AD_SW implementations common functional blocks can be identified, as indicated in the figure. On the contrary, The "Platoon_Logic" (see D3.1) is a common SW module provided by DLR whose implementation is necessary for controlling the state machine used for building, maintaining, and terminating a platoon in exactly the same way at both the Hyundai and DLR CAVs. Both the AD_SW and Platoon_Logic are interfaced to the V2X communication module for providing and receiving the information to be cooperatively exchanged over the radio channel for running the MAVEN use cases described in Section 2. Regarding the internal functionality of the AD_SW, the following modules can be identified:

1) Sensor interface: consists of the necessary conversion modules to transform sensor-specific outputs into common formats reusable by the sensor fusion module.
2) Digital map: provides a high-precision digital representation of the driving environment that the vehicles use to match their position and hence localize themselves onto it.
3) Sensor Fusion/Perception module: prepares trajectory planning decisions by providing an assessment of the environmental situation in the vehicle surrounding. Also, it takes into account information received via V2X by other CAVs and CI (e.g. speed advices, lane changes, collective perceptions).
4) Trajectory planning & Vehicle control: By considering the outputs of the Sensor Fusion/Perception module, it implements the functions for the CAV to drive highly automated (also while platooning). These include trajectory planning and all necessary low level controlling that make additional use of cooperative V2X interactions with CIs and CAVs.
5) Collective Perception tx/rx filtering: includes functionalities to filter information associated to collective perception. At the transmitting side, CAVs will make sure to filter out detected objects that are not relevant for V2X sharing (e.g. pedestrians far from the carriageway, hence not representing a danger for any receivers). At the receiving side, the AD_SW will prepare the inclusion of objects detected by other stations in the local sensor data fusion by filtering out objects that are not relevant for the current ego-vehicle situation (e.g. the vehicle is currently in a very far zone from where the object has been detected).

The rest of the CAV architecture includes vehicle sensors, vehicle actuators and HMI. Vehicle sensors include positioning sensors (GPS and other modules for improving the positioning correctness), perception sensors (e.g. LiDAR, Radars, front camera, etc.), as well as in-vehicle sensors (e.g. measuring velocity, acceleration, yaw rate, etc. of the car). Vehicle Actuators apply the vehicle automation longitudinal and lateral control outputs into signals for the actuation of the computed acceleration and steering. Finally the HMI represents an engineering implementation used on MAVEN vehicles only for debugging and demonstration purposes.

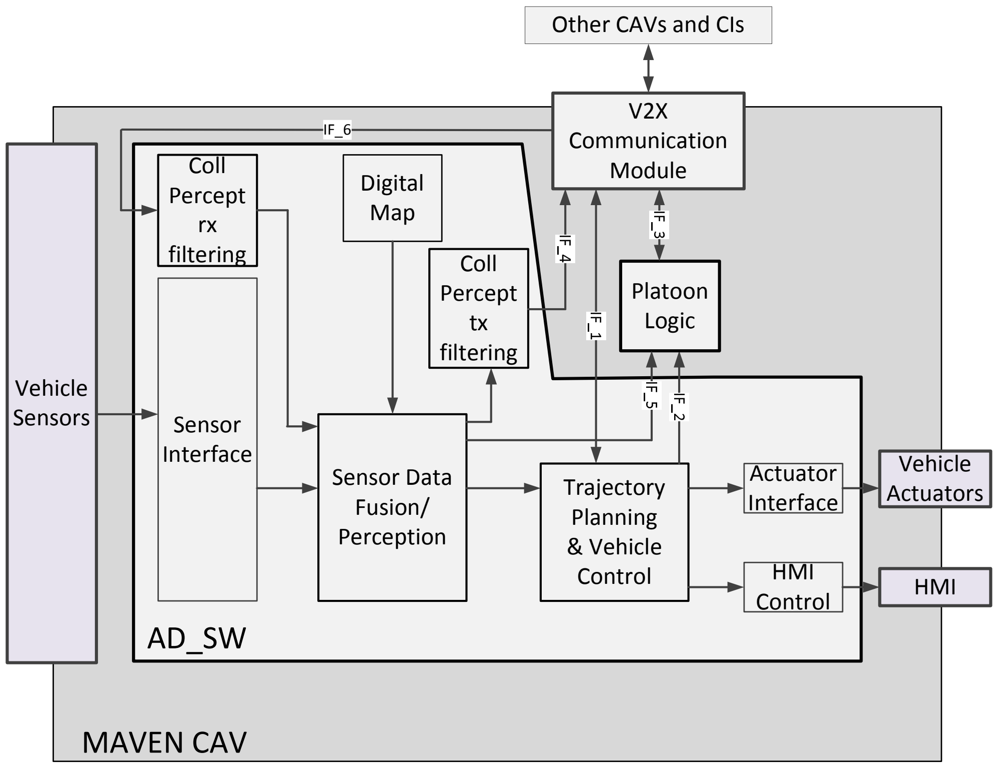


Figure 5 – MAVEN CAV communication architecture and interfacing

The interfacing between the above described vehicle automation modules and the V2X communication module is schematically described in Figure 5 and explained below.

IF1_AD2V2X (from AD_SW to V2X communication module):
The AD_SW continuously provides directly to the V2X communication module data needed for:

- V2V platooning use cases, where opportunities for initializing or joining a platoon must be detected (desired speeds, planned routes, etc)
- I2V interactions, where V2I data is needed for starting negotiations (planned routes, number of car occupants, dist from prec/follow vehicles, etc.), and closing negotiations (acknowledgements that speed or lane changes advices can be executed, etc.)

The data provided through this interface to the V2X communication module is later on used for populating MAVEN extended CAMs suitable to the above listed needs, and partially CPMs. This data is:

1) Standard CAM info (CAV reference position, speed, heading, driving direction, longitudinal acceleration, etc.)
2) Lane position
3) Acceleration capability
4) Desired speed range for platooning
5) Planned route of intersections to cross

6) Planned route at intersection (ingress/egress lanes and signal group for planned manoeuvre at next intersection)
7) Number of vehicle occupants
8) Distance to following car
9) Distance to preceding car
10) GLOSA acknowledgment information (indicating if the speed advice is currently adopted on the currently driven ingressing lane)
11) Lane changing acknowledgment information (indicating whether the CAV is currently accepting or rejecting the lane change advice

IF1_V2X2AD (from V2X communication module to AD_SW):
The AD_SW receives the data relative to I2V advices (GLOSA and Lane change, as part of the infra-vehicle negotiation process). The AD_SW receives and processes data structures continuously provided by the V2X communication module and including data extrapolated from cooperative messages received from CIs (SPAT/MAPs and LAMs). The data structures include the following information:

1) Relevant Intersection topology: List of lanes (ingressing and egressing lanes) relevant for the vehicle currently planned manoeuvre: lanes on intersection approaches where the vehicle is not currently driving are useless and hence not provided
2) Relevant current traffic lights signals info: List of relevant signal groups (including speed advices relative to the ingressing lanes relevant for the vehicle)
3) Lane change advisory status: lane change requests to specific vehicles or platoons (including lane to change to)

IF3_PL2V2X (from Platoon_Logic to V2X communication module):
When the Platoon_logic activates the V2V transmission of MAVEN extended CAMs for managing and controlling platoons, it starts providing the following data:

1) Control information for activation/deactivation of such CAMs
2) Platoon identifier
3) Local followers in the platoon
4) Planned path (this information is in turn received from the trajectory planning module via IF_2)
5) Planned lane (this information is in turn received from the trajectory planning module via IF_2)
6) Platoon state machine flags (as described in [4])
7) Emergency flag (as described in [4])

Moreover, the Platoon_Logic needs to provide some data that CIs need to receive to support I2V interactions. Some of this information is already listed above (e.g. Platoon identifier, local followers). In addition to that, when the ego-vehicle is acting as a platoon leader it will include in extended CAMs the following information:

8) Desired platoon speed (calculated by the leader based on followers' desired speeds for platooning)

IF3_V2X2PL (from V2X communication module to Platoon_Logic):
The Platoon_logic receives and processes data structures relative to remote V2X-equipped vehicles and needed for the platooning state machine to check the conditions for state changes (e.g. presence of vehicle behind/ahead with similar route/speed/acceleration capability, platoon ID, Platoon followers and state machine flags [4]). These structures include, per each remote vehicle, data extrapolated from received MAVEN extended CAMs:

1) Standard CAM info (CAV reference position, speed, heading, driving direction, longitudinal acceleration, etc.)
2) Lane position
3) Acceleration capability
4) Desired speed range for platooning
5) Planned Route of intersections to cross
6) Planned route at intersection (ingress/egress lanes and signal group for planned manoeuvre at next intersection)
7) Platoon identifier
8) Local followers in the platoon
9) Planned path
10) Planned lane
11) Platoon state machine flags (as described in[4])
12) Emergency Flag (as described in [4])

IF4_CP2V2X (from CP Tx Filtering to V2X communication module):
The V2X communication module is continuously provided with the data structures needed to populate collective perception messages. These structures include, per each detected object the following information:

1) Object identifier (to let other vehicle track the ego vehicle's detected object)
2) Time of measurement
3) Object position (relative to the ego-vehicle)
4) Object speed (relative to the ego-vehicle, if available)
5) Object acceleration (relative to the ego-vehicle, if available)
6) Object dimensions (if available)
7) Object type (pedestrian, vehicle, bike, unknown, etc.)

IF6_V2X2CP (from V2X communication module to CP Rx Filtering):
The AD_SW continuously receives and processes data structures relative to obstacles detected by remote V2X-equipped vehicles or CI and received via CPMs. These structures include, per each remote vehicle or CI, data extrapolated from received CPMs:

1) Dynamic information about the remote V2X-vehicle (present only in case the originating station is a vehicle, and similar to standard CAM info, i.e. reference position, speed, heading, driving direction, longitudinal acceleration, etc.)
2) Information about the remote CI (present only in case the originating station is a an RSU, and containing the identifier of the intersection)
3) Information about the sensing capabilities of the V2X-equipped originating station (includes sensors' FoV and ranges, or explicitly indicates the areas where detections are possible by the originating station)
4) Information about detected objects (including, per each detected object, the information as described for IF4)

3.1.1 V2X communication module architecture

V2X communications in MAVEN are enabled by the use of commercially available ETSI ITS G5 communication modules compatible with the latest stable versions of the ETSI ITS and SAE DSRC standards [5]-[15]. MAVEN has implemented its communication protocols and message sets on the top of these communication modules thanks to the extensibility properties offered by them. The resulting MAVEN V2X communication module architecture is depicted in Figure 6. As it can be seen, a MAVEN communication module is compliant to the standard ETSI ITS communication architecture [6], and supports transmission and reception of V2X messages over the ETSI ITS G5 radio technology as profiled in [14]. The adopted network and transport layer protocols are exactly the same as standardized in [9]-[13] and implemented in the commercially available V2X modules, which provides a straightforward approach to bring MAVEN implementations on real-road tests. On the contrary, the standard ETSI ITS Facilities layer has been extended to accommodate the needs of the MAVEN use cases. Several V2X services have been either extended on the top of standard services (e.g. the CA service, SPAT/MAP services), or created from scratch (like the CP service or the Lane Change Advisory service). This is represented in Figure 6 by the Message Management module of the MAVEN Facilities layer. This module implements the functionalities to manage V2X messages to be transmitted and/or received, including UPER co/decoding and information processing. As it can be seen in the figure, the CA and CP services are reused in CAVs for both receiving and transmitting sessions. On the transmitting path (red in the figure), these services populate CAMs and CPMs by taking the information received from the AD_SW or Platoon_Logic and locally stored in the Vehicle State Database of the V2X communication module. On the receiving path (blue in the figure), the CA and CP services decode the received messages, process the contained data and pass it to the Local Dynamic Map, where local management (inclusion of new entries, update of pre-existing entries, deletion of old entries, etc.) is done before passing it to the AD_SW or Platoon_Logic. Finally, the SPAT/MAP and Lane Change Advisory services are used on CAVs only on the receiving path. In fact, SPAT/MAPs and LAMs are transmitted exclusively by CIs. On CAVs the corresponding services make sure that these messages are correctly decoded and processed. Some check on the relevance of the information contained in SPATs and MAPs with respect to the CAV position are performed in the LDM. For example, the LDM can filter out speed advices for lane groups where the vehicle is not currently driving before sending this information to the AD_SW.

In the Section 4, the MAVEN communication services and the associated implementation solutions are described in detail.

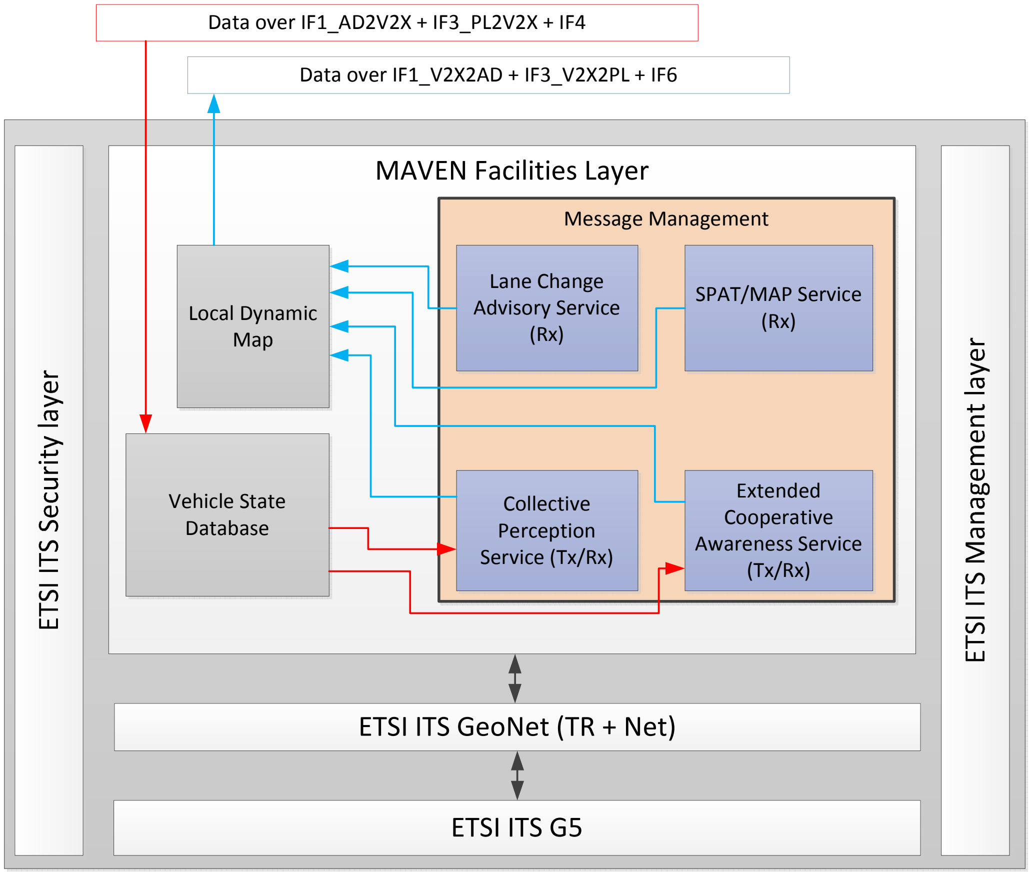


Figure 6 – MAVEN V2X communication module architecture

3.2 CI communication architecture

The functional architecture for the infrastructure is presented in D2.2 [16] focussing on several key use cases. For the communication other components are essential and they are included in Figure 7.

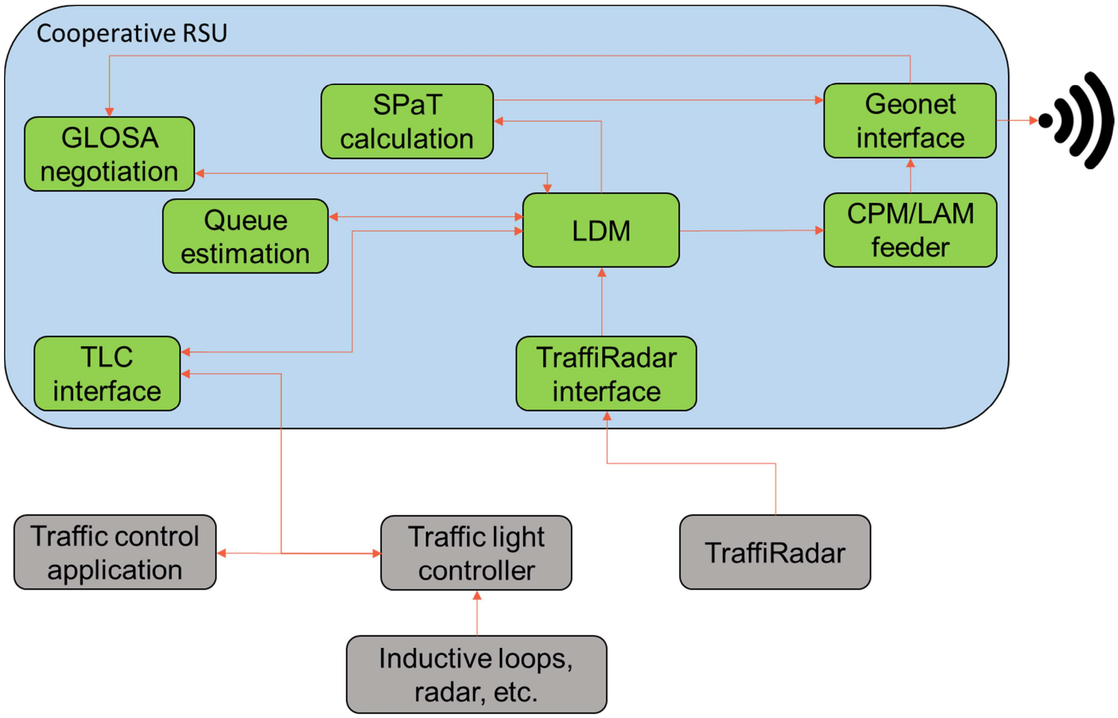


Figure 7 - Intersection communication architecture

The Local Dynamic Map (LDM) is the central data collection point. All traffic relevant dynamic data is stored here with logical geographic references. This means it can be linked to the topology defined in the MAP message. Vehicle positions are stored as lane number and distance to the stop line. The interface towards the LDM is described in detail in D4.1 [18], both human readable JSON and binary ASN.1 PER encoded messages are provided. All components connect to the LDM using the same interface. The CPM content is according to the principles described in Section 4.4.

The interface towards the Traffic Light Controller (TLC) is more complicated in the Netherlands since the introduction of a new reference architecture. This architecture splits the controller which connects to the signal heads and the sensors from the control algorithm. In theory all information should be available from the controller, as the algorithm should post its data about for example signal predictions to the controller as well.

The TraffiRadar is a new kind of sensor and is therefore directly connected to the RSU through a dedicated interfacing process. The sensor is required for the lane advice as it provides a new kind of information: the amount of vehicles on a certain lane. The TLC is not yet ready for this and therefore a direct interface is required. For large scale deployments, this should of course be migrated with the other sensors to the TLC. Similarly, the new or adjusted MAVEN messages have their own process associated to encode the messages, resulting in the CPM/LAM feeder and SPaT calculation for encoding and the GLOSA negotiation for decoding the extended CAM.

The GeoNet interface is responsible for transmitting and receiving encoded packets. It follows the ETSI ITS communication architecture standards to transmit the message correctly through the lower layers of the communication stack [10]-[14]. Normally it is connected only to the ETSI ITS Facilities component to feed the LDM, but this component is disabled due to the experimental messages used in MAVEN. A schematic overview of the interface is given in Figure 8.

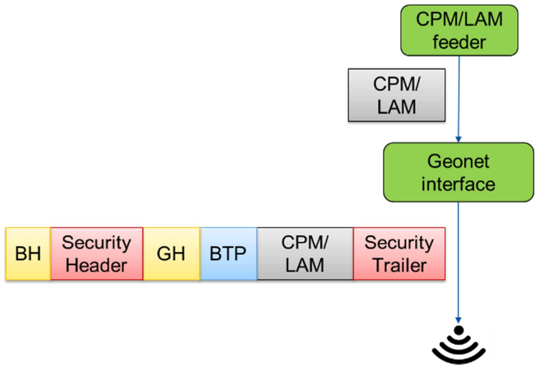


Figure 8 - Geonet interface overview

The GeoNet interface opens a UDP port where messages can be sent together with Basic Transport Protocol (BTP) port numbers. The GeoNet interface then adds the Basic Header (BH), security header, GeoNet Header (GH), BTP header, the actual message and a security trailer. It is a component that was already developed in the Compass4D project and here reused for MAVEN.

4 Communication services

This section details the communication services implemented in the MAVEN project to fulfil the requirements of Section 2 and respecting the architecture and interfaces presented in Section 3. As it will be explained in the following sections, dedicated CAM extensions have been defined to implement the MAVEN platooning algorithm and the I2V negotiation processes at the CAV side. At the CI side, the negotiation is executed by use of a Lane change Advisory Service and a Lane-specific GLOSA. Finally, both CAVs and the CI, continuously run the Collective Perception Service for the exchange of information about conventional vehicles and VRUs detected via local sensors.

4.1 MAVEN CAM extensions

4.1.1 Concept

As anticipated in Section 2, in the design of V2X communications protocols running at CAVs for supporting MAVEN platooning and interaction with the C-ITS infrastructure, two aspects have been taken into account. From one hand, these protocols must support the advanced functionalities of automated vehicles and platoons while efficiently using the available radio resources, hence trying to reuse as far as possible already available message sets. From the other hand, they must also ensure that cooperative legacy (not-automated) vehicles and existing C-ITS infrastructure (RSUs) keep receiving the necessary information available at preliminary V2X deployments. In MAVEN, this is accomplished by using ETSI ITS CAM [5] extensions. The standard CAM is a periodic broadcast message including vehicle dynamic information (position, heading, speed, acceleration, etc.), as well as static attributes (width, length, vehicle type, etc.) and semi-static information for special vehicles (emergency vehicles, roadworks vehicles, etc.). The generation rate of CAMs varies dynamically in the range [1-10Hz] to capture sudden variations of vehicle dynamics while ensuring acceptable levels of radio channel load. In a first phase of V2X deployment (starting in 2019 [1]), the information received in standard CAMs will be used to implement Day1 applications such as detection of Traffic Jams ahead (at not-automated vehicles) or estimation of incoming traffic demands (at C-ITS infrastructure/RSUs). By defining MAVEN messages for platooning and I2V interactions as CAM extensions, backward compatibility is achieved: automated cars and MAVEN-capable infrastructure will be able to process the whole message including the extensions; legacy vehicles and infrastructure will just discard the extensions yet processing the rest of the message.

4.1.2 CAM extensions structure and generation rules

As also indicated in Figure 9, two separate extended CAMs are used in MAVEN (the message extensions defined by MAVEN are highlighted in light grey):

1) Extended CAM on SCH0: carries information for CAVs to detect opportunities to initialize a platoon as well CAV and/or platoon features reusable by the infrastructure (planned route, desired speed, platoon ID, participants, etc.) to perform traffic management calculations. As indicated in Figure 9, this information is contained in an optional special vehicle container called MAVENAutomatedVehicleContainer, and hence ensures backward compatibility with pre-existing Day1 systems in this channel. The MAVENAutomatedVehicleContainer is appended to Day1 CAMs and hence the generation rules for Extended CAM on SCH0 are exactly the same as in [5]. The MAVENAutomatedVehicleContainer is appended to the CAM with low frequency (i.e. every 500ms), applying exactly the same rules for the inclusion of the BasicVehicleContainerLowFrequency [5].

2) Extended CAM on SCHx: carries the needed information to manage and control platoons of MAVEN CAVs in a distributed manner. It is transmitted at a fixed higher frequency [10-30Hz][4] and using a separate ITS channel not to overload Day1 systems on the SCH0 (the same approach is suggested in other R&D projects [23]and pre-standardization studies [24]). Its transmission is triggered during the platoon initialization phase. Then, the message is populated following the distributed platoon logic running at individual vehicles and described in D3.1. An AutomatedVehicleContainerHighFrequency is always transmitted to carry important information that CAVs consider for close-following driving. The AutomatedVehicleContainerLowFrequency is included every *n* messages[5], mostly with information reflecting the platooning state machine running at each vehicle and used for distributed platoon management.

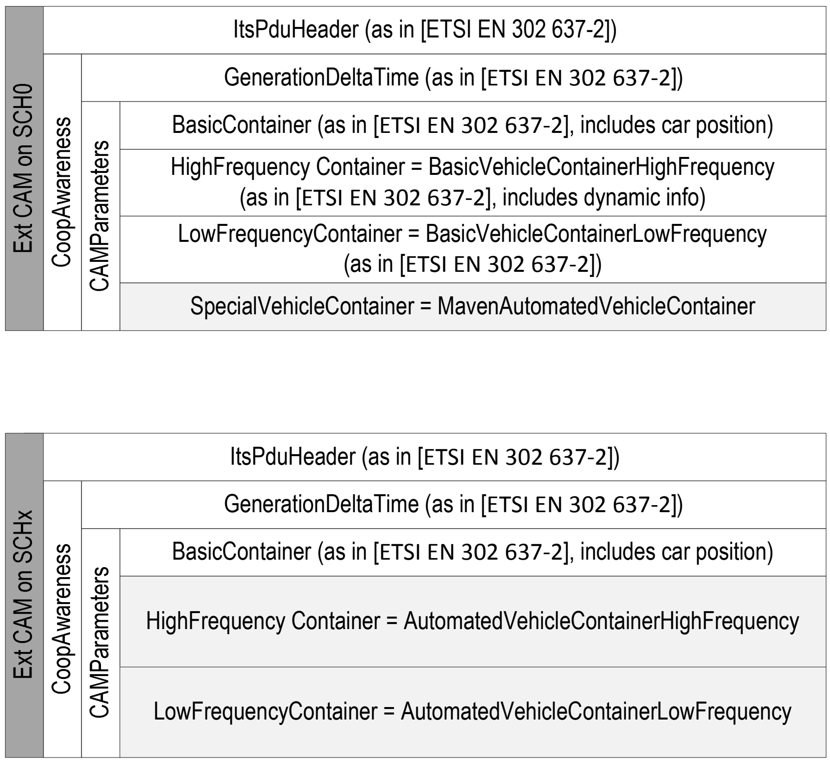


Figure 9 – MAVEN extended CAMs structure

From a communication protocol point of view, the selection of CAM as a periodic broadcast message (instead of for example on-demand request/reply unicast messages) makes sense for MAVEN platooning. As explained in Section 2.2, in MAVEN vehicle control (in a C-ACC fashion) and platoon management is executed independently at each individual vehicle following a common distributed protocol which uses the information available locally (on-board sensors as well as V2X receptions). Adopting dedicated alternative messages instead of recurring to small extensions to

[4] The suitable generation rate for these CAMs is currently object of investigation in WP3. Here, simulations of MAVEN platooning are performed and the performance is measured by varying the design parameters.

[5] *n* is another platooning design parameter that will depend on the chosen generation frequency for extended CAMs transmitted on the SCHx.

already deployed CAM messages would imply additional channel load (due to the presence of the lower layers' protocol headers) without necessarily providing increased reliability.
The next subsections briefly describe the CAM extensions implemented for platooning and I2V interaction separately. Then, a comparison with the CAM extension approach presented by previous EU R&D projects is given. A more detailed description of the MAVEN extended CAM structure and definition of the data fields and element is provided in Annex A1. Annex B1 presents the ASN.1 definitions needed to use the MAVEN extended CAMs on real V2X transceivers. Please notice that the ASN.1 definitions for the MAVEN extended CAMs have required extensions of the ETSI ITS Common Data Dictionary standard [8], whose ASN.1 definitions are reported in Annex B4. Finally, Section 5 describes the V2X hardware test bench and associated simulation setup adopted for the correctness verification of the designed message set.

4.1.3 CAM extensions used for platooning

The platooning-related information included in the MAVEN extended CAMs are depicted in Table 6 and Table 7. Urban platooning must react quickly to different traffic situations. Therefore platoon messages must provide information suitable to detect platoon initialization chances as well as information about the changing platoon status and features. This information shall support decisions on whether an approaching vehicle could join a platoon (e.g. if it has the same route or desired speed) and is contained in the MAVENAutomatedVehicleContainer of the extended CAM on the SCH0 as depicted in Table 6. Moreover, platoon vehicles need to exchange information to dynamically manage situations like platoon leaving, merging, brake-up or termination. As this information is not time critical, it is contained in the AutomatedVehicleContainerLowFrequency of the extended CAM on the SCHx (Table 7). Most importantly, each platoon vehicle must transmit its dynamics data with enough frequency to allow followers driving at closer distances. For this purpose, suitable data elements are contained in the AutomatedVehicleContainerHighFrequency of the extended CAM on the SCHx (Table 7).

Table 6: Platooning-related content of the extended CAM on SCH0[6]

	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

[6] Please refer to the MAVEN deliverable D3.1 [17] for a description of how these data elements are used for platooning.

Table 7: Platooning-related content of the extended CAM on SCHx[7]

	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	Indicated 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 [4]
	PlatoonFormingState	Forming state of the platoon that the vehicle is currently in [4]
	PlatoonDistanceState	Distance state of the platoon that the vehicle is currently in [4]

4.1.4 CAM extensions used for I2V interactions

In order to optimally manage CAVs in MAVEN, the C-ITS infrastructure at road intersections must be informed about several information about approaching CAVs and platoons. It needs to know the plans of CAVs and platoons (e.g. in terms of in/out lanes for crossing the next intersection, or route in terms of next *n* intersections to cross), their goals (e.g. desired speeds), their features (number of occupants, distance from preceding and following vehicles). Moreover, the platoon leader must inform about the platoonID and its participants. The infrastructure uses all this information to calculate speed or lane change advices that are transmitted to the CAVs with suitable messages (SPaTs and LAMs). When receiving these advices, the recipient CAVs individually evaluate the possibility to apply the suggestions based on the current situations in which they are driving, and inform the infrastructure about their compliance to them. Thanks to these feedbacks, the infrastructure can eventually refine its suggestions by updating the transmitted advisories. For the CAVs to provide all the above mentioned information (including feedbacks to infrastructure suggestions), the following data elements of the MAVENAutomatedVehicleContainer on the SCH0 are used (Table 8).

[7] Please refer to the MAVEN deliverable D3.1 [17] for a description of how these data elements are used for platooning.

Table 8: I2V interactions-related content of the extended CAM on SCH0[8]

	Data Field/Element	Description
MAVEN Automated Vehicle Container	*RouteAtIntersection*	Planned route at next intersection (in/out lane). Includes a feedback to indicate if the vehicle is compliant to the suggested speed advisory for the driven lane
	IntersectionRoute	Planned route in terms of next intersections to cross
	DesiredPlatoonSpeed	Speed the platoon desires to adopt (tx by platoon leader only when approaching a cooperative intersection)
	NumberOfOccupants	Number of occupants in the vehicle
	DistanceToFollowingVehicle	Distance to the following vehicle in the same lane
	DistanceToPrecedingVehicle	Distance to the preceding vehicle in the same lane
	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)
	LaneChanging	Feedback to indicate if the vehicle is compliant to the suggested lane change advisory

4.1.5 Comparison with AutoNet2030/GCDC/Adaptive projects extensions

The AutoNet2030-AdaptIVe-iGame projects prepared a joint CAM extension proposal presented in [25]. The proposed additional fields are shown in Figure 10. These additional fields cover data that CAVs need to periodically share with their neighbours.

[8] Please refer to the MAVEN deliverable D4.1 [18] and later deliverables of MAVEN WP4 for a description of how these data elements are used for I2V interaction.

Parameter	Data Requirement	Optionality
Operating Mode	The operating mode of the CABS. Shall be set to either *Normal Mode* or *High Awareness Mode*.	Mandatory
Driving Mode	The level of automation of the ego-vehicle: semi- or fully automated	Mandatory
Automated Control	The automated driving functions engaged by the ego-vehicle	Mandatory
Target Speed	The target speed of the ego-vehicle.	Mandatory
Target Longitudinal Acceleration	The target acceleration in the longitudinal direction of the ego-vehicle	Mandatory
Braking Capacity	The maximum brake capacity of the ego-vehicle. This value may be calculated on-line taking into account e.g. the vehicle's weight, weather conditions, tire conditions, etc.	Mandatory
Target Distance to Preceding Vehicle	The target distance between the ego-vehicle's front bumper and the rear bumper of the immediate preceding vehicle in the same lane.	Optional; Provided when available
Target Distance to Following Vehicle	The target distance between the ego-vehicle's rear bumper and the front bumper of the immediate following vehicle in the same lane.	Optional; Provided when available
Path Prediction	Trajectory prediction of the ego-vehicle	Optional; Provided when available
Group Identifier	Identifier of the platoon or convoy in which the ego-vehicle is driving	Optional; Provided when driving in a platoon or convoy
Group Speed	Target speed of the convoy or platoon	Optional

Figure 10 – AutoNet2030/GCDC/Adaptive extensions [25]

In this context, it is important to say that MAVEN inherits from AutoNet2030 the use of the newly defined AutomatedVehicleContainerHighFrequency and AutomatedVehicleContainerLowFrequency as a possible option for the Low- and HighFrequencyContainer of the CAM standard. Moreover, MAVEN also makes use, like AutoNet2030, of parallel CAM transmissions on one SCHx, not to overload the Day1 SCH0. However, some differences in the definition and use of CAM extensions can be identified between MAVEN and AutoNet2030. A comparison between the AutoNet2030 and the MAVEN approaches is indicated and motivated in Table 9.

Table 9: Comparison between MAVEN and AutoNet2030 CAM extension approaches

Data Field/Element	Comparison with MAVEN CAM extension approach
OperatingMode	Initially not adopted in MAVEN, as CAMs for high awareness applications like platooning are always transmitted on a parallel SCHx with a fixed higher frequency. Hence, there is no need to indicate when CAMs are transmitted with higher frequency generation rules.
DrivingMode	Initially not adopted in MAVEN, as MAVEN vehicles are by definition highly automated vehicles. The inclusion of the MAVENAutomatedVehicleContainer implicitly indicates this property
AutomatedControl	Initially not adopted in MAVEN, as not needed for the MAVEN use cases. Can be easily added to the MAVENAutomatedVehicleContainer or to one of the AutomatedVehicleContainers
TargetSpeed	Initially not adopted in MAVEN, as not needed for the MAVEN use cases. Can be easily added to the MAVENAutomatedVehicleContainer or to one of the AutomatedVehicleContainers
TargetLongitudinalAcceleration	Initially not adopted in MAVEN, as not needed for the MAVEN use cases. Can be easily added to the MAVENAutomatedVehicleContainer or to one of the AutomatedVehicleContainers
BrakingCapacity	Included in the *AccelerationCapability* data field of the MAVENAutomatedVehicleContainer
TargetDistanceToPrecedingVehicle	Initially not adopted in MAVEN, as not needed for the MAVEN use cases. Can be easily added to the MAVENAutomatedVehicleContainer or to one of the AutomatedVehicleContainers
TargetDistanceToFollowingVehicle	Initially not adopted in MAVEN, as not needed for the MAVEN use cases. Can be easily added to the MAVENAutomatedVehicleContainer or to one of the AutomatedVehicleContainers
PathPrediction	Included as PlannedPath data field of the AutomatedVehicleContainers
GroupID	Included as PlatoonID in the MAVENAutomatedVehicleContainer and AutomatedVehicleContainers
GroupSpeed	Included as *DesiredPlatoonSpeed* in the MAVENAutomatedVehicleContainer

4.2 Lane Change Advisory

In order to build on previous standardization work, the LAM was designed in a way to use as many pre-existing elements of SAE J2735 standardized messages [15] as possible. The locations are referenced building on the MAP to prevent sending topology information twice. The message is built up following the same principles, starting with an ItsPduHeader that indicates the type of message and the originating station id. This is followed by a generation time stamp and a list of lane advices. An example of a possible entry to this lane advice list is provided in Figure 11.

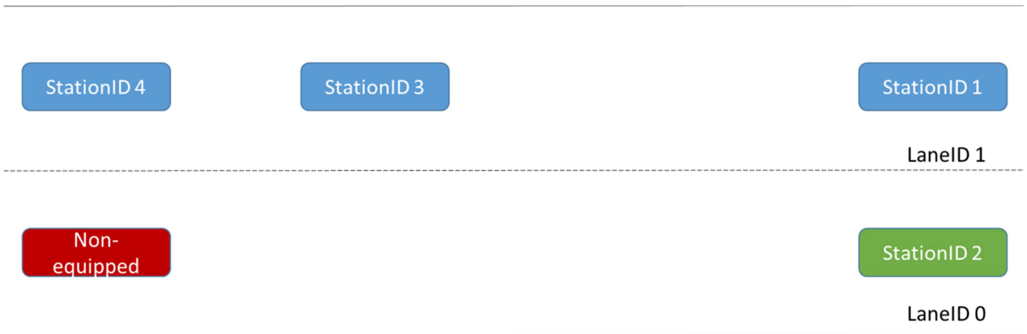


Figure 11 - Lane advice vehicle 2 (green) to merge between 1 and 3 (blue)

In this situation, the vehicle with station id 2 gets an advice to change to lane 1. Since both the vehicle in front of the gap and behind the gap are cooperative, the LAM can provide information about the neighbouring vehicles as well. However, as indicated by the presence of a red non-equipped vehicle, this is not always the case and therefore the neighbour indications are optional. The location where the lane change should take place and at which time instant are also optional, but provided by the RSU when it has sufficient knowledge to help the vehicle merge at the optimal moment. For emergency situations where lane 1 is already full, the RSU can simply advise to merge and then it's up to the vehicle to find a gap. The target vehicle, lane, and intersection are mandatory because leaving these out would make interpretation of the advice impossible. The reason for the advice is also mandatory, so vehicles can assess the criticality of the situation.

The advice for the situation in Figure 11 could be summarized by the following JSON string:

```
LaneAdvice {
      targetStationID StationID = 2,
      adviceIntersectionID IntersectionID = 701,
      adviceLaneID LaneID = 1,
      adviceReason LaneAdviceReason = PlatoonForming,
      targetMoy = the current or next minute,
      targetTimeStamp   = e.g. 5 seconds from now
      targetDistance ZoneLength = e.g. 50m ahead
      leadingStationID StationID = 1,
      trailingStationID StationID = 3
}
```

More details on the LAM definitions can be found in Annex A2: LAM description and Annex B2: LAM ASN.1 specification. Encoding and decoding of the message was tested using independent ASN.1 encoding/decoding software. This way it was ensured that the ASN.1 specification can be interpreted and shared with other partners and projects as well.

4.3 Lane Specific GLOSA

Even with a lane advice it is still possible that two lanes have different speed advice. The goal of lane advice is not to completely balance all lanes, routing or vehicle class restrictions can still cause imbalances. However, with the current profiling of MAP and SPaT messages [19], it is difficult to distinguish between different lanes. There is a mapping between lane-connections and signal groups in the MAP message. Details of the messages structure are shown in Figure 12. This figure is based on the ASN.1 structure and also shows the hierarchy of the elements, so one can see that for example “laneID” is part of “GenericLane”. The “connectionID” in the MAP can be used to identify lane-specific connections, but in the SPaT it is linked to the “ManeuverAssistList”, which can only hold queue length information and no speed advice. It would be possible to extend the information held by this element, but since MAP and SPaT are mature standards used by many projects, it is not likely that an extension to the standard will be adopted. Additionally, further detailing the profiling will not result in incompatibility issues with other cooperative vehicles using the old profiling.

For the aforementioned reasons, in MAVEN it was decided to define extra traffic light Signal Groups (SGs) for lanes with separate speed advice to be included in the SPaT and MAP messages. This is not in conflict with the current profiling in [19] and can be deployed easily. The concept is illustrated in Figure 13. The TLC uses a different numbering than the MAP and SPaT. This is to indicate lane differences. Signal Group 2 of the TLC has two lanes and is indicated as SG1 for the rightmost lane and SG2 for the leftmost lane in the SPaT/MAP.

Figure 12 – MAP (left) and SPaT (right) structure

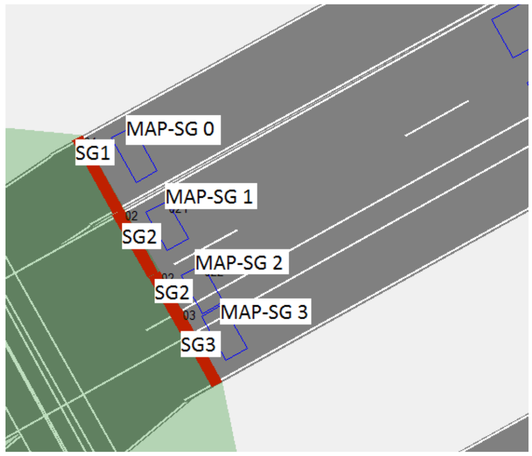


Figure 13 – Signal Group numbering, TLC vs. MAP

4.4 Collective Perception

Collective Perception (CP), is a V2X service which aims at sharing information about the current driving environment by letting vehicles and RSUs transmit data about detected objects (i.e. other road participants, obstacles and alike) in abstract descriptions. These abstract descriptions are included in messages called CP messages (CPMs).
Some background on the meaning and use of the CP can be found in previous scientific publications [28][29] focusing on collision avoidance and proposing a first attempt of common message format, yet oriented to research-purposes and not completely suitable to real-world implementations. Similarly, the AutoNet2030 project proposed a so-called Cooperative Sensing Message containing relevant data fields for the description of locally perceived objects but missing important information such as the used sensors' field of view [23]. The first MAVEN-suitable definition of a collective perception message can be found in [31]. This message includes, besides a list of detected objects and their characteristics, also a list of supported local sensors and their capabilities. This message has been the basis to start the CPM standardization currently ongoing at ETSI ITS [32][33]. However, as mentioned in Section 2.3, this message was initially only suitable for vehicles as originating CPM stations, not considering RSUs.
A fundamental discussion point at the beginning of the standardization activity was whether the CPM would allow transmission of raw sensor data. This possibility was suddenly discarded, as it would require sensor-specific representations and cause important amounts of radio channel load. Moreover, it had to be clear which objects are allowed to be represented in the message (e.g. among static, dynamic, traffic signs, etc.). Another discussion point in the standardization activity was whether the transmitted abstract descriptions of CPM objects would be resulting from multiple measurements of individual transmitter's sensors, or from a single measurement made by the transmitter's sensor fusion. With the first approach, data processing delays are avoided at the transmitting side. In this case, the received object description would more accurately represent the actual current properties of the detected object as seen by the transmitter's detecting sensors. With the second approach, a simpler and practically feasible solution is enabled. In fact, with this second approach the receiver is not requested to fuse descriptions of the same detected object deriving from multiple measurements made by different sensors at the transmitting side. To fill the above mentioned standardization gaps and open questions, the MAVEN project has participated in the ETSI activities by providing the MAVEN use cases requirements (Section 2.3), and presenting

suitable proposals to accommodate their needs. The MAVEN CPM definitions, aligned with the ETSI work at the moment of writing this deliverable, are presented in the following.

4.4.1 Concept

In general, an originating station (in MAVEN a CAV or a CI) continuously transmits CPMs carrying abstract representations of detected objects (e.g. distance from the detecting station, object's heading, speed, etc.). According to the current ETSI draft definitions [33], objects to be included in the CPM shall be shared with the objective of increasing traffic safety. Sharing detections of traffic signs and traffic light information is out of scope. Objects relevant for traffic safety are either static, i.e. do not move but are located on the driving lanes, or dynamic, i.e. move or have the ability to move (e.g. pedestrians walking on walkways). In MAVEN, a further assumption is done. In order to reduce the system complexity at the receiving side and radio channel load, originating stations have to transmit only objects that might be "directly" relevant for receiving stations: this means non-relevant object like parked cars along the carriageway and/or pedestrian walking far from the driving lanes shall be filtered out (see the Coop Sensing Tx Filtering box in Figure 5) and not transmitted.
The CPM detected object descriptions are generated according to a local coordinates system which depends on the type of CPM originating station. In the case of a vehicle, this coordinates system takes the centre-front of the car as origin (vehicle's reference point), with the x_v axis aligned to the direction of the vehicle length and pointing towards the front, and the y_v axis aligned to the lateral vehicle dimension [34] (see Figure 14). This system will point to a different direction as the vehicle moves. In case the originating station is an RSU, the adopted system is centred in a point close to the CI (RSU's reference point), and its coordinates x and y (see Figure 15) are aligned to east and north, respectively as done in for SPAT/MAP representations [15]. More detailed definitions of these coordinates systems and further figures are given in Annex A3.

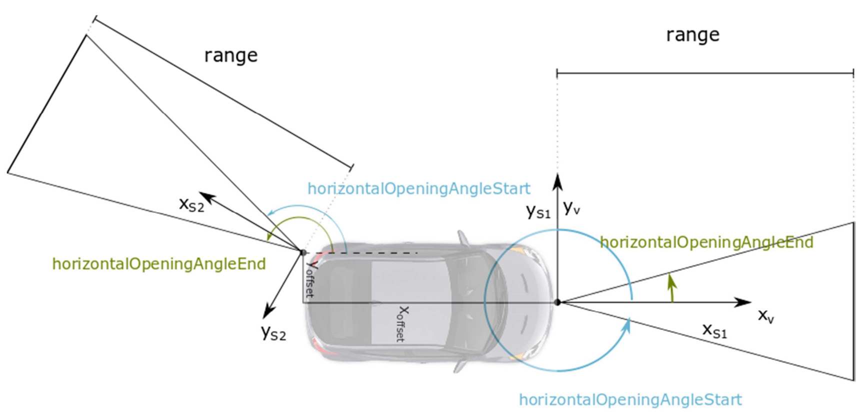


Figure 14 – CPM definitions on vehicle coordinate system

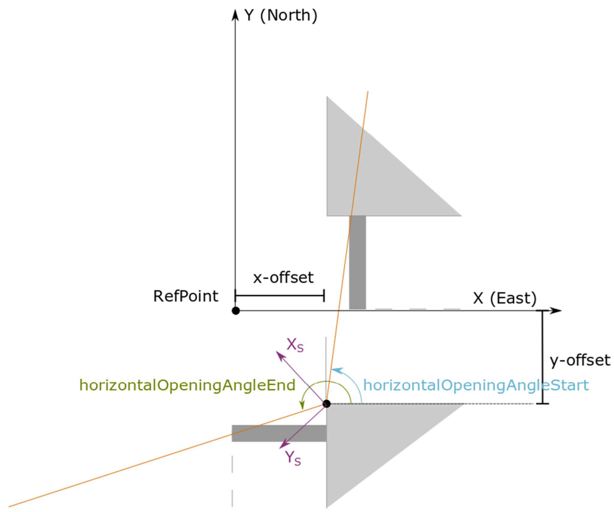


Figure 15 – CPM definitions on RSU coordinate system

At receiving stations, a coordinate transformation process is needed to map the received objects descriptions onto the receiver's local coordinate system. A transformation process example at a receiving ego-vehicle example is depicted in Figure 16. To allow the coordinate system transformation process at the receiving side, the originating station has to always transmit data about its coordinate system (e.g. reference position, and in the case of a vehicle also speed, orientation, etc.).
Besides this, each originating station must indicate with CPM transmissions its ability to detect objects in the space around it. This ability is indicated by transmitting a description of its detecting capabilities in terms of installed sensors and their associated fields of view (FoVs). As a result, receiving stations are able to derive the expected total FoV of the transmitter, and to sum the transmitter's FoV to their own FoV. In this way, when an originating station is transmitting a CPM not containing objects in a given direction, a receiver can estimate if that information reflects the reality by analysing the received FoV information: if the received FoV information says that the transmitter has no sensors covering that direction, objects can be actually present in the reality.

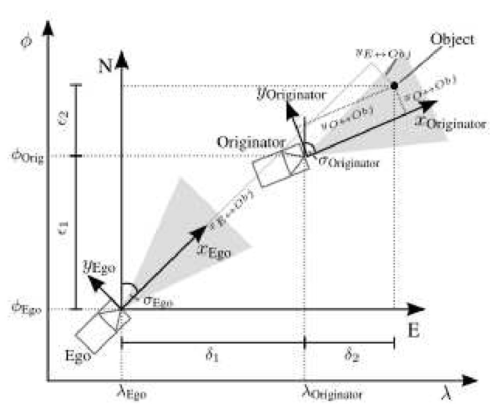


Figure 16 – Coordinate transformation process example at CPM receiving vehicle [31]

4.4.2 CPM structure and generation rules

The structure of a CPM message is depicted in the Figure 17 below and better detailed in the next subsections.

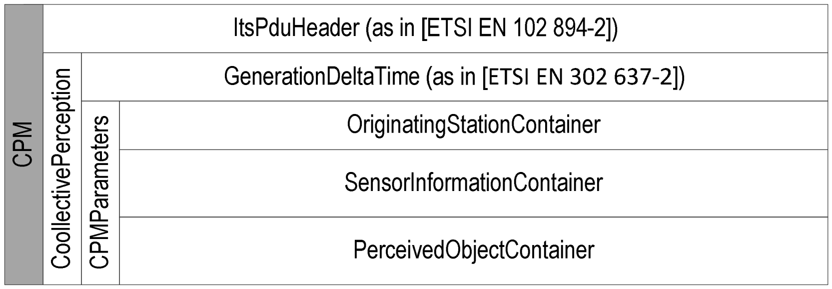


Figure 17 – CPM structure

As it can be seen, while the high-level structure is inherited from the CAM message (presence of and ItsPduHeader followed by a CollectivePerception container including the GenerationDeltaTime), the CPM is characterized by the presence of three main containers in the CPMParameters data field:

1) Originating ITS-Station Container (MANDATORY): includes information related to the originating station of the CPM. This information includes the data elements required by receiving stations for the coordination transformation process. This Originating ITS-S Container is divided into a Basic Container and a Station Data Container. The Basic Container is common for vehicles or RSUs originating stations: it specifies the station type (vehicle or RSU), and contains information about the originating station's reference point. The station data container can be a choice between an Originating Vehicle Container and an Originating RSU Container depending on whether the originating station is a vehicle or an RSU. In case of a vehicle, the Originating Vehicle Container indicates the dynamic properties of the vehicle (heading, speed, acceleration, orientation, etc. see details in Annex A3). In case of an RSU, the Originating RSU Container does not include dynamic properties (the RSU is not moving). On the contrary, it contains the standard identifier of the intersection or road segment where the objects are detected. As this identifier is the same as transmitted by the RSU in MAP messages, the detected objects' positions can be mapped on the intersection or road topology descriptions conveyed in MAP messages. This would support the cooperative sensing approach and use cases realized by the XCYCLE project, where detected VRUs' positions are expressed in terms of distance to the beginning of a given intersection's lane [35].

2) Sensor Information Container (OPTIONAL): includes information indicating the detecting capabilities of the originating station that can be used by the receiving stations to select appropriate prediction models. This container allows indicating the sensing capabilities of originating station's separate sensors or the overall sensing capability of its sensor fusion. In case the first option is adopted, the container allows including a sequence of SensorEntry data fields, each dedicated to a specific sensor. The SensorEntry includes an unambiguous sensor identifier and type. The SensorEntry can be further specified in different ways, selecting among various representation choices allowed by its SensorDetails subfield. In fact, the SensorDetails can be chosen among representations suitable for originating vehicle stations (i.e. VehicleSensor data field) or alternatively for RSU originating stations (StationarySensorRadial, StationarySensorPolygon,

StationarySensorCircular, StationarySensorEllipse, StationarySensorRectangle). In this context, the VehicleSensor and StationarySensorRadial allow representing the detecting capabilities in terms of sensor mounting position, opening angles and sensor ranges as depicted in Figure 14 and Figure 15, respectively. By using these values, the receiving stations have to extrapolate the region where the originating station can theoretically perform objects detections. On the contrary, the options StationarySensorPolygon, StationarySensorCircular, StationarySensorEllipse, StationarySensorRectangle provide means to directly and explicitly specify the position and shape of the regions where the CI is capable to perform object detections. These shapes are graphically represented in Figure 18. Further details on the definitions of these data fields can be found in Annex A3.

3) Perceived Object Container (OPTIONAL): consists of a sequence[9] of ObjectData elements each providing an abstract description of a detected object. Each detected object shall be marked with an identifier in order to let the receiver track it as long as possible. Moreover, the identifier of the sensor with which the object is detected shall also be included in order to retrieve the corresponding sensor information from the Sensor Information Container. Other mandatory data elements for the ObjectData are the time of measurement, as well as the object's distance with respect to the originating station's reference point in the originating station's coordinates system. In order to correctly interpret this data at the receiving side, the ObjectData shall also contain the position of the object's reference point considered for the calculation. A possibility to classify the detected object (e.g. pedestrian, bicycle, moped, passenger car, etc.) is also given by the ObjectData field.
   Several other object description elements are allowed as optional in the ObjectData (relative speed and acceleration with respect to the originating station, yaw angle, dimensions, dynamic status etc.). For the implementation of use cases requiring a matching of the detected object position onto the MAP message representation, a MatchedPosition data field is introduced. This field includes the LaneID of the lane where the object is detected, as well as its position from the first node point of the lane as transmitted in the MAP message describing the topology of the intersection or road segment indicated in the Originating RSU Container.

The CP service running at the V2X communication module implements the generation rules for CP messages. This includes the frequency of CPM transmissions and their content. The frequency of CPM generation can be selected in a range [1-5Hz] according to the selected generation method. In the periodic generation method (adopted by MAVEN), the generation frequency is fixed and corresponds to a generation period T_GenCpm that can be chosen in the range [200-1000ms]. Every consecutive CPM shall contain the Originating Station Container. The optional Sensor Information Container shall be included after 1000ms from its last inclusion. The optional Perceived Object Container shall be included in every consecutive CPM as long as at least one object is detected and shall contain all the objects detected by the originating station[10].

The next subsections briefly describe the content and definitions of the CPM containers separately. A more detailed description of the MAVEN CPM structure and definition of the data fields and

[9] As indicated in Annex A3 and B3, the message accounts for 255 object descriptions. For the inclusion of such a high number of information in CPM messages, fragmentation techniques are being investigated.

[10] Please notice that the ETSI draft [32] foresees the use of an alternative object-based CPM generation rule that triggers new CPMs based on whether considerable variations of relative dynamics are observed by the originating station compared to the detected objects. This solution, that tends to emulate the CAM generation rules of [5], is still under discussion at ETSI, and hence not considered in MAVEN.

elements is provided in Annex A3. Annex B3 presents the ASN1 definitions needed to use the MAVEN CPM on real V2X transceivers. Please notice that the ASN.1 definitions for the MAVEN CPMs have required extensions of the ETSI ITS Common Data Dictionary standard [8], whose ASN.1 definitions are reported in Annex B4.

4.4.3 CPM originating station container

A detailed description of the structure and data elements of the Originating Station Container is given in Table 10. For a further detailed description of the implementation aspects of this container, please refer to Annex A3.

Table 10: Content of CPM originating ITS-S container

	Data Field/Element		Description
Originating Station Ccntainer	*BasicContainer*		Specifies the position of the reference point and station type of the originating station
	StationData choice between:	*Originating Vehicle Container*	Indicates the dynamic properties of the vehicle (heading, speed, acceleration, orientation, etc.)
		Originating RSU Container	Contains the standard identifier of the intersection or road segment where objects are detected. It is used for matching objects positions on transmitted MAP messages

4.4.4 CPM sensor information container

A detailed description of the structure and data elements of the Sensor Information Container is given in Table 11. For a further detailed description of the implementation aspects of this container, please refer to Annex A3.

Table 11: Content of CPM sensor information container

<table>
<tr><th></th><th colspan="4">Data Field/Element</th><th>Description</th></tr>
<tr><td rowspan="8">SensorI nformation Ccntainer</td><td rowspan="8">Sequence of N SensorEntry</td><td rowspan="8">SensorEntry</td><td colspan="2">SensorID</td><td>Random ID number of sensor which may change over time</td></tr>
<tr><td colspan="2">SensorType</td><td>Describes the type of attached sensor (e.g. undefined, radar, lidar(2), etc.)</td></tr>
<tr><td rowspan="6">SensorDetails choice between:</td><td>VehicleSensor</td><td>Represents the detecting capabilities of a vehicular sensor in terms of sensor mounting position, opening angles and sensor ranges</td></tr>
<tr><td>StationarySensorRadial</td><td>Represents the detecting capabilities of an intersection sensor in terms of sensor mounting position, opening angles and sensor ranges</td></tr>
<tr><td>StationarySensorPolygon</td><td>Describes a polygonal area where an intersection sensor is capable of detecting objects</td></tr>
<tr><td>StationarySensorCircular</td><td>Describes a circular area where an intersection sensor is capable of detecting objects</td></tr>
<tr><td>StationarySensorEllipse</td><td>Describes an ellipsoidal area where an intersection sensor is capable of detecting objects</td></tr>
<tr><td>StationarySensorRectangle</td><td>Describes a rectangular area where an intersection sensor is capable of detecting objects</td></tr>
</table>

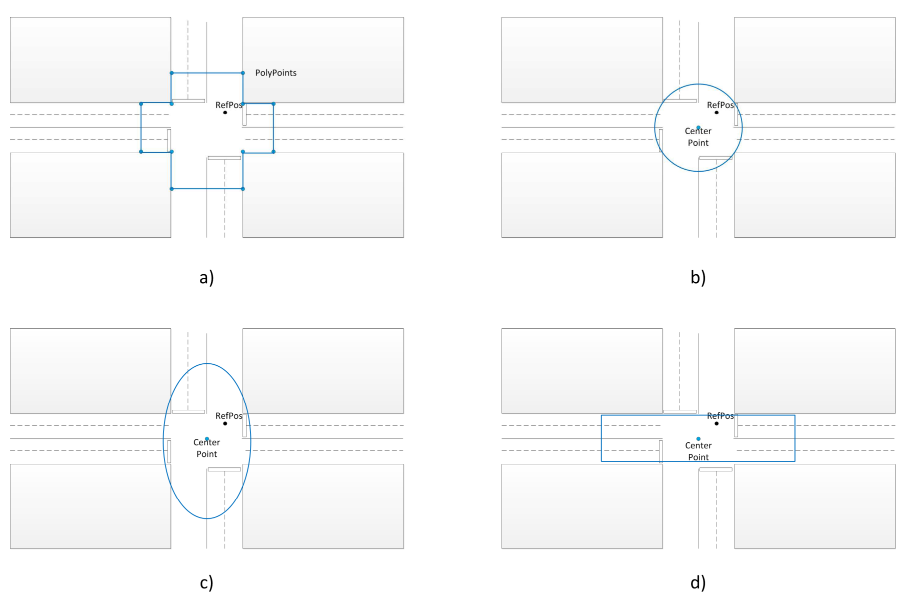


Figure 18 – Possible SensorDetails representations: a) StationarySensorPolygon, b) StationarySensorCircular, c) StationarySensorEllipse, d) StationarySensorRectangle

4.4.5 CPM perceived object container

A detailed description of the structure and data elements of the Perceived Object Container is given in Table 12. For a further detailed description of the implementation aspects of this container, please refer to Annex A3.

Table 12: Content of CPM perceived object container

	Data Field/Element			Description
Perceived Object Ccntainer	Sequence of N *ObjectData*	*ObjectData*	ObjectID	Quasi random number for detected object which may change over time.
			SensorID	Pseudonym ID of sensor which provided the measurement data. Refers to the sensorID in the SensorInformationContainer.
			TimeOfMeasurement	Time difference with respect to the generation delta time for the provided measurement
			Object age	Age of object in, i.e. for how long the object has been observed on the disseminating station.
			Object confidence	Standarised Confidence for object description
			Distance	Absolute distance and confidence to detected object from the ITS-S's reference point
			RelativeSpeed	Relative speed and confidence of detected object from the ITS-S's reference point
			RelativeAcceleration	Relative acceleration and confidence of detected object from the ITS-S's reference point
			Yaw Angle	Relative yaw angle and confidence of object from the ITS-S's reference point
			PlanarObject Dimensions	First and second dimensions of object as provided by the sensor or object model. The first dimension is always contained in the plane perpendicular to the direction of the angle indicated by the yawAngleValue and containing the object reference point. The second dimension is perpendicular to the value provided by the first dimension extending towards absolute increasing object distance with orientation according to the object's yawAngleValue
			Vertical Object Dimension	Vertical dimension of the object as provided by the sensor or object model
			Object Ref Point	Reference point of measurement for the object dimensions. All provided state variables of this object are given relative to the reference point. The point is included in the plane perpendicular to the direction of the yawAngleValue
			Dynamic status	Indication whether the detected object is classified as a dynamic (i.e. moving) object. This value indicates whether an object has the capability to move, i.e. change its position
			Classification	Classification of the detected object, if applicable. Possible values are unknown(0), pedestrian(1), cyclist(2), moped(3), motorcycle(4), passengerCar(5), bus(6), lightTruck(7), heavyTruck(8), trailer(9), specialVehicles(10), tram(11)
			Matched position	Indicates the position of the object mapped on the intersection toplogy description transmitted in MAP msg

5 Test bench and simulation setup for verification

Figure 19 describes a sample of the test bench adopted to verify the correctness of the communication services described in Section 4.

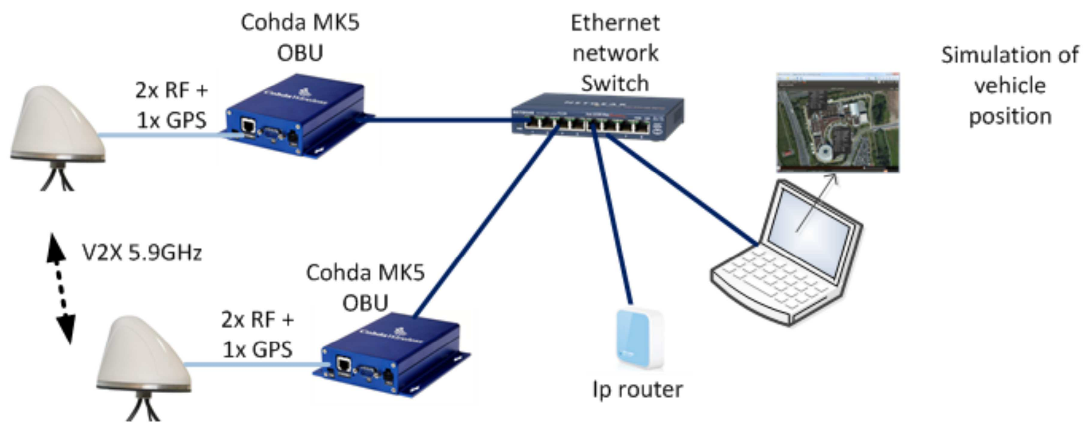


Figure 19 – Test bench setup used for V2X protocols verification

As V2X communication modules, two Cohda MK5 OBUs [36] are used, which are interconnected in a LAN together with a PC running the Cohda SDK. The Cohda OBUs are capable to transmit simultaneously on two parallel ITS G5 channels as required by the MAVEN CAM extensions. The SDK provided from Cohda includes a SW to compile the SW applications running at the Cohda OBUs for V2X transmissions and receptions. Also, the SDK runs a SW for the simulation of vehicle positions, which is needed for the correct execution of the OBU applications. The MAVEN communication schemes' verification method is described in Figure 20:

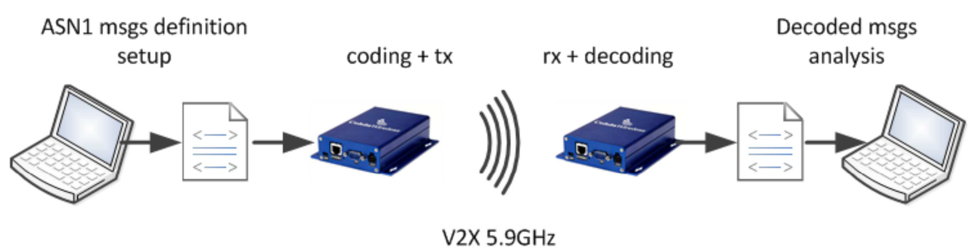


Figure 20 – Adopted verification method

A V2X test application is implemented in the SDK and later on installed and run on the Cohda OBUs. At the transmitting side, the application populates the V2X messages according to the MAVEN ASN.1 definitions. Messages are UPER encoded and periodically transmitted. At the receiving side, the messages are received and UPER decoded. Captures of the received messages as well as the decoded messages are analysed on the controlling PC. The received messages are analysed in a customized MAVEN version of wireshark to verify that the messages are transmitted on the wanted ITS G5 channels and according to the communication protocols of the ETSI ITS architecture layers and MAVEN communication services (see in Figure 21 a wireshark screenshot of the MAVEN extended CAMs transmitted over parallel ITS G5 channels)

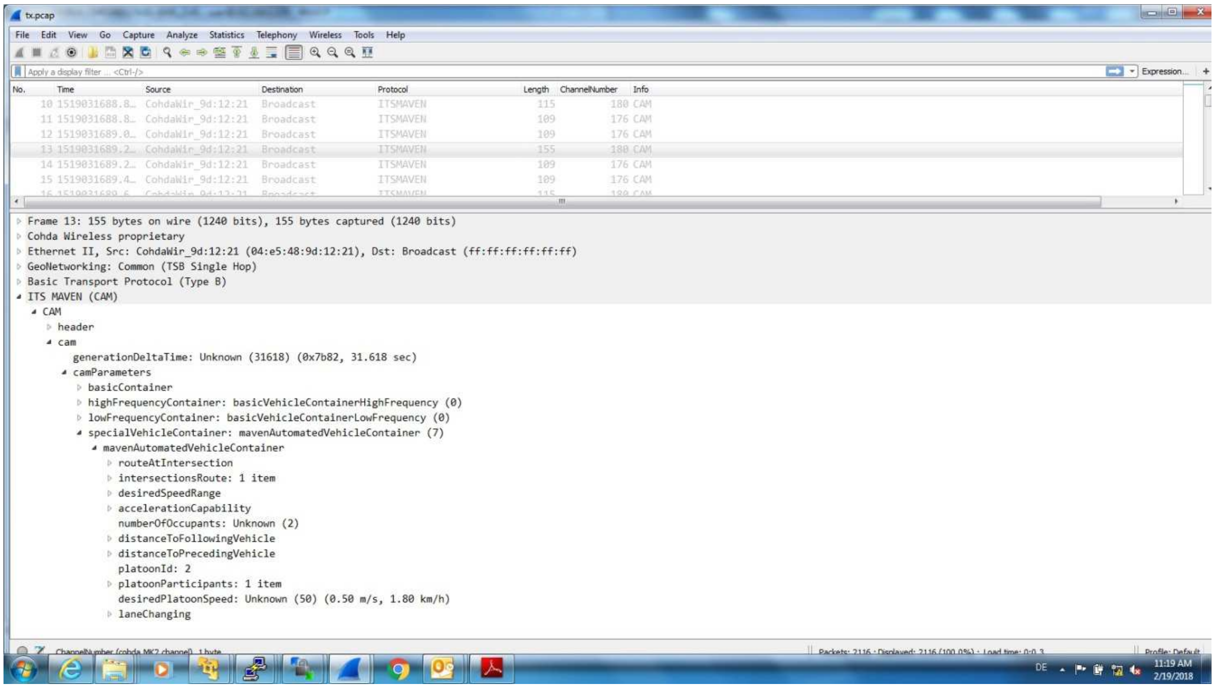
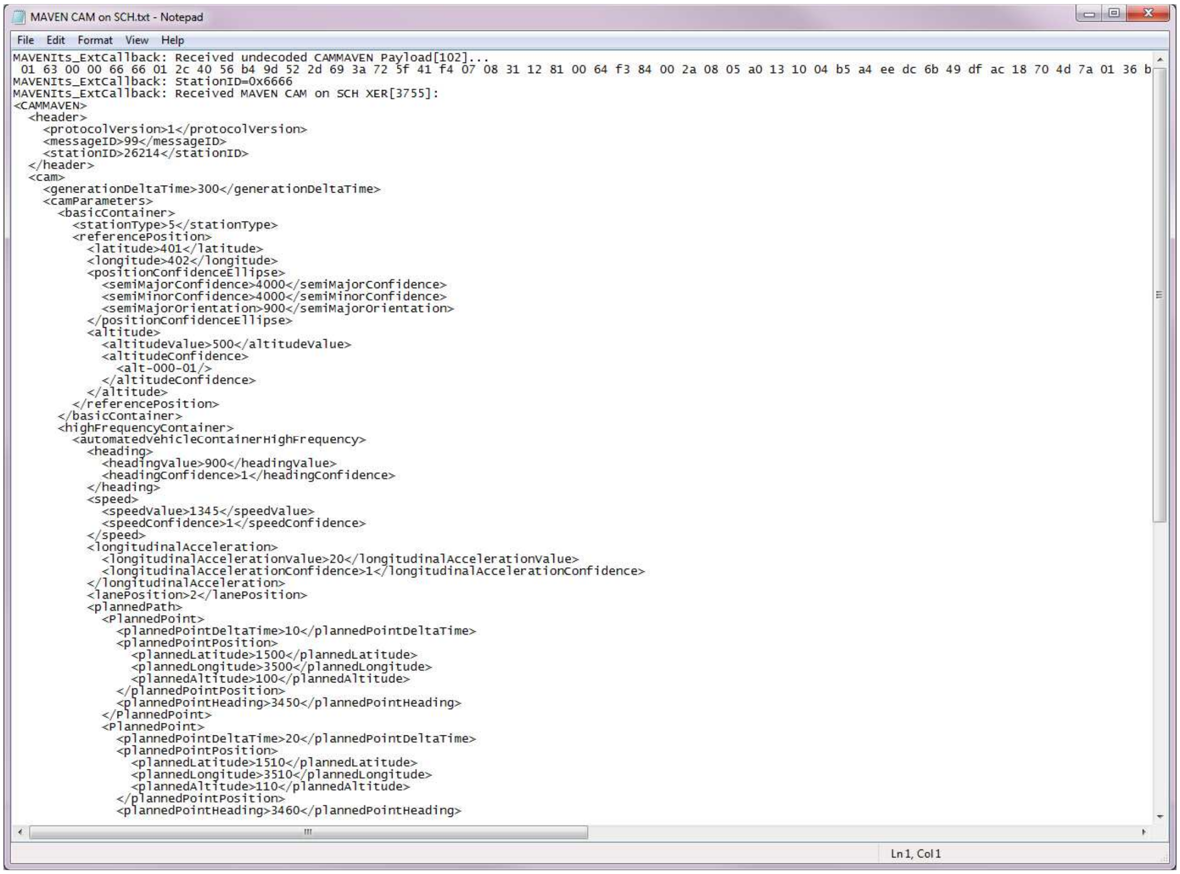


Figure 21 – Wireshark screenshot for MAVEN CAMs transmission verifications

Alternatively, the decoded messages at the receiving side can be converted by the Cohda OBU into a human-readable XER representation to verify the correctness of the exchanged messages (see Figure 22)




```
MAVENIts_ExtCallback: Received undecoded CAMMAVEN Payload[102]...
 01 63 00 00 66 66 01 2c 40 56 b4 9d 52 2d 69 3a 72 5f 41 f4 07 08 31 12 81 00 64 f3 84 00 2a 08 05 a0 13 10 04 b5 a4 ee dc 6b 49 df ac 18 70 4d 7a 01 36 b
MAVENIts_ExtCallback: StationID=0x6666
MAVENIts_ExtCallback: Received MAVEN CAM on SCH XER[3755]:
<CAMMAVEN>
  <header>
    <protocolVersion>1</protocolVersion>
    <messageID>99</messageID>
    <stationID>26214</stationID>
  </header>
  <cam>
    <generationDeltaTime>300</generationDeltaTime>
    <camParameters>
      <basicContainer>
        <stationType>5</stationType>
        <referencePosition>
          <latitude>401</latitude>
          <longitude>402</longitude>
          <positionConfidenceEllipse>
            <semiMajorConfidence>4000</semiMajorConfidence>
            <semiMinorConfidence>4000</semiMinorConfidence>
            <semiMajorOrientation>900</semiMajorOrientation>
          </positionConfidenceEllipse>
          <altitude>
            <altitudeValue>500</altitudeValue>
            <altitudeConfidence>
              <alt-000-01/>
            </altitudeConfidence>
          </altitude>
        </referencePosition>
      </basicContainer>
      <highFrequencyContainer>
        <automatedVehicleContainerHighFrequency>
          <heading>
            <headingValue>900</headingValue>
            <headingConfidence>1</headingConfidence>
          </heading>
          <speed>
            <speedValue>1345</speedValue>
            <speedConfidence>1</speedConfidence>
          </speed>
          <longitudinalAcceleration>
            <longitudinalAccelerationValue>20</longitudinalAccelerationValue>
            <longitudinalAccelerationConfidence>1</longitudinalAccelerationConfidence>
          </longitudinalAcceleration>
          <lanePosition>2</lanePosition>
          <plannedPath>
            <PlannedPoint>
              <plannedPointDeltaTime>10</plannedPointDeltaTime>
              <plannedPointPosition>
                <plannedLatitude>1500</plannedLatitude>
                <plannedLongitude>3500</plannedLongitude>
                <plannedAltitude>100</plannedAltitude>
              </plannedPointPosition>
              <plannedPointHeading>3450</plannedPointHeading>
            </PlannedPoint>
            <PlannedPoint>
              <plannedPointDeltaTime>20</plannedPointDeltaTime>
              <plannedPointPosition>
                <plannedLatitude>1510</plannedLatitude>
                <plannedLongitude>3510</plannedLongitude>
                <plannedAltitude>110</plannedAltitude>
              </plannedPointPosition>
              <plannedPointHeading>3460</plannedPointHeading>
```


Figure 22 – XER analysis of decoded MAVEN CAMs

6 Conclusion

V2X communications are a cornerstone for the MAVEN solutions since they constitute the link between vehicle automation and C-ITS traffic management. This document has demonstrated how the MAVEN V2X communications schemes can satisfy the need of the use cases addressed in the project. From the C-ITS infrastructure point of view, a novel I2V Lane Change Advisory service and a dedicated profiling of the Signal Phase and Time (SPaT) and MAP for lane-specific GLOSA can enable I2V suggestions that CAVs can apply to more granularly distribute the incoming traffic demand on intersection approaches. From the vehicle point of view, backward-compatible extensions of standard CAM messages permit CAVs to interact with CIs to communicate planned manoeuvres, desired intentions, vehicle/platoon characteristics, or to notify the applicability of the received I2V advices. Further backward-compatible CAM extensions are developed for enabling V2V communications to support a distributed algorithm for initiation, management and control of CAV platoons. Finally, the currently under standardization Collective Perception service has been adapted to the needs of the MAVEN project to support CAV applications aimed at increasing the safety of VRUs and vehicle drivers. The developed schemes have been tested in small test benches aimed at evaluating the technical functionality of the developed solutions from a communication point of view. This opens a link to the work ongoing in WP6 where V2X communication modules and services are being integrated in full CAV and CI prototypes for the future evaluation of the MAVEN use cases performed in WP7. In WP7, additional work is also expected on the evaluation of some of the here described communication functionalities in communication simulation environments.

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Annex A: MAVEN messages description

Annex A1: CAM extensions description

Table 13: MAVENAutomatedVehicleContainer definitions

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from		Description
							ETSI CDD	SAE J2735	
routeAtIntersection		SEQUENCE							Planned route at next intersection (in/out lane). Includes a feedback to indicate if the vehicle is compliant to the suggested speed advisory for the driven lane
intersectionID		INTEGER	0	65535	N/A	N/A		7.55	Identifier of the intersection the CAV is driving towards
ingressingLaneID		INTEGER	0	255	N/A	N/A		7.87	Identifier of the ingressing lane the CAV is currently driving on
egressingLaneID		INTEGER	0	255	N/A	N/A		7.87	Identifier of the egressing lane the CAV plans driving on
signalGroupID	x	INTEGER	0	255	N/A	N/A		7.171	Identifier of the SPAT/MAP signal group the CAV is currently considering
maneuver	x	BITSTRING						7.4	Identifies the maneuver the CAV pland to perform at the intersection
speedAdviceCompliance	x	ENUM	0	2					Indicates whether the CAV is currently applying the speed advice suggested by the SPAT message in its zone. Can assume values unknown, compliant, not_compliant
intersectionsRoute		SEQUENCE	1	10	N/A	N/A			Planned route in terms of next intersections to cross expressed as a sequence of IntersectionIDs
intersectionID		INTEGER	0	65535	N/A	N/A		7.55	
desiredSpeedRange									Desired min and max speed for a CAV to start driving in a platoon
minSpeed		INTEGER	0	16383	m/s	0.01	A.74		Desired min speed value for a CAV to start driving in a platoon
maxSpeed		INTEGER	0	16383	m/s	0.01	A.74		Desired max speed value for a CAV to start driving in a platoon
accelerationCapability		SEQUENCE	0	4294967295	N/A	N/A	A.77		Supported max positive and negative accelerations for a CAV to start driving in a platoon
maxNegativeAcceleration		INTEGER	-160	161	m/s2	0.1	A.45		Supported max negative acceleration value for a CAV to start driving in a platoon
maxPositiveAcceleration		INTEGER	-160	161	m/s2	0.1	A.45		Supported max positive acceleration value for a CAV to start driving in a platoon
numberOfOccupants	x	INTEGER	0	127	person	1	A.46		Number of occupants in the CAV
distanceToFollowingVehicle	x	INTEGER	0	65535	milli s	1			Distance to the following vehicle in the same lane
distanceValue		INTEGER	0	511	m	0.1			Distance value
distanceConfidence		INTEGER	1	32	m	0.1			Distance confidence
distanceToPrecedingVehicle	x								Distance to the preceding vehicle in the same lane
distanceValue		INTEGER	0	511	m	0.1			Distance value
distanceConfidence		INTEGER	1	32	m	0.1			Distance confidence
platoonId	x	INTEGER	0	4294967295	N/A	N/A			Identifier of the platoon the CAV is currently in (if a CAV is in a platoon)
platoonParticipants	x	SEQUENCE							List of following vehicle IDs (tx by platoon leader only when approaching a cooperative intersection)
stationID		INTEGER	0	4294967295	N/A	N/A	A.77		Identifier of the follower CAV
desiredPlatoonSpeed	x	INTEGER	0	16383	m/s	0.01	A.74		Speed the platoon desires to adopt (tx by platoon leader only when approaching a cooperative intersection)
laneChanging	x	SEQUENCE							Feedback to the CI to indicate if the vehicle is compliant to the suggested lane

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
									change advice
laneAdviceIntersectionID		INTEGER	0	65535	N/A	N/A		7.55	Identifier of the intersection for which the lane change advice applies
laneAdviceRequestID		INTEGER	0	4294967295	N/A	N/A			Identifier of the request used for the lane change advice
laneAdviceCompliance		ENUM	0	5	N/A	N/A			Indicates if the CAV is currently implementing the lane change advice and if yes, how (see details in the ASN.1 definitions)

Table 14: AutomatedVehicleContainerHighFrequency and AutomatedVehicleContainerLowFrequency definitions

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
AutomatedVehicleContainerHighFrequency		SEQUENCE							
heading		SEQUENCE					A.112		Heading and heading accuracy of the vehicle movement (calculated taking into account the speed vector) of the originating ITS-S with regards to the true north. The heading accuracy provided in the DE headingConfidence value shall provide the accuracy of the measured vehicle heading with a confidence level of 95 %. Otherwise, the value of the headingConfidence shall be set to unavailable
speed		SEQUENCE					A.126		Driving speed and speed accuracy of the originating ITS-S. The speed accuracy provided in the DE speedConfidence shall provide the accuracy of the speed value with a confidence level of 95 %. Otherwise, the speedConfidence shall be set to unavailable. It shall be presented as specified in clause A.126 of the CDD
longitudinalAcceleration							A.116		Vehicle longitudinal acceleration of the originating ITS-S in the centre of the mass of the empty vehicle. It shall include the measured vehicle longitudinal acceleration and its accuracy value with the confidence level of 95 %. Otherwise, the longitudinalAccelerationConfidence shall be set to unavailable. It shall be presented as specified in clause A.116 of the CDD
lanePosition	x	INTEGER	-1	14	N/A	N/A	A.40		Lane the vehicle is currently driving
plannedPath	x	SEQUENCE	1	23					Planned vehicle trajectory in terms of future positions and headings. It is a sequence of plannedPoints
plannedPoint		SEQUENCE							Future position and heading of the CAV at a given future time instant
plannedPointDeltaTime		INTEGER	1	1024	ms	10			Indicates the time offset in the future which the plannedPoint refers to
plannedPointPosition		SEQUENCE							Indicates the planned position at the corresponding future time offset
plannedLatitude		INTEGER	-900000000	900000001	Micro degrees	0.1	A.41		Latitude of the planned point
plannedLongitude		INTEGER	-180000	1800000001	Micro degre	0.1	A.44		Longitude of the planned point

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
			0000		es				
plannedAltitude		INTEGER	-100000	800001	cm	1	A.9		Altitude of the planned point
plannedPointHeading		INTEGER	0	3601	degrees	0.1	A.35		Indicates the planned heading at the corresponding future time offset
plannedLane	x	INTEGER	-1	14	N/A	N/A	A.40		Lane the vehicle plans to drive to
emergencyFlag	x	BOOLEAN	0	1	N/A	N/A			Indicates that an emergency situation is locally ongoing on the CAV
AutomatedVehicleContainerLowFrequency		SEQUENCE							
platoonId		INTEGER	0	4294967295	N/A	N/A			Identifier of the platoon the CAV is currently in (if a CAV is in a platoon)
platoonFollowers	x	SEQUENCE							List of following vehicleIDs
stationID		INTEGER	0	4294967295	N/A	N/A	A.77		Identifier of the follower CAV
platoonVehicleState		INTEGER	-160	161	m/s2	0.1	A.45		State of the platoon that the vehicle is currently in according to [4]
platoonFormingState		INTEGER	-160	161	m/s2	0.1	A.45		Forming state of the platoon that the vehicle is currently in according to [4]
platoonDistanceState		INTEGER	0	511	m	0.1			Distance state of the platoon that the vehicle is currently in according to [4]
plannedPath	x	SEQUENCE	1	23					Planned vehicle trajectory in terms of future positions and headings. It is a sequence of plannedPoints
plannedPoint		SEQUENCE							Future position and heading of the CAV at a given future time instant
plannedPointDeltaTime		INTEGER	1	1024	ms	10			Indicates the time offset in the future which the plannedPoint refers to
plannedPointPosition		SEQUENCE							Indicates the planned position at the corresponding future time offset
plannedLatitude		INTEGER	-900000000	900000001	Microdegrees	0.1	A.41		Latitude of the planned point
plannedLongitude		INTEGER	-1800000000	1800000001	Microdegrees	0.1	A.44		Longitude of the planned point
plannedAltitude		INTEGER	-100000.	800001	cm	1	A.9		Altitude of the planned point
plannedPointHeading		INTEGER	0	3601	degrees	0.1	A.35		Indicates the planned heading at the corresponding future time offset
plannedLane	x	INTEGER	-1	14	N/A	N/A	A.40		Lane the vehicle plans to drive to

Annex A2: LAM description

The elements of the LAM message are schematically described in Figure 23:

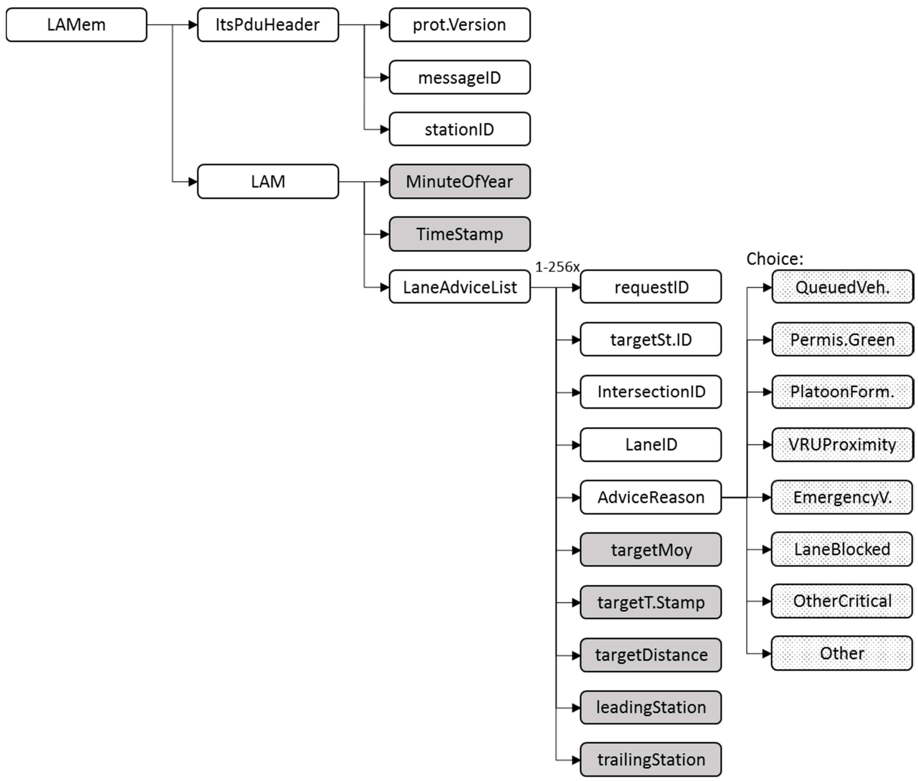

Figure 23 - LAM message structure, some element names are shortened.

In this figure the optional elements are marked grey. The message allows for any number of lane advices between 1 and 256. The advice reason is a choice, this is marked as grey dotted elements, one of the 8 reasons has to be chosen. The elements are further explained in Table 15, the colour of the rows is lighter according to the nesting level.

Table 15: LAM definitions

Data Field / Data Element			Optional	Type	Reference From		Description
					SAE J2735	ETSI CDD	
header				Sequence		A.114	ETSI CDD Its Header extended to accommodate LAM definition
	protocolVersion			Integer 0 - 255			
	messageID			Integer 0 - 255			Use 8 for LAM.
	stationID			Integer 0 - 4294967295			Can be a pseudonym, but RSU will not do this in practise.
LAM				Sequence			
	MinuteOfTheYear		x	Integer 0 - 527040	7.99		Minute since the start of the current year of the message generation. 527040 is used for invalid.
	TimeStamp		x	Integer 0 - 65535	7.39		Millisecond within the current minute of the message generation. Values over 60000 are not sensible.
	LaneAdviceList			Sequence size 1 – 256 of LaneAdvice			List of lane advice, one per vehicle
		LaneAdvice		Sequence			Single lane advice object

Data Field / Data Element	Optional	Type	Reference From		Description
			SAE J2735	ETSI CDD	
requestId		Integer 0 – 255			Used to reference the advice so receivers can acknowledge the advice in their CAM.
targetStationID		Integer 0 - 4294967295		A.77	StationID of the vehicle the advice is targeted at
adviceIntersectionID		Integer 0 – 65535	7.55		IntersectionID to which the advice is referencing for the corresponding MAPEM message.
adviceLaneID		Integer 0 – 255	7.87		The lane number towards which the vehicle should move. The value 0 represents unknown and should not be used, while 255 is reserved for future use
adviceReason		Enumeration - choice			Indicates the reason why the CAV should perform the lane change
QueuedVehiclesOnLane		Enumeration – option 0			The queue in the current lane is longer than in the lane of the advice.
HaltingForPermissiveGreen		Enumeration – option 1			There are vehicles in the current lane, which have to give right of way to conflicting traffic due to permissive green.
PlatoonForming		Enumeration – option 2			A vehicle platoon is on another lane that can be joined by changing lanes.
VRUProximityRisk		Enumeration – option 3			Abnormal proximity of a VRU to the edge of the road, with a risk of entering the road, e.g. an infant playing near the road edge in contrast to a pedestrian waiting near the road edge to cross
EmergencyVehicleApproach		Enumeration – option 4			An emergency vehicle is approaching and requires a clear path to pass
LaneBlocked		Enumeration – option 5			The lane is blocked due to e.g. maintenance, accident, parked emergency vehicle
OtherCriticalReason		Enumeration – option 6			Other critical reason to change lane
Other		Enumeration – option 7			Other non-critical reason
targetMoy	x	Integer 0 - 527040	7.99		Minute since the start of the current year when the lane change should be made.
targetTimeStamp	x	Integer 0 - 65535	7.39		Millisecond within the current minute when the lane change should be made. Values over 60000 are not sensible.
targetDistance	x	Integer 0 – 10000	7.230		Position where the lane change should take place in units of 1 meter since the start of the lane. Higher numbers go against traffic flow direction, so 0 is at the stop line where the lane starts, while 100 is 100m upstream of the intersection. When the LAM is used outside an intersection 0 is simply where the lane starts.
leadingStationID	x	Integer 0 - 4294967295		A.77	StationID of the vehicle intended to be ahead of the target vehicle after merging.
trailingStationID	x	Integer 0 - 4294967295		A.77	StationID of the vehicle intended to be behind of the target vehicle after merging.

Annex A3: CPM description

Table 16 CPM definitions

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
header		SEQUENCE					A.114		ETSI CDD Its Header extended to accommodate CPM definition
protocolVersion		INTEGER	0	255	N/A	N/A			
messageID		INTEGER	0	255	N/A	N/A			
stationID		INTEGER	0	4294967295	N/A	N/A	A.77		The ITS-S ID may be a pseudonym. It may change over space or/or over time
CollectivePerception									includes generation delta time and cpm parameters
generationDeltaTime		INTEGER	0	65535	milli s	1			Time corresponding to the time of the reference position in the CPM, considered as time of the CPM generation. The value of the DE shall be wrapped to 65 536. This value shall be set as the remainder of the corresponding value of TimestampIts divided by 65 536 as below: generationDeltaTime = TimestampIts mod 65 536
CpmParameters									includes originating station container, sensor information container, and perceived objects container
OriginatingStationContainer									includes basic container, and station data
Basic Container		SEQUENCE							includes reference position and station type
stationType		INTEGER	0	255	N/A	N/A	A.78		The type of technical context the ITS-S is integrated in. The station type depends on the integration environment of ITS-S into vehicle, mobile devices or at infrastructure. It shall be presented as specified in clause A.78 of the CDD
Reference Position		SEQUENCE					A.124		Position and position accuracy measured at the reference point of the originating ITS-S. The measurement time shall correspond to generationDeltaTime. If the station type of the originating ITS-S is set to one out of the values 3 to 11 the reference point shall be the ground position of the centre of the front side of the bounding box of the vehicle. If the station type is set to 15 (RSU), the reference point shall be the ground position of any point around the RSU position. The positionConfidenceEllipse provides the accuracy of the measured position with the 95 % confidence level. Otherwise, the positionConfidenceEllipse shall be set to unavailable.If semiMajorOrientation is set to 0° North, then the semiMajorConfidence corresponds to the position accuracy in the North/South direction, while the semiMinorConfidence corresponds to the position accuracy in the East/West direction. This definition implies that the semiMajorConfidence might be smaller than the semiMinorConfidence.
StationData		CHOICE							choice between vehicle and RSU as originating station
Originating Vehicle Container		SEQUENCE							

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from		Description
							ETSI CDD	SAE J2735	
Heading		SEQUENCE					A.112		Heading and heading accuracy of the vehicle movement (calculated taking into account the speed vector) of the originating ITS-S with regards to the true north. The heading accuracy provided in the DE headingConfidence value shall provide the accuracy of the measured vehicle heading with a confidence level of 95 %. Otherwise, the value of the headingConfidence shall be set to unavailable.
Speed		SEQUENCE					A.126		Driving speed and speed accuracy of the originating ITS-S. The speed accuracy provided in the DE speedConfidence shall provide the accuracy of the speed value with a confidence level of 95 %. Otherwise, the speedConfidence shall be set to unavailable. It shall be presented as specified in clause A.126 of the CDD
orientationDeltaAngle	X	SEQUENCE							Angle and angle accuracy of the angle between the vehicle heading (calculated taking into account the speed vector) and the vehicle orientation (corresponding to the x direction of the ISO 8855 coordinate system) looking on the horizontal plane xy. The confidence denotes the accuracy of the measured AngleValue for a confidence level of 95 %.
orientationDeltaAngleValue		INTEGER	0	3601	degrees	0.1			Value of the angle between the vehicle heading (corresponding to the speed vector) and the vehicle orientation (corresponding to the x direction of the ISO 8855 coordinate system) looking on the horizontal plane xy. the angle is measured with positive values considering the vehicle orientation turning clockwise starting from the heading.
orientationDeltaAngleConfidence		INTEGER	1	127	degrees	0.1	A.34		The absolute accuracy of a reported angle value for a predefined confidence level (e.g. 95 %).
driveDirection		ENUMERATED	0	2	N/A	N/A	A.22		It denotes whether a vehicle is driving forward or backward. When the information is unavailable, the value shall be set to 2. It shall be presented as specified in clause A.22 of the CDD
longitudinalAcceleration	X	SEQUENCE					A.116		Vehicle longitudinal acceleration of the originating ITS-S in the centre of the mass of the empty vehicle. It shall include the measured vehicle longitudinal acceleration and its accuracy value with the confidence level of 95 %. Otherwise, the longitudinalAccelerationConfidence shall be set to unavailable. It shall be presented as specified in clause A.116 of the CDD
lateralAcceleration	X	SEQUENCE					A.115		Vehicle lateral acceleration of the originating ITS-S in the centre of the mass of the empty vehicle. It shall include the measured vehicle lateral acceleration and its accuracy value with the confidence level of 95 %. It shall be presented as specified in clause A.115 of the CDD
verticalAcceleration	X	SEQUENCE					A.129		Vertical Acceleration of the originating ITS-S in the centre of the mass of the empty vehicle. This DE shall be present if the data is available at the originating ITS-S. It shall include the measured vehicle vertical acceleration and its accuracy value with the confidence level of 95 %. It shall be

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from		Description
							ETSI CDD	SAE J2735	
									presented as specified in clause A.115 of the CDD
yawRate	X	SEQUENCE					A.132		yawRateValue denoting rotation around the center of mass of the empty vehicle and yawRateConfidence denoting the accuracy for the 95 % confidence level. Otherwise, the value of yawRateConfidence shall be set to unavailable. It shall be presented as specified in clause A.132 of the CDD
pitchAngle	X	SEQUENCE							Angle and angle accuracy between the ground plane and the current orientation of the vehicle's x-axis with respect to the ground plane about the y-axis according to the ISO 8855
pitchAngleValue		INTEGER	0	3601	degrees	0.1			Angle from the x-axis of the once-rotated intermediate frame to the body fixed local x-axis. The right hand rotation is about the y -axis of the once-rotated intermediate frame.
pitchAngleConfidence			1	127	degrees	0.1			The absolute accuracy of a reported angle value for a predefined confidence level (e.g. 95 %).
rollAngle	X	SEQUENCE							Angle and angle accuracy between the ground plane and the current orientation of the vehicle's y-axis with respect to the ground plane about the x-axis according to the ISO 8855
rollAngleValue		INTEGER	0	3601	degrees	0.1			Angle from the y-axis of the once-rotated intermediate frame to the body-fixed local y-axis. The right hand rotation is about the x -axis of the once-rotated intermediate frame.
rollAngleConfidence		INTEGER	1	127	degrees	0.1			The absolute accuracy of a reported angle value for a predefined confidence level (e.g. 95 %).
OriginatingRSUContainer									This container contains the Id of the intersection or road segment where detected objects can be mapped based on the topology descriptions conveyed in transmitted MAP messages
IntersectionReferenceID	X	SEQUENCE						6.36	conveys the combination of an optional RoadRegulatorID and of an IntersectionID that is unique within that region. When the RoadRegulatorID is present the IntersectionReferenceID is guaranteed to be globally unique.
roadSegmentReferenceID	X	SEQUENCE						6.107	conveys theRoadSegmentID which is unique to a given road segment of interest, and also the RoadRegulatorID assigned to the region in which it is operating
sensorInformationContainer	X	SEQUENCE							list of N data fields of type SensoEntry (one per supported sensor) at either vehicle or Infra
SensoEntry									Composed by a common part (to vehicle and Infra) defining for sensorID and Type followed by a more specific part SensorDetails
sensorID		INTEGER	0	255	N/A				Pseudonym ID of sensor which may change over time
sensorType		INTEGER	0	15	N/A				Describes the type of attached sensor. [undefined(0), radar(1), lidar(2), monovideo(3), stereovision(4), induction loop (5), spherical camera (6) nightvision(7), ultrasonic(8), pmd(9), fused(10)]

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
sensorDetails		CHOICE							Choice for container which describes the sensor perception characteristics, i.e. vehicleSensor, stationarySensorRadial, stationarySensorPolygon, stationarySensorCircular, stationarySensorRectangle, stationarySensorEllipse
vehicleSensor									See Figure 14
refPointID		INTEGER	0	255	N/A				Required in case several reference point Ids are provided, e.g. in case a trailer is present. In case of a sensor mounted on a trailer, this field is to denote which point shall be taken as the reference. default is "0" i.e. the main vehicle
xOffset		INTEGER	-5000	0	m	0.01			Mounting position of sensor in negative x-direction from Reference Point indicated by the refPointID
yOffset		INTEGER	-1000	1000	m	0.01			Mounting position of sensor in y-direction from Reference Point indicated by the refPointID
zOffset	X	INTEGER	0	500	m	0.01			Mounting position of sensor in z-direction from Reference Point indicated by the refPointID
range		INTEGER	0	10000	m	0.1			Range of sensor within the indicated OpeningAngle
horizontalOpeningAngleStart		INTEGER	0	3601	degrees	0.1			Start of the sensor's horizontal OpeningAngle extension relative to the body of the vehicle. The value is provided with respect to a body-fixed coordinate system according to the ISO 8855 specification with angles counted positive in the counter-clockwise direction starting from the Xv-axis in the xV-yV plane. The opening angle always extends from the horizontalOpeningAngleStart to the horizontalOpeningAngleEnd in counter-clockwise direction. See Figure 24. 3601 shall be set if the value is unavailable.
horizontalOpeningAngleEnd		INTEGER	0	3601	degrees	0.1			End of the sensor's horizontal OpeningAngle extension relative to the body of the vehicle. The value is provided with respect to a body-fixed coordinate system according to the ISO 8855 specification with angles counted positive in the counter-clockwise direction starting from the Xv-axis in the xV-yV plane. The opening angle always extends from the horizontalOpeningAngleStart to the horizontalOpeningAngleEnd in counter-clockwise direction. See Figure 24. 3601 shall be set if the value is unavailable.
verticalOpeningAngleStart	X	INTEGER	0	3601	degrees	0.1			Start of the sensor's vertical OpeningAngle extension described in a sensor-centric coordinate system where the xS-axis points in the direction of half of the horizontalOpeningAngle in the horizontal plane and the and the zS-axis points up. The angle is provided in a counter-clockwise fashion starting from the xS axis in the xS-zS plane. The opening angle always extends from the verticalOpeningAngleStart to the verticalOpeningAngleEnd in counter-clockwise direction. See Figure 24. 3601 shall be set if the value is unavailable.

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from		Description
							ETSI CDD	SAE J2735	
verticalOpeningAngleEnd	X	INTEGER	0	3601	degrees	0.1			End of the sensor's vertical OpeningAngle extension described in a sensor-centric coordinate system where the xS-axis points in the direction of half of the horizontalOpeningAngle in the horizontal plane and the and the zS-axis points up. The angle is provided in a counter-clockwise fashion starting from the xS axis in the xS-zS plane. The opening angle always extends from the verticalOpeningAngleStart to the verticalOpeningAngleEnd in counter-clockwise direction. See Figure 24. 3601 shall be set if the value is unavailable.
stationarySensorRadial									See Figure 15
range		INTEGER	0	10000	m	0.1			Range of sensor within the indicated OpeningAngle. The maximum value of this parameter , together with the min and max values of the NodeOffsetPointXY, ensures that any detected object has a distance in the x direction (compared to the reference point) limited by xDistanceValue_MAX. Same applies to y direction.
horizontalOpeningAngleStart		INTEGER	0	3601	degrees	0.1			Start of the sensor's horizontal OpeningAngle extension described in a non-vehicle centric right-hand coordinate system in which the x-axis points towards East and the y-axis towards the North and the z-axis points up. The angle is provided in a counter-clockwise fashion starting from the x-axis in the x-y plane. The opening angle always extends from the horizontalOpeningAngleStart to the horizontalOpeningAngleEnd in counter-clockwise direction. See Figure 25. 3601 shall be set if the value is unavailable
horizontalOpeningAngleEnd		INTEGER	0	3601	degrees	0.1			End of the sensor's horizontal OpeningAngle extension described in a non-vehicle centric right-hand coordinate system in which the x-axis points towards East and the y-axis towards the North and the z-axis points up.The angle is provided in a counter-clockwise fashion starting from the x-axis in the x-y plane. The opening angle always extends from the horizontalOpeningAngleStart to the horizontalOpeningAngleEnd in counter-clockwise direction. See Figure 25. 3601 shall be set if the value is unavailable
verticalOpeningAngleStart	X	INTEGER	0	3601	degrees	0.1			Start of the sensor's vertical OpeningAngle extension described in a sensor-centric coordinate system where the xS-axis points in the direction of half of the horizontalOpeningAngle in the horizontal plane and the and the zS-axis points up. The angle is provided in a counter-clockwise fashion starting from the xS axis in the xS-zS plane. The opening angle always extends from the verticalOpeningAngleStart to the verticalOpeningAngleEnd in counter-clockwise direction. See Figure 25. 3601 shall be set if the value is unavailable.

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from		Description
							ETSI CDD	SAE J2735	
verticalOpeningAngleEnd	X	INTEGER	0	3601	degrees	0.1			End of the sensor's vertical OpeningAngle extension described in a sensor-centric coordinate system where the xS-axis points in the direction of half of the horizontalOpeningAngle in the horizontal plane and the and the zS-axis points up. The angle is provided in a counter-clockwise fashion starting from the xS axis in the xS-zS plane. The opening angle always extends from the verticalOpeningAngleStart to the verticalOpeningAngleEnd in counter-clockwise direction. See Figure 25. 3601 shall be set if the value is unavailable.
NodeOffsetPointXY **SensorPositionOffset**		INTEGER (both x and y offset)	-32768	32767	m	0.01		6.75	x and y offset of position relative to the provided reference position described in a non-vehicle centric right-hand coordinate system in which the x-axis points towards East and the y-axis towards the North and the z-axis points up. the offset of this point in the x and y direction (compared to the reference point) is max 327,768m. this has been taken into account for the definition of the yDistanceValue_MAX and yDistanceValue_MAX such that xDistanceValue_MAX = (SensorNodeOffsetX_MAX + Range_MAX) and yDistanceValue_MAX = (SensorNodeOffsety_MAX + Range_MAX)
sensorHeigth	X	INTEGER	-5000	5000	m	0.01			Height of sensor position relative to altitude provided by the reference position. sensors can also be located in a negative z-direction wrt. The reference poin
stationarySensorPolygon									it can be an isolated poligon associated to a given sensor or the union of two or more poligons associated to distinct sensors field of views and resulting in one combined poligon. In this case the sensor type is put to "fusion". See Figure 18
volumeHeight	X	INTEGER	-5000	5000	m	0.01			height of polygon relative to road surface
polyPlane		SEQUENCE	3	16					sequence of PoliPoints each represented as an offset point to the previous one. The first in the list is an offset to the reference point. The second is an offset to the first and so on. the offset of any Polypoint in the x and y directions (compared to the reference point) shall be max 327,768m such that xDistanceValue_MAX = (PoliPointOffsetX_MAX + Range_MAX) and yDistanceValue_MAX = (PoliPointOffsety_MAX + Range_MAX
NodeOffsetPointXY **PoliPoint**		INTEGER (both x and y offset)	-32768	32767	m	0.01		6.75	x and y offset of node position compared to previous considered point described in a non-vehicle centric right-hand coordinate system in which the x-axis points towards East and the y-axis towards the North and the z-axis points up.
stationarySensorCircular									See Figure 18
NodeOffsetPointXY **CenterPoint**	X	INTEGER (both x and y offset)	-32768	32767	m	0.01		6.75	x and y offset of CenterPoint position relative to the provided reference position in an horizontal plane containing a coordinate system where y corresponds to the North direction and x with the East direction. Optional in case reference point is also center of the description

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
radius		INTEGER	0	100000	m	0.01			Radius of the circular sensor area. The maximum value of this parameter ensures any point of the circle to have an offset in the x direction (compared to the reference point) lower than the max detectable distance xDistanceValue_MAX. Same applies to y direction.
stationarySensorEllipse									See Figure 18
NodeOffsetPointXY CenterPoint	X	INTEGER (both x and y offset)	-32768	32767	m	0.01		6.75	x and y offset of CenterPoint position relative to the provided reference position in an horizontal plane containing a coordinate system where y corresponds to the North direction and x with the East direction. Optional in case reference point is also center of the description
semiMinorAxisLength		INTEGER	0	100000	m	0.01			Half-length of the minor axis of the sensor area in the shape of an ellipse.
semiMajorAxisLength		INTEGER	0	100000	m	0.01			Half-length of the major axis of the sensor area in the shape of an ellipse. the maximum value of this parameter ensures any point of the ellipse to have an offset in the x direction (compared to the reference point) lower thanthe maximum detectable distance xDistanceValue_MAX. Same applies to y direction
majorAxisOrientation		INTEGER	0	3601	degrees		A.35		Orientation of the ellipse major axis of the sensor area ellipse with regards to WGS84 north. 361 shall be set if the value is unavailable
stationarySensorRectangle									See Figure 18
NodeOffsetPointXY CenterPoint	X	INTEGER (both x and y offset)	-32768	32767	m	0.01		6.75	x and y offset of CenterPoint position relative to the provided reference position in an horizontal plane containing a coordinate system where y corresponds to the North direction and x with the East direction. Optional in case reference point is also center of the description
semiFirstDimension		INTEGER	0	100000	m	0.01			half -length of the first dimension of the rectangular sensor area. the maximum value of this parameter ensures any point of the rectangle to have an offset in the x direction (compared to the reference point) lower than xDistanceValue_MAX. Same applies to y direction.
semiSecondDimension		INTEGER	0	100000	m	0.01			half -length of the second dimension of the rectangular sensor area. the maximum value of this parameter ensures any point of the rectangle to have an offset in the x direction (compared to the reference point) lower than xDistanceValue_MAX. Same applies to y direction.
FirstDimensionOrientation		INTEGER	0	3601	degrees	0.1	A.35		Orientation of the first dimension of the sensor area rectangle with regards to WGS84 north. 3601 shall be set if the value is unavailable
perceivedObjectContainer	X	SEQUENCE							list of N data fields of type Object data (one per detected object)
objectData		SEQUENCE							
objectID		INTEGER	0	255	N/A	N/A			Pseudonym of detected object which may change over time. The object ID may be used for indicating data association performed by the disseminating station. Perceived objects with persistent IDs indicate that the disseminating station associated these measurements to the

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
									same object.
sensorID		INTEGER	0	255	N/A	N/A			Pseudonym ID of sensor which provided the measurement data. Refers to the sensorID in the SensorInformation Container.
timeOfMeasurement		INTEGER	-15000	15000	ms	0.1			Time difference with respect to the generation delta time for the provided measurement. Positive values indicate measurement data that suceeds the generationDeltaTime. Negative valued antedate the timestamp indicated by the generationDeltaTime.
objectAge	X	INTEGER	0	15000	ms	0.1			Age of object in, i.e. for how long the object has been observed on the disseminating station. A value of 15000 indicates that the object has been observed for more than 1.5s
objectConfidence	X	INTEGER	0	100	-	-			
xDistance		SEQUENCE							
xDistanceValue		INTEGER	-132767	132767	m	0.01			Absolute distance to detected object from the ITS-S's reference point in x-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction. xDistanceValue has to be bounded by the max range + the max offset of the sensor position in the x direction compared to the reference point. xDistanceValue_MAX = (SensorNodeOffsetX_MAX + Range_MAX)
xDistanceConfidence		INTEGER	0	102	m	0.01			Absolute accuracy of measurement to a confidence level of 95%, 101 shall be set if the accuracy is out of range, 102 shall be set if the accuracy data is unavailable
yDistance		SEQUENCE							
yDistanceValue		INTEGER	-132767	132767	m	0.01			Absolute distance to detected object from the ITS-S's reference point in y-direction at the time of measurement . For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction. yDistanceValue has to be bounded by the max range + the max offset of the sensor position in the y direction compared to the reference point. yDistanceValue_MAX = (SensorNodeOffsetX_MAX + Range_MAX)
yDistanceConfidence		INTEGER	0	102	m	0.01			Absolute accuracy of measurement to a confidence level of 95%, 101 shall be set if the accuracy is out of range, 102 shall be set if the accuracy data is unavailable

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from: ETSI CDD	Reference from: SAE J2735	Description
zDistance	X	SEQUENCE							
zDistanceValue		INTEGER	-105000	105000	m	0.01			Absolute distance to detected object from the ITS-S's reference point in z-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction. zDistanceValue has to be bounded by the max range + the max offset of the sensor position in the z direction compared to the reference point. zDistanceValue_MAX = (SensorHeigth_MAX + Range_MAX)
zDistanceConfidence		INTEGER	0	102	m	0.01			Absolute accuracy of measurement to a confidence level of 95%, 101 shall be set if the accuracy is out of range, 102 shall be set if the accuracy data is unavailable
XRelativeSpeed	X	SEQUENCE							
xSpeedValue		INTEGER	-16384	16383	m/s	0.01			Relative speed of detected object from the ITS-S's reference point in x-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction.
xSpeedConfidence		INTEGER	1	127	m/s	0.01	A.72		Absolute accuracy of measurement to a confidence level of 95%, 126 shall be set if the measurement is out of range, 127 shall be set if the accuracy data is unavailable
YRelativeSpeed	X	SEQUENCE							
ySpeedValue		INTEGER	-16384	16383	m/s	0.01			Relative speed of detected object from the ITS-S's reference point in y-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction.
ySpeedConfidence		INTEGER	1	127	m/s	0.01	A.72		Absolute accuracy of measurement to a confidence level of 95%, 126 shall be set if the measurement is out of range, 127 shall be set if the accuracy data is unavailable
ZRelativeSpeed	X	SEQUENCE							
zSpeedValue		INTEGER	-16384	16383	m/s	0.01			Relative speed of detected object from the ITS-S's reference point in z-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction.
zSpeedConfidence		INTEGER	1	127	m/s	0.01	A.72		Absolute accuracy of measurement to a confidence level of 95%, 126 shall be set if the measurement is out of range, 127 shall be set if the accuracy data is unavailable
XRelativeAcceleration	X	SEQUENCE							

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
xAccelerationValue		INTEGER	-160	161	m/s^2	0.1	A.45		Relative acceleration of detected object from the ITS-S's reference point in x-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction.
xAccelerationConfidence		INTEGER	0	102	m/s^2	0.1	A.1		Absolute accuracy of measurement to a confidence level of 95%, 101 shall be set if the measurement is out of range, 102 shall be set if the accuracy data is unavailable
YRelativeAcceleration	X	SEQUENCE							
yAccelerationValue		INTEGER	-160	161	m/s^2	0.1	A.42		Relative acceleration of detected object from the ITS-S's reference point in y-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction.
yAccelerationConfidence		INTEGER	0	102	m/s^2	0.1	A.1		Absolute accuracy of measurement to a confidence level of 95%, 101 shall be set if the measurement is out of range, 102 shall be set if the accuracy data is unavailable
ZRelativeAcceleration	X	SEQUENCE							
zAccelerationValue		INTEGER	-160	161	m/s^2	0.1	A.96		Relative acceleration of detected object from the ITS-S's reference point in z-direction at the time of measurement. For a vehicle, it is according to the coordinate system provided by ISO 8855. For an RSU, it is according to a coordinate system where y corresponds to the North direction, x with the East direction, and z with the vertical direction.
zAccelerationConfidence		INTEGER	0	102	m/s^2	0.1	A.1		Absolute accuracy of measurement to a confidence level of 95%, 101 shall be set if the measurement is out of range, 102 shall be set if the accuracy data is unavailable
yawAngle	X	SEQUENCE							
yawAngleValue		INTEGER	0	3601	degrees	0.1			Relative yaw angle of object from the ITS-S's reference point. For a vehicle, it is according to the vehicle x direction in the coordinate system provided by ISO 8855. For a RSU, it is according to the x direction in a coordinate system where y corresponds to the North direction, x to the East direction, and z to the vertical direction. The angle is measured with positive values considering the object orientation turning counter-clockwise starting from the x-direction. 3601 shall be set if the value is unavailable
yawAngleConfidence		INTEGER	1	127	degrees	0.1			Absolute accuracy of measurement to a confidence level of 95%, 126 shall be set if the accuracy is out of range, 127 shall be set if the accuracy data is unavailable

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
planarObjectDimension1	X	SEQUENCE							First dimension of object as provided by the sensor or object model. This dimension is always contained in the plane perpendicular to the direction of the angle indicated by the yawAngleValue and containing the object reference point
planarObjectDimensionValue		INTEGER	0	1023	m	0.1			value of the First dimension of object as provided by the sensor or object model with respect to the object reference point. If the reference point is in the middle, this value represents half of the actual object's first dimension
planarObjectDimensionConfidence		INTEGER	0	50	m	0.1			Accuracy of provided dimension value with a predefined confidence level (e.g. 95%). 0 shall indicate that the accuracy is not available
planarObjectDimension2	X	SEQUENCE							Second dimension of object as provided by the sensor or object model, perpendicular to the value provided by planarObjectDimension1 extending towards absolute increasing object distance with orientation according to the object's yawAngleValue
planarObjectDimensionValue		INTEGER	0	1023	m	0.1			value of the second dimension of object as provided by the sensor or object model
planarObjectDimensionConfidence		INTEGER	0	50	m	0.1			Accuracy of provided dimension value with a predefined confidence level (e.g. 95%). 0 shall indicate that the accuracy is not available
verticalObjectDimension	X	SEQUENCE							
verticalObjectDimensionValue		INTEGER	0	1023	m	0.1			Vertical dimension of object as provided by the sensor or object model
verticalObjectDimensionConfidence		INTEGER	0	50	m	0.1			Accuracy of provided dimension value with a predefined confidence level (e.g. 95%). 0 shall indicate that the accuracy is not available
ObjectRefPoint		INTEGER	0	8	N/A	N/A			Reference point of measurement for the object dimensions. All provided state variables of this object are given relative to the reference point. The point is included in the plane perpendicular to the direction of the yawanglevalue The possible values are 0 (mid) 1 (bottom left) 2 (mid left) 3 (top left) 4 (bottom mid) 5 (top mid) 6 (bottom right) 7 (mid right) 8 (top right):
dynamicStatus	X	INTEGER	0	3	N/A	N/A			Indication whether the detected object is classified as a dynamic (i.e. moving) object. This value indicates whether an object has the capability to move, i.e. change its position. the possible values are 0 (dynamic) 1 (has been dynamic) 2 (static). "Has been dynamic" indicates whether an object has been in stationary before.
classification		INTEGER	0	255	N/A	N/A	A.78		Classification of the detected object, if applicable. Possible values are unknown(0), pedestrian(1), cyclist(2), moped(3), motorcycle(4), passengerCar(5), bus(6), lightTruck(7), heavyTruck(8), trailer(9), specialVehicles(10), tram(11)

Data Field / Data Element	Optional	Type	Min value	Max value	Unit	Scale	Reference from ETSI CDD	Reference from SAE J2735	Description
matchedPosition	X	SEQUENCE	-1	14	N/A	N/A			Indicates the position of the object mapped on the intersection toplogy description transmitted in MAP messages
laneID		INTEGER	0	255	N/A	N/A		7.87	conveys an assigned index that is unique within the intersection with IntersectionReferenceId of the OriginatingRSUContainer
distanceFromFirstNode		SEQUENCE							Absolute distance and accuracy of the object from the first node of the lane over the lane with laneID
distanceFromFirstNodeValue		INTEGER	0	1024	m	1			Absolute distance and accuracy of the object from the first node of the lane over the lane with laneID
distanceFromFirstNodeConfidence		INTEGER	1	102	m				Absolute accuracy of measurement to a confidence level of 95%, 101 shall be set if the accuracy is out of range, 102 shall be set if the accuracy data is unavailable

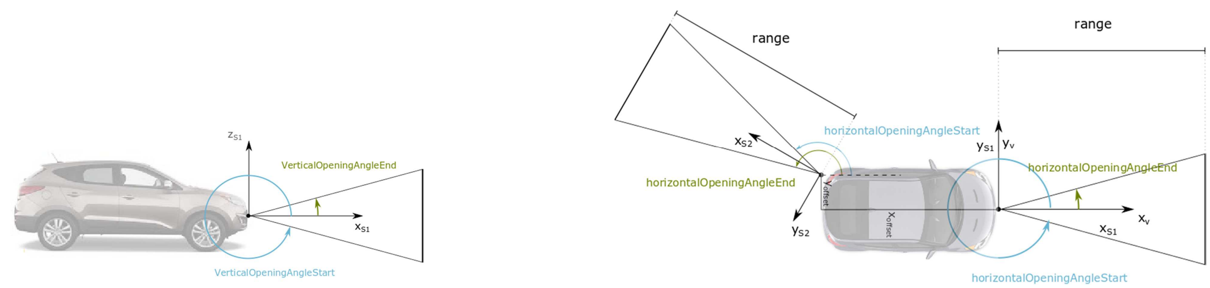

Figure 24 – Horizontal and vertical opening angles for originating vehicle station

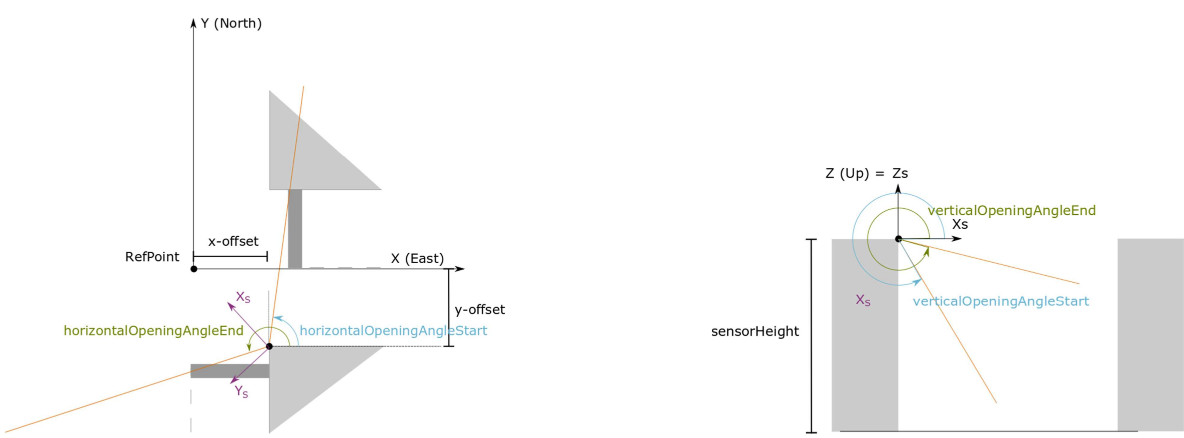

Figure 25 – Horizontal and vertical opening angles for originating RSU station

Annex B: MAVEN messages ASN.1 specifications

Annex B1: CAM extensions ASN.1 specification

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MAVEN-CAM DEFINITIONS AUTOMATIC TAGS ::=

BEGIN

IMPORTS
   ItsPduHeader, CauseCode, ReferencePosition, AccelerationControl, Curvature,
CurvatureCalculationMode, Heading, LanePosition, EmergencyPriority, EmbarkationStatus, Speed,
DriveDirection, LongitudinalAcceleration, LateralAcceleration, VerticalAcceleration, StationType,
ExteriorLights, DangerousGoodsBasic, SpecialTransportType, LightBarSirenInUse, VehicleRole,
VehicleLength, VehicleWidth, PathHistory, RoadworksSubCauseCode, ClosedLanes, TrafficRule,
SpeedLimit, SteeringWheelAngle, PerformanceClass, YawRate, ProtectedCommunicationZone, PtActivation,
Latitude, Longitude, ProtectedCommunicationZonesRSU, CenDsrcTollingZone,

   -- newly included from ETSI CDD
   NumberOfOccupants, SpeedValue
   FROM ITS-Container {itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) ts
(102894) cdd (2) version (1)}

   -- included from CDD extensions
   RouteAtIntersection, IntersectionsRoute, DesiredSpeedRange, AccelerationCapability,
VehicleDistance, PlatoonId, PlatoonVehicles, DesiredPlatoonSpeed, LaneChanging, PlannedPath,
EmergencyFlag, PlatoonFollowers, PlatoonVehicleState, PlatoonFormingState, PlatoonDistanceState
   FROM CDD-extensions;


CAM ::= SEQUENCE {
       header  ItsPduHeader,
       cam     CoopAwareness
}

 CoopAwareness ::= SEQUENCE {
   generationDeltaTime GenerationDeltaTime,
   camParameters CamParameters
 }

 CamParameters ::= SEQUENCE {
  basicContainer BasicContainer,
  highFrequencyContainer HighFrequencyContainer,
  lowFrequencyContainer LowFrequencyContainer OPTIONAL,
  specialVehicleContainer SpecialVehicleContainer OPTIONAL,
  ...
 }


 HighFrequencyContainer ::= CHOICE {
  basicVehicleContainerHighFrequency BasicVehicleContainerHighFrequency,
  rsuContainerHighFrequency RSUContainerHighFrequency,
  ...,
  automatedVehicleContainerHighFrequency AutomatedVehicleContainerHighFrequency,
  ...
 }

 LowFrequencyContainer ::= CHOICE {
  basicVehicleContainerLowFrequency BasicVehicleContainerLowFrequency,
  ...,
  automatedVehicleContainerLowFrequency AutomatedVehicleContainerLowFrequency,
  ...
 }

 SpecialVehicleContainer ::= CHOICE {
  publicTransportContainer PublicTransportContainer,
  specialTransportContainer SpecialTransportContainer,
  dangerousGoodsContainer DangerousGoodsContainer,
  roadWorksContainerBasic RoadWorksContainerBasic,
  rescueContainer RescueContainer,
  emergencyContainer EmergencyContainer,
  safetyCarContainer SafetyCarContainer,
```

```
  ...,
 mavenAutomatedVehicleContainer MavenAutomatedVehicleContainer,
  ...
}

BasicContainer ::= SEQUENCE {
 stationType StationType,
 referencePosition ReferencePosition,
  ...
}

BasicVehicleContainerHighFrequency ::= SEQUENCE {
 heading Heading,
 speed Speed,
 driveDirection DriveDirection,
 vehicleLength VehicleLength,
 vehicleWidth VehicleWidth,
 longitudinalAcceleration LongitudinalAcceleration,
 curvature Curvature,
 curvatureCalculationMode CurvatureCalculationMode,
 yawRate YawRate,
 accelerationControl AccelerationControl OPTIONAL,
 lanePosition LanePosition OPTIONAL,
 steeringWheelAngle SteeringWheelAngle OPTIONAL,
 lateralAcceleration LateralAcceleration OPTIONAL,
 verticalAcceleration VerticalAcceleration OPTIONAL,
 performanceClass PerformanceClass OPTIONAL,
 cenDsrcTollingZone CenDsrcTollingZone OPTIONAL
}

BasicVehicleContainerLowFrequency  ::= SEQUENCE {
 vehicleRole VehicleRole,
 exteriorLights ExteriorLights,
 pathHistory PathHistory
}

PublicTransportContainer ::= SEQUENCE {
 embarkationStatus EmbarkationStatus,
 ptActivation PtActivation OPTIONAL
}

SpecialTransportContainer ::= SEQUENCE {
 specialTransportType SpecialTransportType,
 lightBarSirenInUse LightBarSirenInUse
}

DangerousGoodsContainer ::= SEQUENCE {
 dangerousGoodsBasic DangerousGoodsBasic
}

RoadWorksContainerBasic ::= SEQUENCE {
 roadworksSubCauseCode RoadworksSubCauseCode OPTIONAL,
 lightBarSirenInUse LightBarSirenInUse,
 closedLanes ClosedLanes OPTIONAL
}

RescueContainer ::= SEQUENCE {
 lightBarSirenInUse LightBarSirenInUse

}

EmergencyContainer ::= SEQUENCE {
 lightBarSirenInUse LightBarSirenInUse,
 incidentIndication CauseCode OPTIONAL,
 emergencyPriority EmergencyPriority OPTIONAL
}

SafetyCarContainer ::= SEQUENCE {
 lightBarSirenInUse LightBarSirenInUse,
 incidentIndication CauseCode OPTIONAL,
 trafficRule TrafficRule OPTIONAL,
 speedLimit SpeedLimit OPTIONAL
}
```

```
RSUContainerHighFrequency ::= SEQUENCE {
  protectedCommunicationZonesRSU ProtectedCommunicationZonesRSU OPTIONAL,
  ...
}


MavenAutomatedVehicleContainer ::= SEQUENCE {
  routeAtIntersection RouteAtIntersection,
  intersectionsRoute IntersectionsRoute,
  desiredSpeedRange   DesiredSpeedRange,
  accelerationCapability AccelerationCapability,
  numberOfOccupants NumberOfOccupants OPTIONAL,
  distanceToFollowingVehicle VehicleDistance OPTIONAL,
  distanceToPrecedingVehicle VehicleDistance OPTIONAL,
  platoonId PlatoonId OPTIONAL,
  platoonParticipants PlatoonVehicles OPTIONAL,
  desiredPlatoonSpeed SpeedValue OPTIONAL,
  laneChanging LaneChanging OPTIONAL,
  ...
}

AutomatedVehicleContainerHighFrequency ::= SEQUENCE {
  heading Heading,
  speed Speed,
  longitudinalAcceleration LongitudinalAcceleration,
  lanePosition LanePosition OPTIONAL,
  plannedPath PlannedPath OPTIONAL,
  plannedLane LanePosition OPTIONAL,
  emergencyFlag EmergencyFlag OPTIONAL,
  ...
}

AutomatedVehicleContainerLowFrequency ::= SEQUENCE {
  platoonId PlatoonId,
  platoonFollowers PlatoonVehicles OPTIONAL,
  platoonVehicleState PlatoonVehicleState,
  platoonFormingState PlatoonFormingState,
  platoonDistanceState PlatoonDistanceState,
  plannedPath PlannedPath OPTIONAL,
  plannedLane LanePosition OPTIONAL,
  ...
}


GenerationDeltaTime ::= INTEGER { oneMilliSec(1) } (0..65535)

END
```

Annex B2: LAM ASN.1 specification

```
LAM  DEFINITIONS AUTOMATIC TAGS::=

BEGIN

IMPORTS

ZoneLength, LaneID, IntersectionID, MinuteOfTheYear, DSecond

FROM DSRC { iso (1) standard (0) signalizedIntersection (19091) profilec(2) dsrc (2) version
(1) }

StationID

FROM ITS-Container { itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) ts
(102894) cdd (2) version (1) };

LAMEM ::= SEQUENCE {
    header     ItsPduHeader,
    lam LAM
}

-- the lam(8) is added here, so the header from the original DSRC package should be overwritten
ItsPduHeader ::= SEQUENCE {
    protocolVersion INTEGER{currentVersion(1)} (0..255),
    messageID INTEGER{denm(1),cam(2), poi(3), spat(4), map(5), ivi(6), ev-rsr(7), lam(8)} (0..255),
    stationID StationID
}

LAM ::= SEQUENCE {
    moy          MinuteOfTheYear OPTIONAL,
    -- Minute of current UTC year
    -- used only with messages to be archived
    timeStamp    DSecond OPTIONAL,
    -- the mSec point in the current UTC minute that
    -- this message was constructed
    laneAdviceSet LaneAdviceList
    -- list of lane advice for individual vehicles
}

LaneAdviceList ::= SEQUENCE (SIZE(1..256)) OF LaneAdvice

LaneAdvice ::= SEQUENCE {
    requestID INTEGER (0..255)
    -- Used by individual vehicles to acknowledge the request in the CAM
    targetStationID StationID,
    adviceIntersectionID IntersectionID,
    adviceLaneID LaneID,
    adviceReason LaneAdviceReason,
    targetMoy          MinuteOfTheYear OPTIONAL,
    -- Minute of current UTC year for the lane change to occur
    -- should be used in conjuction with the targetTimeStamp
    targetTimeStamp    DSecond OPTIONAL,
    -- the mSec point in the current UTC minute that the lane change should occur
    -- should be used in conjuction with the targetMoy
    targetDistance ZoneLength OPTIONAL,
    -- location where the lane change maneuver should be initiated
    leadingStationID StationID OPTIONAL,
    -- StationID of the vehicle ahead on the new lane
    -- only supplied when infrastructure is certain about the lane the vehicle is in,
    -- which is the case for cooperative automated vehicles
    trailingStationID StationID OPTIONAL
    -- StationID of the vehicle behind on the new lane,
    -- only supplied when infrastructure is certain about the lane the vehicle is in,
    -- which is the case for cooperative automated vehicles
}

LaneAdviceReason ::= ENUMERATION{
    QueuedVehiclesOnLane,
    -- The queue in the current lane is longer than in the lane of the advice
    HaltingForPermissiveGreen,
```

```
    -- There are vehicles in the current lane, which have to give right of
    -- way to conflicting traffic due to permissive green
    PlatoonForming,
    -- A vehicle platoon is on another lane that can be joined by changing lanes
    VRUProximityRisk,
    -- Abnormal proximity of a VRU to the edge of the road, with a risk of entering the road
    -- E.g. an infant playing near the road edge in contrast to a pedestrian waiting near
    -- the road edge to cross
    EmergencyVehicleApproaching,
    -- An emergency vehicle is approaching and requires a clear path to pass
    LaneBlocked,
    -- The lane is blocked due to e.g. maintenance, accident, parked emergency vehicle
    OtherCriticalReason,
    -- Other critical reason to change lane
    Other
    -- Other non-critical reason
}


END
```

Annex B3: CPM ASN.1 specification

```
MAVEN-CPM DEFINITIONS AUTOMATIC TAGS ::=

BEGIN

IMPORTS

   -- included from CDD

   ItsPduHeader, HeadingValue, SpeedConfidence, LongitudinalAccelerationValue,
AccelerationConfidence, StationType, Heading, Speed,  DriveDirection, LongitudinalAcceleration,
LateralAcceleration, VerticalAcceleration, YawRate

   FROM ITS-Container {itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) ts
(102894) cdd (2) version (1)}

   -- included from from CDD extensions

   AngleConfidence, OrientationDeltaAngle, PitchAngle, RollAngle

   FROM CDD-extensions

   -- included from CAM
   GenerationDeltaTime, BasicContainer

   FROM MAVEN-CAM

   -- included from SAE-J2735-March2016
   NodeOffsetPointXY, LaneID, IntersectionReferenceID, RoadSegmentReferenceID

   FROM DSRC { iso (1) standard (0) signalizedIntersection (19091) profilec(2) dsrc (2) version
(1) };


CPM ::= SEQUENCE {
       header         ItsPduHeader,
       cpm            CollPerception
}

 CollPerception ::= SEQUENCE {
   generationDeltaTime       GenerationDeltaTime,
   cpmParameters             CpmParameters
 }

 CpmParameters ::= SEQUENCE {
  originatingStationContainer        OriginatingStationContainer,
  sensorInformationContainer         SensorInformationContainer OPTIONAL,
  perceivedObjectContainer           PerceivedObjectContainer OPTIONAL,
  ...
 }


 OriginatingStationContainer ::= SEQUENCE {
  basicContainer      BasicContainer,
  stationData         StationData,
  ...
 }

 SensorInformationContainer ::= SEQUENCE SIZE(1..20) OF SensorEntry

 PerceivedObjectContainer ::= SEQUENCE SIZE(1..256) OF ObjectData

 StationData ::= CHOICE {
  originatingVehicleContainer        OriginatingVehicleContainer,
  originatingRSUContainer            OriginatingRSUContainer,
  ...
 }

 OriginatingVehicleContainer ::= SEQUENCE {
    heading                          Heading,
    speed                            Speed,
```

```
   orientationDeltaAngle            OrientationDeltaAngle OPTIONAL,
   driveDirection                   DriveDirection,
   longitudinalAcceleration         LongitudinalAcceleration OPTIONAL,
   lateralAcceleration              LateralAcceleration OPTIONAL,
   verticalAcceleration             VerticalAcceleration OPTIONAL,
   yawRate                          YawRate OPTIONAL,
   pitchAngle                       PitchAngle OPTIONAL,
   rollAngle                        RollAngle OPTIONAL,
   ...
}

 OriginatingRSUContainer     ::= SEQUENCE {
   intersectionReferenceID   IntersectionReferenceID OPTIONAL,
   roadSegmentReferenceID    RoadSegmentReferenceID,
   ...
}


SensorEntry ::= SEQUENCE {
 sensorID            SensorID,
 sensorType          SensorType,
 sensorDetails       SensorDetails
}


SensorDetails ::= CHOICE {
 vehicleSensor               VehicleSensor,
 stationarySensorRadial      StationarySensorRadial,
 stationarySensorPolygon     StationarySensorPolygon,
 stationarySensorCircular    StationarySensorCircular,
 stationarySensorEllipse     StationarySensorEllipse,
 stationarySensorRectangle   StationarySensorRectangle,
 ...
}

VehicleSensor ::= SEQUENCE {
 refPointID                         ReferencePointID,
 xOffset                            XOffset,
 yOffset                            YOffset,
 zOffset                            ZOffset OPTIONAL,
 range                              SensorRange,
 horizontalOpeningAngleStart        SensorHorizontalOpeningAngleStart,
 horizontalOpeningAngleEnd          SensorHorizontalOpeningAngleEnd,
 verticalOpeningAngleStart          SensorVerticalOpeningAngleStart OPTIONAL,
 verticalOpeningAngleEnd            SensorVerticalOpeningAngleEnd OPTIONAL,
 ...
}

StationarySensorRadial ::= SEQUENCE {
 range                              SensorRange,
 horizontalOpeningAngleStart        SensorHorizontalOpeningAngleStart,
 horizontalOpeningAngleEnd          SensorHorizontalOpeningAngleEnd,
 verticalOpeningAngleStart          SensorVerticalOpeningAngleStart OPTIONAL,
 verticalOpeningAngleEnd            SensorVerticalOpeningAngleEnd OPTIONAL,
 sensorPositionOffset               NodeOffsetPointXY,
 sensorHeight                       SensorHeight,
 ...
}

StationarySensorPolygon ::= SEQUENCE {
 volumeHeight        VolumeHeight OPTIONAL,
 polygonPlane        PolygonPoints,
 ...
}

StationarySensorCircular ::= SEQUENCE {
 centerPoint         NodeOffsetPointXY OPTIONAL,
 radius              Radius
}

StationarySensorEllipse ::= SEQUENCE {
 centerPoint                 NodeOffsetPointXY OPTIONAL,
 semiMinorAxisLength         EllipseSemiAxisLength,
```

```
  semiMajorAxisLength         EllipseSemiAxisLength,
  majorAxisOrientation        HeadingValue,
  ...
 }

 StationarySensorRectangle ::= SEQUENCE {
  centerPoint                 NodeOffsetPointXY OPTIONAL,
  semiFirstDimension          SemiDimensionLength,
  semiSecondDimension         SemiDimensionLength,
  firstDimensionOrientation   HeadingValue,
  ...
 }

 ObjectData ::= SEQUENCE {
  objectID                           ObjectID,
  sensorID                           SensorID,
  timeOfMeasurement                  TimeOfMeasurement,
  objectAge                          ObjectAge OPTIONAL,
  objectConfidence                   ObjectConfidence OPTIONAL,
  xDistance                          XDistance,
  yDistance                          YDistance,
  zDistance                          ZDistance OPTIONAL,
  xSpeed                             XRelativeSpeed OPTIONAL,
  ySpeed                             YRelativeSpeed OPTIONAL,
  zSpeed                             ZRelativeSpeed OPTIONAL,
  xAcceleration                      XRelativeAcceleration OPTIONAL,
  yAcceleration                      YRelativeAcceleration OPTIONAL,
  zAcceleration                      ZRelativeAcceleration OPTIONAL,
  yawAngle                           YawAngle OPTIONAL,
  planarObjectDimension1             PlanarObjectDimension1 OPTIONAL,
  planarObjectDimension2             PlanarObjectDimension2 OPTIONAL,
  verticalObjectDimension            VerticalObjectDimension OPTIONAL,
  objectRefPoint                     ObjectRefPoint,
  dynamicStatus                      DynamicStatus OPTIONAL,
  classification                     StationType,
  matchedPosition                    MatchedPosition OPTIONAL,
  ...
 }


 SensorID ::= INTEGER(0..255)


 SensorType ::= ENUMERATED {
       undefined (0),
       radar (1),
       lidar (2),
       monovideo (3),
       stereovision (4),
       inductionLoop (5),
       sphericalCamera (6),
       nightvision (7),
       ultrasonic (8),
       pmd (9),
       fused(10),
       ...
}

 PolygonPoints ::= SEQUENCE SIZE(3..16) OF NodeOffsetPointXY

 SensorHorizontalOpeningAngleStart ::= INTEGER(0..3601)

 SensorHorizontalOpeningAngleEnd ::= INTEGER(0..3601)

 SensorVerticalOpeningAngleStart ::= INTEGER(0..3601)

 SensorVerticalOpeningAngleEnd ::= INTEGER(0..3601)

  ReferencePointID ::= INTEGER(0..255)

  Xoffset ::= INTEGER(-5000..0)

  YOffset ::= INTEGER(-1000..1000)
```

```
  ZOffset ::= INTEGER(0..1000)

  SensorRange ::= INTEGER(0..10000)

  SensorHeight ::= INTEGER {OneCm(1)}(-5000..5000)

  VolumeHeight ::= INTEGER(-5000..5000)

  Radius ::= INTEGER(0..100000)

  EllipseSemiAxisLength ::= INTEGER(0..100000)

  SemiDimensionLength ::= INTEGER(0..100000)

  ObjectID ::= INTEGER(0..255)

  TimeOfMeasurement ::= INTEGER {oneMillisecond(10)}(-15000..15000)

  ObjectAge ::= INTEGER {oneMillisecond(10)} (0..15000)

  ObjectConfidence ::= INTEGER (0..100)

 XDistance ::= SEQUENCE {
  xDistanceValue      PlanarDistanceValue,
  xDistanceConfidence PlanarDistanceConfidence
 }

 YDistance ::= SEQUENCE {
  yDistanceValue      PlanarDistanceValue,
  yDistanceConfidence PlanarDistanceConfidence
 }

 ZDistance ::= SEQUENCE {
  zDistanceValue      VerticalDistanceValue,
  zDistanceConfidence VerticalDistanceConfidence
 }

  PlanarDistanceValue ::= INTEGER {oneCentimeter(1)}(-132767..132767)

  PlanarDistanceConfidence ::= INTEGER {oneCentimeter(1), outOfRange(101), unavailable(102)}
(0..102)

  VerticalDistanceValue ::= INTEGER {oneCentimeter(1)}(-105000..105000)

  VerticalDistanceConfidence ::= INTEGER {oneCentimeter(1), outOfRange(101), unavailable(102)}
(0..102)

 XRelativeSpeed ::= SEQUENCE {
  xSpeedValue         RelativeSpeedValue,
  xSpeedConfidence    SpeedConfidence
 }

 YRelativeSpeed ::= SEQUENCE {
  ySpeedValue         RelativeSpeedValue,
  ySpeedConfidence    SpeedConfidence
 }

 ZRelativeSpeed ::= SEQUENCE {
  zSpeedValue         RelativeSpeedValue,
  zSpeedConfidence    SpeedConfidence
 }

  RelativeSpeedValue  ::= INTEGER {MinusOneCentimeterPerSec(-1), standstill(0),
oneCentimeterPerSec(1), unavailable(16383)} (-16384..16383)

 XRelativeAcceleration ::= SEQUENCE {
  xAccelerationValue         LongitudinalAccelerationValue,
  xAccelerationConfidence    AccelerationConfidence
 }

 YRelativeAcceleration ::= SEQUENCE {
  yAccelerationValue         LongitudinalAccelerationValue,
```

```
  yAccelerationConfidence     AccelerationConfidence
 }

 ZRelativeAcceleration ::= SEQUENCE {
  zAccelerationValue          LongitudinalAccelerationValue,
  zAccelerationConfidence     AccelerationConfidence
 }

 YawAngle ::= SEQUENCE {
  yawAngleValue       YawAngleValue,
  yawAngleConfidence  AngleConfidence
 }

    YawAngleValue ::= INTEGER {OneDegreeFromXaxisInCounterClockwiseDirection(10),
unavailable(3601)}(0..3601)

 PlanarObjectDimension1 ::= SEQUENCE {
  planarObjectDimensionValue1        PlanarObjectDimensionValue1,
  planarObjectDimensionConfidence    PlanarObjectDimensionConfidence
 }

  PlanarObjectDimensionValue1 ::= INTEGER {TenCentimeters(1)} (0..1023)
  PlanarObjectDimensionConfidence ::= INTEGER {unavailable(0), equalOrWithinTenCentimeters (1)}
(0..50)

 PlanarObjectDimension2 ::= SEQUENCE {
  planarObjectDimensionValue2        PlanarObjectDimensionValue2,
  planarObjectDimensionConfidence    PlanarObjectDimensionConfidence
 }

  PlanarObjectDimensionValue2 ::= INTEGER {TenCentimeters(1)} (0..1023)

 VerticalObjectDimension ::= SEQUENCE {
  verticalObjectDimensionValue       VerticalObjectDimensionValue,
  verticalObjectDimensionConfidence  VerticalObjectDimensionConfidence
 }

  VerticalObjectDimensionValue ::= INTEGER {TenCentimeters(1)} (0..1023)

  VerticalObjectDimensionConfidence ::= INTEGER (0..50)

  ObjectRefPoint ::= INTEGER {mid(0), bottomLeft(1), midLeft(2), topLeft(3), bottonMid(4),
topMid(5), bottonRight(6), midRight(7), topRight(8)} (0..8)

  DynamicStatus ::= INTEGER {dynamic(0), hasBeenDynamic(1), static(2)} (0..2)

 MatchedPosition ::= SEQUENCE {
   laneID                     LaneID,
   distanceFromFirstNode      DistanceFromFirstNode
 }

  DistanceFromFirstNode::= SEQUENCE {
   distanceFromFirstNode Value               DistanceFromFirstNodeValue,
   distanceFromFirstNode Confidence  DistanceFromFirstNode Confidence
 }

  DistanceFromFirstNode Value ::= INTEGER (0..1024)

  DistanceFromFirstNode Confidence ::= INTEGER {equalOrWithinOneMeter (1), outOfRange(101),
unavailable(102)} (1..102)


END
```

Annex B4: CDD extensions ASN1 specifications

```
CDD-extensions DEFINITIONS AUTOMATIC TAGS ::=

BEGIN

IMPORTS
   IntersectionID, LaneID, SignalGroupID, AllowedManeuvers

   FROM DSRC { iso (1) standard (0) signalizedIntersection (19091) profilec(2) dsrc (2) version
(1) }

   SpeedValue, LongitudinalAccelerationValue, StationID, HeadingValue, Latitude, Longitude,
AltitudeValue

   FROM ITS-Container {itu-t (0) identified-organization (4) etsi (0) itsDomain (5) wg1 (1) ts
(102894) cdd (2) version (1)};

RouteAtIntersection ::= SEQUENCE
{
       intersectionID IntersectionID,
       ingressingLaneID LaneID,
       egressingLaneID LaneID,
       signalGroupID SignalGroupID OPTIONAL,
       maneuver AllowedManeuvers OPTIONAL,
       speedAdviceCompliance SpeedAdviceCompliance OPTIONAL,
       ...
}

SpeedAdviceCompliance ::= ENUMERATED {
       unknown (0), -- advice received, yet no decision taken
       compliant (1), -- advice adopted
       notCompliant (2), -- advice cannot be adopted
       ...
}

IntersectionsRoute ::= SEQUENCE SIZE(1..10) OF IntersectionID

DesiredSpeedRange ::= SEQUENCE
{
       minSpeed       SpeedValue,
       maxSpeed       SpeedValue
}

AccelerationCapability ::= SEQUENCE
{
       maxNegativeAcceleration      LongitudinalAccelerationValue,
       maxPositiveAcceleration      LongitudinalAccelerationValue
}

VehicleDistance ::= SEQUENCE {
    distanceValue VehicleDistanceValue,
    distanceConfidence VehicleDistanceConfidence
}

VehicleDistanceValue ::= INTEGER {dotOneMeter(1), outOfRange(510), unavailable(511)} (0..511)

VehicleDistanceConfidence ::= INTEGER { equalOrWithinDotOneMeter(1), equalOrWithinDotTwoMeter(2),
outOfRange(31), unavailable(32) } (1..32)

PlatoonId ::= INTEGER(0..4294967295)

PlatoonVehicles ::= SEQUENCE SIZE(1..10) OF StationID

LaneChanging ::= SEQUENCE {
    laneAdviceIntersectionID IntersectionID,
    laneAdviceRequestID AdvRequestID,
    laneAdviceCompliance LaneAdviceCompliance
}

LaneAdviceCompliance ::= ENUMERATED{
       unknown (0),
```

```
       -- the advice was received, but there has not yet been a decision
    CompliantBeforeTimeBeforeDistance (1),
    -- the vehicle is currently adopting the lane change advice before the time and distance
indicated in the request
    CompliantBeforeTimeAfterDistance (2),
    -- the vehicle is currently adopting the lane change advice before the time but after the
distance indicated in the request
    CompliantAfterTimeBeforeDistance (3),
    -- the vehicle is currently adopting the lane change advice after the time but before the
distance indicated in the request
    CompliantAfterTimeAfterDistance (4),
    -- the vehicle is currently adopting the lane change advice after the time and distance
indicated in the request
       NotCompliant (5),
    -- the vehicle cannot currently adopt the lane change advice
       ...
}

AdvRequestID ::= INTEGER(0..4294967295)

PlannedPath ::= SEQUENCE SIZE (1..23) OF PlannedPoint

PlannedPoint ::= SEQUENCE {
  plannedPointDeltaTime PlannedPointDeltaTime,
  plannedPointPosition PlannedPointPosition,
  plannedPointHeading HeadingValue,
  ...
}

PlannedPointDeltaTime ::= INTEGER {tenMilliSecondsInFuture(1)} (1..1024, ...)

PlannedPointPosition ::= SEQUENCE {
  plannedLatitude Latitude,
  plannedLongitude Longitude,
  plannedAltitude AltitudeValue
}

EmergencyFlag ::= BOOLEAN

PlatoonVehicleState ::= ENUMERATED{
   notAble (0),
    wantToForm (1),
    inPlatoon (2),
    leaving (3),
       ...
}

PlatoonFormingState ::= ENUMERATED{
    waitingTrajectory (0),
    currentlyForming (1),
    normalPlatooning (2),
       ...
}

PlatoonDistanceState ::= ENUMERATED{
    close (0),
    normal (1),
    gap (2),
       ...
}

AngleConfidence ::= INTEGER {equalOrWithinZeroPointOneDegree (1), equalOrWithinOneDegree (10),
outOfRange(126), unavailable(127)} (1..127)

  OrientationDeltaAngle ::= SEQUENCE {
    orientationDeltaAngleValue OrientationDeltaAngleValue,
    orientationDeltaAngleConfidence AngleConfidence
 }

  OrientationDeltaAngleValue ::= INTEGER {OneDegreeFromHeadingInClockwiseDirection(10),
unavailable(3601)}(0..3601)

  PitchAngle ::= SEQUENCE {
```

```
    pitchAngleValue PitchAngleValue,
    pitchAngleConfidence AngleConfidence
 }

  PitchAngleValue ::= INTEGER {OneDegreeFromGroundPlane(10), unavailable(3601)}(0..3601)

  RollAngle ::= SEQUENCE {
    rollAngleValue RollAngleValue,
    rollAngleConfidence AngleConfidence
 }

  RollAngleValue ::= INTEGER {OneDegreeFromGroundPlane(10), unavailable(3601)}(0..3601)


END
```

Annex C: List of contributions to V2X standardization and specification

1) *M. Rondinone (Hyundai Motor Europe Technical Center), "MAVEN project introduction as input to the C2C-CC roadmap", presentation at the C2C-CC Working Group Roadmap meeting, 8 June 2017:* Introducing MAVEN approaches for consideration in the C2C-CC roadmapping
2) *M. Rondinone (Hyundai Motor Europe Technical Center), participation at the ETSI ITSWG1-Collective Perception drafting session, 31 August 2017:* Introducing MAVEN approaches for Collective Perception
3) *M. Rondinone (Hyundai Motor Europe Technical Center), participation at the ETSI ITSWG1-Collective Perception small drafting session, 11 October 2017:* representing MAVEN Collective Perception contributions provided to ETSI
4) *M. Rondinone (Hyundai Motor Europe Technical Center), "Updates of the C2C-CC Roadmaps", keynote presentation at the 2017 Car2Car Forum, 28 Nov. 2017, available at https://www.car-2-car.org/index.php?id=283:* Introducing various MAVEN use cases (e.g. V2X maneuver sharing for platoon and I2V negotiation purposes and well as I2V-assisted intersection crossing) and technical V2X solutions (e.g. use of CAMs on parallel SCHs, use of CPM, etc) as part of the C2C-CC Roadmaps for use cases and technology to be deployed at later stages after Day1
5) *M. Rondinone (Hyundai Motor Europe Technical Center), participation at the ETSI ITSWG1-Collective Perception small drafting session, 23 January 2018:* representing MAVEN Collective Perception contributions (MAVEN ASN.1 definitions) provided to ETSI