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M Series: Mobile, radiodetermination, amateur and related satellite services

# Connected automated vehicles

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# REPORT ITU-R M.2534-0

## Connected automated vehicles

(Question ITU-R 261/5)

(2023)

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**Scope**

This Report provides Connected Automated Vehicle (CAV) terminology, descriptions of radiocommunication methods and radiocommunication systems for CAV, as well as radiocommunication requirements and initial spectrum needs for CAV. The status of global development of CAV is also included. The scope of this Report is focused on the ad hoc, short range radiocommunication for Intelligent Transport Systems (ITS) among vehicles, and among vehicles and infrastructure. The cellular network connectivity aspects are covered in more detail in Report ITU-R M.2520.

**Keywords**

Automated Vehicle (AV), Connected Automated Driving (CAD), Connected Automated Vehicles (CAV), Connected and Cooperative Automated Mobility (CCAM), Connected and Cooperative Automated Vehicle (CCAV), Connected Vehicle (CV), Cooperative ITS (C-ITS), Vehicle to Everything (V2X).

## 1 Introduction

There are around 1.5 billion road vehicles in the world, including trucks and buses. Connected Automated Vehicles (CAVs) have the potential to reduce crashes, thereby reducing traffic fatalities and crash-related injuries. CAVs also provide information to road operators about congestion and traffic crashes to support increased efficiency of traffic and comfortable driving.

There is a potential for CAVs to smooth traffic flows. This can reduce the congestion, increase fuel and energy economy, and increase the road and highway capacity.

Higher levels of vehicle automation are currently under extensive development. Automated Vehicles (AVs), also sometimes referred to as driverless vehicles or autonomous vehicles, are under development by most of the major global automakers. Developments are important in technical areas, but also in regulatory areas, as the potential impacts on society become better understood.

Wireless radiocommunication requirements are a consideration for inclusion of coordinated automated driving manoeuvres and other advanced use cases in connected automated vehicle developments and deployments. Harmonization of frequency bands facilitates global markets and innovation. As well, spectrum harmonization may be the best approach to facilitate interoperability among CAVs.

It takes around three-to-five years for adding a new feature to a vehicle, this long product development cycle is due to the rigorous process of placing safe products on the market. Vehicles have an average lifetime of 12 years. Given the long product development cycles and expected life-time, certainty of continuity is of utmost importance for vehicle manufacturers. Further, new technology for inclusion in vehicles needs to be mature when the product development starts, and it needs to be available for at least the vehicle development time and full lifespan of the vehicles. This may be accomplished by using hardware and software maintenance processes.

CAVs are being planned to be or are deployed in various regions encompassing various stages of automation involving different levels of human intervention. Radiocommunication for CAVs may be implemented in frequency bands already allocated to the land mobile service, since CAV radiocommunication is part of Intelligent Transport Systems (ITS). ITS is an application operated under mobile service allocations in Article **5** of the Radio Regulations.

ITS is an application in the land mobile service, and use cases represent specific functionalities within that application. The use case definition for V2X referenced in this Report can be found in § 4.4, with CAV use cases outlined in § 5. The term "Advanced ITS" is defined in § 4.5.

This Report addresses overall objectives and radiocommunication requirements for CAVs.

## 2 Vocabulary

### 2.1 Vocabulary of terms

There are some specific terms used that are related to CAV, including:

1) Connected Vehicle (CV). A vehicle is referred to as a CV if V2X radiocommunication equipment is mounted and an Advanced ITS application is supported by using cooperative V2X connectivity.

2) Automated Vehicle (AV). A vehicle is referred to as an AV if in-vehicle perception sensors like automotive radar, camera, lidar are mounted and automated driving applications are supported using those sensors only.

To better define what is meant by the term “AV”, SAE International has developed a standard description of six levels of vehicle automation, ranging from Level 0 – no automation, to Level 5 – full automation[1]. These descriptions of the six levels of driving automation provide a thorough, systematic technical definition of CAVs. While the capabilities for Level 5 – full automation in all conditions – have generated public expectations, the realization of Level 5 automation has not proceeded as rapidly as initially thought. For the purposes of this Report, Levels 3, 4 and 5 form the ‘automated’ portion of the CAV definition. This is viewed as necessary, but not yet sufficient, for the overall CAV definition.

3) Connected Automated Vehicles (CAV). A vehicle is referred to as a CAV if in-vehicle perception sensors and V2X radiocommunication equipment are mounted and automated driving applications are supported using both in-vehicle perception sensors and cooperative V2X connectivity.

For the purposes of this Report, the definition of CAV is:

CAVs are vehicles with V2X radiocommunication capability blended with automated functionality beginning at SAE Level 2 up to Level 5. Automated functionality consists of a combination of Advanced Driver Assistance Systems (ADAS) at SAE Level 2; and Automated Driving Systems at SAE Levels 3 through 5. These systems use sensors such radar camera, and lidar (line-of-sight technologies) in conjunction with computer algorithms to perform various degrees of automated vehicle control. The V2X radiocommunication extends the awareness horizon of ADAS by obtaining information outside the detection range of on-board sensors, providing information of one’s own vehicle, and communicating intention mutually with other vehicles and infrastructure via V2X connectivity as well as by charting both location and intention of other road users such as vehicles, and it has the ability to “see” and “talk” beyond other objects in real-time (non-line-of-sight). This can enhance safety and efficiency in automated driving control based on the automated driving system.

4) Connected and Cooperative Automated Vehicle (CCAV). The intended understanding is essentially the same as CAV above.

5) Connected and Cooperative Automated Mobility (CCAM). The intended understanding is essentially the same as CAV above.

6) Connected Automated Driving (CAD). The intended understanding is essentially the same as CAV above.

7) Vehicle to Everything (V2X). V2X consists of short range radiocommunication – V2V, V2I, V2P; and, optionally, long range radiocommunication with V2N. Both short range and long range V2X support a hybrid radiocommunication concept to serve for CAV use cases.

8) Cooperative ITS (C-ITS). Refers to a system in which road users and traffic managers fuse information from many sources in real-time, exchange and share that road-segment specific information, and use it to coordinate their actions. This cooperative element – enabled by digital radiocommunications connectivity between vehicles and between vehicles and transport infrastructure – is expected to significantly improve road safety through crash

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[1] https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic.

prevention, increase transportation system and traffic efficiency, support the safety and speed of first responders, address the environmental degradation brought about by transportation, and support the comfort and ease of driving, by helping the driver (or with automation, the vehicle) to take the right decisions and adapt to the traffic situation including avoid emerging threats and hazards.

## 2.2 Acronyms and abbreviations

| | |
|---|---|
| ACC | Adaptive cruise control |
| ADAS | Advanced driver assistance system |
| AV | Automated vehicle |
| BSM | Basic safety message |
| CAD | Connected automated driving |
| CAM | Cooperative awareness message |
| CAV | Connected automated vehicle |
| CCAM | Connected and cooperative automated mobility |
| CCAV | Connected and cooperative automated vehicle |
| CCSA | China Communications Standards Association |
| C-ITS | Cooperative Intelligent Transport Systems |
| CLPMM | Connectionless platooning management message |
| CPM | Collective perception message |
| DENM | Decentralized environmental notification message |
| DSM | Driver status monitor |
| ITS | Intelligent transport system |
| JCS | Joint communication and sensing |
| MAP | Map message |
| MCM | Manoeuvre coordination message |
| OBE | On-board equipment |
| PCM | Platooning control message |
| RSC | Roadside coordination |
| RSM | Roadside safety message |
| RSI | Roadside information |
| RSE | Roadside equipment |
| SPaT | Signal phase and timing |
| SM | Surrounding monitor |
| SSM | Sensor sharing message |
| VIR | Vehicle intention and request |
| V2I | Vehicle to infrastructure |
| V2N | Vehicle to network |

| | |
|---|---|
| V2N2V | Vehicle to network to vehicle |
| V2P | Vehicle to pedestrian |
| V2V | Vehicle to vehicle |
| V2X | Vehicle to everything |
| V2VRU | Vehicle-to-vulnerable road user |
| VRU | Vulnerable road user |

## 3 Related ITU-R texts

Recommendation ITU-R M.1452 – Millimetre wave vehicular collision avoidance radars and radiocommunication systems for intelligent transport system application

Recommendation ITU-R M.1453 – Intelligent transport systems - Dedicated short range communications at 5.8 GHz

Recommendation ITU-R M.1890 – Operational radiocommunication objectives and requirements for advanced Intelligent Transport Systems

Recommendation ITU-R M.2057 – Systems characteristics of automotive radars operating in the frequency band 76-81 GHz for intelligent transport systems applications

Recommendation ITU-R M.2084 – Radio interface standards of vehicle-to-vehicle and vehicle-to-infrastructure two-way communications for Intelligent Transport System applications

Recommendation ITU-R M.2121 – Harmonization of frequency bands for Intelligent Transport Systems in the mobile service

Report ITU-R M.2228 – Advanced intelligent transport systems (ITS) radiocommunications

Report ITU-R M.2322 – Systems characteristics and compatibility of automotive radars operating in the frequency band 77.5-78 GHz for sharing studies

Report ITU-R M.2444 – Examples of arrangements for Intelligent Transport Systems deployments under the mobile service

Report ITU-R M.2445 – Intelligent transport systems (ITS) usage

Report ITU-R M.2520 – The use of the terrestrial component of International Mobile Telecommunications for the Cellular-Vehicle-to-Everything

Handbook on Land Mobile (including Wireless Access) – Volume 4: Intelligent Transport Systems. Year 2021

## 4 Connected automated vehicles in the context of ITS

### 4.1 CAV Definition

CAV provides advanced ITS and automated driving use cases to improve the vehicle safety and comfortable driving. It uses onboard sensors and V2X radiocommunications in vehicle and infrastructure domain. The advanced ITS use cases are described in ITS usage Report ITU-R M.2445 – Intelligent transport systems (ITS) usage. The automated driving use cases potentially supported by IMT capabilities are described in Report ITU-R M.2520 – The use of the terrestrial component of International Mobile Telecommunications for the Cellular-Vehicle-to-Everything.

As indicated in the definition of CAV in § 2.1, V2X radiocommunication is an essential component of CAVs. V2X radiocommunication provides “ears and mouth” to the automated vehicle and enables cooperative ITS where the end users are not only consuming information but also providing it. V2X radiocommunication can enable and/or enhance use cases intended to improve road traffic safety and boost road traffic efficiency on all SAE levels.

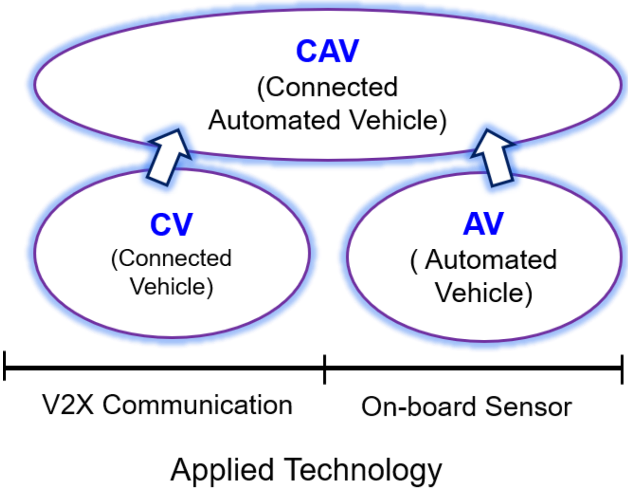
A vehicle possesses information on its own status and the surrounding traffic environment obtained from GNSS and on-board sensors. Such information is required for, and contributes to, smooth automatic driving. In addition, cooperative V2X connectivity enables mutual communication among the vehicles or between the vehicle and the external stakeholders, such as road administrators and traffic managers. Negotiation between the vehicles can be initiated with communicating the intentions to the surrounding vehicles or other travellers such as pedestrians or bicyclists. Requests for mediation may be made by the vehicle to the traffic manager.

There are specific relationships between applied technologies and vehicle functionality. The vehicles can be classified into Connected Vehicle (CV), Automated Vehicle (AV), Connected and Automated Vehicle (CAV) (or CAV equivalent terminologies) from the view of applied technologies and expected vehicle functionality. CAV contains the scope and contents of the CV and AV domains to enhance the in-vehicle perception sensors (ADAS) of AV with short range ad hoc V2X radiocommunication.

Figure 1 illustrates the relationship between CAV, CV and AV.

FIGURE 1

**Relationship between CAV, CV and AV**




### 4.2 Relationship between increased crash avoidance capabilities and short range ad hoc radiocommunication and Advanced Driver Assistance Systems

I) Vehicle versus vehicle crashes: when looking at vehicle versus vehicle crashes, different driving scenarios can be distinguished where ADAS can avoid a certain percentage of such accidents. A BASt study[2] gives potential percentages of the total crash avoidance depending on different driving manoeuvres. Overall, up to 50% of vehicle versus vehicle road traffic crashes can be addressed by ADAS, see Table 1.

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[2] BASt, German Federal Highway Authority. “Requirements to ADAS from the road safety perspective”, 2007. https://www.bast.de/BASt_2017/DE/Publikationen/Archiv/Infos/2007-2006/11-2007.html.

TABLE 1

**Driving manoeuvres and corresponding crash avoidance potential by ADAS. Source BASt**

| | **All crashes** | **Severe crashes** |
|---|---|---|
| Turning-in/crossing vehicle | 16.3% | 21.2% |
| Turning with oncoming vehicle | 2.2% | 4.1% |
| Turning with rear-end crash | 3.8% | 2.4% |
| Longitudinal traffic with real-end crash | 21.9% | 15.1% |
| Longitudinal traffic with lane-change crash | 6.1% | 3.1% |
| **Total** | **50%** | **46%** |

Direct radiocommunication among vehicles, or V2V, has the potential to address approximately 80 percent of unimpaired[3] multi-vehicle crashes[4] and if collective perception service is included in combined V2V and V2I technologies the potential to address vehicles versus VRU crashes is also around 80 percent to protect VRU (based on crash data, in Japan 76%, in Germany 83% and in US 84%)[5]. However, the combination of direct V2X radiocommunication with in-vehicle perception ADAS technologies offers additional safety benefits beyond those that either technology could provide on its own. V2V, V2I and Vehicle-to-Pedestrian (V2P) or Vehicle-to-Vulnerable Road User (V2VRU) radiocommunication systems complement the Line-of-Sight (LoS) ADAS with additional information such as Non-Line-of-Sight (NLoS) object detection, intention recognition, vehicle speed, acceleration information, as well as other status information. V2V message types like Basic Safety Messages (BSM), Cooperative Awareness Message (CAM), Decentralized Environmental Notification Message (DENM), Collective Perception Messages (CPM), Manoeuvre Coordination Messages (MCM) and V2I message types like SPaT and MAP are used to communicate directly among V2X vehicles and the infrastructure. Using direct V2X radiocommunication, there will be fewer restrictions due to LoS obscuration. Also, kinematics data and driver behaviour information such as pedal actuation is exchanged.

Short range ad hoc radiocommunication is able to close the gap and to address vehicle versus vehicle crashes which cannot be prevented by in-vehicle perception ADAS alone.

II) Vehicle versus Vulnerable Road User (VRU) crashes: The effectiveness of preventing vehicle versus VRU crashes using in-vehicle perception ADAS has been analysed in PROSPECT D2.3[6]. An overall potential of 55% in fatality and injury reduction was determined for state of the art ADAS.

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3 Unimpaired motor vehicle crashes refer to crashes in which the driver was not impaired by alcohol or drugs.

4 https://www.safercar.gov/Vehicle-Shoppers/Safety-Technology/v2v%E2%80%93comms#:~:text=NHTSA%20estimates%20that%20when%20fully,percent%20of%20multi%2Dvehicle%20crashes; Federal Motor Vehicle Safety Standards; V2V Communications, 82 Fed. Reg. 3854, 3985 (Jan. 12, 2017).

5 "Reducing Traffic Fatalities using Collective Perception in V2X Communication based on Crash Data in Japan/Germany/US", Bettina Erdem, Harald Feifel, Dr. Marc Menzel, Jeffrey Skvarce, Robert Gee, Continental Teves AG & Co. oHG, Germany, Continental Automotive Systems, USA, paper published at 27th ITS World Congress October 2021 in Hamburg.

6 European H2020 research project PROSPECT, PROactive Safety for PEdestrians and CyclisTs, analyse and tested in-vehicle perception ADAS to protect VRUs, finalized 2018. Deliverable D2.3, https://ec.europa.eu/inea/en/horizon-2020/projects/H2020-Transport/Safety/PROSPECT.

Short range ad hoc radiocommunication is able to close the gap and help reduce the number of vehicles versus VRU crashes which cannot be prevented by ADAS.

### 4.3 Transmission modes used for CAV radiocommunication

Three types of transmission methods are used for CAV radiocommunications.

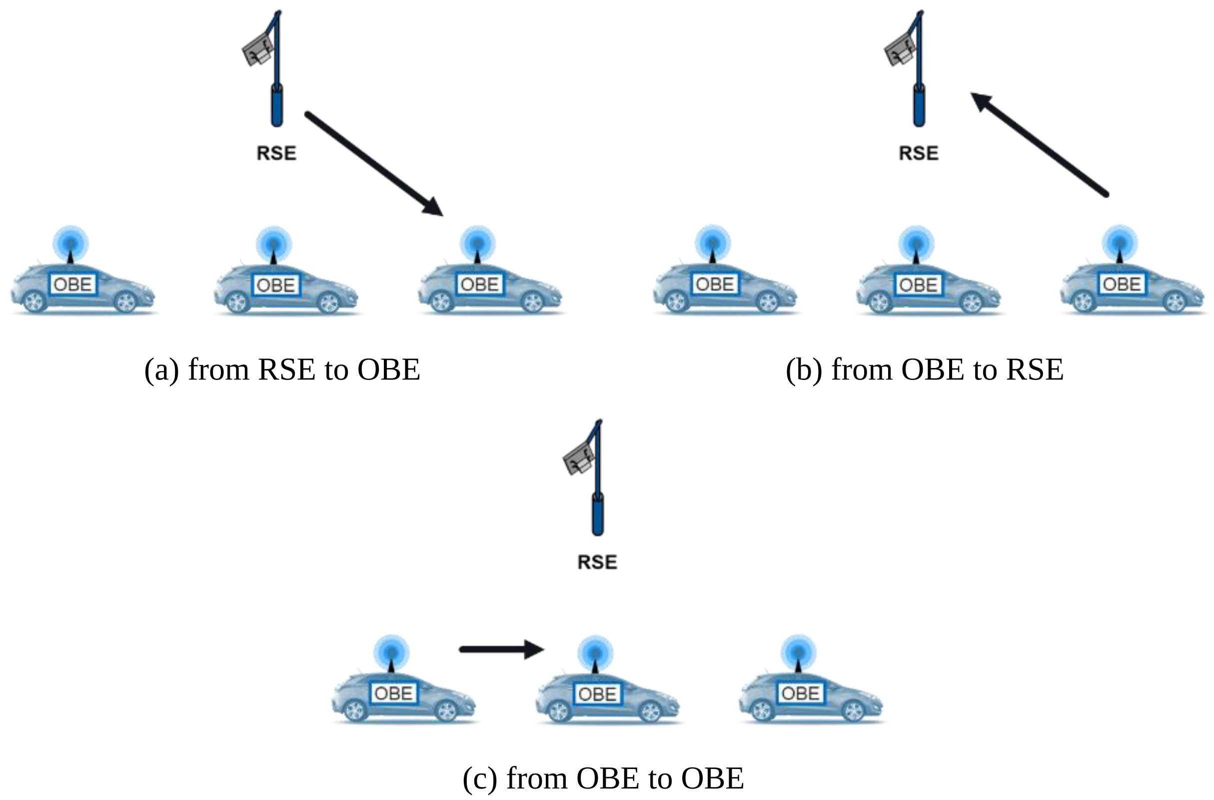
Transmission of a message from one point to another point can be implemented by unicast, while a message transmission from one point to multiple points can be implemented by multicast or broadcast. The unicast can also be used to deliver the same message to multiple points by transmitting it to multiple destinations sequentially, that is, there is some flexibility in selecting which type of transmission in communication to be used for implementing the V2V/V2I/V2N radiocommunications, depending on use cases.

#### 4.3.1 Unicast

Unicast is a transmission of a piece of information from a single source to a specified destination. This method is used for 1 to 1 radiocommunication. This type of transmission is useful when there is a single source and a single recipient. As an example, a message may be sent by the V2X server to a specific vehicle's V2X client. Figure 2 shows unicast transmission mode.

FIGURE 2

**Unicast transmission mode**



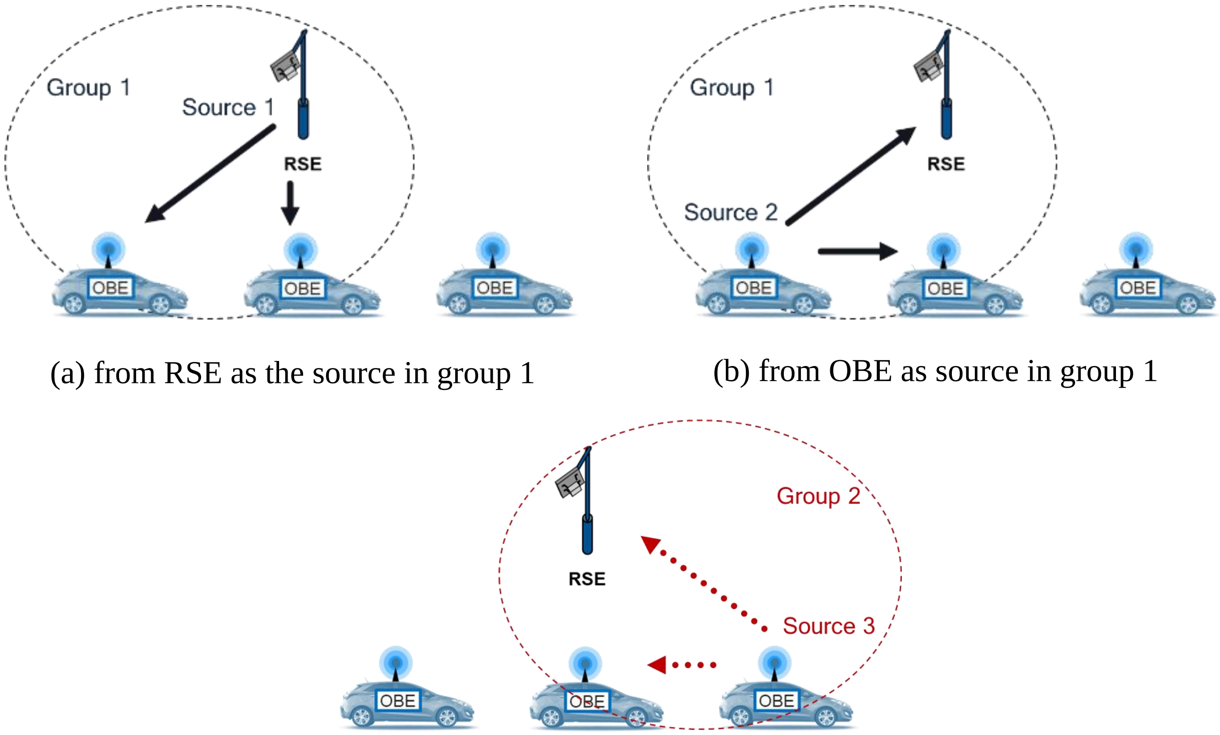

*Note to Fig. 2*: Lines show a peer-to-peer transmission.

#### 4.3.2 Multicast/Groupcast

Multicast is a transmission of a piece of information from a single source to multiple destinations. This method is used for one-to-multiple radiocommunication, for example, group communication. The source of the transmission is the same, with more than one recipient. As an example, an OBE may send a message to a certain OBE in a selected group that satisfy the specified criteria (as shown in Fig. 3-a) or V2X server hosted in a roadside infrastructure may send a message to the V2X clients of a selected group of vehicles that satisfy some classification criteria (as shown in Fig. 3-b). Unlike broadcast transmission below, multicast receivers/clients receive a stream of information only if they have previously determined to do so by joining the specific multicast group. Multicast transmission can provide traffic bandwidth savings, up to *1*/*N* of the bandwidth being compared with *N* separate unicasts. Figure 3 shows groupcast transmission mode.

FIGURE 3

**Multicast/Groupcast mode**




(a) from RSE as the source in group 1

(b) from OBE as source in group 1

(c) from OBE as source in group 2

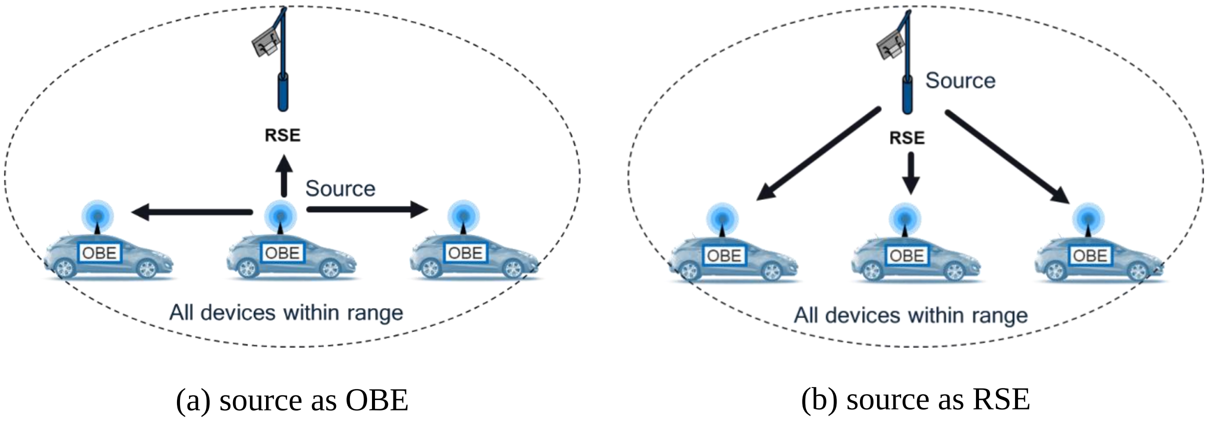
*Note to Fig. 3*: Lines show multi-destination transmission from a single source within a group.

### 4.3.3 Broadcast

Broadcast is a transmission of a piece of information from a single source to all other connected destinations. This may also involve multiple transmissions where the source of the transmission can be different, so it is N to M. This method is used for CAV radiocommunication among an unspecified number of vehicles. As an example, an emergency vehicle may send information about its status (time, direction, position, speed, size, etc.) which may be received by multiple vehicles nearby and at the same time an RSE may also transmit the speed-limit alert information which may be received by multiple OBEs. Figure 4 shows broadcast transmission mode.

FIGURE 4

**Broadcast mode**




*Note to Fig. 4*: Lines show a transmission from a single source.

## 4.4 Radiocommunications approaches for CAV

There are two main radiocommunication approaches for operation of CAVs – ad hoc wireless direct radiocommunication and cellular connectivity (requiring base station coverage). Ad hoc radiocommunication is essential for CAVs and is the focus of this Report. Cellular network connectivity using IMT systems is also important, and is described in detail in Report ITU-R M.2520. The radiocommunication technologies (or access layer technologies) are also supported by higher layer technologies, as described later in this report, for supporting the V2X messages.

The complete use-case definition for V2X includes all the protocol layers involving an end-to-end communication between the multiple entities involved. This includes both the radio access layer and the higher layer communication. The relationship between the two layers is important to understand the technical performance and capabilities required to satisfy the V2X use-case.

At a conceptual level, the vehicles may desire to exchange certain information (that includes some amount of message size, reliably within a certain timeframe). The use-case itself imposes the desired performance metrics to be achieved to support the safety / utility function. The application layer or higher layer standards provide the information to be exchanged using a common language. And finally, the radio access layers enable the actual transfer of messages between the entities.

## 4.5 Summary

"Advanced ITS" is a term that is meant to separate the level of ITS use cases enabled by G5/WAVE and C-V2X technologies from the legacy ITS use cases (for example, toll collection) based upon older radiocommunication technologies. The "Basic Safety" terminology used in this Report refers to safety-related Advanced ITS use cases that are able to be supported by LTE V2X, called "day-1 use cases" in related literature[7]. These basic safety use cases, as well as many of the other advanced ITS use cases are able to be supported by G5/WAVE radiocommunication technologies. At a fundamental level, the basic safety use cases described, for example, in Report ITU-R M.2445 – Intelligent transport systems (ITS) usage (the terminology "applications" is used for "use cases" in Report ITU-R M.2445), provide the foundational safety-of-operation required for CAVs. These use cases also provide the rationale for the inclusion of wireless radiocommunication capabilities as a basis for the definition of CAVs. Therefore, the advanced ITS radio interface standards in

7 https://5gaa.org/wp-content/uploads/2021/10/5GAA_Day1_and_adv_Use_Cases_Spectrum_Needs_Study_V2.0.pdf.

Recommendation ITU-R M.2084 – Radio interface standards of vehicle-to-vehicle and vehicle-to-infrastructure two-way communications for Intelligent Transport System applications, provide the minimum connectivity requirement in the definition of CAVs. Furthermore, CAV developments are expected to generate additional radiocommunication requirements necessary for SAE Level 4 automation – in the next several years. These additional radiocommunication requirements for CAVs may extend beyond the current requirements for advanced ITS (as further described in § 6.3).

## 5 CAV use cases

Diverse use cases are associated with CAV which in turn generate demands from the system capabilities and require diverse response in terms of radiocommunication. The automotive industry report provides a framework for grouping and classification of use cases[8]. The use-case groups are listed below:

1) Safety
2) Vehicle Operations Management
3) Convenience
4) Autonomous Driving
5) Platooning
6) Traffic Efficiency and Environmental Friendliness
7) Society and Community.

Each use case may belong to one or more groups according to the different needs they are called on to fulfil as well as the stakeholders benefiting from them[9]. A brief description of the use case groups is provided below.

**Safety**

This group includes use cases that provide enhanced safety for vehicles and drivers. Examples of use cases include emergency braking, intersection management, assisted collision warning, and lane change.

These use cases would typically apply equally to autonomous vehicles or to provide assistance to drivers, with some notable exceptions such as ‘see-through’ camera assistance for human drivers.

**Vehicle Operations Management**

This group includes use cases that provide operational and management value to the vehicle manufacturer. Use cases in this group would include sensor monitoring, ECU software updates, remote support, etc.

From a business and monetisation modelling point of view, these are use cases that could be provided by vehicle manufacturers (OEMs) to improve the efficiency of vehicle maintenance, and vehicle monitoring. Some use cases, such as remote support, could possibly be sold to vehicle owners/drivers and transport/delivery companies.

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8 5GAA TR T-200111: Working Group Use Cases and Technical Requirements, “C-V2X Use Cases and Service Level Requirements Volume I”, https://5gaa.org/wp-content/uploads/2020/12/5GAA_T-200111_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_I-V3.pdf.

9 5GAA TR T-200116: Working Group Use Cases and Technical Requirements, “C-V2X Use Cases and Service Level Requirements Volume II”, https://5gaa.org/wp-content/uploads/2020/10/5GAA_White-Paper_C-V2X-Use-Cases-Volume-II.pdf.

**Convenience**

This group includes use cases that provide value and convenience to the driver. Examples for this group can include infotainment, assisted and cooperative navigation, and autonomous smart parking. These are use cases that may not be mandated from a safety programme point of view, but which provide significant value to the driver or passengers in the vehicles.

From a business-modelling point of view, these are use cases that could be purchased by vehicle drivers or passengers.

**Autonomous Driving**

This use case group address use cases that are relevant for Autonomous/self-driving vehicles (level 4 and 5), examples in this group are Control if autonomous driving is allowed or not, Tele-operation (potentially with Augmented Reality support), handling of dynamic maps (update/download), some of the Safety use cases that require cooperative interaction between vehicles to be efficient and safe.

These use cases are from a business modelling point of view of value to OEMs that can sell the features to vehicle owners/drivers, transport/delivery companies.

**Platooning**

This use case group address use cases that are relevant for platooning, examples in this group are platoon management, for example, collect and establish a platoon, determine position in platoon, dissolve a platoon, manage distance within platoon, leave a platoon, control of platoon in steady state, request passing through a platoon.

These use cases are of interest to transport companies and potentially by road operators/road traffic authorities since road infrastructure could be used more efficiently. Potentially also for society as it could provide environmental benefits such as reduced emissions.

These use cases are from a business modelling point of view of value to OEMs that can sell the features to vehicle owners/drivers, transport/delivery companies.

**Traffic Efficiency and Environmental Friendliness**

This group includes use cases that provide enhanced value to infrastructure or city providers, where the vehicles will be operating. Examples of this use case group include green light optimal speed advisory (GLOSA), traffic jam information, routing advice, for example, smart routing.

From a business-modelling point of view, these use cases are of value to OEMs and service providers who can sell the features to vehicle owners/drivers and transport/delivery companies, and could potentially receive public subsidises, as there are environmental benefits involved.

**Society and Community**

This group includes use cases that are of value and interest to society and the public in general, for example, public services such as road authorities, the police force, fire brigade and other emergency or government services. Examples in this group are emergency vehicle approaching, traffic light priority, patient monitoring, and crash reporting.

From a business-modelling point of view, these are of value to OEMs that can sell the features to the public/private sector.

Looking at worldwide R&D towards service deployment of CAVs, current prototype use cases include Cooperative Driving/Coordinated automated driving manoeuvres, Platooning, Automated Valet Parking. The radiocommunication system architecture of CAV is basically the same as that of Advanced ITS.

Coordinated automated driving manoeuvres are one of the main reasons that wireless radiocommunications are being viewed as a possible complement for AVs. One of the first use cases in this category is platooning but coordinated merging and coordinated lane changing are also being developed.

## 5.1 Advanced ITS use cases for CAVs and other vehicles

### 5.1.1 Cooperative awareness[10]

In this use case, the Cooperative Awareness Message (CAM) is periodically sent by a vehicle to provide real-time information about its status, for example, its geographical position and/or speed. The use cases include safe intersection with traffic light information, the coordination of the signal phase and timing of the traffic lights to minimize the number of vehicles stops at the traffic lights and signal request message by emergency vehicles.

Traffic signal information, including current traffic signal colour and traffic signal phase and timing information, is provided by the roadside infrastructure, or through the network, to vehicles entering intersections or crosswalk to assist deceleration and stopping with a margin. Vehicles are assisted to slow down gently in advance, based on the information on the signal cycle provided. This avoids the vehicle entering an area (dilemma zone) where it can neither pass nor stop if the signal changes to yellow.

Intersections are among the most likely places for accidents to occur in the city, due to the high traffic density and dynamic environment with vulnerable road users like pedestrians. To avoid collision at the intersections, vehicles must understand what other vehicles and road users are going to do at the intersection. By providing information on the position and speed of those users approaching the intersection, vehicles are assisted to pass through or make a turn at the intersection even with many blind spots.

Integration of vulnerable road users such as pedestrians and bicycles into V2X communication enables them to enhance their protection and prevent traffic accidents[11]. Their presence and behaviour are transmitted from the devices equipped on the VRU and notified to vehicles and other road users via the road infrastructure. This works in a variety of situations, such as encounter accidents at non-signalised intersections, contact with vehicles overtaking VRUs, and overlooking vehicles turning.

### 5.1.2 Collective perception using messages

On-board perception sensors are able to recognize and identify moving and fixed objects in Line-of-Sight view of sensors built in vehicles or infrastructure. Vehicles and infrastructure can share such identified objects to other V2X traffic participants, by radiocommunication, even if they are not in Line-of-Sight. This is known as collective perception, object sharing, cooperative sensing driving as well as extended sensor sharing.

Collective Perception with object sharing means exchange of sensed object data between vehicles and vehicles with smart infrastructure as well as between vehicles and smart infrastructure itself. Cameras, radars, lidar sense all object types (such as vehicles, pedestrians, bicycles, scooters, motorcycles or other road users) in the Line-of-Sight environment and transmit the object data to all

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[10] Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service, ETSI EN 302 637-2.

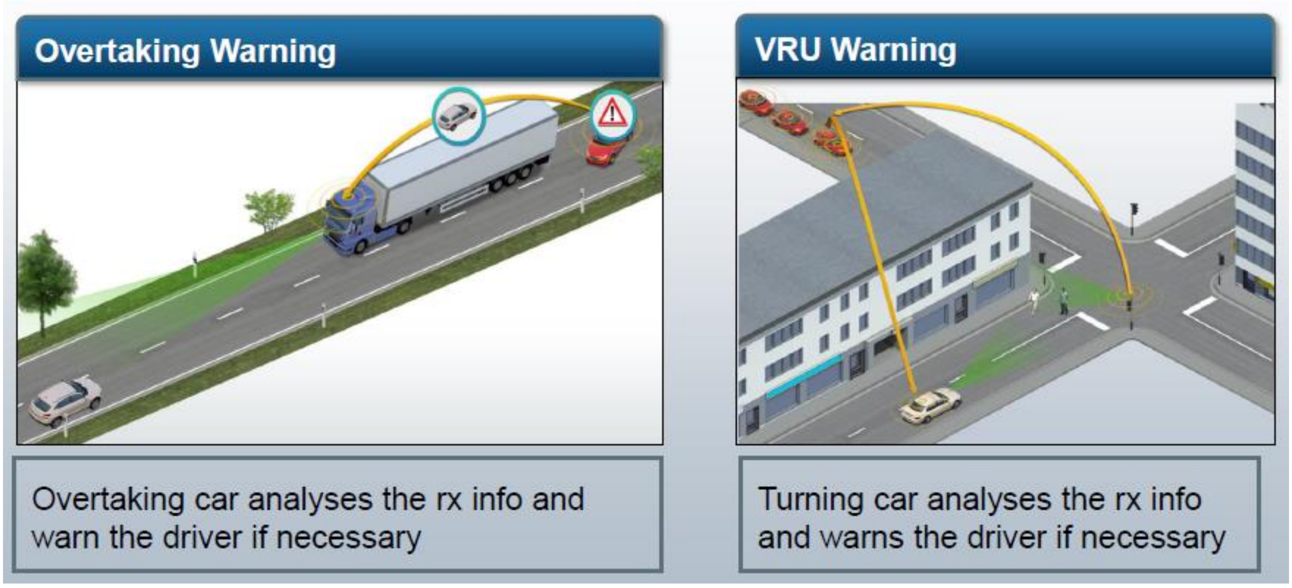
[11] ITS Forum of Japan: RC-016; Experimental Communication Messages Guidelines of Bicycle/Pedestrian Accident Prevention Support System; https://itsforum.gr.jp/Public/E3Schedule/p37/ITS_FORUM_RC-016eng_v10.pdf.

ITS traffic participants, including roadside infrastructure. Pedestrians are not equipped with camera, radar, lidar and cannot send sensed object data.

The collective perception can be performed with abstracted messages of Collective Perception Messages (CPM), but not with raw sensor data, as shown in Fig. 5. This abstraction can reduce the amount of radiocommunication data traffic and can ease the burden of radiocommunication.

FIGURE 5

**Sensing driving by Collective Perception Messages**[12]




Vulnerable road users such as pedestrians are especially protected by collective perception services.

In cases where direct V2V radiocommunication is impossible due to non-connected participants (like VRU, non-connected vehicles), cooperative sensing driving adds additional traffic safety by exchanging object data through indirect radiocommunication. CPM provides information about objects such as other traffic participants or other road user in the surrounding area as detected by the vehicle or infrastructure, using their own radars, cameras, or lidar. Collective perception capability enhances the radiocommunication between V2X-equipped participants and incorporates non-equipped V2X traffic participants. CPM can accelerate the effective V2X radiocommunication rate by using information from third-party vehicles or from smart infrastructure as an information source. Thus, CPM can help protect vehicles and VRUs which are not yet equipped with V2X.

CPM also helps interaction of CAVs with non CAVs such as VRUs and non-CAV vehicles.

Extended Sensors enables the exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSEs, devices of pedestrians and V2X application servers. The raw data sharing is described in § 5.2.4 in detail.

### 5.1.3 Urban / Highway Driving

Urban driving is challenging for the complex environment and road layouts, and dynamic interaction with many different road users. Use cases for urban driving include traffic signal information and collision avoidance at intersection, which are described in § 5.1.1 above.

[12] C-ITS in Europe, Niels Peter Skov Andersen, SIP-adus workshop 2021, 29 October 2021. https://en.sip-adus.go.jp/evt/workshop2021/file/bw/andersen.pdf.

On highways, automated cars with Levels 2 and 3 capabilities are already in use, where the system detects the lane and the car in front and takes over from the driver to steer the car and keep a certain distance. More advanced cooperative and automated driving are being developed, such as assisting with merging and lane changing, and using look-ahead information beyond the range of on-board sensor detection.

In merging/lane change assistance, vehicles interact with other vehicles and the infrastructure to negotiate and determine a time to intersect based on the positions and predicted paths of travel during a merging or lane changing manoeuvre.

The use of look-ahead information allows the driver to avoid collisions, change driving plans and avoid emergency vehicles by communicating information on objects and events that are beyond the detection range of the on-board sensors and that are on the planned route or in blind spots. A system monitors an own vehicle's speed, the speed of the other vehicles, and the position of these vehicles, and traffic congestion, obstacles, and construction work, so that it can provide collision avoidance, trajectory planning change and emergency vehicle notification.

In urban and highway driving, infrastructure and vehicle data are used to inform vehicles about road conditions, traffic congestion, accidents, construction sites, parking availability and traffic signal phase and timing (SPaT).

## 5.2 Use cases specifically for CAVs

### 5.2.1 Coordinated merging

Coordination among merging vehicles is a fundamental use case for CAVs. This is viewed as an essential component of a number of the other CAV use cases, for example, in Cooperative Driving with Manoeuvre Coordination (MC) service, described in the next subsection. In the Coordinated Merging use case the merging vehicles coordinate their expected trajectories continuously upon approaching the merge point to negotiate necessary adjustments in operational control parameters (for example, acceleration, braking, steering) to allow a safe merge manoeuvre. At an overall systems level, this use case must meet strict reliability requirements. However, in order to ensure the safe operation of this automated manoeuvre, crash-avoidance safety systems using both radiocommunication and onboard sensor inputs are expected to provide failsafe backup for this use case.

### 5.2.2 Cooperative driving with manoeuvre coordination service

Cooperative driving with manoeuvre coordination (MC) service also called Coordinated Driving or Advanced Driving enables use cases such as coordinated merging, coordinated lane change of semi-automated or fully automated vehicles. In this use case, MC exchanges the large message of information on future trajectory/ path planning, for safer and more efficient cooperative driving. The functional elements of the Cooperative Driving are described in § 6.4, in detail.

FIGURE 6

**Radiocommunications between vehicles in cooperative merging on highway**

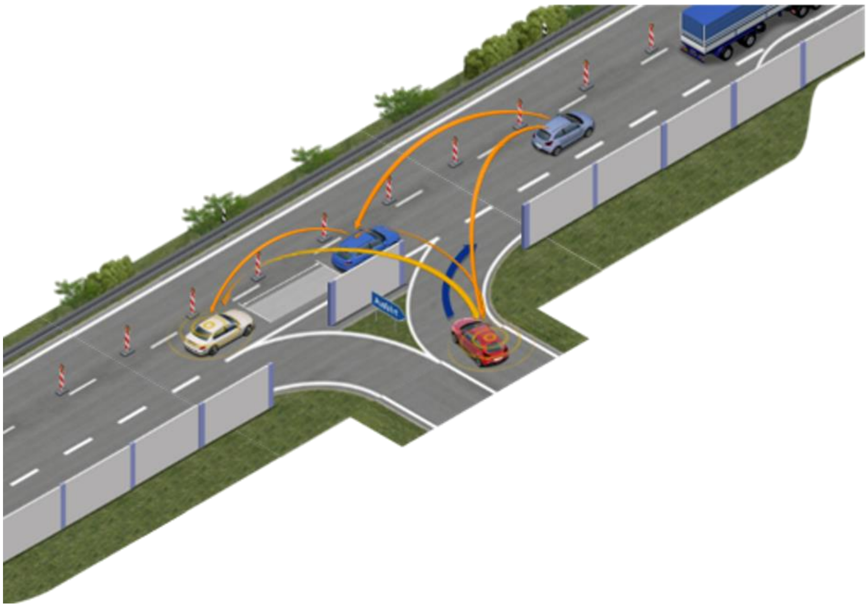
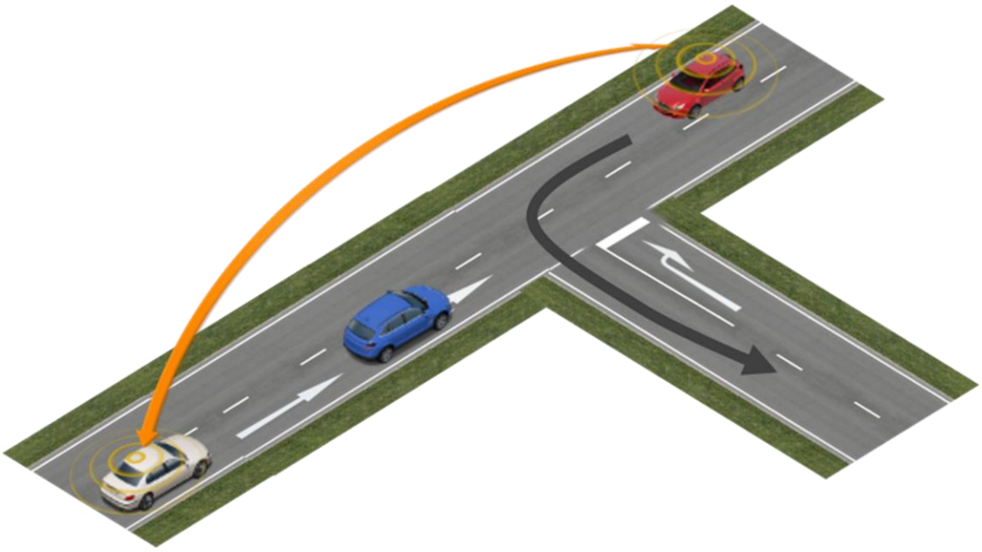


FIGURE 7

**Radiocommunications between vehicles in cooperative turning at junctions**



"Cooperative Automated Driving (CAD)[13] brings together driving automation technology with V2X radiocommunication in order to enable vehicles to coordinate their driving manoeuvres and achieve a common global understanding of their surroundings, leading to safer and more efficient driving. At present, developments to bring about CAD have been made in several countries around the world. The IMAGinE[14] research project developed a CAD system based on collective perception and

[13] Note that CAD has the same meaning as CAV.

[14] IMAGinE is a German research project implementing Collective Perception Service and Manoeuvre Coordination Service into passenger cars, https://imagine-online.de/en/home/:

cooperative manoeuvre coordination, one example of CAD is a connected lane merge function"[15]. By exchanging manoeuvre coordination messages (MCM), the intentions of the vehicles are shared and are transparent to nearby vehicles, which can negotiate the most efficient trajectories and thereby avoid incidents and accidents. Another example is the SIP-adus programme in Japan, which conducted a technical study and demonstrated, inter alia, merge assistance on motorways[16]. In this test demonstration, it was confirmed that the merging vehicles and the main-lane vehicles can negotiate and agree on room for the merging vehicle in the vicinity of the merging area, via V2V radiocommunication by adding functions to Japan's ITS radiocommunication standard (ARIB STD-T109).

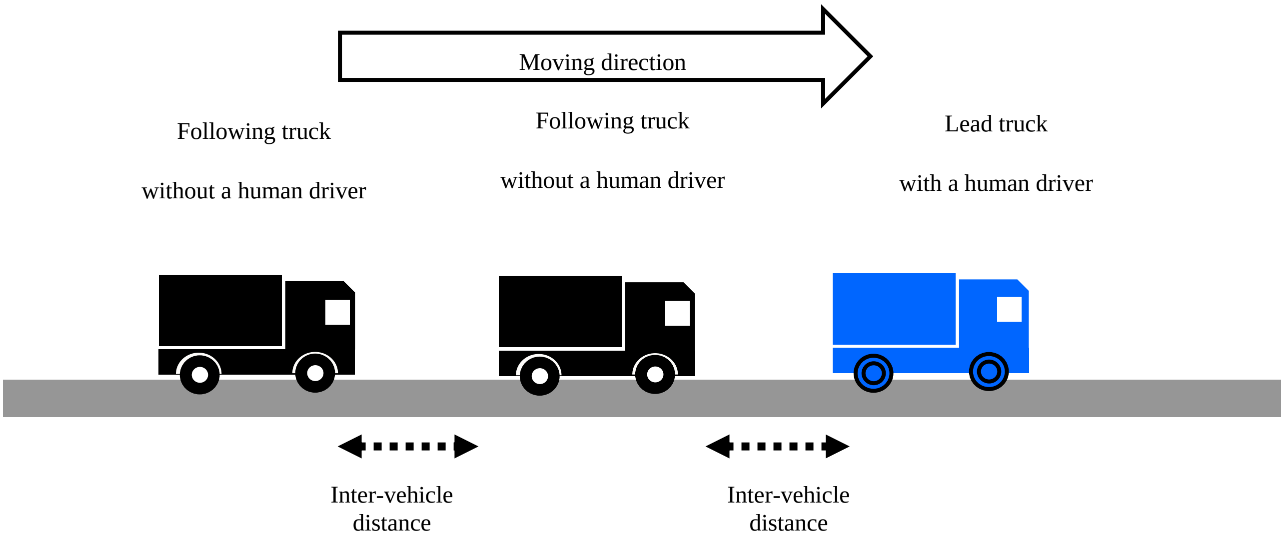
Cooperative merging and coordinated lane change are included as functional elements in § 6.4.

### 5.2.3 Platooning

Platooning is one of the use cases of scenario-specific MC. Platooning involves multiple vehicles driving together in a convoy. The platoon is controlled as a unit by using inter-vehicle radiocommunication. In truck platooning, the leading truck is driven by a human driver while following trucks follow the leading truck by keeping a certain inter-vehicle distance using Automatic Cruise Control (ACC) and automated-steering/automatic-tracking of the previous truck, as shown in Fig. 8.

FIGURE 8

**Truck platooning**




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

[15] Ignacio Llatser, Thomas Michalke, Maxim Dolgov, Florian Wildschütte, Hendrik Fuchs, IEEE 2nd 5G World Forum "Cooperative Automated Driving Use Cases for 5G V2X Communication", 2019.

[16] https://www.sip-adus.go.jp/evt/workshop2017/file/evt_ws2017_s5_HideakiNanba.pdf.

Development to implement platooning is currently underway in several countries around the world. For example, in Japan, field trials of truck platooning are underway[17], as shown in Fig. 9.

FIGURE 9

**Field trial of truck platooning (CACC and automated steering) on a highway**

a) Rear view b) Bird view

Several social issues can be resolved through the use of truck platooning. Platooning can enable trucks to drive closer together to reduce wind resistance, which can reduce fuel consumption and reduce $CO_2$ emissions. It has been shown that a platoon of three trucks travelling 4 m apart at 80 km/h consumes 15% less fuel[18]. If the distance between trucks is reduced to 2 metres, the fuel consumption would be reduced by 25%. Reducing the distance between vehicles can also increase the traffic capacity of roads, that is, the number of vehicles per km, mitigating congestion. This could further reduce fuel consumption and $CO_2$ emission.

In some countries, including Japan, an aging driver population and driver overwork, due to shortage of truck drivers, are also social issues, so truck platooning can reduce the burden on drivers and increase safety.

Adaptive Cruise Control (ACC) measures the distance between a lead vehicle and following vehicle using radar or other technology and maintains a safe separation between vehicles according to their cruising speed. ACC has been implemented and many vehicles are already equipped with it. However, when controlling based only on the measured distance between vehicles, there is a significant delay between when the lead truck begins to slow down and when the following distance changes. There is further delay until the following truck begins to slow down. For this reason, if only ACC is used, a longer following distance must be maintained to prevent collisions.

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[17] M. Mikami and H. Yoshino, "Field Trial on 5G Low Latency Radio Communication System Towards Application to Truck Platooning," pp. 1447-1457, IEICE Transactions on Communications Vol.E102-B, No.8, Aug. 2019. https://www.jstage.jst.go.jp/article/transcom/E102.B/8/E102.B_2018TTP0021/_pdf/-char/en.

[18] K. Aoki, "Current Activities of Development on the Automated Truck Platoon" pp. 303-309, IPSJ Journal, Vol. 54 No. 4, Apr. 2013 (in Japanese).

On the other hand, Cooperative ACC (CACC) controls vehicle speed based on other vehicles' speed and position information sent from other trucks to a truck by inter-vehicle radiocommunication, which can greatly improve control of the following distance when the truck needs to brake suddenly. This also enables stable operation with less fluctuation in following distance (hunting or vibration) due to less control delay. Fuel consumption can be further reduced and traffic capacity of roads, that is, number of vehicles per km, can also be increased while maintaining safety by further reducing the following distance and increasing the number of platooned trucks, if reliable and low-latency radiocommunication would be applied to the radio communication between the vehicles.

There are two radiocommunications in truck platooning; (1) direct V2V radiocommunication and (2) V2V and/or V2N radiocommunication via a cellular base station.

The V2V direct radiocommunication between vehicles in a platoon needs group radiocommunication which is carried out within a specific platoon, that is, a group of trucks which forms platooning.

The direct radiocommunication needs to support three types of radiocommunication; (i) message radiocommunication for vehicle control, may require (ii) video radiocommunication for safety monitoring of rear and side views, being sent from the trailing vehicles to the lead vehicle human driver, and (iii) message radiocommunication for information of auxiliary equipment, for example, fuel indicator, handbrake status, warning lamps and/or position of transmission gear. The above (i) requires small packet but low latency radiocommunication, for example, less than 100msec depending on applications, for the control of the vehicles in a platoon, particularly in case of multiple vehicles form a platoon to avoid hunting/vibration of the inter-vehicle distance and to keep the control of the vehicles more stable. The above (ii) may require the transmission of full HD (1920 × 1080, that is, 2.07 million pixels) video with around 60 fps, with the latency of 50 ms (glass-to-glass, including video coding and decoding), considering the requirements of 1 million pixels, 30 fps with the latency of 200 ms, which are defined for electric rear-view mirrors in Regulation 46 by United Nations European Commission, also taking some margins to them. The (iii) above requires very short messages and allows relatively higher latency but need to periodically exchange messages. Coverage area is less than a few hundred meters in diameter in most of the cases in the direct V2V radiocommunications. Higher frequency range, for example, upper portion of microwave or mm-wave may be considered for the direct-V2V group radiocommunications in a platoon, since radiocommunication distances are relatively short.

The V2V and/or V2N radiocommunication via a cellular base station may be used in cooperative merging and lane change assistance (see Table 3, (1) and (3)) of the truck platooning. They are very useful for smooth merging of the platoon and other single-vehicles, particularly at highway branches and exits since the platoon is very long being compared with typical trucks and/or trailers. In addition, the truck platooning may need to be monitored (all the time) and controlled (in case of emergency), at a remote operation and monitoring centre. The radiocommunication via a base station requires the similar requirements as discussed in (i) and (ii) above. Typical cellular coverage is required for platooning radiocommunication via a base station.

### 5.2.4 Raw perception data sharing

Raw perception data of video camera, radar and lidar from other vehicles/infrastructures may be helpful for vehicles in non-Line-of-Sight to get complementary information for more advanced and safer automated driving. One simple example of the raw perception data sharing is the use case of "See-through" as depicted in Fig. 6. In the collective perception use case, the perception data is sensed and analysed by the on-board unit in a truck, and transmitted to a red passenger car as CPM, while in the raw perception data sharing use case, raw perception data is directly transmitted to the red car. The raw perception data sharing may need wider spectrum bandwidth and it can also be transmitted and used by other cars for their automated driving.

To enable driving safety for Level 5 full automation of CAVs, automated driving vehicles of different manufacturers may have different data processing algorithms and vehicle control decisions based on raw perception data from sensors, such as video, radar, and lidar, whatever they are coming from sensors on-board or sensors of other vehicles. In terms of the susceptible perception data from various sensors, the raw perception data sharing among CAVs should be considered to perform the effective perception data fusion and utilization for Level 5 full automation. Therefore, the data rate and latency requirements for the raw perception data sharing among CAVs would be in the order of Gbit/s and msec. For example, as shown in the 3GPP Technical Report[19] for its Release 16 specifications in the "Collective perception of environment" scenario which can enhance the perception of environment of vehicles to avoid accidents for high-level automatic driving vehicles, the end-to-end delay requirement for collision prevention is as low as 3 ms, and the transmission rate is required to be more than 1 Gbit/s. Therefore, it requires wider spectrum bandwidth at both lower and higher frequency ranges, if possible, for raw data exchange and radio sensing with higher accuracy and resolution would be possible at the same time by exploiting the nature of its wider spectrum bandwidth. Such a future technology is described, as the Joint Communication and Sensing (JCS) in § 7.4.1 of this Report, for the future efficient use of radio spectrum in such a broadband radiocommunication.

FIGURE 10

**Typical scenario of raw perception data sharing among CAVs**

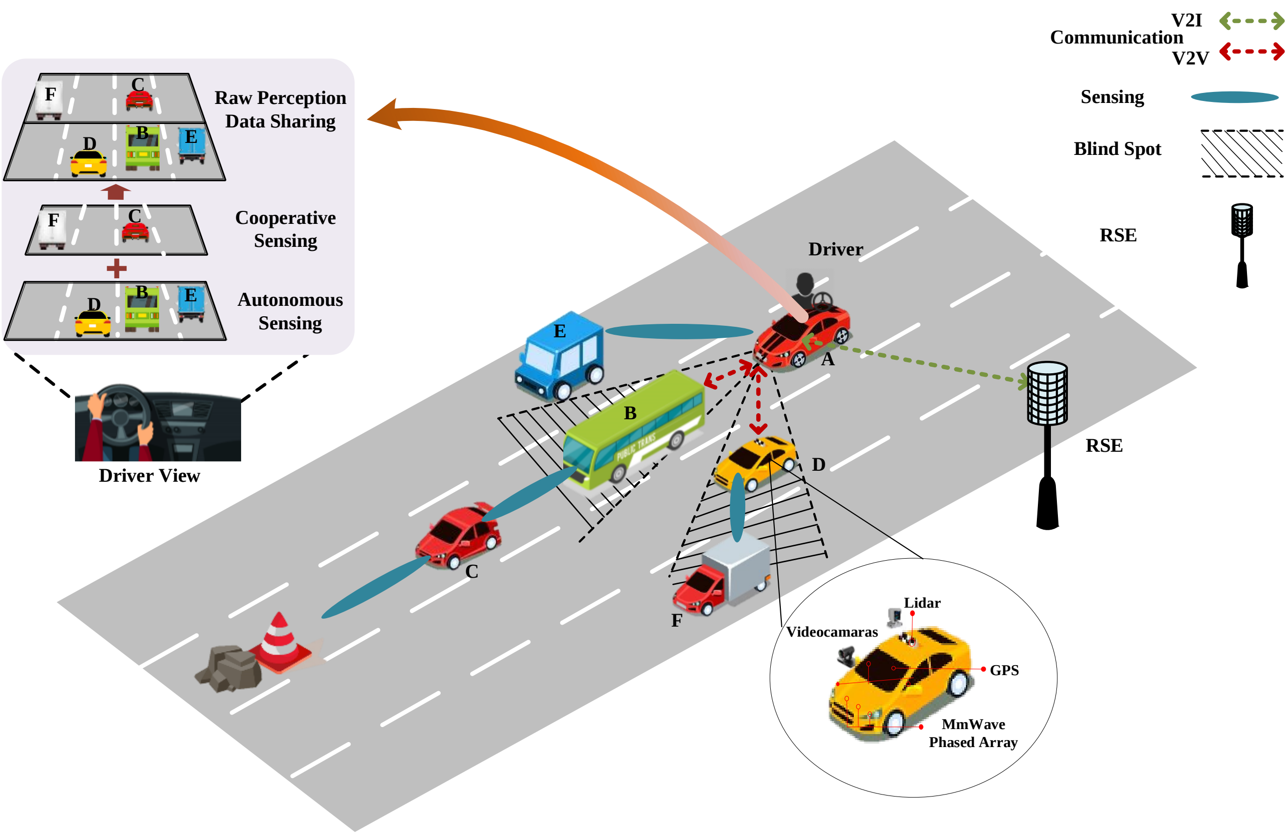


Figure 10 depicts typical scenario of raw perception data sharing among CAVs. There are multiple sensors in CAV, such as video camera, lidar and other on-board sensors. Both low-frequency and high-frequency bands need to be considered to provide broadband radiocommunication ability among CAVs and roadside equipment (RSE). In the Figure, it is assumed that vehicles B, D and E are the targets that can be directly detected by sensors such as video camera, radar or lidar of vehicle A.

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[19] 3GPP TR 22.886, "Study on enhancement of 3GPP Support for 5G V2X Services (Rel.16)", December 2018.

However, due to the blockage of vehicles B and D in front, the sensing range of vehicle A is greatly limited, resulting in vehicles C and F in the blind area of vehicle A. Therefore, in order to expand the detection range of vehicle A, the broadband V2V radiocommunication links can be used to transmit the raw perception information from radar or camera of vehicle B and D to vehicle A. Vehicle A carries out the multi-source perception information fusion to improve the "See-through" ability. The use of raw data is considered effective to enhance the safety of CAVs for distributed verification of local and remote sensor data[20]. However, in some cases, V2V radiocommunication links are limited. The raw perception data needs to be shared through the RSE. Therefore, V2I radiocommunication links can also be used to transmit the raw perception information to vehicle A.

For example, the raw data rate of computer vision-based video camera would be 100-700 Mbit/s[21] (for example, six cameras with a resolution of 1280 × 720, 24 bit per pixel, 30 frames per second), which will rely on vendors' specific classifiers[22, 23]. The raw data rate will reach gigabit-class[24] because raw perception data sharing is real-time data sharing, which requires low latency transmission[25]. Extended sensing for high-level automated driving should not only consider sharing the results of detection targets. The sharing of raw sensing data can reduce the further propagation of errors caused by sensor failures and signal processing algorithm errors.

As shown in Fig. 10, vehicle B can sense the surrounding environment through sensors and generate raw perception data, which could be calculated locally to make decision. The decision can be shared with vehicle A to improve the "See-through" ability. However, if the target recognition algorithm of vehicle B exists errors, the wrong decision information shared with vehicle A may lead to an accident[26]. Therefore, by sharing the raw perception data among vehicles, the traffic accidents caused by incorrect decision propagation may be extensively minimized.

Broadband, low-latency services such as collective environmental awareness/perception and extended sensing may promote the evolution of CAV radiocommunication systems to higher frequency bands (for example, millimetre-wave band) to meet their ultra-gigabit-level data rate requirements.

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[20] S. W. Kim *et al.*, "Multivehicle Cooperative Driving Using Cooperative Perception: Design and Experimental Validation" in IEEE Transactions on Intelligent Transportation Systems, vol. 16, no. 2, pp. 663-680, Apr. 2015.

[21] J. Choi, N. González-Prelcic, R. Daniels, C. R. Bhat, and R. W. Heath, Jr., "Millimeter Wave Vehicular Communication to Support Massive Automotive Sensing", IEEE Communications Magazine, vol. 54, no. 12, pp. 160-167, Dec. 2016.

[22] N. Andersen, C2C-Consortium "Towards Accident Free Driving", ETSI Summit "5G from Myth to Reality", 2016.

[23] 3GPP TR 22.886, "Study on enhancement of 3GPP Support for 5G V2X Services (Rel.16)", December 2018.

[24] Continental Engineering Services, SRR 308-21 Short Range Radar 24 GHz Data sheet, http://conti-engineering.com/wp-content/uploads/2020/02/SRR308-21_EN_HS.pdf.

[25] MAVEN consortium, "Deliverable D5.1: V2X communications for Infrastructure assisted automated driving," February 2018.

[26] "Collision Between Vehicle Controlled by Developmental Automated Driving System and Pedestrian. Tempe, Arizona. March 18, 2018." Accident Report. National Transportation Safety Board (NTSB/HAR – 19/03). Access via: https://www.ntsb.gov/investigations/accidentreports/reports/har1903.pdf.

### 5.2.5 Remote driving/teleoperation

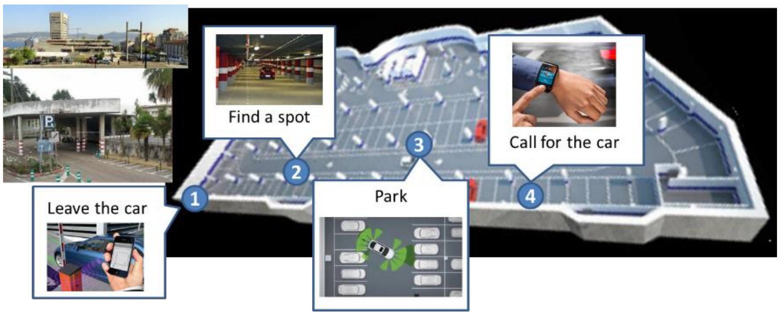
There are several cases where remote driving/teleoperation is used. One is when, in a traffic environment where automated driving is difficult, a remote operator assists the service vehicle based on image transmitted from it. Remote Driving/Teleoperation also enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive themselves or a remote vehicle located in dangerous environments. Remote Driving/Teleoperation requires a wireless link between the vehicle and the remote operator at the remote location. There are two modes of remote operation of CAVs. Remote monitoring provides live monitoring of how the CAV is being autonomously driven. Remote support and operation include direct real-time control of the CAV, usually for a significant period of time. In either case, it is necessary to transmit information such as video image captured by on-board cameras, vehicle location, speed, etc. from the vehicle to the remote operator with low latency according to the driving speed and road environment.

### 5.2.6 Automated valet parking

As Valet Parking is served in hotel personnel, Automated Valet Parking (AVP) is to automate the valet parking using the CAV technology. In Fig. 11, the vehicle will park itself after the driver has left the car at a drop-off point, which may be located near the entrance of a parking lot. When the driver wants to leave the site, he/she will simply request the vehicle to return itself to the collect point, using a smartphone app. To navigate safely around the parking lot to its destination, the automated vehicle uses driving functions based on knowledge about the environment around the vehicle. This is referred from the deliverables of European AUTOPILOT project.

FIGURE 11

**Automated valet parking sequence**

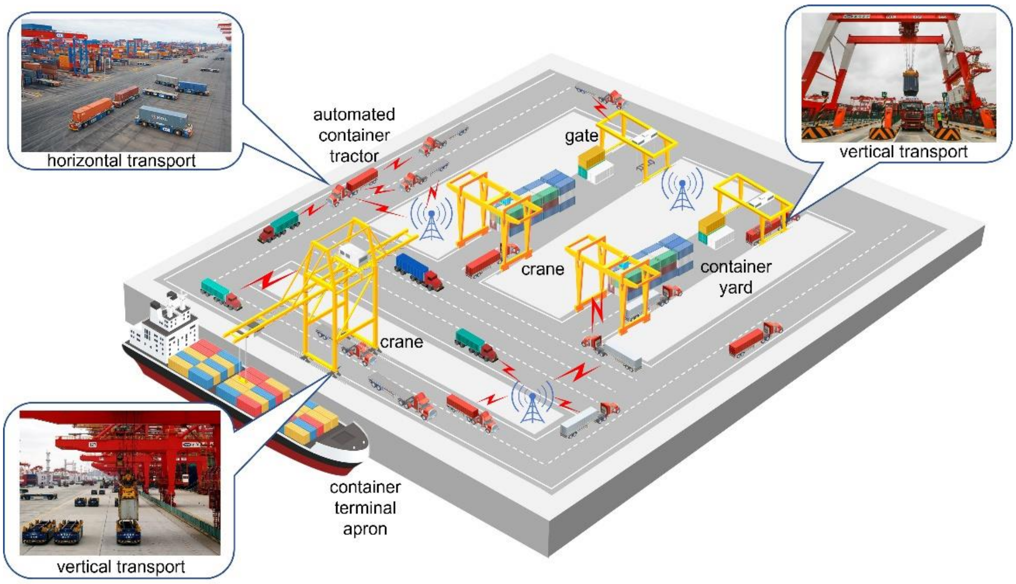



### 5.2.7 Port Automated Vehicles

In the port scenario, CAVs primarily facilitate the transfer of cargo containers between the port and the container yard. They operate in a closed area consisting of the container terminal apron, container yard, and intermediate routes, to support the automation of cargo transportation. As depicted in Fig. 12, once the cargo ship docks, a high-precision coordinated scheduling between the CAVs and the quayside container cranes (QCC) is required to ensure that the CAVs accurately stop under the designated QCC for cargo container unloading. Subsequently, through collaborative scheduling, the CAVs transport the container beneath the rubber-tire gantry crane (RTG), which then stacks the container. To ensure efficiency and safety, multiple vehicles need to transport the containers between the container terminal apron and the container yard according to a pre-planned schedule and route. Ultimately, the container is transported to the designated QCC or RTG for uploading or unloading. This scenario necessitates a precise, fast, and sufficiently fault-tolerant communication environment to ensure the automated operation of the entire port area.

FIGURE 12

**Port automated vehicles**




## 6 Overall objectives and radiocommunication requirements for CAVs

The development of CAV is an evolution. CAVs will exist side-by-side with other non-automated road users, for example, pedestrians, bicyclists, pedelecs, non-automated vehicles for the foreseeable future. Different use cases and levels of automation have different requirements. SAE level 1 and level 2 automation systems are already on the market illustrated through, for example adaptive cruise control and lane keep assistance systems, these are solely based on line-of-sight sensors such on-board camera and radar. Ad hoc V2X radiocommunication can be considered as an additional sensor providing data to the CAV.

Ad hoc V2X radiocommunication based on IEEE 802.11p as part of IEEE 802.11-2016 are deployed in Road Side Equipment and vehicles in all three regions, Europe (ITS-G5), US (WAVE) and Japan (ITS Connect), for increasing road traffic safety by extending the awareness horizon for the driver (increasing the time to react on dangerous events). Until the end of 2021, LTE V2X has been deployed in China with more than 4 000 Road Side Equipment devices with 3,500 kilometres in more than 20 cities and multiple expressways, and several vehicle OEMs, such as Ford, Shanghai Automotive Industry Corporation (SAIC), etc., have been offered LTE V2X in mass production of vehicles. Next step is to marry ADAS with ad hoc V2X radiocommunication and include the ad hoc V2X radiocommunication as a new sensor to the overall sensor fusion framework towards V2X enhanced ADAS.

In the CAV domain, vehicles will support additional functionalities with the evolution of new use cases and capabilities. Once the ad hoc V2X sensor is included in the sensor set, new V2X features, like cooperative manoeuvres for automated driving operations, will be enabled, as well as enhancements to ADAS features such as cooperative ACC that can avoid rear-end collisions as well as increase road traffic efficiency (closer spacing between vehicles and reduced fuel consumption). Technologies for ad hoc V2X radiocommunication include IEEE 802.11p (ITS-G5, WAVE, ITS-Connect) that has been proven for safety-related radiocommunications through extensive testing, and deployment; and 3GPP LTE V2X that has demonstrated safety-related radiocommunications and has been tested and verified. The pre-commercial and commercial deployment have been promoted with four National Pilot Areas and multiple National Demonstration Areas in China[27]. With a continued roadmap, the future technology development as NR V2X becomes available for testing.

In addition to the perspective of the vehicles providing and obtaining information using V2V and V2I, it is also important to address the perspective of the infrastructure collecting and aggregating data from vehicles (for example, location and speed) and generating information for automated driving. The information generated and provided by infrastructure to vehicles includes those for traffic flow optimization and updating dynamic maps. With these, vehicles are able to keep up with the latest road conditions, such as traffic congestion and traffic restrictions due to accidents.

The CAV use cases, however, cannot be supported by one single radio on one frequency channel. The necessary exchange of data by direct radiocommunication to support CAV use cases is estimated by automotive and other industry proponents to need at least-70-75 MHz of spectrum[28, 29]. A study from an automotive and mobile industry association also notes that the evaluation of the spectrum needs for advanced use cases is not a trivial task, in the sense that many CAV use cases may or may not occur at the same time and place, and this can result in a highly time variable demand for spectrum at any given location. Nevertheless, the study concludes that 70-75 MHz of ITS spectrum in the 5.9 GHz band (as presently allocated in many regions and under consideration in other regions) is needed to support the basic safety and advanced use cases under consideration today. Like any emerging sector, there could be unforeseen ITS use cases that would require even more spectrum as the market evolves[30].

The proposed application layer use cases in the CAV domain result in a certain performance requirement at the radio access layer. The radio performance requirements are supported by IEEE 802.11p based V2X technologies, NR V2X and LTE V2X technologies. Certain higher layer messages under standardization at ETSI (including, for example, platooning, cooperative maneuvering and collective perception, as described in § 7.1) are tested for IEEE 802.11p based V2X technologies.

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[27] China Academy of Information and Communications Technology (CAICT), "White Paper on Internet of Vehicles", Dec. 2021. http://www.caict.ac.cn/english/research/whitepapers/202201/P020220110401942024949.pdf (English version: 5GAA Whitepaper, C-V2X Pilot and Demonstration Areas in China, https://5gaa.org/content/uploads/2022/10/C-V2X-Pilot-and-Demonstration-Areas-in-China.pdf).

[28] Communication technology independent CAR-2-CAR Communication Consortium Spectrum Study for V2V and V2I safety message types defined in ETSI and SAE: "Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving" https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_TR_2050_Spectrum_Needs.pdf.

[29] 5GAA TR S-200137: Working Group Standards and Spectrum, "Study of spectrum needs for safety related intelligent transportation systems - day 1 and advanced use cases", pg 42, https://5gaa.org/wp-content/uploads/2020/06/5GAA_S-200137_Day1_and_adv_Use_Cases_Spectrum-Needs-Study_V2.0-cover.pdf.

[30] 5GAA TR S-200137: Working Group Standards and Spectrum, "Study of spectrum needs for safety related intelligent transportation systems - day 1 and advanced use cases", https://5gaa.org/wp-content/uploads/2020/06/5GAA_S-200137_Day1_and_adv_Use_Cases_Spectrum-Needs-Study_V2.0-cover.pdf.

## 6.1 Higher layer requirements for CAV

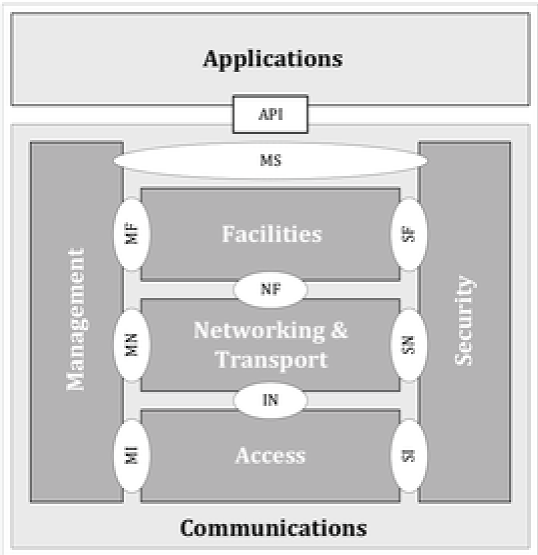
**CAV requirements (higher layer including application layer requirements):**

Ad hoc V2X radiocommunication will be an essential part for CAVs. Nevertheless, there are many other parts in the CAV domain that need more attention, such as: functional safety, robust positioning, sensor fusion, machine learning, high definition maps etc. All parts need to be carefully orchestrated to make CAVs happen. In this respect, radiocommunication is just one element in this complex system.

For example, ISO 21217 standard for ITS communication provides continuous access for land mobiles (CALM) architecture, which may support CAV applications in general. CALM architectural ITS station consists of higher application layer and lower communication layer. The communication layer has three independent entities: facility layer, networking and transport layer, and access layer. And security and management entities are interconnected vertically. Figure 13 shows ITS station reference architecture with named interfaces.

FIGURE 13

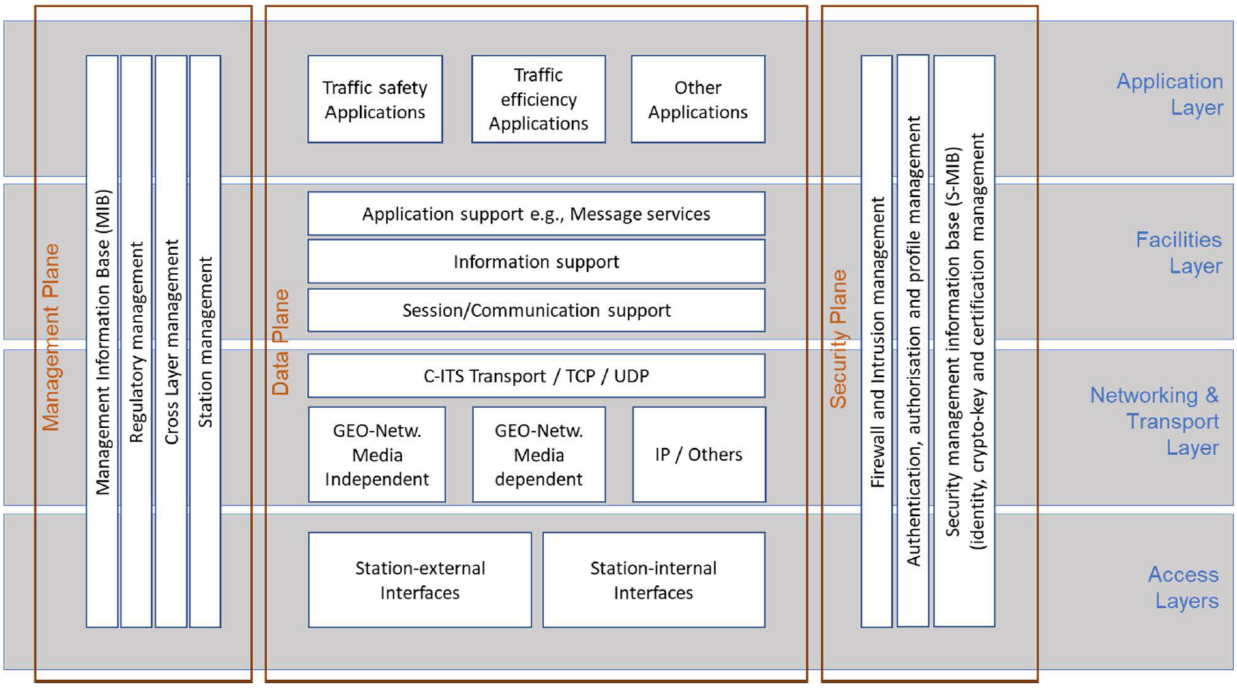
**ITS station reference architecture with named interfaces**




Another example with a detailed functional view on the station V2X architecture can be found in ETSI TS 103 696 v2.1.1, see Fig. 14.

FIGURE 14

**ETSI ITS station architecture**




Higher layer technologies for V2X above the access layer, pertinent to CAVs, are provided by standards, for example:

– ETSI ITS set of standards;
– CEN set of standards;
– IEEE 1609 set of standards;
– SAE set of standards;
– CCSA set of standards;
– China-SAE set of standards.

These standards, and the Countries or Regions in which they apply, are described in more detail in § 7.5 of Report ITU-R M.2445.

V2N network specific requirement for CAV are being considered for:

– full road coverage with cellular radiocommunication;
– cross-border interoperability (for example, session continuity via Edge Computing);
– cross-MNO interoperability.

## 6.2 Security requirements

Security requirements for V2X radiocommunication, pertinent to CAV radiocommunication, are presented in Recommendation ITU-T X.1372 – Security guidelines for vehicle-to-everything (V2X) radiocommunication.

## 6.3 Radiocommunication requirements for CAV

*1) Transmission topology:*

By nature, V2X radiocommunication is a many-to-many omnidirectional type of transmission in radiocommunication. Some use cases may be able to leverage unicast, multicast (groupcast), as well.

*2) Dynamic channel:*

The highly mobile environment of road traffic leads to much higher requirements on the V2X receiver. Consequently, CAV use cases using the ad hoc V2X radio require continuous adaption to the current channel status, which is affected by, for example, severe multipath, and/or doppler effect of the channel resources. IEEE 802.11p V2X receivers need to comply with dynamic channel conditions as described in, for example, ETSI EN 302 663 Annex A. 3GPP V2X receivers need to comply with dynamic channel conditions as described in for example, 3GPP TS 36.101 and 38.101 for LTE V2X and NR V2X respectively. Despite the reason for wireless radiocommunication performance degradation, CAV use cases need to have graceful performance degradation.

*3) Dynamic number of participants:*

Dynamic loading changes in the channel occur due to few to very many traffic participants at the same time in the radiocommunication range of ITS stations. High density scenarios show that 100-800 vehicles can be in the functional relevant distance of the radiocommunications zone. Vulnerable Road Users (VRU) like bicyclist and pedestrians can be V2X traffic participants and have to be calculated in addition to motor vehicles.

*4) Dynamic use of channels:*

Further, not all CAV services can be hosted on one channel, but rather may need to be divided between channels using several radios and multi-channel operation.

*5) Dynamic V2X message:*

For the most efficient use of spectrum V2X messages are generated only if required and necessary content is adapted by the application layer to the minimum number of messages. For many V2X use cases, the V2X messages change dynamically in sending rate and message size over time with an aperiodic behaviour. An analysis of this behaviour for the broadly used ETSI Cooperative Awareness Message (CAM) is given in IEEE "Empirical Models for the Realistic Generation of Cooperative Awareness Messages in Vehicular Networks"[31]. Other CAV related messages such as Collective Perception Messages (CPM), Manoeuvre Coordination Messages (MCM), Personal Safety Messages (PSM) / Vulnerable Road User (VRU) Awareness Messages (VAM), deploy the same dynamic generation rules. In addition to spectrum efficiency, this dynamic generation supports the principle of data minimization for privacy reasons.

*6) Radiocommunication ranges:*

V2X use cases intended to reduce traffic accidents in short range need 80-90% packet success rate at 150 m in urban, suburban environment and up to 500 m in highway environment or fast rural environment in combination with omnidirectional radiocommunication requirement[32]. Automotive

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[31] R. Molina-Masegosa, M. Sepulcre, J. Gozalvez, F. Berens and V. Martinez, "Empirical Models for the Realistic Generation of Cooperative Awareness Messages in Vehicular Networks," in IEEE Transactions on Vehicular Technology, Vol. 69, No. 5, pp. 5713-5717, May 2020, doi: 10.1109/TVT.2020.2979232.

[32] *See* Booz Allen Hamilton, FHWA-JPO-17-483, *Development of DSRC Device and Communication System Performance Measures: Recommendations for DSRC OBE Performance and Security Requirements,* 52 (2016) produced for the U.S. National Highway Traffic Safety Administration. Please see section 8 in this document for additional details and attribution of source.

safety proponents have established requirements of 300 meter range with at least 90% "Service Level Reliability" to ensure less than 5% probability of two consecutive failed vehicle safety messages[33].

*7) Selection of V2X modulation characteristics:*

The requirements for most CAV use cases, especially CAV safety use cases, (V2X radiocommunications using the following messages BSM/CAM, CPM, MCM, PSM/VAM) are:

– dynamic radio channel changes, for example, mobile environment,

– dynamic message generation, for example, dynamic changes in Tx rate and message size from message to message,

– omnidirectional radiocommunication,

– dynamic channel load at up to "99.9% Service Level Reliability at 300 m range"[34], and at least 500 m range with Packet Success Rate of 90%.

These requirements lead to a preferred selection of low data rates and the choice of a robust modulation like QPSK½ [35]. There are some CAV use cases which can use higher order modulations and/or multiple/directional antenna systems, for example, truck platooning.

*8) Service level latency:*

Service level latency is below 10 ms as shown in Table 2.

From the view of wireless connectivity, V2X radiocommunication technology for many new CAV use cases needs to support lower latency and higher reliability. The 3rd Generation Partnership Project (3GPP) specifications, and ETSI, SAE, and IEEE standards provide the categories of enhanced V2X use cases and technical radiocommunication requirements in terms of packet size, data latency, reliability, and data rate for currently-defined CAV use cases. Based on these specifications and standards, the radio communication technology for certain latency-sensitive CAV use cases requires less than 10 ms in packet latency at the service/application level[36] and greater than 90% packet success rate. While Packet Success Rate has been a generic metric in V2X radiocommunications requirements, the newer Service Level Reliability metric, which establishes statistical performance requirements for consecutive packets lost for certain use cases such as cross traffic left-turn assist (as shown in the following table), is considered the most critical requirement for ensuring reliable operation of V2X crash imminent safety use cases by automotive safety proponents. The algorithms for V2X crash imminent safety use cases for automated driving typically combine radiocommunication information with onboard sensor information through sensor fusion to achieve a very high overall system reliability level. For automated operations, crash-avoidance safety use cases using both radiocommunication and onboard sensor inputs are expected to provide failsafe backup for specific CAV use cases, such as Coordinated Merging.

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[33] For example, see "Cross-Traffic Left-Turn Assist", pp 15-22, in 5GAA "C-V2X Use Cases and Service Level Requirements, Volume I" at: https://5gaa.org/wp-content/uploads/2020/12/5GAA_T-200111_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_I-V3.pdf.

[34] 5GAA "C-V2X Use Cases and Service Level Requirements, Volume I" for cross traffic left-turn assist at: https://5gaa.org/wp-content/uploads/2020/12/5GAA_T-200111_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_I-V3.pdf.

[35] D. Jiang, Q. Chen, L. Delgrossi, "Optimal data rate selection for vehicle safety communications", *Proc. ACM international workshop on VehiculAr Inter-NETworking (VANET)*, San Francisco, California, USA, pp. 30-38, 15 Sept. 2008.

[36] 5GAA white paper "C-V2X Use Cases Volume II: Examples and Service Level Requirements".

TABLE 2

**Technical characteristics of radiocommunication for Advanced ITS and CAV**

| Items | Advanced ITS | CAV |
|---|---|---|
| Example use cases | Cooperative awareness<br>Cooperative perception | Cooperative driving with manoeuvre coordination service<br>Platooning<br>Raw perception data sharing<br>Remote driving /Teleoperation (1)<br>Automated Valet Parking |
| ITS connectivity scope | V2V, V2I, V2N (1),V2P | V2V, V2I, V2N (1), V2P |
| Radio performance | | |
| Typical coverage range | Short range ad hoc and direct radiocommunication up to 1 000 m | Short range ad hoc and direct radiocommunication up to 1 000 m<br>Short range radiocommunication also may include hybrid use of cellular radiocommunication (1) |
| Packet size including necessary overheads and security certificate | 380 bytes – 1 900 bytes | 400 bytes – 6 000 bytes |
| Service level latency (2) | Less than 100 ms | Less than 10 ms |
| Packet success rate[37] | Greater than 90% in highway scenario within 500 m radiocommunication range<br>Greater than 90% in suburban scenario within 150 m radiocommunication range<br>Greater than 90% in urban scenario within 150 m radiocommunication range | Greater than 90% |
| Service level reliability (3)[38] | "90% – sufficient to ensure the requirement of less than 5% probability of two consecutive safety message failures at a range of 300 m" | "up to 99.9% – sufficient to allow zero-error automated vehicle operation" |

[37] Packet Success Rate is one minus Packet Error Rate (PER), both expressed as a percentage. PER as a metric for vehicle safety communication is described in https://www.qualcomm.com/media/documents/files/c-v2x-congestion-control-study.pdf, page 17.

[38] 5GAA "C-V2X Use Cases and Service Level Requirements, Volume I" for cross traffic left-turn assist at: https://5gaa.org/wp-content/uploads/2020/12/5GAA_T-200111_TR_C-V2X_Use_Cases_and_Service_Level_Requirements_Vol_I-V3.pdf.

*Notes relatives to Table 2*:

(1) V2N radiocommunication has performance characteristics that are very different from direct radiocommunications used for V2V, V2I, and V2P. The cellular network connectivity aspects for V2N radiocommunications are described in Report ITU-R M.2520.

(2) Radiocommunication latency is part of service level latency. The radiocommunication latency covers the time for sending an ITS message from OSI-Layer 2 and 1 of ITS device 1 plus airtime plus the time to receive the ITS message at corresponding OSI-Layer 1 and 2 of ITS device 2.

(3) The service reliability level shown has been estimated by the 5GAA industry group and the 3GPP specification group, and is only relevant for the radiocommunication portion of the overall system. The reliability requirement may vary on a case-to-case basis.

### 6.3.1 Conclusion

The initial, and continuing, focus on most AV development has been upon on-board sensors to provide the necessary sensory inputs to the AV computational systems to enable automated operation. Thus, there have been major investments in video systems, radar systems, and lidar systems to provide these on-board sensors. These sensors replicate the human driver's function of sight; and, arguably, can provide better reliability, detailed discrimination, and wide-angle coverage than human eyesight. This should allow better safety performance for vehicles with these systems that replace the human drivers' eyesight.

There are functional limits to the on-board sensors, however, since these are inherently line-of-sight sensors. This limitation is shared by human vision. Wireless radiocommunication, however, offers the possibility to provide AVs with 'extra-sensory' perception especially in Non-Line-of-Sight conditions. Besides detecting potential hazards hidden behind line-of-sight obstructions, wireless radiocommunication can allow AVs to share driving intentions, collectively negotiate and execute manoeuvres and share on-board sensor data. These additional capabilities will greatly enhance the safety and efficiency of AV operations.

## 6.4 Functional elements of the CAV use cases

### 6.4.1 Concept of Connected Automated Vehicles (CAV)

The automated vehicles achieve automated driving control by using information obtained from on-board sensors of one's own vehicle. Meanwhile, the connected automated vehicles achieve advanced automated driving by adding information obtained through radiocommunication to the connected vehicles. The CAVs were defined based on the above concepts.

**1) Improved efficiency in automated driving control**

This refers to enabling driving control with enough time margin by adding information obtained through radiocommunication to the automated vehicles (in which automated driving system makes the final judgment on driving control) based on the information obtained through on-board sensors of one's own vehicle. Specific examples include the following:

a) Preliminary acceleration and deceleration/speed adjustment toward lane change and merging

b) Mutual concessions and mediation with other traffic participants

c) Selection of an optimal route

d) Response to control instructions.

**2) Information outside the detection range of on-board sensors**

Information outside the detection range of on-board sensors refers to the following:

a) Information beyond the detection range of on-board sensors of the automated vehicles

b) Definite information in the future (for example, traffic signal phase and timing information)

c) Statistical prediction information (for example, traffic congestion prediction information).

**3) Providing information of one's own vehicle**

Providing information of one's own vehicle refers to providing information about the status of one's own vehicle and the surrounding traffic environment obtained from GNSS, on-board sensors, etc. to the infrastructure.

**4) Mutual radiocommunication by using V2I and V2V**

Mutual radiocommunication by using V2I and V2V refers to radiocommunication between an automated vehicle and vehicles around it, and between an automated vehicle and infrastructure, respectively. Specifically, it refers to the following:

a) Transmission of intention of an automated vehicle to vehicles around it (unspecified)

b) Mutual radiocommunication between an automated vehicle and vehicles around it (specified or unspecified)

c) Provision of information from external stakeholders related to a vehicle's driving (for example, road administrators, traffic managers) to the vehicle or vice versa

d) Driving behaviour instructions from external stakeholders related to a vehicle's driving (for example, road administrators, traffic managers) to the vehicle, or requests for mediation from the vehicle to external stakeholders.

### 6.4.2 Functional elements of the use cases

This section presents functional elements which are derived from the use cases collected as described in § 5. Those functional elements compiled based on classification by function are listed in Table 3, details of which are presented in Annex 1.

TABLE 3[39]

**Functional elements for CAV use cases**

**(1) Functional elements in which information outside the detection range of on-board sensors must be obtained**

| Functional elements of use cases | Description of the functional elements of use cases | Overview |
|---|---|---|
| a. Merging/lane change assistance | a-1-1. Merging assistance by preliminary acceleration and deceleration | Information, such as the speed of vehicles driving on the main lane at the measurement location on the main lane and predicted time to arrive at a merging section, is provided by the infrastructure to merging vehicles to assist preliminary acceleration and deceleration. |
| | a-1-2. Merging assistance by targeting the gap on the main lane | Continuous measurement information (for example, location and speed of vehicles driving on the main lane) is continuously provided by the infrastructure to merging vehicles to assist merging by targeting the gap between vehicles driving on the main lane. |

[39] https://en.sip-adus.go.jp/rd/rddata/usecase.pdf.

TABLE 3 (*continued*)

| **Functional elements of use cases** | **Description of the functional elements of use cases** | **Overview** |
|---|---|---|
| b. Traffic signal information | b-1. Driving assistance by using traffic signal information | Current traffic signal colour and traffic signal phase and timing information (the next traffic signal colour and the time until change), etc. at intersections are provided by the roadside infrastructure to vehicles or through the network to vehicles that enter intersections to assist deceleration and stopping, and complement detection capability of the camera in even difficult environment. |
| c. Lookahead information: collision avoidance | c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly | Sudden braking information as well as location and speed information are provided by the vehicle that suddenly decelerates to the following vehicles to prompt them to stop or decelerate in advance and prevent multiple-vehicle collision accidents. |
| | c-2-1. Driving assistance based on intersection information (V2V) | Location and speed information of vehicles that approach intersections is provided by the approaching vehicles to other vehicles that approach or pass through intersections to assist them to pass through or make a turn across oncoming traffic at intersections with many blind spots. |
| | c-2-2. Driving assistance based on intersection information (V2I) | Location and speed information of vehicles that approach intersections, which is obtained from roadside sensors or vehicles, is provided by the infrastructure to other vehicles that approach or pass through intersections to assist them to pass through or make a turn across oncoming traffic at intersections with many blind spots. |
| | c-3. Collision avoidance assistance by using hazard information | When an automated driving vehicle performs emergency deceleration or emergency lane change, emergency hazard information is transmitted to the following vehicles to assist smooth avoidance control. |
| | c-4. Collision avoidance assistance with provision of blind spot information ahead (see-through) | The road situation ahead captured by a camera is provided by a vehicle to the vehicles to assist collision avoidance. |
| | c-5. Collision avoidance assistance at intersections | Location and speed information is exchanged between vehicles that approach intersections to assist collision avoidance. |
| d. Lookahead information: trajectory change | d-1. Driving assistance by notification of abnormal vehicles | Event information of abnormal vehicles that are stopped on roads (for example, malfunctioning vehicles, vehicles involved in accidents) and location information (sections and lanes where such vehicles are located) are provided by the infrastructure to the surrounding vehicles or by abnormal vehicles to the surrounding vehicles to assist lane change and trajectory change at an early stage. |
| | d-2. Driving assistance by notification of wrong-way vehicles | Location and speed information of wrong-way vehicles and information about the presence of wrong-way vehicles are provided by the infrastructure to the surrounding vehicles to prompt lane change, etc. in advance and assist collision avoidance. |

TABLE 3 (*continued*)

| Functional elements of use cases | Description of the functional elements of use cases | Overview |
|---|---|---|
| | d-3. Driving assistance based on traffic congestion information | Traffic congestion status information obtained from vehicles that are caught in traffic congestion is provided by the infrastructure to the surrounding vehicles to assist driving. |
| | d-4. Traffic congestion assistance at branches and exits | Information about traffic congestion on shoulders (location, speed) is provided by the infrastructure to vehicles on the main lane to assist entry to branches. |
| | d-5. Driving assistance based on hazard information | Information about obstacles, construction work, traffic congestion, etc. is provided by the infrastructure to the surrounding vehicles to assist driving. |
| e. Lookahead information: emergency vehicle notification | e-1. Driving assistance based on emergency vehicle information | Information about the driving direction, speed, and planned driving route (planned driving lane) of emergency vehicles is provided by the emergency vehicles to the surrounding vehicles to prompt the surrounding vehicles to drive at reduced speed or to stop, etc. and thereby assist the emergency vehicles to pass smoothly. |
| i. Vulnerable Road User Protection | i-1. Integration of Vulnerable Road Users into V2X radiocommunication | The type, presence, location and speed of vulnerable road users (VRUs) such as bicyclists and pedestrians are notified to vehicles and infrastructure in order to create and enhance awareness of the vulnerable road users through integration into the V2X communication. |

**(2) Functional elements in which information of one's own vehicle must be provided**

| Functional elements of use cases | Description of the functional elements of use cases | Overview |
|---|---|---|
| f. Information collection/ distribution by infrastructure | f-1. Request for rescue (e-Call) | Rescue information is transmitted from abnormal vehicles (for example, vehicles involved in accidents) to the infrastructure to request rescue. |
| | f-2. Collection of information to optimize the traffic flow | Information about the location and speed of driving vehicles is collected via the infrastructure to analyse and optimize the traffic flow. |
| | f-3. Update and automatic generation of maps | Vehicles' information is collected by the infrastructure to update and automatically generate the map data. |
| | f-4. Distribution of dynamic map information | Dynamic map information is provided by the infrastructure to vehicles. |

**(3) Functional elements in which V2V and V2I interaction must be ensured**

| Functional elements of use cases | Description of the functional elements of use cases | Overview |
|---|---|---|
| a. Merging/lane change assistance | a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control | Measurement information (for example, location, speed) of vehicles driving on certain range of main lane is provided by the infrastructure to merging vehicles. Meanwhile, instructions (for example, adjustment of the gap between vehicles) are given by the infrastructure to vehicles on the main lane to assist merging. |
| | a-1-4. Merging assistance based on negotiations between vehicles / Decentral path coordination and decision between multiple CAV | During merging to a main lane with heavy traffic, vehicles on the main lane communicate with merging vehicles (for example, location and speed information, gap adjustment requests) to conduct negotiations between vehicles for merging assistance. |
| | a-2. Lane change assistance when the traffic is heavy | During lane change to a lane with heavy traffic, the location and speed information and the intention of lane change, etc. are communicated between vehicles for lane change assistance. |
| | a-3. Entry assistance from non-priority roads to priority roads during traffic congestion | At unsignalized intersections, location and speed information and the intention of entry are communicated between vehicles near intersections for driving assistance to enter priority roads from non-priority roads. |
| g. Platooning/ adaptive cruise control | g-1. Platooning of driverless follower in vehicles by electronic towbar | Operation information, etc. of platooning vehicles is communicated between trucks that form a platoon to assist platooning (electronic towbar). In addition, before the realization of fully automated driving of SAE level 4, there is a need to transmit video image data for a lead-vehicle human driver, in such cases as Surrounding Monitor (SM) by using electric mirrors at the follower vehicles and Driver Status Monitor (DSM) by using in-vehicle video cameras to monitor the drivers, who are not in operation, at the platoon member vehicles. |
| | g-2. Adaptive cruise control and platooning with driver of following vehicles using adaptive cruise control | Location and speed information and driving operation information of vehicles at the front, etc. are communicated with the following vehicles to assist adaptive cruise control. |
| h. Teleoperation | h-1. Operation and management of mobility service vehicles | In a traffic environment that is difficult for an automated driving system, an operation manager in a remote location communicates a remote control instruction to the mobile service car based on video information from the mobile service vehicle. |

### 6.5 Summary of the radiocommunication requirements to meet the CAV functionalities of the presented use cases

Each of the functional elements of the use cases can be broken down into a group of individual functional elements. Some of such elements are commonly used in multiple use cases. For examples, assistance for merging or lane change would be activated in the situation during Urban Driving and Manoeuvre Coordination/Cooperative Driving/Advanced Driving.

This Report provides a list of functional elements for the CAVs as a basis for identifying radiocommunication requirements in Table 4.

TABLE 4

**Functional elements of radiocommunication for CAV**

| Functional element | Description | Message set example (Note 1) | Connection mode (Note 2) | Transmission interval in Hz (min/max/static or dynamic (Note 3) | Message size in Byte (min/max/typical) (Note 4) | Service level latency in ms (Note 5) |
|---|---|---|---|---|---|---|
| (a) Merging/lane change assistance | – Merging assistance by<br>• (a-1-1) preliminary acceleration and deceleration<br>• (a-1-2) targeting the gap on the main lane<br>– (a-1-3) Cooperative merging assistance with vehicles on the main lane by roadside control | ETSI MCM,<br>SAE MSCM,<br>CSAE, VIR | V2I | 10/static | 1000/1300/1150 | 10 |
| | – (a-1-4) Merging assistance based on negotiations between vehicles/Decentral path coordination and decision between multiple CAV<br>– (a-2) Lane change assistance when the traffic is heavy<br>– (a-3) Entry assistance from non-priority roads to priority roads during traffic congestion | ETSI MCM,<br>SAE MSCM,<br>CSAE, VIR | V2V | 1/10/dynamic | 1000/1300/1150 | 10 |
| (b) Traffic signal information | (b-1) Driving assistance by using traffic signal information | ISO SPaTEM,<br>SAE SPAT,<br>CCSA SPAT, ISO MAPEM, SAE MAP, ISO IVI, CCSA RSI | V2I | 2/10/static | 1200 | 100 |

TABLE 4 (*continued*)

| Functional element | Description | Message set example (Note 1) | Connection mode (Note 2) | Transmission interval in Hz (min/max/static or dynamic (Note 3) | Message size in Byte (min/max/typical) (Note 4) | Service level latency in ms (Note 5) |
|---|---|---|---|---|---|---|
| (c) Lookahead information: collision avoidance | (c-1) Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly | ETSI DENM,<br>SAE BSM, CCSA BSM | V2V | 10/static | 1000 | 100 |
| | (c-2-1) Driving assistance based on intersection information | ETSI CAM, SAE BSM, CCSA BSM, CSAE SSM | V2V | 1/10/dynamic | 400/700/550 | 100 |
| | (c-2-2) Driving assistance based on intersection information | ETSI, CPM, SAE SDSM<br>CCSA RSM,<br>CSAE SSM | V2I | 1/10/dynamic | 1000/1900/1450<br>250/4000/1000<br>400/700/550 | 100 |
| | (c-3) Collision avoidance assistance by using hazard information | ETSI DENM, SAE BSM, ETSI CPM, SAE SDSM, CCSA BSM, CSAE SSM | V2V | | | |
| | (c-4) Collision avoidance assistance with provision of blind spot information ahead (see-through) | ETSI CPM, SAE SDSM, CSAE SSM | V2V | 1/10/dynamic | 1000/1900/1450 | 100 |
| | (c-5) Collision avoidance assistance at intersections | ETSI CAM, SAE BSM<br>CCSA BSM, CSAE SSM | V2V | 1/10/dynamic | 400/700/550 | 100 |

TABLE 4 (*continued*)

| Functional element | Description | Message set example (Note 1) | Connection Mode (Note 2) | Transmission Interval in Hz (min/max/static or dynamic (Note 3) | Message Size in Byte (min/max/typical) (Note 4) | Service Level Latency in ms (Note 5) |
|---|---|---|---|---|---|---|
| (d) Lookahead information: trajectory change | – Driving assistance by<br>• (d-1) notification of abnormal vehicles<br>• (d-2) by notification of wrong-way vehicles<br>• (d-3) based on traffic congestion information<br>• (d-4) Traffic congestion assistance at branches and exits<br>• (d-5) based on hazard information | ETSI MCM,<br>SAE MSCM, CCSA RSM, ETSI DENM, ETSI IVI | V2I | 10/static | 1000/1300/1150 | 10 |
| (e) Lookahead information: emergency vehicle notification | (e-1) Driving assistance based on emergency vehicle information | ETSI DENM,<br>ETSI CPM,<br>SAE BSM, SAE SDSM, CCSA BSM, CCSA RSM, CSAE SSM | V2V<br>V2I | 10/static | 1000<br>1000/1900/1450 | 100 |
| (f) Information collection/distribution by infrastructure | (f-1) Request for rescue (e-Call) | – | V2N | – | – | – |
| | (f-2) Collection of information to optimize the traffic flow | ETSI CAM, SAE BSM, CCSA BSM, CSAE SSM, ETSI DENM, CPM | V2I | | | |
| | (f-3) Update and automatic generation of maps | – | V2N | – | – | – |
| | (f-4) Distribution of dynamic map information | ISO MAPEM,<br>SAE MAP, CCSA MAP | V2N | 2/10/static | 1200 | 100 |

TABLE 4 (*end*)

| Functional element | Description | Message set example (Note 1) | Connection Mode (Note 2) | Transmission Interval in Hz (min/max/static or dynamic (Note 3) | Message Size in Byte (min/max/typical) (Note 4) | Service Level Latency in ms (Note 5) |
|---|---|---|---|---|---|---|
| (g) Platooning/ adaptive cruise control | (g-1) Platooning of driverless follower vehicles by electronic towbar<br>(g-2) Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control | ETSI PCM,<br>SAE CCM, CSAE CLPMM, ETSI CAM | V2V | 20/50 | 400/1400 | 10 |
| (h) Teleoperation | (h-1) Operation and management of mobility service cars | – | V2N | – | – | – |
| (i) Vulnerable Road User protection | (i-1) Integration of Vulnerable Road Users into V2X radiocommunication (Note 6) | ETSI VAM, SAE PSM, CSAE PSM | V2P | 1/10/dynamic | 350 | 100 |
| | | ITS Forum RC-016, ETSI CPM | P2V, P2I, V2I, V2V | 10/10/static | 45/100/72.5 (P2V, P2I);<br>100/12 000/500 (V2I) | 100 |

Note 1: Message sets may enable multiple use cases.

Note 2: Although V2N is not in scope of this report, some are listed for reference.

Note 3: Static: Tx rate constant; dynamic: may vary depending on for example, vehicle speed, steering dynamic, acceleration.

Note 4: Message set size can vary depending on the design (for example, protocols), configuration (for example, overhead) and settings applied.

Note 5: Radiocommunication latency is part of service level latency. The radiocommunication latency covers the time for sending an ITS message from OSI-Layer 2 and 1 of ITS device 1 plus airtime plus the time to receive the ITS message at corresponding OSI-Layer 1 and 2 of ITS device 2.

Note 6: V2P may include V2VRU (bicyclists, motorcycles, scooters).

## 7 Radiocommunication technologies that support CAV

Wireless radiocommunication technologies for CAV are on an accelerating innovation cycle.

Access layer technologies:

The ad hoc access layer V2X radiocommunication technologies are:

– IEEE based,

– 3GPP based.

IEEE technology is based on the amendment to IEEE 802.11 called IEEE 802.11p (2010), now part of IEEE 802.11-2016[40]. This access technology is deployed in Europe under the name of ITS-G5, and dedicated short range communication (DSRC) in the US, as well as ITS Connect in Japan. An extension to IEEE 802.11p has been standardized in IEEE under the name IEEE 802.11bd.

3GPP based access layer technology is an enhancement on the initial work on D2D radiocommunications defined as part of ProSe services (in Release 12 and Release 13 specifications) for supporting ad hoc radiocommunication are LTE V2X (from Release 14 to Release 15) and NR V2X (from Release 16 to the current Release 18). Further, 3GPP Release 18 is currently working on standardizing aspects related to sidelink based positioning, improved co-channel co-existence between LTE and NR V2X, etc. Additionally, the cellular connectivity for V2N is based on 4G and 5G respectively, requiring coverage by base stations and subscriptions to mobile network operators.

### 7.1 IEEE Family

IEEE technology is based on the amendment to IEEE 802.11 called IEEE 802.11p (2010), now part of IEEE 802.11-2016[40]. Technologies based on IEEE 802.11p are deployed in Europe under the name of ITS-G5 and dedicated short range communication (DSRC) in the US, as well as ITS Connect in Japan. An extension to IEEE 802.11p has been standardized in IEEE under the name IEEE 802.11bd.

IEEE 802.11p supports already today CAV requirements especially in terms of latency. IEEE 802.11bd-2022 "Telecommunications and information exchange between systems Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Next Generation V2X"[41] is targeted to enhance the robustness of the physical layer thereby increasing the reliability at longer distances (the information horizon will increase for the automated vehicle).

IEEE 802.11p may support the necessary End to End Service Level Latency given in Table 2 of 10 ms for CAV with a sufficient low radiocommunication latency[42, 43, 44] for typical network load assumed in this Report, see § 8.2 and corresponding § A2.1. In addition to the radiocommunication latency the further latency increase based on higher layer processing and security up to the application layer is heavily implementation related and independent of the deployed access layer technology.

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[40] In the following 802.11p is used to refer to the relevant part for V2X communication in the IEEE 802.11-2016 "Outside the Context of a Basic Service Set (OCB)".

[41] https://standards.ieee.org/ieee/802.11bd/7451/.

[42] Y. Y. Nasrallah, I. Al-Anbagi, H. T. Mouftah, "A realistic analytical model of IEEE 802.11p for wireless access in vehicular networks," in Proceedings of IEEE 2014 International Conference on Connected Vehicles and Expo (ICCVE).

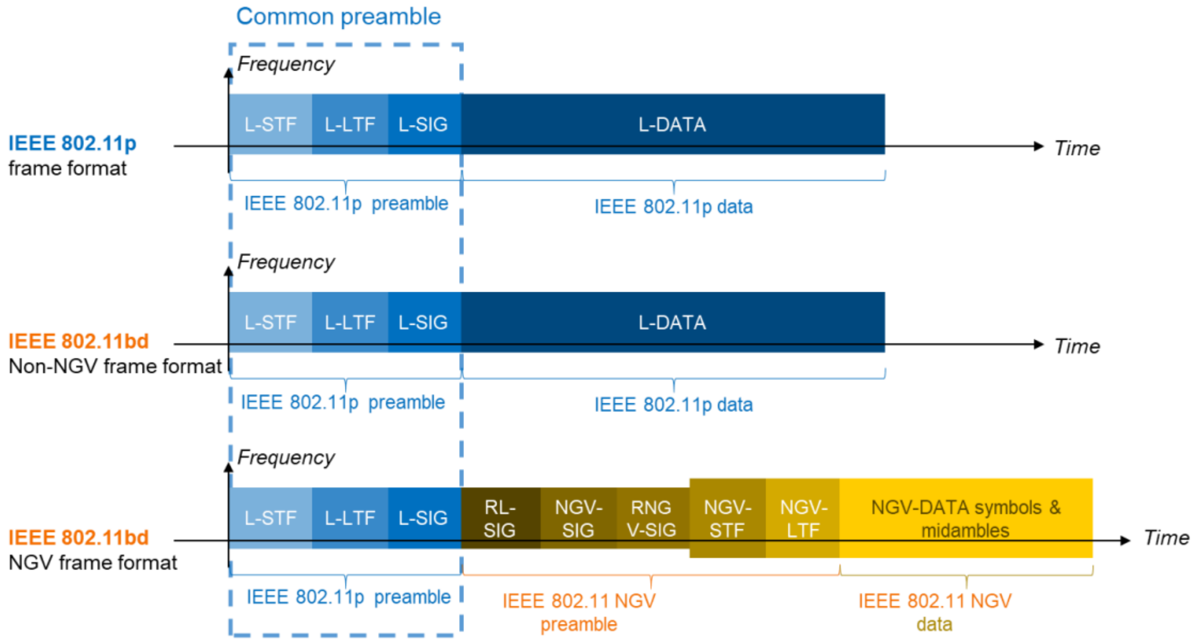
[43] "Throughput and Delay Limits of 802.11p and Its Influence on Highway Capacity". Yunpeng Wanga *et al*. 3th COTA International Conference of Transportation Professionals (CICTP 2013). Beijing, China. 2013.

[44] "A Simulative Analysis of the Performance of IEEE 802.11p and ARIB STD-T109". Julian Heinovski *et al*. Paderborn, Germany. Computer Communications, Volume 122, 2018, Pages 84-92.

Both IEEE 802.11p and IEEE 802.11bd can use the same frequency channel in the same geographical area utilizing different time instances[45]. IEEE 802.11bd supports backward compatibility and co-channel coexistence at the radio access layer by two transmission formats. One transmission format is fully backward compatible (IEEE 802.11p compatible), while the other one uses a new extended frame format (called NGV). Due to a common preamble legacy device based on IEEE 802.11p can take into account the existence of NGV frames in the MAC layer channel access procedure and vice-versa without requiring the capability of decoding the data content of the frames. In addition, devices based on IEEE 802.11bd can fully decode the data content of frames transmitted using the legacy IEEE 802.11p based encoding. The frame format of IEEE802.11bd, along with the legacy IEEE 802.11p preamble, is depicted in Fig. 15.

FIGURE 15

**Coexistence by design with common preamble: IEEE 802.11bd packet format with legacy preamble and IEEE 802.11p frame format**

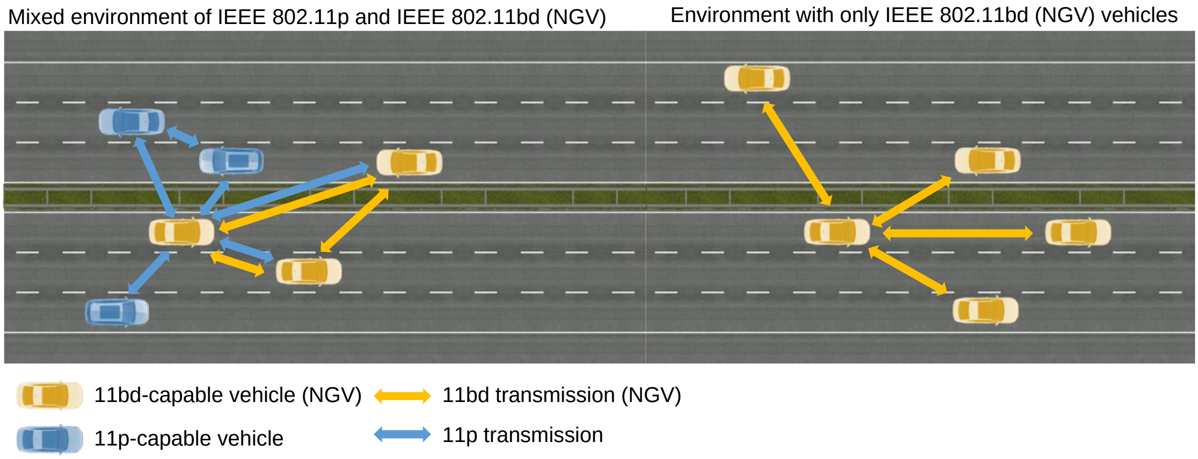



The mapping of a data packet delivered by an application onto a legacy or a NGV access layer frame format will be controlled by higher layer (for example, IEEE WAVE, ETSI ITS-G5 Multi-Channel Operation) entities based on application requirements and the known capabilities of the ITS devices in the vicinity, see Fig. 15. So, for one application either a legacy or a NGV frame format is chosen.

[45] CAR 2 CAR Communication Consortium white paper,, Next Generation V2X – IEEE 802.11bd as fully backward compatible evolution of IEEE 802.11p"; https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_WP_2098_IEEE_802.11bd_TheV2XEvolution_V1.0.pdf.

FIGURE 16

**Interaction between existing ETSI ITS-G5 based IEEE 802.11p vehicles and enhance ETSI ITS-G5 based on IEEE 802.11bd vehicles**[46]




NOTE – For mixed environment, the 11p and 11bd transmissions will utilize different time instances, controlled by the higher layers.

In a scenario where 802.11bd and 802.llp devices operate co-channel in a mixed environment, as shown in Fig. 16, 802.11bd-capable vehicles will notify other 802.11bd-capable vehicles by setting a flag at the MAC layer level to ensure those devices are notified of their 802.11bd capabilities[47].

The IEEE has initiated IEEE P802.11-Task Group BD – "Enhancements for Next Generation V2X"[48] which includes "Automated Driving Support" and "Sensor Sharing" use cases, as well as the "Basic Safety" use cases currently supported by IEEE 802.11 and IEEE 1609.x WAVE standards. The IEEE 802.11bd standard is planned for completion by the middle of 2022. CAV use cases and their requirements need to be validated through vehicle implementation and testing in field operational tests. The following CAV use cases were successfully implemented and tests finalized:

– Multi-brand truck platooning implemented with ITS-G5 in ENSEMBLE[49]

– Cooperative Perception Service, also known as Collective Perception Service or Sensor Sharing, was implemented with ITS-G5 in IMAGinE[50]

– Cooperative Manoeuvre Coordination, also known as Cooperative Driving, with cooperative merging on highways, cooperative longitudinal control on highways, cooperative overtaking on rural roads, cooperative strategic traffic distribution, cooperative turning at junctions, cooperative overtaking by heavy-goods vehicles on highways was implemented with ITS-G5 in IMAGinE.

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46 See chapter 3.4 in CAR 2 CAR Communication Consortium white paper,, Next Generation V2X – IEEE 802.11bd as fully backward compatible evolution of IEEE 802.11p"; https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_WP_2098_IEEE_802.11bd_TheV2XEvolution_V1.0.pdf.

47 G. Naik, B. Choudhury and J. -M. Park, "IEEE 802.11bd & 5G NR V2X: Evolution of Radio Access Technologies for V2X Communications," in *IEEE Access*, vol. 7, pp. 70169-70184, 2019, doi: 10.1109/ACCESS.2019.2919489.

48 https://www.ieee802.org/11/Reports/tgbd_update.htm.

49 https://platooningensemble.eu/.

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

## 7.2 3GPP – Sidelink

LTE V2X supports the Day 1 use cases which are covered in the 5GAA reports[51] and already today some of the CAV use cases. This technology has been tested to validate support for those Day 1 use cases and some CAV use cases.[52, 53, 54] Sections 8.2, 10.3.1 and A2 provide initial estimated spectrum needs for several Day 1 use cases.

The support for 3GPP C-V2X was developed by introducing enhancements with evolving 3GPP Releases. LTE V2X is from Release 14 to Release 15, and NR V2X is from Release 16 to the current Release 18 and the future Releases.

3GPP Release 14, LTE V2X specification, work was completed in March 2017, which was designed to support the radiocommunications needs of use cases in ITU-R M.2445 (which are referred to as "applications" in that report). The sidelink, based on the PC5 interface, was supported and working on frequency band 5.9 GHz.

3GPP Release 15 specification work was completed in June 2018. It not only included the enhancement for LTE V2X which mainly focused on carrier aggregation, high order modulation to improve transmission data rate and reduce transmission latency. With the addition of NR, more advanced and comprehensive V2X use cases may be supported.

Key performance indicators for the use cases were utilized to show the capability of LTE V2X.[55, 56, 57, 58]

3GPP Release 16 specification work was completed in June 2020, supporting advanced V2X use cases based on multiple technologies; for example, NR V2X complements LTE V2X for advanced V2X use cases, including connected and automated driving, and is also capable of supporting advanced ITS use cases. The 3GPP Release 16 specifications are designed to support three categories of advanced V2X use cases, including fully automated driving vehicle scenarios. Some of these use cases may require network connectivity, which is explained in section 7.3. These categories are:

– Platooning Vehicles – enables the vehicles to dynamically form a group travelling together.

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[51] 5GAA TR S-200137: Working Group Standards and Spectrum, "Study of spectrum needs for safety related intelligent transportation systems – day 1 and advanced use cases", p. 42, https://5gaa.org/wp-content/uploads/2020/06/5GAA_S-200137_Day1_and_adv_Use_Cases_Spectrum-Needs-Study_V2.0-cover.pdf.

[52] Project Convex Deliverable D7.1: Final Report on Field Test and Evaluation Results https://convex-project.de/onewebmedia/D7.1_Final_Report_Field.pdf.

[53] Shanzhi Chen, Jinling Hu, Yan Shi, Li Zhao, Wen Li, A Vision of C-V2X: Technologies, Field Testing and Challenges with Chinese Development. IEEE Internet of Things Journal, vol. 7, no. 5, p3872-3881, Feb. 2020.

[54] 5GAA Whitepaper, C-V2X Pilot and Demonstration Areas in China, https://5gaa.org/content/uploads/2022/10/C-V2X-Pilot-and-Demonstration-Areas-in-China.pdf.

[55] 3GPP, 3GPP TS 22.185, Service Requirements for V2X Services, https://www.3gpp.org/DynaReport/22185.htm.

[56] 3GPP, 3GPP TS 22.186, Enhancement of 3GPP Support for V2X Scenarios, https://www.3gpp.org/DynaReport/22186.htm.

[57] 3GPP, 3GPP TR 22.885, Study on LTE Support for Vehicle to Everything (V2X) Services, https://www.3gpp.org/DynaReport/22885.htm.

[58] 3GPP TR 22.886, Study on enhancement of 3GPP Support for 5G V2X Services (Rel.16), https://www.3gpp.org/DynaReport/22886.htm.

– Extended Sensors – enables the exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSEs, devices of vulnerable road users and V2X application servers.
– Advanced Driving – enables semi-automated or fully automated driving.

All the advanced use case categories described above require ubiquitous, highly reliable, low-latency wireless communications. Key performance indicators for these use cases were developed and used to guide the design of the 3GPP Release 16 capabilities. 3GPP technologies were fully standardized since Release 16 to fulfil CAV requirements.

In Release 17, which was essentially completed in Q2-2022, 3GPP extends the flexibility of the cellular technologies into an expanding number of vertical industries. 3GPP Release 17 has added further V2X enhancements, for example, power, efficiency, better latency, enhanced reliability, and improved ranging and positioning. Further evolution currently underway in Release 18 will introduce other features important to CAV, for example, sidelink based positioning, improved co-channel co-existence between LTE and NR V2X, as well as other improvements.

### 7.3 IMT network connected V2X for CAVs

Regarding V2N cellular network connectivity, many CAV use cases can benefit from a ubiquitous coverage of roadways and interoperability.

The V2N connectivity also enables a remote driver or a V2X application to operate a remote vehicle for those passengers who cannot drive themselves or a remote vehicle located in dangerous environments[59]. In certain use-cases, the remote operation of a vehicle may be for short durations of time.

The cellular network provides a means for the mobile network operator to authorize a UE supporting the C-V2X application of IMT systems to perform V2X radiocommunication when served by a cellular network. The cellular network also supports integrity protection of the transmission for a V2X use case. Subject to regional regulations and/or operator policy for a V2V/V2I use case, the cellular network should support pseudonymity and privacy of a UE in the use of a V2V/V2I use case, such that no single party (operator or third party) can track a UE identity in that region.

The cellular connectivity aspects are covered in more detail in Report ITU-R M.2520.

### 7.4 Future technical enablers

There are additional advanced use cases emerging for automated driving, for which possible radiocommunication use cases have not yet been identified. These use cases are expected to become better defined during the next few years as the developments in both technology and regulation become better understood for Level 4 and Level 5 automated driving.

#### 7.4.1 Joint communication and sensing technology

Joint Communication and Sensing (JCS) refers to integrated radiocommunication and sensing systems with the joint design of air interface and protocol, the multiplexing of time-frequency space resources, and the sharing of hardware equipment, promoting the mutual benefit between the two independent radio subsystems, i.e., radiocommunication subsystem and radio sensing subsystem.

Future networks will go beyond traditional communication and provide ubiquitous sensing services to measure or even to image surrounding environments. Particularly, JCS in higher frequency ranges can achieve higher precision/resolution sensing as well as higher data rate radiocommunication,

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[59] Note: This use case category appears to be one that requires ubiquitous cellular network connectivity.

simultaneously. CAVs and/or RSEs will then act as sensors, providing new sensing capabilities to help CAVs and/or RSE creating a detailed map of the environment or even digital twins of the surrounding physical scenario[60, 61].

With the development of radiocommunication system radio sensing and communication systems are both evolving towards higher frequency bands. In addition, radio sensing and communication systems are also moving toward larger antenna arrays and miniaturization, thereby becoming increasingly similar in terms of hardware architectures, channel characteristics, and signal processing. The above similarities provide an opportunity for the convergence of the sensing and communication functions into systems and devices. From the communication perspective, large bandwidth and antenna arrays can boost the communication capacity and provide massive connections. From the sensing perspective, increasing the bandwidth and number of antennas will also considerably improve the sensing performance in range and angular resolutions.

The JCS technology could multiplex the spectrum resources, reduce the cost of sensor deployment and improve the sensing capability. For example, with the joint design of radiocommunication and radio sensing systems, a large number of signal-processing processes and hardware modules such as base-band units, RF unit, and antennas, can be shared within the JCS system[62]. Besides, mmWave JCS system could reduce the response time delay of sensing data transfer between radiocommunication and radio sensing subsystems for radio sensing information sharing among CAVs[63], such as the raw perception data sharing use case.

In CAV networks, joint communication and sensing (JCS) and in the use cases relating to collective perception, object sharing, cooperative perception driving, and extended sensor sharing in § 5.1.2. These use cases involve the perception data sharing with low latency and high reliability requirements to improve driving safety and efficiency. Thus, ubiquitous deployment of sensors and raw perception data sharing may be important considerations and requirements to improve the safety and efficiency of vehicle operation in CAV networks.

In highly dynamic CAV networks, for sensory sharing services such as extended sensing and raw and collective perception data sharing, the JCS system will bring more obvious advantages[64]: for example, lower inter-system interaction overhead; sensing results to assist millimetre wave antenna alignment; and sensing side to provide multi-state channel estimation feedback to assist the radiocommunication side in the equalization process.

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[60] Nicol`o Decarli, Stefania Bartoletti and Barbara M. Masini, "Joint Communication and Sensing in 5G-V2X Vehicular Networks," in 2022 IEEE 21st Mediterranean Electrotechnical Conference (MELECON), pp. 295-300, June 2022.

[61] Zhiqing Wei, Yuan Wang, Liang Ma, Shaoshi Yang, Zhiyong Feng, Chengkang Pan, Qixun Zhang, Yajuan Wang, HuiciWu and Ping Zhang, "5G PRS-Based Sensing: A Sensing Reference Signal Approach for Joint Sensing and Communication System," IEEE Transactions on Vehicular Technology, Vol. 72, No. 3, pp. 3250-3263, March 2023.

[62] F. Liu, C. Masouros, A. P. Petropulu, H. Griffiths and L. Hanzo, "Joint Radar and Communication Design: Applications, State-of-the-Art, and the Road Ahead," IEEE Transactions on Communications, vol. 68, no. 6, pp. 3834-3862, Jun. 2020.

[63] Q. Zhang, H. Sun, X. Gao, X. Wang and Z. Feng, "Time-Division ISAC Enabled Connected Automated Vehicles Cooperation Algorithm Design and Performance Evaluation," IEEE Journal on Selected Areas in Communications, vol. 40, no. 7, pp. 2206-2218, Jul. 2022.

[64] Z. Feng, Z. Fang, Z. Wei, X. Chen, Z. Quan and D. Ji, "Joint radar and communication: A survey," China Communications, vol. 17, no. 1, pp. 1-27, Jan. 2020.

Future JCS systems at very high frequency ranges, e.g. millimetre wave or higher, with very wide bandwidth and massive antenna arrays, will enable sensing solutions with very fine ranges, Doppler, and angular resolutions, as well as localization to cm-level degree of accuracy[65]. The JCS systems, however, will need to design its communication signal wave form so that the following features are enabled: (i) good sensing performance in terms of range and resolution in 4D (range, velocity, azimuth and elevation angle); (ii) good communication performance in terms of spectral and power efficiency; (iii) flexibility between communications and sensing needs as well as for different sensing needs (e.g., short-range/long-range and different resolutions).

## 8 Initial spectrum needs for CAV radiocommunication

The initial spectrum needs for CAV radiocommunication identified in § 8 of this Report are preliminary and summary-level in nature. It is expected that a more detailed understanding of CAV spectrum needs will occur as CAVs are further developed and deployed with increasingly higher levels of automation. More detailed understanding of CAV spectrum needs may in the future be provided into a new ITU-R deliverable, such as a report and/or recommendation.

### 8.1 Suitable frequency bands

Recommended spectrum for global and regional harmonization of ITS wireless radiocommunication was included in Recommendation ITU-R M.2121 – Harmonization of frequency bands for Intelligent Transport Systems in the mobile service. However, this Recommendation does not directly address emerging automated driving use cases. The spectrum needs for automated driving are expected to be further clarified as CAV developments and resulting radiocommunication requirements become better known.

Spectrum other than that previously recommended for ITS may be desirable for CAV radiocommunications. For example, it may be possible that platooning and/or other very close range cooperative manoeuvring radiocommunications could be effectively supported in Extremely High Frequency (EHF) (30-300 GHz) bands which includes mmWave (around 60 GHz in various administrations). Laboratory experimentation and field test results becoming available during this ITU-R study period are likely to identify suitable frequency bands, if any, for these types of transmission in radiocommunication, which could be specifically used for CAV use cases.

### 8.2 Initial spectrum needs

Currently, the Basic Safety use cases for CVs are supported by the spectrum as described in Recommendation ITU-R M.2121. CAVs need to be interoperable with CVs for the Basic Safety use cases; however, different spectrum may be needed to support CAV-specific use cases. One of the initial major considerations to answer Question ITU-R 261/5 is to determine the spectrum needs for CAV Radiocommunication, including suitable bands and spectrum bandwidth needed.

CAVs require spectrum dedicated to safety-related radiocommunication. Spectrum may need to be physically uncorrelated to provide fully redundant radiocommunication conditions. Tables 5, 6 and 7 summarize estimated spectrum needs and plans for CAV direct radiocommunication in different countries and regions. Tables 5, 6 and 7 do not address the spectrum needs for cellular network connectivity such as 4G/5G, which is subject to another spectrum regime, but as described above may also be used to support CAVs. Many CAV use cases are expected to use cellular network capabilities on cellular spectrum. CAV use of the capabilities of IMT is described in Report ITU-R M.2520.

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[65] Carlos De Lima *et al*, “Convergent Communication, Sensing and Localization in 6G Systems: An Overview of Technologies, Opportunities and Challenges,” IEEE Access, vol. 9, pp. 26902-26925, 2021.

In the process of spectrum bandwidth needed calculation, the variety of vehicle density and traffic conditions in different regions and countries should be considered, which will lead to different spectrum needs. Tables 5, 6 and 7 only represents the potential spectrum needs for CAVs in specific regions and countries.

TABLE 5

**Current and future spectrum needs for CAVs in 5.9 GHz band**

| Frequency band | Status/description | Current availability | CAV current and foreseen spectrum needs |
|---|---|---|---|
| 5.9 GHz | Main spectrum today for deployment of road traffic safety and efficiency use cases | 5.9 GHz band (5 850/5 855-5 925 MHz or parts thereof) is recommended for evolving ITS needs (see Recommendation ITU-R M.2121); and 70-75 MHz of bandwidth is allocated in several parts of the world (see Report ITU-R M.2444) | Spectrum needs estimated are provided in Annex A.2 |
| Regional and Country notes on use of 5.9 GHz band for CAV.<br>The United States of America has identified 5 895-5 925 MHz to ITS generally, not specific to CAV. | | | |

TABLE 6

**Current and future spectrum needs for CAVs in mm wave bands**

| Frequency band | Status/description | Current availability | CAV current and future spectrum needs |
|---|---|---|---|
| mmWave | Short-range, high-capacity and low-latency radiocommunication potentially combined with radio location capabilities | Europe has an allocation of mmWave for ITS at 60 GHz | Current estimation are at least 2 GHz, but more research is required to determine the needs for CAV |

TABLE 7

**Current and future spectrum needs for CAVs in bands below 1 GHz**

| Frequency band | Status/description | Current availability | CAV current and foreseen spectrum needs |
|---|---|---|---|
| < 1 GHz | For long range strategic control information between CAVs, redundant radiocommunication channel to enable certain functional safety levels | Japan has an allocation at 760 MHz band for road traffic safety | At least 10 MHz |

Taking into account the radiocommunication parameters for different functional elements described in this report in combination with spectrum efficiencies, minimum, maximum and typical spectrum needs has been calculated by industry and detailed in Annex 2.

Estimated spectrum needs for CAV radiocommunication provided by Germany can be found in § A2.1. Detailed C2C-CC estimated spectrum needs for CAV radiocommunication can be found in § A2.2. A 5GAA white paper[66] report on the results of its studies relating to the evolution of automotive connectivity for the purposes of enhanced road safety, improved traffic efficiency, greener environmental impact, and more comfortable driving. The spectrum needs for basic and advanced driving use cases are highlighted in the report. The report also highlights the need for additional spectrum for network-based radiocommunications for use by mobile operators in delivering advanced driving capabilities in rural and urban environments. The white paper concludes that effectively, 70-75 MHz of ITS spectrum in the 5.9 GHz band is needed to support the basic safety and advanced use cases under consideration today. Further details of the methodology are explained in § A2.3.

## 9 CAV interoperability requirements

Interoperability is of critical importance for safety-related CAV functions. This is especially true for direct ad hoc wireless radiocommunications among CAVs and between CAVs and infrastructure, since these types of transmission in radiocommunications do not depend upon commercial wireless networks, which have been used in the past to provide limited intermediation among different generations of wireless technologies. Direct safety-related radiocommunications, such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I), could therefore likely greatly benefit from harmonization of spectrum. This would support interoperability for vehicles and infrastructure among different Administrations and potentially among different Regions.

Specific CAV functions currently developed, or currently in planning stages, and which are likely to benefit from spectrum harmonization, include, for example:

– Basic crash-avoidance vehicle safety,
– Interaction with non CAVs like such as VRUs and non-CAV vehicles,
– Automated platooning and Cooperative Adaptive Cruise Control C-ACC,
– Object sharing with Collective Perception or Cooperative Perception,
– Cooperative Driving with Intent/Trajectory Sharing.

The rationale for inclusion of basic crash-avoidance safety functions in the CAV category, rather than just in the connected vehicle portion of ITS, is that it is important for CAVs to communicate with less-automated connected vehicles at a basic safety level, in addition to the radiocommunications required among CAVs to support the more advanced CAV functions. There will always be a mixed traffic scenario containing CAVs, non-CAVs, and VRUs. This has to be taken into account in the definition and specification of required functionalities and use cases.

Due to the cross border and cross region nature of road traffic and future automated road traffic, all functions (safety related and road efficiency related) benefit significantly from a world-wide harmonization of designated spectrum resources.

## 10 Status of global CAV development

Detailed status of global CAV deployment can be found in Annex 3.

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[66] 5GAA White Paper, "A visionary roadmap for advanced driving use cases, connectivity technologies, and radio spectrum needs", https://5gaa.org/wp-content/uploads/2020/09/A-Visionary-Roadmap-for-Advanced-Driving-Use-Cases-Connectivity-Technologies-and-Radio-Spectrum-Needs.pdf.

## 10.1 Region 1 – Europe

Several research projects on cooperative and connected and cooperative automated driving were finalized. Example projects are:

- 5G NETMOBIL[67]
- ADAS&ME[68]
- AdaptIVe[69]
- AutoNet2030[70]
- Fraunhofer FOKUS CMP[71]
- ICT4CART[72]
- iKoPA[73]
- IMAGinE[74]
- MAVEN[75]
- MEC-View[76]
- PRoPART[77]
- SecForCARs[78]
- TransAID[79]

While the goal of all projects is to improve the automated driving performance by radiocommunication and automation, not all of the projects actually use automated vehicles. As legal aspects make automated driving still difficult in public roads, radiocommunication and cooperation can well be tested in manually driven cars. In this case V2X messages are exchanged as well and even cooperative driving manoeuvres can be planned based on the messages.

Different automation levels according to SAE J3016 have been tackled by the different projects. Even though cooperation and radiocommunication have a high impact on automated driving, it can be applied at each automation level. Out of the 13 projects, all but two addressed automated driving directly. Most of the projects use different automation levels, ranging over all of the SAE automation levels 0-5. An overview of the different automation levels of the project can be seen in Table 8. While

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[67] https://5g-netmobil.de/.

[68] https://www.adasandme.com/.

[69] http://www.adaptive-ip.eu/.

[70] http://www.autonet2030.eu/.

[71] https://ieeexplore.ieee.org/abstract/document/8375118.

[72] https://www.ict4cart.eu/.

[73] https://ikopa.de.

[74] https://imagine-online.de/en/home/.

[75] http://maven-its.eu/.

[76] http://www.mec-view.de/.

[77] http://propart-project.eu/about/.

[78] https://www.secforcars.de.

[79] https://www.transaid.eu/.

in most projects actual driving is performed, PRoPART and 5G NETMOBIL use simulation for evaluation.

TABLE 8

**Automation level of projects**

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

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

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

## 10.2 Region 2 – Americas

### 10.2.1 Canada

In Canada, all levels of government, industry and other stakeholders are actively researching, testing and collecting data in a number of state-of-the-art facilities and test-beds to evaluate and characterize the safety and environmental performance of AV/CV technologies. Safety is paramount to successfully designing and deploying AV/CVs. A number of examples of pilot deployments, research facilities and testing programs in Canada are provided in Annex 3.

Although Canada has not specified any frequency spectrum for CAV, 30 MHz (i.e. 5 895-5 925 MHz) has been designated for ITS and mandated for the use of 3GPP based Cellular Vehicle-to-Everything (C-V2X) technology.

### 10.2.2 United States of America

The U.S. Government is actively pursuing a range of regulatory and non-regulatory activities that will enable the adoption of AVs, with the overall goal to facilitate the safe and full integration of AV technologies into the national surface transportation system. Integration would help realize the great potential AV technologies have for enhancing public safety, making systems more efficient, and facilitating economic vitality.[80]

The United States has not identified any spectrum specific to CAV. In 2020, the U.S. regulator decided to reduce the 75 MHz of spectrum previously assigned for ITS to 30 MHz at 5 895-5 925 MHz and

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80 https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/360956/ensuringamericanleadershipav4.pdf.

specified the use of 3GPP Cellular-Vehicle to Everything Technology. As of July 2023, initial waivers are being reviewed for LTE-based C-V2X deployment. Final rules and operating parameters are still being finalized by the Federal Communications Commission.

## 10.3 Region 3 – Asia

### 10.3.1 China (People's Republic of)

China has planned 20 MHz (5 905~5 925 MHz) of spectrum for LTE V2X radiocommunication system. The deployed connected vehicle pilot zones (Wuxi, Changsha, Tianjin, etc.) basically cover scenarios such as urban roads and rural roads, with intelligent networked infrastructures.

China has clearly supported the selection of C-V2X as the technical route of China's V2X technologies and standards system for CAV.

**Spectrum related work for CAV**

In November 2018, the Bureau of State Radio Regulation of MIIT of China officially released "Regulations on the Use of the 5 905~5 925 MHz Frequency Band for Direct Communication of the Connected Vehicles (Provisional)", planning to use the 5 905~5 925 MHz frequency band as the working frequency band for the direct radiocommunication based on LTE-V2X technology.

Under the guidance of the Bureau of State Radio Regulation of MIIT of China, the Offices of Industry and Information Technology of many provinces in China have officially issued the licenses of testing frequency of V2X direct radiocommunication for qualified applicant companies. The clear spectrum policy plays an important and positive role in promoting large-scale applications and the progress of CAV related tests, verifications and demonstrations.

**New four-layer tests activities for CAV**

C-V2X Working Group of the IMT-2020 (5G) Promotion Group organized the large-scale "New Four-Layer" C-V2X test activities in 2021 and 2022 in the real road environment. The diverse chips and modules, terminals, vehicles, security platforms, and graph quotients were tested and verified for the interoperability and maturity of C-V2X applications.

The C-V2X Day 1 Application Verification Demonstration is oriented to support the basic road safety applications with mass production. Day 1 Applications were tested, verified and demonstrated with full coverage of roadside information of traffic lights and speed limit in several demonstration areas of China (e.g. Wuxi, Liuzhou, and Suzhou, etc.). For Day 2 Applications, the typical CAV applications were selected (e.g. Sensor Data Sharing, Cooperative Lane Change, Cooperative Vehicle Merge, Cooperative ACC, Cooperative Speed Control, etc.) to verify the interaction process and the confidence and accuracy of the road-vehicle cooperative processing.

### 10.3.2 Japan

The recent progress in automated driving technology has brought the era of automated driving to the forefront in Japan, with Level 3 (conditional automated driving) automated vehicles having launched in the market in 2021.The Government of Japan is actively carrying out various initiatives towards the early introduction of advanced automated driving in Japan.

One of its initiatives was the study by the Ministry of Internal Affairs and Communications (MIC) of Japan in its Study Group on Japan's approach to next-generation ITS communications for cooperative automated driving[81]. The key issues studied were use cases for the next-generation of ITS

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[81] Ministry of Internal Affairs and Communications, Japan, Press release dated 9 February 2023, https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/pressrelease/2023/2/09_02.html.

communications, measures to interwork between V2X and V2N communications, draft allocation policy and deployment roadmap for 5.9 GHz band V2X communications. The Study Group provided that consideration should be firstly given to allocating up to 30 MHz of bandwidth in the 5 895-5 925 MHz frequency band for V2X communications, and that towards the target of introducing 5.9 GHz-band V2X communication equipment around 2030 and deploying cooperative automated driving such as mediated and negotiated merging assistance around 2040, the roadmap should be specified with use cases to be demonstrated and verified and environmental improvements.

The Government of Japan also worked on the cross-ministerial research and development programme of Automated Driving for Universal Services, called SIP-adus[82] aiming to solve issues of concern in today's society through realizing automated driving, including reducing traffic accidents, alleviating traffic congestion and securing a means of transportation for people with limited mobility, such as the elderly living in remote regions, among other issues. The programme envisioned a scenario for the commercialization and service of fully automated driving by 2025. For this, it targeted to establish the cooperative areas technologies essential for implementation by 2023 and to create multiple example cases for commercialization through Field Operational Test (FOTs) by involving various businesses and local governments.

### 10.3.3 Republic of Korea

The typical use case in urban driving is intersection safety warning. This use case uses traffic signal information which is transformed into LDM (Local Dynamic Map) and transmitted to the connected automated vehicle. This use case also needs V2X communication with low latency and high reliability. Platooning is tested on highway by using C-ITS digital infrastructure and V2X communication technologies (example, IEEE 802.11p and LTE). The service functions of FCEV automated bus include getting on and off at a stop station, recognizing signal intersections and pedestrian cross-walking, and sharing the BRT (Bus Rapid Transit) route with a manual driving.

Automated shuttle bus drives the test route by using 5G NR communication technology. This use case needs high accurate positioning, traffic signal timing and status and blind spot information. 5G communication can support the required information and supports automated driving. Remote control can monitor the vehicle and road status by sending on-board sensors data to the server, and control the vehicle driving remotely. The remote control may be applied for vehicle emergency rescue operation. Entertainment use cases are UHD (Ultra High Definition) display and augmented reality for passengers. These use cases are enabled to use gigabit rate performance of 5G communication technology.

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3GPP TR 22.886, Study on enhancement of 3GPP Support for 5G V2X Services (Rel.16): https://www.3gpp.org/DynaReport/22886.htm.

3GPP TS 23.285: Architecture enhancements for V2X services: https://www.3gpp.org/DynaReport/23285.htm.

[82] For further information, see https://en.sip-adus.go.jp/.

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5GAA "A Visionary Roadmap for Advanced Driving Use Cases, Connectivity Technologies, and Radio Spectrum Needs" relates to Question 3 and introduces a timeline related to identified Use Cases.

5GAA "Study of spectrum needs for safety related intelligent transportation systems – day 1 and advanced use cases" relates to Question 6 and provides an analysis on spectrum requirements for the implementation of ITS services.

5GAA "White Paper C-V2X Use Cases Volume II: Examples and Service Level Requirements" and Technical Report "C-V2X Use Cases and Service Level Requirements Volume I" relate to Question 3 and detail Use Cases and related requirements.

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# Annex 1

## A1 The functional elements of CAV[83]

### A1.1 Explanation for the diagrams of functional elements

To present the functional elements in an easy-to-understand manner, images and additional information were compiled as diagrams.

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[83] This Annex was developed, initially based on SIP-adus studies, subsequently in the ITU-R through reviewing and refining it as well as reflecting proposed modifications from membership.

FIGURE A1-1

**How to read the diagrams**

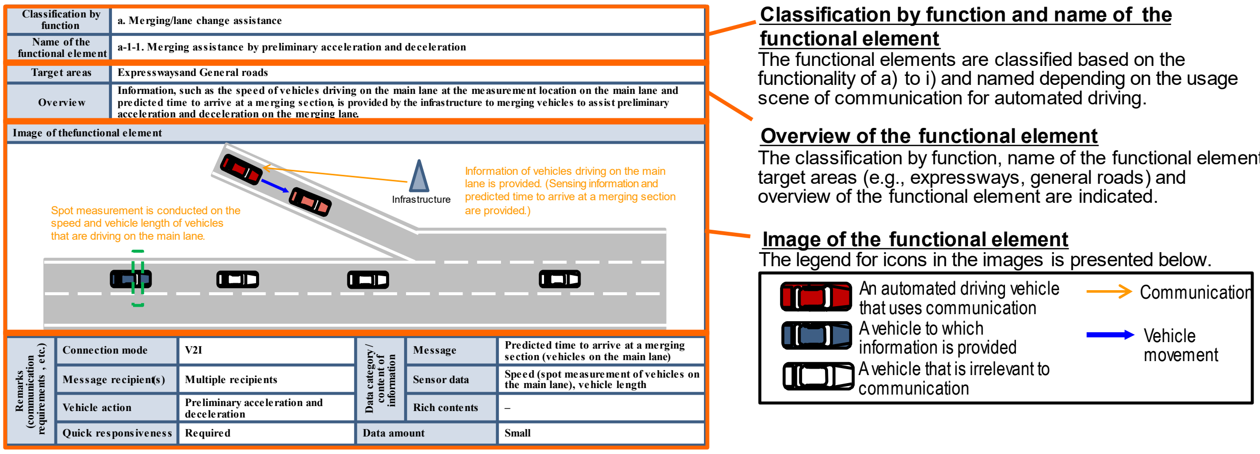



Table A1-1 below presents the definitions of the terms used in the diagrams of functional elements.

TABLE A1-1

**Definitions of the terms used in the diagrams of functional elements**

| Term | Definition |
|---|---|
| Message recipient(s) | 'One recipient' means that message is transmitted to a single recipient. 'Multiple recipients' means that message is transmitted to multiple recipients. |
| Connection mode | Refers to V2V, V2I, V2N, etc. |
| Vehicle action | Actions of the vehicle to be controlled based on the information provided by the radiocommunication in the functional element. |
| Quick responsiveness | Require that the relevant message be communicated to the recipient vehicles and that those recipient vehicles respond/react to it within a short timeframe. |
| Data category/content of information | Typical information that is exchanged through radiocommunication in respective categories (message, sensor data, rich contents). |
| Rich contents | Information of photos, images, etc. (for example, images captured by onboard cameras, locations of features). |
| Data amount | Size of data transmitted, large, medium or small. Sizes can vary depending on the design, configuration and settings applied. |
| Message set example | Example of a message set for V2X radiocommunication. |

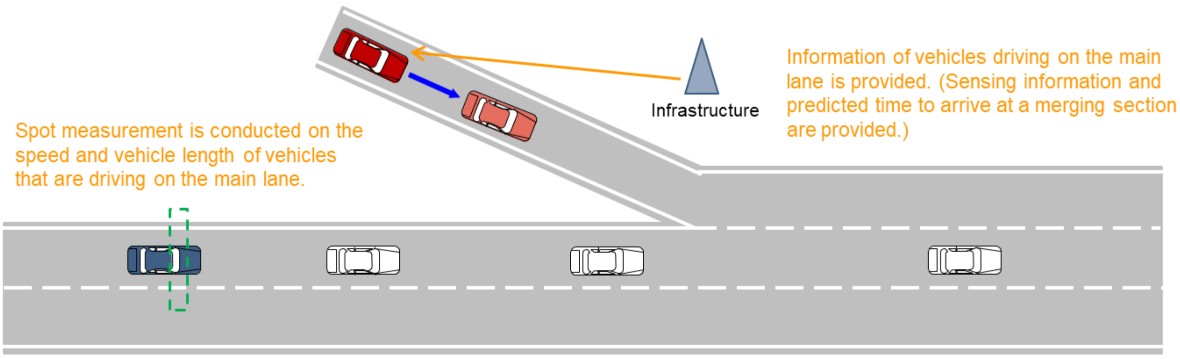
Target vehicles for most of the functional elements include a wide range of vehicles, such as regular cars, trucks, taxis, buses, and privately-owned or government-owned vehicles. They would not exclude new mobility and vehicle forms that may appear in the future.

## A1.2 The diagrams of functional elements of the use case

### (1) Functional elements in which information outside the detection range of on-board sensors must be obtained

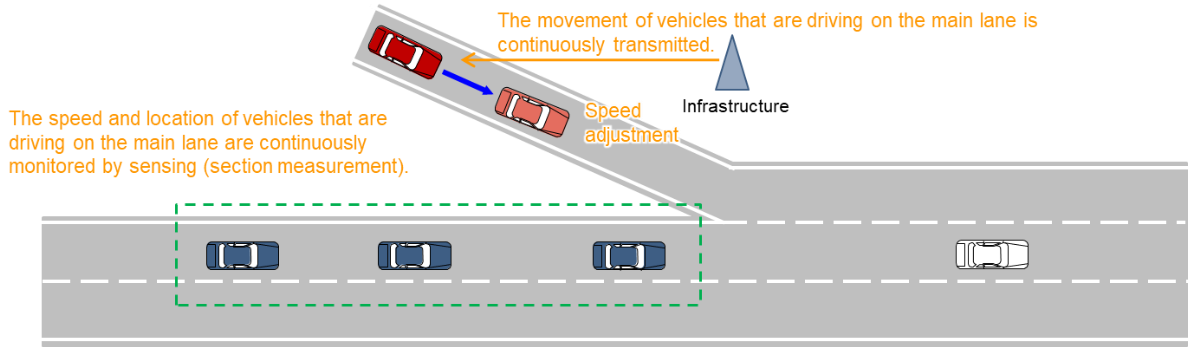
*a. Merging/lane change assistance*

*a-1. Merging assistance by preliminary acceleration and deceleration*

<table>
<tr><td>Classification by function</td><td colspan="5">a. Merging/lane change assistance</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">a-1-1. Merging assistance by preliminary acceleration and deceleration</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">Information, such as the speed of vehicles driving on the main lane at the measurement location on the main lane and predicted time to arrive at a merging section, is provided by the infrastructure to merging vehicles to assist preliminary acceleration and deceleration on the merging lane.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2I</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Predicted time to arrive at a merging section (vehicles on the main lane)</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients</td><td>Sensor data</td><td>Speed (spot measurement of vehicles on the main lane), vehicle length</td></tr>
<tr><td>Vehicle action</td><td>Preliminary acceleration and deceleration</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>Required</td><td colspan="2">Data amount</td><td>Small</td></tr>
</table>

*a-2. Merging assistance by targeting the gap on the main lane*

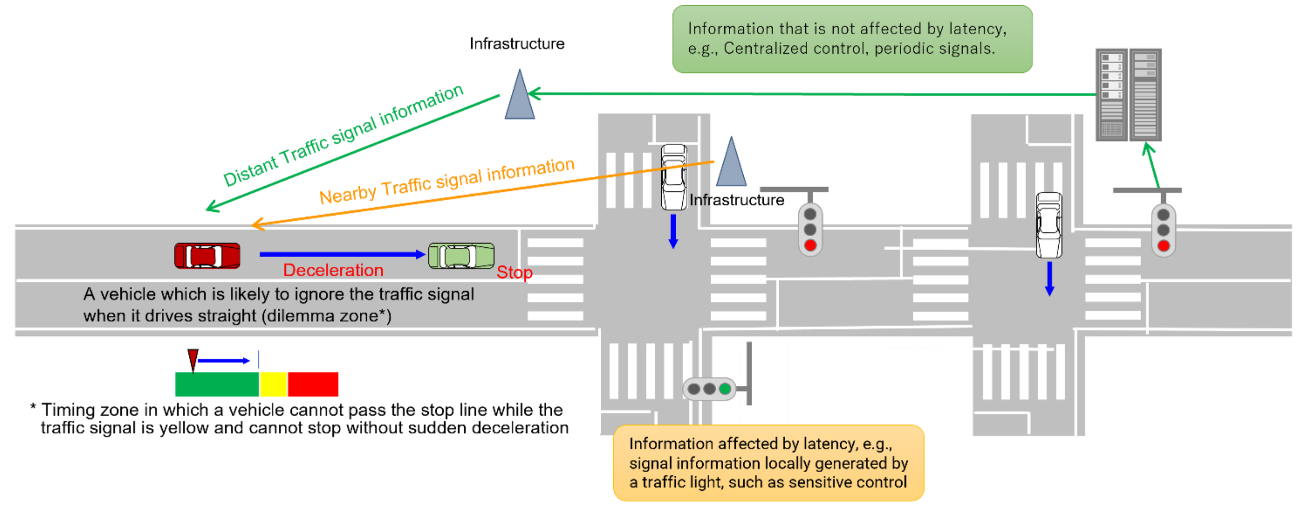
| | |
|---|---|
| **Classification by function** | **a. Merging/lane change assistance** |

<table>
<tr><td>Name of the functional element</td><td colspan="5">a-1-2. Merging assistance by targeting the gap on the main lane</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">Continuous measurement information (for example, location and speed of vehicles driving on the main lane) is continuously provided by the infrastructure to merging vehicles to assist merging by targeting the gap between vehicles driving on the main lane.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2I</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Predicted time to arrive at a merging section (vehicles on the main lane)</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients</td><td>Sensor data</td><td>Speed, location (continuous measurement of vehicles on the main lane), vehicle length</td></tr>
<tr><td>Vehicle action</td><td>Speed adjustment</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>Required</td><td colspan="2">Data amount</td><td>Small</td></tr>
</table>

*b. Traffic signal information*

*b-1. Driving assistance by using traffic signal information (V2I)*

| | |
|---|---|
| **Classification by function** | **b. Traffic signal information** |
| **Name of the functional element** | **b-1. Driving assistance by using traffic signal information** |
| **Target areas** | **General roads and Expressways** |
| **Overview** | **Current traffic signal colour and traffic signal phase and timing information (the next traffic signal colour and the time until change), etc. at intersections are provided by the roadside infrastructure to vehicles or through the network to vehicles that enter intersections to assist deceleration and stopping, and complement detection capability of the camera in even difficult environment.** |
| **Image of the functional element** | |

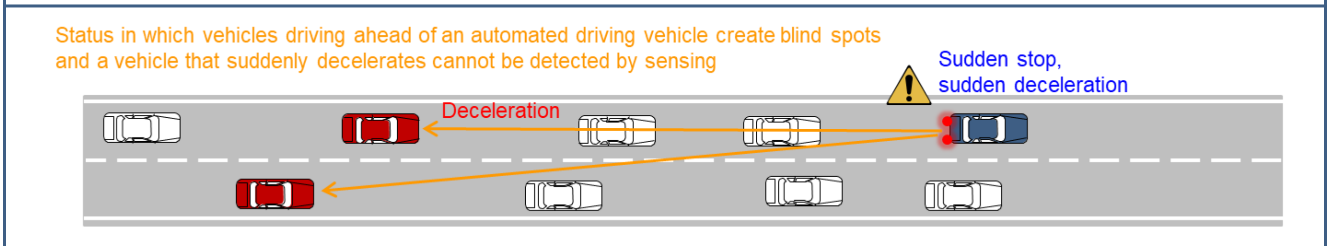



| | | | | | |
|---|---|---|---|---|---|
| **Remarks (radiocommunication requirements, etc.)** | ***Connection mode*** | **V2I, V2N** | **Data category/ content of information** | **Message** | **Current traffic signal colour, traffic signal phase and timing information** |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | **–** |
| | **Vehicle action** | **Speed adjustment, stop** | | **Rich contents** | **–** |
| | **Quick responsiveness** | **Required** | **Data amount** | | **Small** |

*c. Lookahead information: collision avoidance*

*c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly*

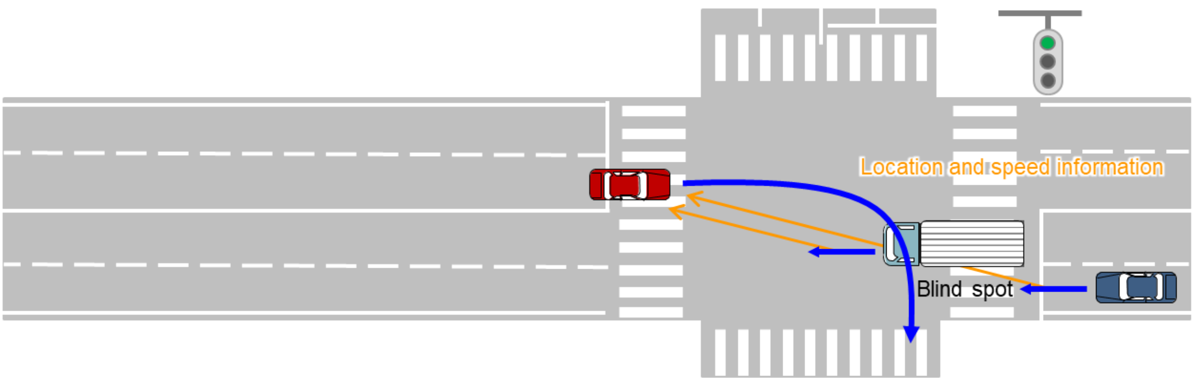
| | |
|---|---|
| **Classification by function** | **c. Lookahead information: collision avoidance** |
| **Name of the functional element** | **c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly** |
| **Target areas** | **Expressways and General roads** |
| **Overview** | **Sudden braking information as well as location and speed information are provided by the vehicle that suddenly decelerates to the following vehicles to prompt them to stop or decelerate in advance and prevent multiple-vehicle collision accidents.** |
| **Image of the functional element** | |



| | | | | | |
|---|---|---|---|---|---|
| Remarks (radiocommunication requirements, etc.) | *Connection mode* | V2V | Data category/ content of information | Message | Sudden braking information |
| | Message recipient(s) | Multiple recipients | | Sensor data | Location, speed |
| | Vehicle action | Speed adjustment, stop | | Rich contents | – |
| | Quick responsiveness | Required | Data amount | | Small, medium |

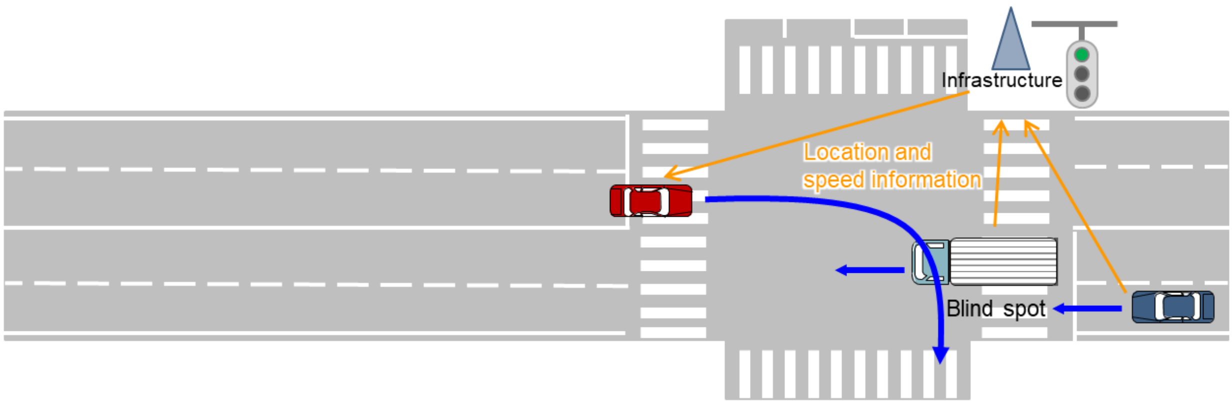
*c-2-1. Driving assistance based on intersection information (V2V)*

| | |
|---|---|
| Classification by function | c. Lookahead information: collision avoidance |
| Name of the functional element | c-2-1. Driving assistance based on intersection information (V2V) |
| Target areas | General roads |
| Overview | Location and speed information of vehicles that approach intersections is provided by the approaching vehicles to other vehicles that approach or pass through intersections to assist them to pass through or make a turn across oncoming traffic at intersections with many blind spots. |
| Image of the functional element | |



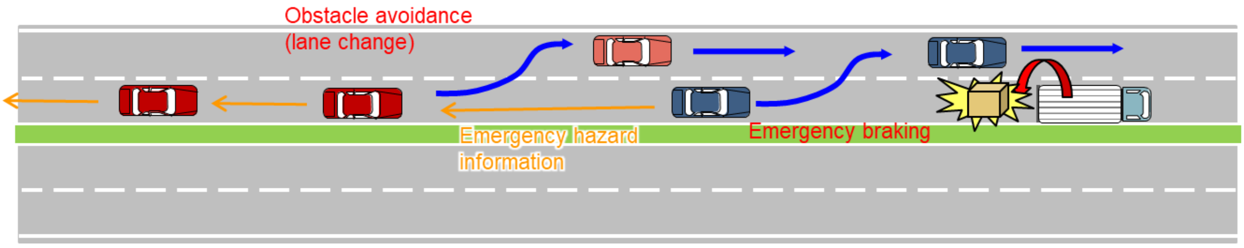

| | | | | | |
|---|---|---|---|---|---|
| Remarks (radiocommunication requirements, etc.) | *Connection mode* | V2V | Data category/ content of information | Message | – |
| | Message recipient(s) | Multiple recipients | | Sensor data | Location, speed |
| | Vehicle action | Judgment whether the vehicle can start, speed adjustment, stop | | Rich contents | – |
| | Quick responsiveness | Required | Data amount | | Small |

*c-2-2. Driving assistance based on intersection information*

| | | | | | |
|---|---|---|---|---|---|
| **Classification by function** | **c. Lookahead information: collision avoidance** | | | | |
| **Name of the functional element** | **c-2-2. Driving assistance based on intersection information** | | | | |
| **Target areas** | **General roads** | | | | |
| **Overview** | **Location and speed information of vehicles that approach intersections, which is obtained from roadside sensors or vehicles, is provided by the infrastructure to other vehicles that approach or pass through intersections to assist them to pass through or make a turn across oncoming traffic at intersections with many blind spots.** | | | | |
| **Image of the functional element** | | | | | |
|  | | | | | |
| **Remarks (radiocommunication requirements, etc.)** | ***Connection mode*** | **V2I** | **Data category/ content of information** | **Message** | |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | **Location, speed** |
| | **Vehicle action** | **Judgment whether the vehicle can start, speed adjustment, stop** | | **Rich contents** | **–** |
| | **Quick responsiveness** | **Required** | **Data amount** | | **Medium** |

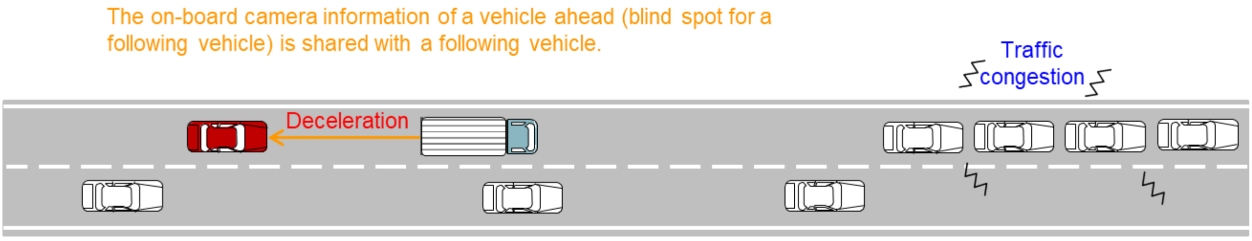
*c-3. Collision avoidance assistance by using hazard information*

| | |
|---|---|
| **Classification by function** | **c. Lookahead information: collision avoidance** |
| **Name of the functional element** | **c-3. Collision avoidance assistance by using hazard information** |
| **Target areas** | **Expressways and General roads** |
| **Overview** | **When a vehicle performs emergency deceleration or emergency lane change, emergency hazard information is transmitted to the surrounding vehicles to assist smooth avoidance control.** |
| **Image of the functional element** | |

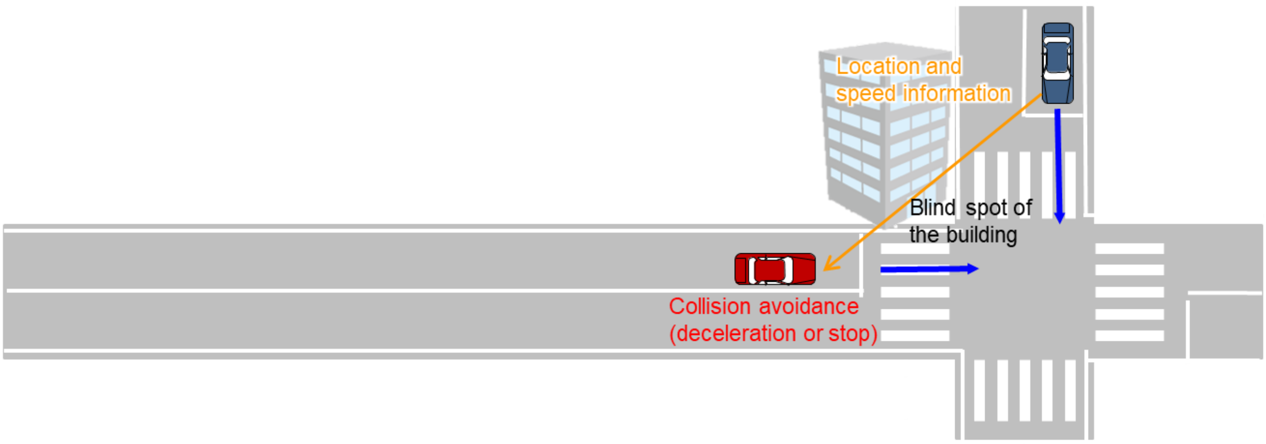



| | | | | | |
|---|---|---|---|---|---|
| **Remarks (radiocommunication requirements, etc.)** | ***Connection mode*** | **V2V** | **Data category/ content of information** | **Message** | **Obstacle information, emergency braking, steering** |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | **Location** |
| | **Vehicle action** | **Trajectory change, lane change, automated driving control assistance level change** | | **Rich contents** | – |
| | **Quick responsiveness** | **Required** | **Data amount** | | **Small – medium** |

*c-4. Collision avoidance assistance with provision of blind spot information ahead (see-through)*

<table>
<tr><td>Classification by function</td><td colspan="5">c. Lookahead information: collision avoidance</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">c-4. Provision of blind spot information ahead (see-through)</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">The road situation, road obstacles and road users including pedestrians and bicyclists ahead captured by a camera and radar is provided by a vehicle to the surrounding vehicles to assist collision avoidance.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2V</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Object list consisting all detected road users</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients</td><td>Sensor data</td><td>Positions and speed of the detected objects, object identification</td></tr>
<tr><td>Vehicle action</td><td>Speed adjustment, stop</td><td>Rich contents</td><td></td></tr>
<tr><td>Quick responsiveness</td><td>Required</td><td colspan="2">Data amount</td><td>Medium</td></tr>
</table>

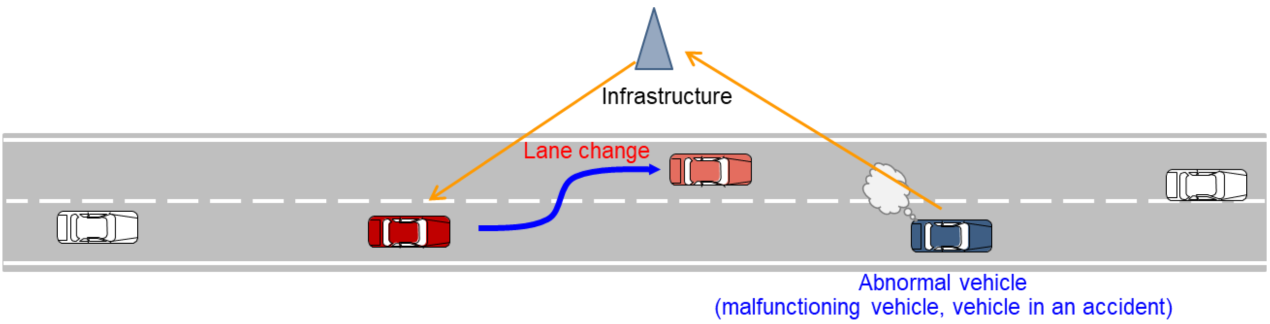
*c-5. Collision avoidance assistance at intersections*

| | | | | | |
|---|---|---|---|---|---|
| **Classification by function** | **c. Lookahead information: collision avoidance** | | | | |
| **Name of the functional element** | **c-5. Collision avoidance assistance at intersections** | | | | |
| **Target areas** | **General roads** | | | | |
| **Overview** | **Location and speed information is exchanged between vehicles that approach intersections to assist collision avoidance.** | | | | |
| **Image of the functional element** | | | | | |
|  | | | | | |
| **Remarks (radiocommunication requirements, etc.)** | **Connection mode** | **V2V** | **Data category/ content of information** | **Message** | **–** |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | **Location, speed** |
| | **Vehicle action** | **Speed adjustment, stop, right and left turns** | | **Rich contents** | **–** |
| | **Quick responsiveness** | **Required** | **Data amount** | | **Small** |

*d. Lookahead information: trajectory change*

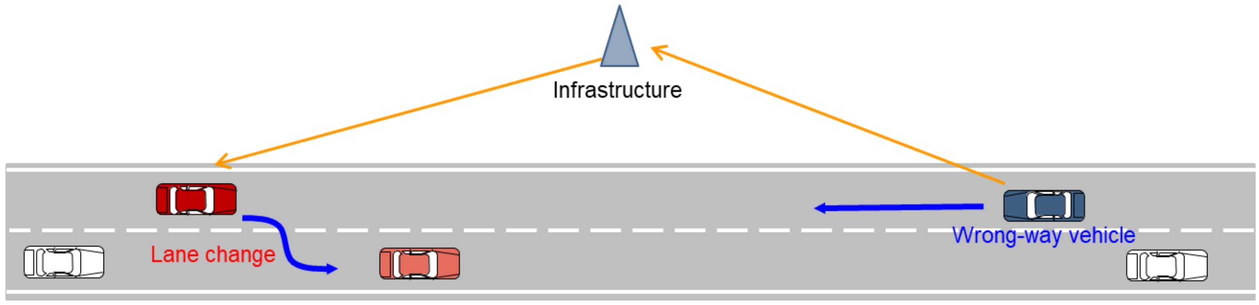
*d-1. Driving assistance by notification of abnormal vehicles*

| | |
|---|---|
| **Classification by function** | **d. Lookahead information: trajectory change** |
| **Name of the functional element** | **d-1. Driving assistance by notification of abnormal vehicles** |
| **Target areas** | **Expressways and General roads** |
| **Overview** | **Event information of abnormal vehicles that are stopped on roads (for example, malfunctioning vehicles, vehicles in accidents) and location information (sections and lanes where such vehicles are located) are provided by the infrastructure to the surrounding vehicles or by abnormal vehicles to the surrounding vehicles to assist lane change and trajectory change at an early stage.** |
| **Image of the functional element** | |



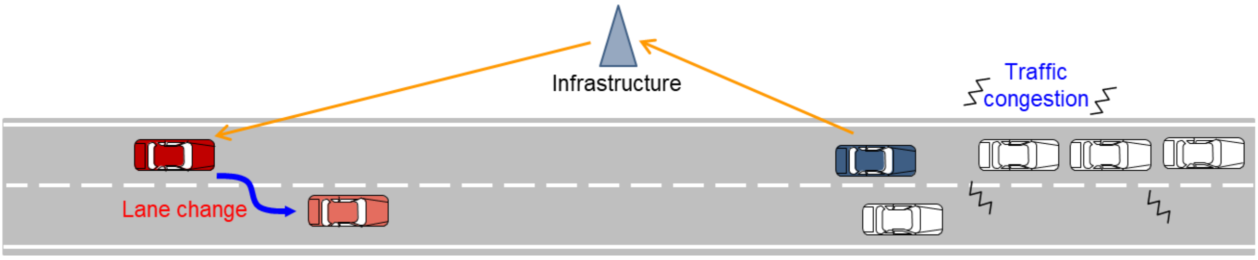

| | | | | | |
|---|---|---|---|---|---|
| **Remarks (radiocommunication requirements, etc.)** | **Connection mode** | **V2I, V2N** | **Data category/ content of information** | **Message** | **Event information of abnormal vehicles** |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | **Location** |
| | **Vehicle action** | **Lane change, trajectory change** | | **Rich contents** | – |
| | **Quick responsiveness** | **Not required** | **Data amount** | | **Small to Medium** |

*d-2. Driving assistance by notification of wrong-way vehicles*

<table>
<tr><td>Classification by function</td><td colspan="5">d. Lookahead information: trajectory change</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">d-2. Driving assistance by notification of wrong-way vehicles</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">Location and speed information of wrong-way vehicles and information about the presence of wrong-way vehicles are provided by the infrastructure to the surrounding vehicles to prompt lane change, etc. in advance and assist collision avoidance.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2I, V2N</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Presence of wrong-way vehicles</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients</td><td>Sensor data</td><td>Location, speed, and lane category of wrong-way vehicles</td></tr>
<tr><td>Vehicle action</td><td>Lane change, trajectory change, pulling over</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>Not required</td><td colspan="2">Data amount</td><td>Small to Medium</td></tr>
</table>

*d-3. Driving assistance based on traffic congestion information*

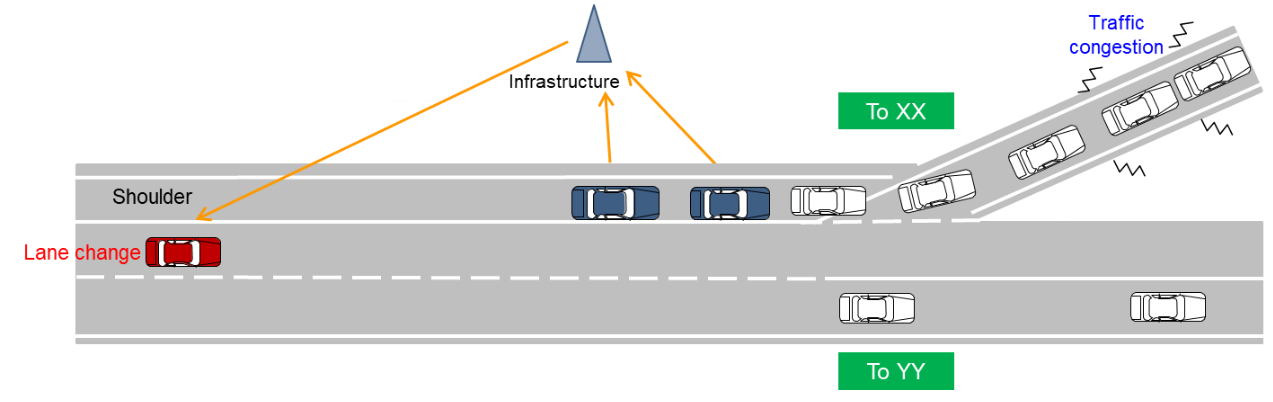
| | |
|---|---|
| **Classification by function** | **d. Lookahead information: trajectory change** |
| **Name of the functional element** | **d-3. Driving assistance based on traffic congestion information** |
| **Target areas** | **Expressways and General roads** |
| **Overview** | **Traffic congestion status information obtained from vehicles that are caught in traffic congestion is provided by the infrastructure to the surrounding vehicles to assist driving.** |
| **Image of the functional element** | |




| | | | | | |
|---|---|---|---|---|---|
| **Remarks (radiocommunication requirements, etc.)** | **Connection mode** | **V2I, V2N** | **Data category/ content of information** | **Message** | **Status of traffic congestion** |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | – |
| | **Vehicle action** | **Trajectory change, speed adjustment, stop** | | **Rich contents** | – |
| | **Quick responsiveness** | **Not required** | **Data amount** | | **Small** |

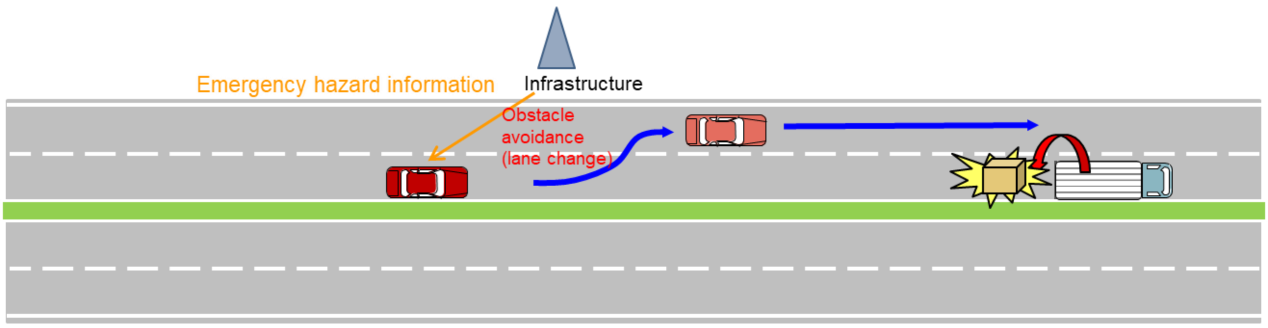
*d-4. Traffic congestion assistance at branches and exits*

| | |
|---|---|
| **Classification by function** | **d. Lookahead information: trajectory change** |
| **Name of the functional element** | **d-4. Traffic congestion assistance at branches and exits** |
| **Target areas** | **Expressways and General roads** |
| **Overview** | **Information about traffic congestion on shoulders (location, speed) is provided by the infrastructure to vehicles on the main lane to assist entry to branches.** |
| **Image of the functional element** | |



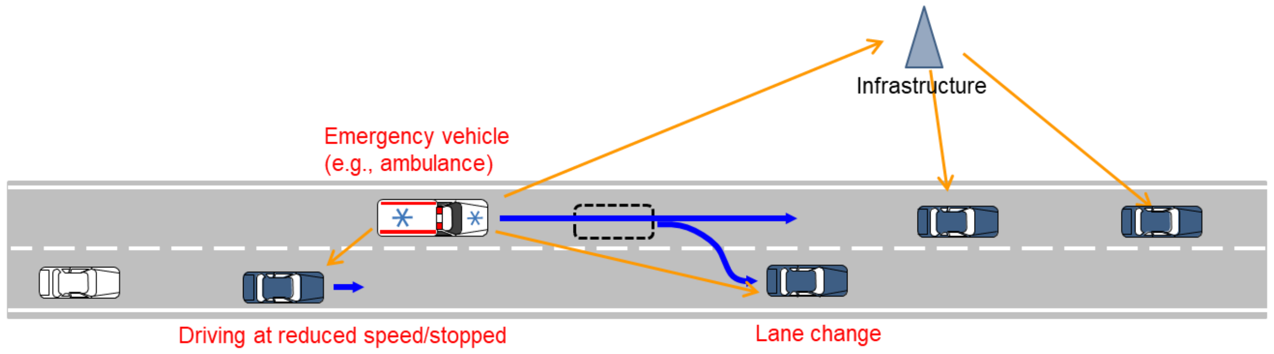

| | | | | | |
|---|---|---|---|---|---|
| **Remarks (radiocommunication requirements, etc.)** | **Connection mode** | **V2I, V2N** | **Data category/ content of information** | **Message** | **Status of traffic congestion on shoulders (toward branches)** |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | **Speed, location** |
| | **Vehicle action** | **Speed adjustment, trajectory change** | | **Rich contents** | **–** |
| | **Quick responsiveness** | **Not required** | **Data amount** | | **Small** |

*d-5. Driving assistance based on hazard information*

<table>
<tr><td>Classification by function</td><td colspan="5">d. Lookahead information: trajectory change</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">d-5. Driving assistance based on hazard information</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">Information about obstacles, construction work, traffic congestion, etc. is provided by the infrastructure to the surrounding vehicles to assist driving.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2I, V2N</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Obstacle information</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients</td><td>Sensor data</td><td>Location</td></tr>
<tr><td>Vehicle action</td><td>Trajectory change, lane change, automated driving control assistance level change</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>Not required</td><td colspan="2">Data amount</td><td>Small</td></tr>
</table>

*e. Lookahead information: emergency vehicle notification*

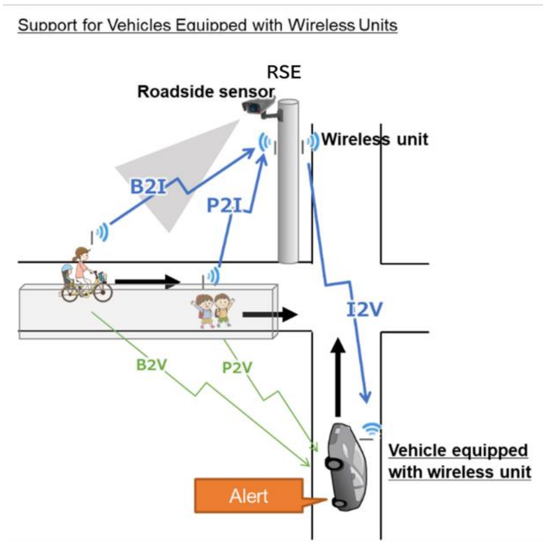
*e-1. Driving assistance based on emergency vehicle information*

<table>
<tr><td>Classification by function</td><td colspan="5">e. Lookahead information: emergency vehicle notification</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">e-1. Driving assistance based on emergency vehicle information</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">Information about the driving direction, speed, and planned driving route (planned driving lane) of emergency vehicles is provided by the emergency vehicles to the surrounding vehicles to prompt the surrounding vehicles to drive at reduced speed or to stop, etc. and thereby assist the emergency vehicles to pass smoothly.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="5">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2V, V2I, V2N</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Information about approaching emergency vehicles</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients</td><td>Sensor data</td><td>Location, speed</td></tr>
<tr><td>Vehicle action</td><td>Speed adjustment, lane change, stop (shoulder)</td><td>Rich contents</td><td>–</td></tr>
<tr><td rowspan="2">Quick responsiveness</td><td rowspan="2">Not required</td><td colspan="2">Data amount</td><td>Small to medium</td></tr>
<tr><td colspan="2">Message set example</td><td>ETSI DENM, ETSI CPM, SAE BSM, SAE SDSM, CCSA RSM, CSAE SSM</td></tr>
</table>

*i. Vulnerable Road User Protection*

*i-1. Integration of Vulnerable Road Users into V2X radiocommunication*

| | |
|---|---|
| **Classification by function** | **i. Vulnerable Road User Protection** |
| **Name of the functional element** | **i-1. Integration of Vulnerable Road Users into V2X radiocommunication** |
| **Target areas** | **General roads** |
| **Overview** | **The type, presence, location and speed of vulnerable road users (VRUs) such as bicyclists and pedestrians are notified to vehicles and infrastructure in order to create and enhance awareness of the vulnerable road users through integration into the V2X communication.** |
| **Image of the functional element** | |

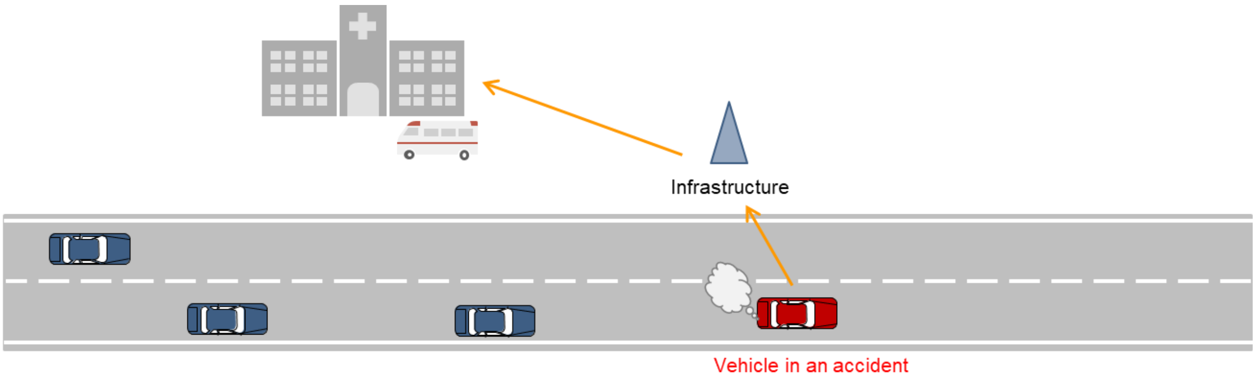



| | | | | | |
|---|---|---|---|---|---|
| **Remarks (communication requirements, etc.)** | **Connection mode** | **V2P, P2I, V2I,** | **Data category/ content of information** | **Message** | **Object information** |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | **Type, location, speed, direction** |
| | **Vehicle action** | **Judgment of whether the vehicle can start, adjust speed, and stop** | | **Rich contents** | **–** |
| | **Quick responsiveness** | **Required** | **Data amount** | | **Small** |

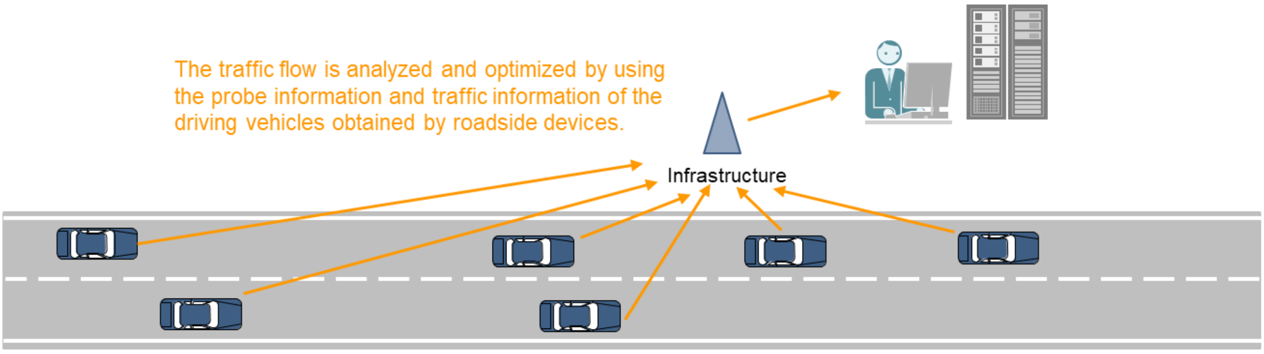
**(2) Functional elements in which information of one's own vehicle must be provided**

*f. Information collection/distribution by infrastructure*

*f-1. Request for rescue (e-Call)*

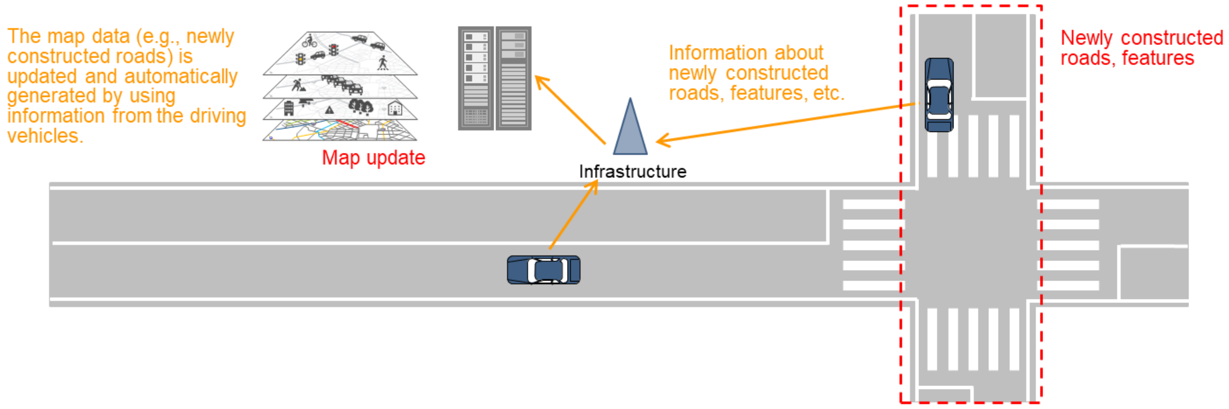
<table>
<tr><td>Classification by function</td><td colspan="5">f. Information collection/distribution by infrastructure</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">f-1. Request for rescue (e-Call)</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">Rescue information is transmitted from abnormal vehicles (for example, vehicles in accidents) to the infrastructure to request rescue.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2N</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Request for rescue</td></tr>
<tr><td>Message recipient(s)</td><td>One recipient</td><td>Sensor data</td><td>Location</td></tr>
<tr><td>Vehicle action</td><td>Notification</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>–</td><td colspan="2">Data amount</td><td>Small</td></tr>
</table>

*f-2. Collection of information to optimize the traffic flow*

<table>
<tr><td colspan="2">Classification by function</td><td colspan="4">f. Information collection/distribution by infrastructure</td></tr>
<tr><td colspan="2">Name of the functional element</td><td colspan="4">f-2. Collection of information to optimize the traffic flow</td></tr>
<tr><td colspan="2">Target areas</td><td colspan="4">Expressways and General roads</td></tr>
<tr><td colspan="2">Overview</td><td colspan="4">Information about the location and speed of driving vehicles is collected via the infrastructure to analyse and optimize the traffic flow.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2I, V2N</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>–</td></tr>
<tr><td>Message recipient(s)</td><td>One recipient</td><td>Sensor data</td><td>Location, speed</td></tr>
<tr><td>Vehicle action</td><td>–</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>–</td><td colspan="2">Data amount</td><td>Small</td></tr>
</table>

*f-3. Update and automatic generation of maps*

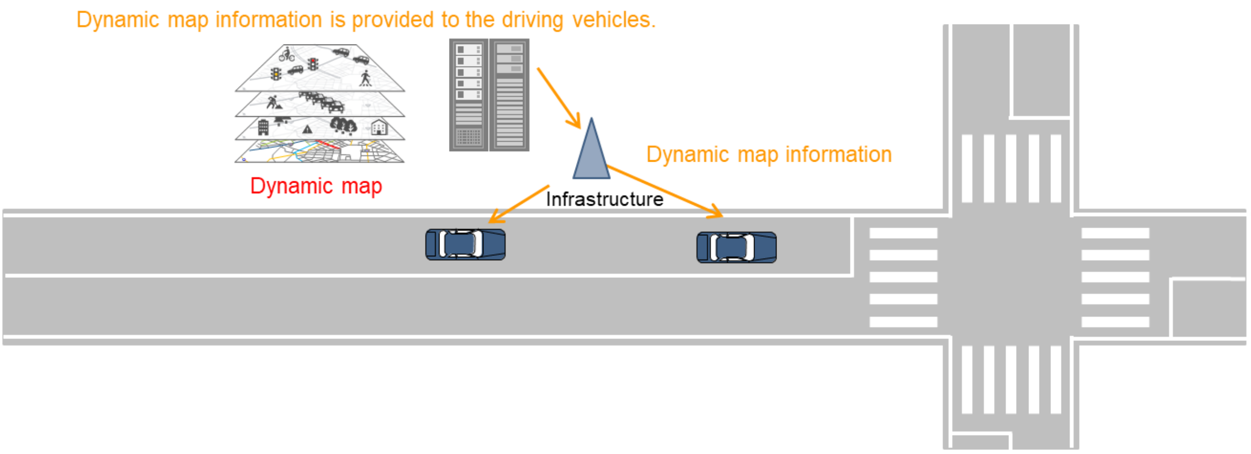
| | |
|---|---|
| **Classification by function** | **f. Information collection/distribution by infrastructure** |
| **Name of the functional element** | **f-3. Update and automatic generation of maps** |
| **Target areas** | **Expressways and General roads** |
| **Overview** | **Vehicles' information is collected by the infrastructure to update and automatically generate the map data.** |
| **Image of the functional element** | |




| | | | | | |
|---|---|---|---|---|---|
| **Remarks (radiocommunication requirements, etc.)** | **Connection mode** | **V2N** | **Data category/ content of information** | **Message** | **–** |
| | **Message recipient(s)** | **One recipient** | | **Sensor data** | **Location** |
| | **Vehicle action** | **–** | | **Rich contents** | **Image captured by on-board cameras** |
| | **Quick responsiveness** | **–** | **Data amount** | | **Large** |

*f-4. Distribution of dynamic map information*

| | |
|---|---|
| **Classification by function** | **f. Information collection/distribution by infrastructure** |
| **Name of the functional element** | **f-4. Distribution of dynamic map information** |
| **Target areas** | **Expressways and General roads** |
| **Overview** | **Dynamic map information is provided by the infrastructure to vehicles including dynamic road situations in for example, road constructions, mobile road works, lane closures** |
| **Image of the functional element** | |



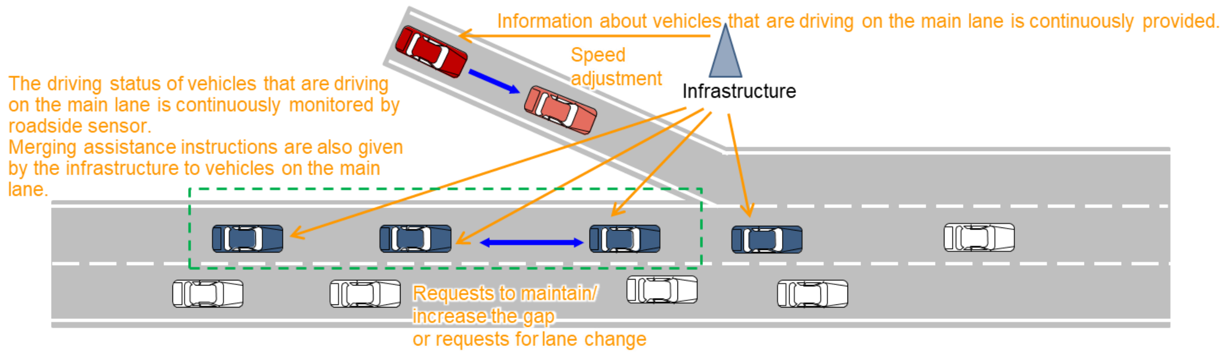

| | | | | | |
|---|---|---|---|---|---|
| **Remarks (radiocommunication requirements, etc.)** | **Connection mode** | **V2N** | **Data category/ content of information** | **Message** | – |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | – |
| | **Vehicle action** | **Trajectory change based on updated vehicle environmental model/map** | | **Rich contents** | **Road data, feature location, etc.** |
| | **Quick responsiveness** | – | **Data amount** | | **Large** |

## (3) Functional elements in which V2V and V2I interaction must be ensured

*a. Merging/lane change assistance*

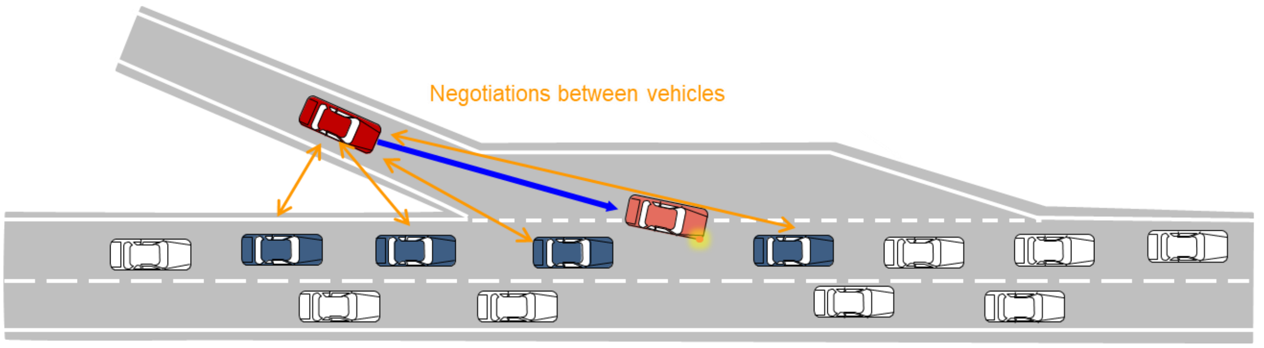
*a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control*

| | |
|---|---|
| **Classification by function** | **a. Merging/lane change assistance** |
| **Name of the functional element** | **a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control** |
| **Target areas** | **Expressways and General roads** |
| **Overview** | **Measurement information (for example, location, speed) of vehicles driving on certain range of main lane is provided by the infrastructure to merging vehicles. Meanwhile, instructions (for example, adjustment of the gap between vehicles) are given by the infrastructure to vehicles on the main lane to assist merging.** |
| **Image of the functional element** | |



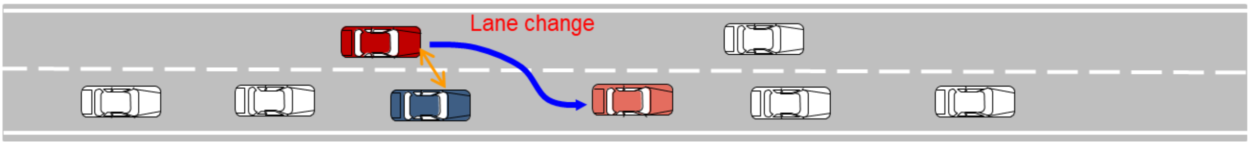

| | | | | | |
|---|---|---|---|---|---|
| **Remarks (radiocommunication requirements, etc.)** | **Connection mode** | **V2I** | **Data category/ content of information** | **Message** | **Time to arrive at a merging section (vehicles on the main lane), requests for gap adjustment** |
| | **Message recipient(s)** | **Multiple recipients** | | **Sensor data** | **Speed, location** |
| | **Vehicle action** | **Speed adjustment, gap adjustment** | | **Rich contents** | – |
| | **Quick responsiveness** | **Required** | **Data amount** | | **Medium** |

*a-1-4. Merging assistance based on negotiations between vehicles/Decentral path coordination and decision between multiple CAV*

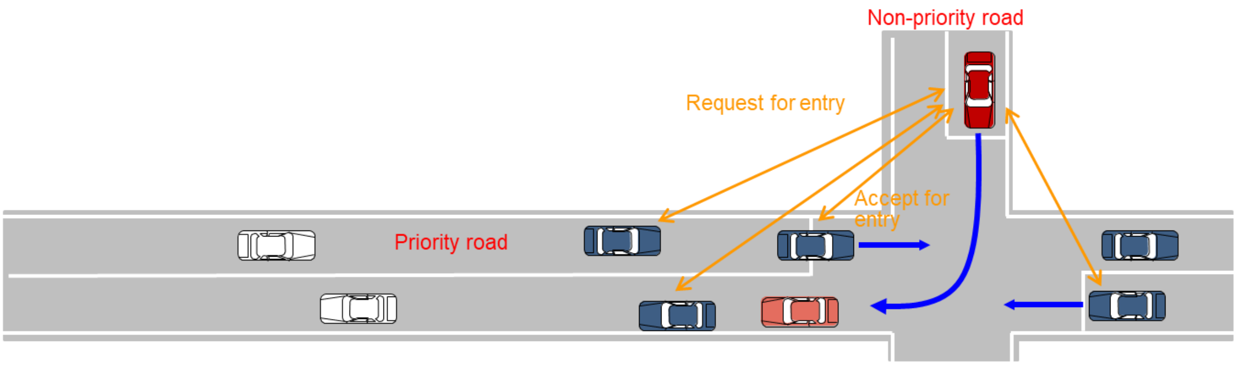
<table>
<tr><td>Classification by function</td><td colspan="5">a. Merging/lane change assistance</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">a-1-4. Merging assistance based on negotiations between vehicles/Decentral path coordination and decision between multiple CAV</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">During merging to a main lane with heavy traffic, vehicles on the main lane communicate with merging vehicles (for example, location and speed information, gap adjustment requests) to conduct negotiations between vehicles for merging assistance. The use case can be generalized to a decentral path coordination and decision making between multiple CAV in any driving scenarios.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2V</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Requests for entry, permission for acceptance; Plan trajectory, requested trajectory</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients → One recipient</td><td>Sensor data</td><td>Speed, location, acceleration, heading</td></tr>
<tr><td>Vehicle action</td><td>Speed adjustment, gap adjustment</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>Required</td><td colspan="2">Data amount</td><td>Small to Medium</td></tr>
</table>

NOTE – Please also see § 5 and https://imagine-online.de/en/home/

*a-2. Lane change assistance when the traffic is heavy*

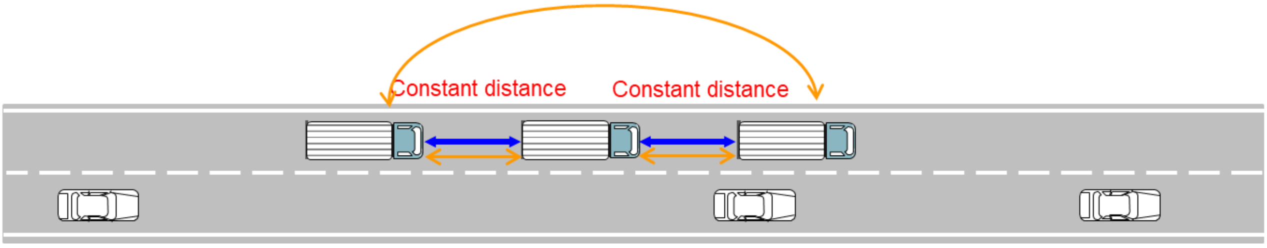
<table>
<tr><td colspan="2">Classification by function</td><td colspan="4">a. Merging/lane change assistance</td></tr>
<tr><td colspan="2">Name of the functional element</td><td colspan="4">a-2. Lane change assistance when the traffic is heavy</td></tr>
<tr><td colspan="2">Target areas</td><td colspan="4">Expressways and General roads</td></tr>
<tr><td colspan="2">Overview</td><td colspan="4">During lane change to a lane with heavy traffic, the location and speed information and the intention of lane change, etc. are communicated between vehicles for lane change assistance.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2V</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Requests for gap adjustment, permission for acceptance</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients → One recipient</td><td>Sensor data</td><td>Speed, location</td></tr>
<tr><td>Vehicle action</td><td>Gap adjustment, lane change</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>Required</td><td colspan="2">Data amount</td><td>Medium</td></tr>
</table>

*a-3. Entry assistance from non-priority roads to priority roads during traffic congestion*

<table>
<tr><td>Classification by function</td><td colspan="5">a. Merging/lane change assistance</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">a-3. Entry assistance from non-priority roads to priority roads during traffic congestion</td></tr>
<tr><td>Target areas</td><td colspan="5">General roads</td></tr>
<tr><td>Overview</td><td colspan="5">At unsignalized intersections, location and speed information and the intention of entry are communicated between vehicles near intersections for driving assistance to enter priority roads from non-priority roads.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2V</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Requests for entry, permission for acceptance; plan trajectory, requested trajectory, ETSI MCM</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients → One recipient</td><td>Sensor data</td><td>Location, speed, acceleration, heading</td></tr>
<tr><td>Vehicle action</td><td>Right and left turns, gap adjustment</td><td>Rich contents</td><td>–</td></tr>
<tr><td>Quick responsiveness</td><td>Required</td><td colspan="2">Data amount</td><td>Small, medium</td></tr>
</table>

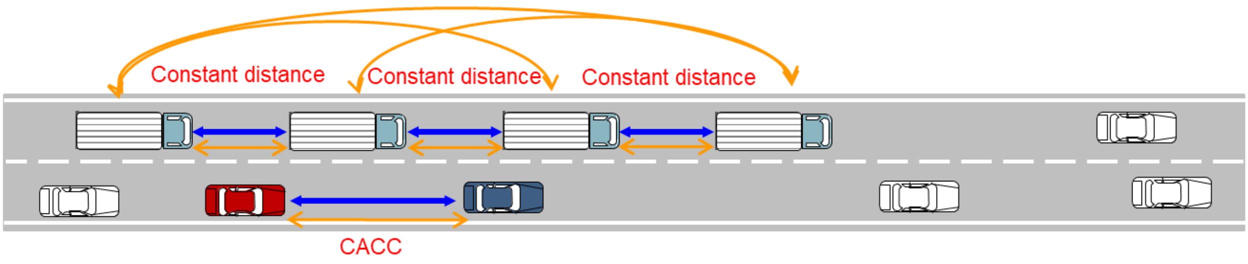
*g. Platooning/adaptive cruise control*

*g-1. Platooning of driverless follower vehicles by electronic towbar*

<table>
<tr><td>Classification by function</td><td colspan="5">g. Platooning/adaptive cruise control</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">g-1. Platooning of driverless follower vehicles by electronic towbar</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways</td></tr>
<tr><td>Overview</td><td colspan="5">Operation information, etc. of platooning vehicles is communicated between trucks that form a platoon to assist platooning (electronic towbar). In addition, before the realization of fully automated driving of SAE level 4, there is a need to transmit video image data for a lead-vehicle human driver, in such cases as Surrounding Monitor (SM) by using electric mirrors at the follower vehicles and Driver Status Monitor (DSM) by using in-vehicle video cameras to monitor the drivers, who are not in operation, at the platoon member vehicles.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2V</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Speed, acceleration, braking, steering operation, information about follower vehicles</td></tr>
<tr><td>Message recipient(s)</td><td>Multiple recipients</td><td>Sensor data</td><td>Location, speed, gap/heading, acceleration/deceleration speed</td></tr>
<tr><td>Vehicle action</td><td>Keeping distance, platoon maintenance</td><td>Rich contents</td><td>Transmission of video image from the follower truck to the lead vehicle for Surrounding Monitoring (SM) and/or Driver Status Monitoring (DSM)</td></tr>
<tr><td>Quick responsiveness</td><td>Required</td><td colspan="2">Data amount</td><td>Large, Small*<br>*The data amount depends on whether the platooning requires the image-based Surrounding Monitor (SM) and/or the image-based Driver Status Monitor (DSM), in which case more data is needed to support this function.</td></tr>
</table>

*g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control*

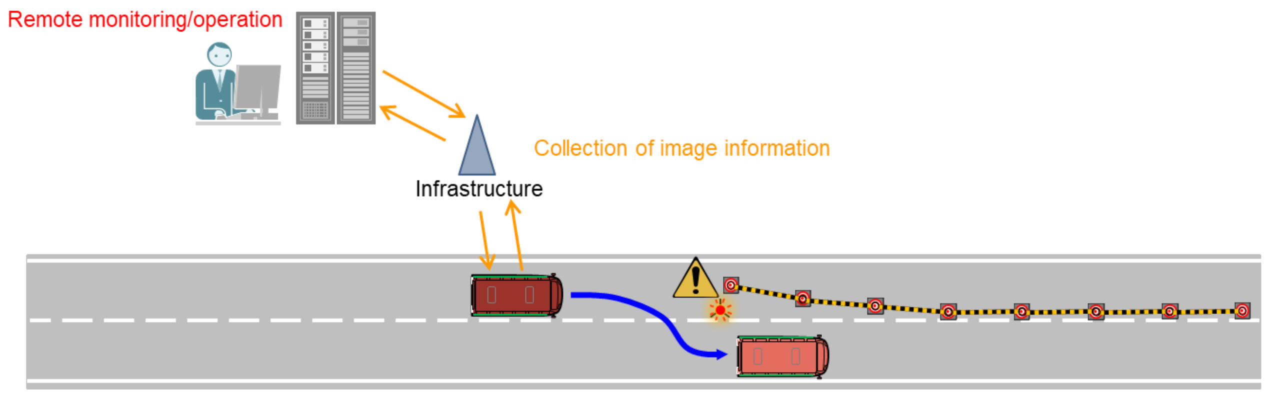
| | |
|---|---|
| **Classification by function** | **g. Platooning/adaptive cruise control** |
| **Name of the functional element** | **g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control** |
| **Target areas** | **Expressways (Logistics service cars)**<br>**Expressways and General roads (Privately owned vehicles)** |
| **Overview** | **Location and speed information and driving operation information of vehicles at the front, etc. are communicated with the following vehicles to assist adaptive cruise control.** |
| **Image of the functional element** | |




| **Remarks (radiocommunication requirements, etc.)** | | | **Data category/ content of information** | | |
|---|---|---|---|---|---|
| | **Connection mode** | **V2V** | | **Message** | **Acceleration/braking operation** |
| | **Message recipient(s)** | **One or multiple recipients** | | **Sensor data** | **Location, speed, acceleration/deceleration speed** |
| | **Vehicle action** | **Keeping distance** | | **Rich contents** | **–** |
| | **Quick responsiveness** | **Required** | **Data amount** | | **Small** |

*h. Teleoperation*

*h-1. Operation and management of mobility service cars*

<table>
<tr><td>Classification by function</td><td colspan="5">h. Teleoperation</td></tr>
<tr><td>Name of the functional element</td><td colspan="5">h-1. Operation and management of mobility service cars</td></tr>
<tr><td>Target areas</td><td colspan="5">Expressways and General roads</td></tr>
<tr><td>Overview</td><td colspan="5">In a traffic environment that is difficult for an automated driving system, an operation manager in a remote location communicates a remote control instruction to the mobile service car based on video information from the mobile service car.</td></tr>
<tr><td colspan="6">Image of the functional element</td></tr>
<tr><td colspan="6">
</td></tr>
<tr><td rowspan="4">Remarks (radiocommunication requirements, etc.)</td><td>Connection mode</td><td>V2N</td><td rowspan="3">Data category/ content of information</td><td>Message</td><td>Teleoperation instructions</td></tr>
<tr><td>Message recipient(s)</td><td>One recipient</td><td>Sensor data</td><td>Location, speed</td></tr>
<tr><td>Vehicle action</td><td>Teleoperation</td><td>Rich contents</td><td>Image captured by on-board cameras</td></tr>
<tr><td>Quick responsiveness</td><td>Required</td><td colspan="2">Data amount</td><td>Large</td></tr>
</table>

# Annex 2

## Estimated spectrum needs

The estimated spectrum needs and details of methodology for CAV radiocommunication are provided by Germany, C2C-CC, and 5GAA from § A2.1 to § A2.3, respectively.

### A2.1 Estimate – A

Taking into account the radio communication parameters for different functional elements from Table 6-5-1 in combination with spectrum efficiencies[84] the following minimum, maximum and typical spectrum needs developed by industry can be calculated, following the formula for spectrum needs[85] in § A2.3.

In reality functional elements occur in same environments in parallel: some of those in minimum and some of those in maximum values, which means that the typical spectrum needs given here could be seen as an estimation for future spectrum needs for CAV.

Table A2-1, based on a study by Germany, details the spectrum needs for awareness driving (CAM, DENM, MAPEM, SPATEM, IVI, VAM), sensing driving (CPM) and cooperative automated driving (MCM, PCM). In summary spectrum bandwidth needs are in urban environment between 31 MHz up to 275.7 MHz with a typical spectrum bandwidth value of 123.7 MHz, while in highway environments these values range between 70.5 MHz to 160.3 MHz with a typical spectrum bandwidth value of 114.5 MHz.

The parameters to calculate the spectrum needs were described in the study[84]. Each parameter can vary to some degree within a certain range. Only the lower end for parameters in the numerator of the spectrum calculation formula[85], and only the higher end for parameters in the denominator of the spectrum calculation formula[85], were chosen to calculate the minimum spectrum needs, which means that the spectrum needs shown are suggested as the minimum requirements to enable these live-saving use cases. For CAV some administrations may wish to choose at least the typical instead of the minimum values of the following parameters, consistent with their individual needs, because all values between best and worst case can occur in realistic scenarios.

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[84] Spectral efficiency * channel utilization factor are based on studies 1) Car 2 Car Communication Consortium, Road Safety and Efficiency Spectrum Needs in 5.9 GHz for C-ITS and Cooperative Automated Driving (2020); and 2) Lu Gao, Yan Li, Jim Misener, Shailesh Patel, C V2X Based Basic Safety Related ITS Spectrum Requirement Analysis (Institute of Electrical and Electronics Engineers, 2017) (presented during IEEE 86th Vehicular Technology Conference, 24-27 Sept., 2017).

[85] See Attachment 1 "Spectrum Needs for CPM Safety-of-Life Applications and MCM Safety-of Life Applications" to *Ex Parte* Letter from Continental Automotive Systems to U.S. Federal Communications Commission, ET Docket No. 19-138 (filed July 10, 2020).

TABLE A2-1

**Industry estimated spectrum needs for CAV radiocommunication**

| | | Min | Max | Typical |
|---|---|---|---|---|
| MCM (Urban) V2V | message size in Byte | 1 000 | 1 300 | 1 150 |
| equivalent MSCM | transmission interval in Hz | 1 | 5 | 3 |
| | number of ITS stations in radiocommunication range | 320 | 640 | 480 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **7.8** | **74.0** | **34.1** |
| MCM (Highways) V2V | message size in Byte | 1 000 | 1 300 | 1 150 |
| equivalent MSCM | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 100 | 200 | 150 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **24.2** | **46.2** | **35.6** |
| MCM (Urban) V2I | message size in Byte | 1 000 | 1 300 | 1 150 |
| equivalent MSCM | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 2 | 6 | 4 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.5** | **1.4** | **0.9** |
| MCM (Highway) V2I | message size in Byte | 1 000 | 1 300 | 1 150 |
| equivalent MSCM | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 1 | 5 | 3 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.2** | **1.2** | **0.7** |
| CAM (Urban) V2V | message size in Byte | 400 | 700 | 550 |
| equivalent BSM | transmission interval in Hz | 1 | 5 | 3 |
| | number of ITS stations in radiocommunication range | 320 | 640 | 480 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **3.1** | **39.8** | **16.3** |

TABLE A2-1 (*continued*)

| | | Min | Max | Typical |
|---|---|---|---|---|
| CAM (Highway) V2V | message size in Byte | 400 | 700 | 550 |
| equivalent BSM | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 100 | 200 | 150 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **9.7** | **24.9** | **17.0** |
| CPM (Urban) V2V | message size in Byte | 1 000 | 1 900 | 1 450 |
| equivalent SDSM | transmission interval in Hz | 1 | 5 | 3 |
| | number of ITS stations in radiocommunication range | 320 | 640 | 480 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **7.8** | **108.1** | **43.0** |
| CPM (Highways) V2V | message size in Byte | 1 000 | 1 900 | 1 450 |
| equivalent SDSM | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 100 | 200 | 150 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **24.2** | **67.6** | **44.8** |
| CPM (Urban) V2I | message size in Byte | 1 000 | 1 900 | 1 450 |
| equivalent SDSM | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 2 | 6 | 4 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.5** | **2.0** | **1.2** |
| CPM (Highways) V2I | message size in Byte | 1 000 | 1 900 | 1 450 |
| equivalent SDSM | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 1 | 5 | 3 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.2** | **1.7** | **0.9** |

TABLE A2-1 (*continued*)

| | | Min | Max | Typical |
|---|---|---|---|---|
| SPaTEM (Urban) V2I | message size in Byte | 1 200 | 1 200 | 1 200 |
| equivalent sPaT | transmission interval in Hz | 2 | 10 | 6 |
| | number of ITS stations in radiocommunication range | 2 | 6 | 4 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.1** | **1.3** | **0.6** |
| SPaTEM (Highway) V2I | message size in Byte | 1 200 | 1 200 | 1 200 |
| equivalent SPaT | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 1 | 5 | 3 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.3** | **1.1** | **0.7** |
| MAPEM (Urban) V2I | message size in Byte | 1 200 | 1 200 | 1 200 |
| equivalent MAP | transmission interval in Hz | 2 | 10 | 6 |
| | number of ITS stations in radiocommunication range | 2 | 6 | 4 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.1** | **1.3** | **0.6** |
| MAPEM (Highway) V2I | message size in Byte | 1 200 | 1 200 | 1 200 |
| equivalent MAP | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 1 | 5 | 3 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.3** | **1.1** | **0.7** |
| IVI (Urban) V2I | message size in Byte | 1 200 | 1 200 | 1 200 |
| | transmission interval in Hz | 2 | 10 | 6 |
| | number of ITS stations in radiocommunication range | 2 | 6 | 4 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.1** | **1.3** | **0.6** |

TABLE A2-1 (*continued*)

| | | Min | Max | Typical |
|---|---|---|---|---|
| IVI (Highway) V2I | message size in Byte | 1 200 | 1 200 | 1 200 |
| | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range | 1 | 5 | 3 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.3** | **1.1** | **0.7** |
| DENM (Urban) V2V | message size in Byte | 1 000 | 1 000 | 1 000 |
| | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range and 5% transmitting DENM | 16 | 32 | 24 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **3.9** | **5.7** | **4.9** |
| DENM (Highway) V2V | message size in Byte | 1 000 | 1 000 | 1 000 |
| | transmission interval in Hz | 10 | 10 | 10 |
| | number of ITS stations in radiocommunication range and 5% transmitting DENM | 5 | 10 | 8 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **1.2** | **1.8** | **1.6** |
| PCM (Urban) V2V | message size in Byte | 400 | 400 | 400 |
| platooning | transmission interval in Hz | 50 | 50 | 50 |
| | number of ITS stations in radiocommunication range | 6 | 10 | 8 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **2.9** | **3.6** | **3.3** |
| PCM (Highways) V2V | message size in Byte | 400 | 400 | 400 |
| platooning | transmission interval in Hz | 50 | 50 | 50 |
| | number of ITS stations in radiocommunication range | 20 | 30 | 25 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **9.7** | **10.7** | **10.3** |

TABLE A2-1 (*end*)

| | | Min | Max | Typical |
|---|---|---|---|---|
| VAM (Urban) V2P | message size in Byte | 350 | 350 | 350 |
| equivalent PSM | transmission interval in Hz | 1 | 3 | 2 |
| | number of ITS stations in radiocommunication range | 500 | 2 000 | 1 250 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **4.2** | **37.3** | **18.0** |
| VAM (Highway) V2P | message size in Byte | 350 | 350 | 350 |
| equivalent PSM | transmission interval in Hz | 1 | 10 | 6 |
| | number of ITS stations in radiocommunication range | 10 | 50 | 30 |
| | spectral efficiency (bit/s/Hz) * channel utilization factor) | 0.33 | 0.45 | 0.388125 |
| | **bandwidth necessary in MHz** | **0.1** | **3.1** | **1.3** |
| **TOTAL in MHz** | **Urban** | **31.0** | **275.7** | **123.7** |
| | **Highway** | **70.5** | **160.3** | **114.5** |

NOTE – The fraction of vehicles/road users transmitting a = 1 for all messages, except for DENM a=0,05.

### A2.2 Estimate – B

A spectrum study[86] (2020) shows that deployed as well as planned use cases for increasing road traffic safety towards cooperative automated driving may consume more than 70 MHz. This study only takes the use cases' minimum needs of bandwidth in MHz into account, and it is radiocommunication technology agnostic. Table A2-2 summarizes the results of this study by tabulating different message types and their spectrum needs in MHz given three different scenarios (urban intersection, suburban intersection, highway fast traffic). The results of the study argue that the 7 × 10 MHz channels are required for existing and planned safety use cases.

However, some administrations, including one that rejected the conclusions of the C2C-CC study, have decided to make only 20-30 MHz available for safety-related use cases in the 5.9 GHz band that might be used for future CAV requirements, as these requirements become better known. One administration is making 20 MHz available for deployment of LTE V2X technology; while the other administration is dedicating 30 MHz for currently defined safety-related V2X use cases.

Table A2-3 also explains the different message types found in Table A2-2, which are already well defined and specified in standardization bodies, such as ETSI.

[86] CAR-2-CAR Communication Consortium Spectrum Study: "Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving" (https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_TR_2050_Spectrum_Needs.pdf).

TABLE A2-2

**Minimum spectrum needs for different message types for direct, V2X radiocommunication Spectrum Need (MHz)**

| Message type | Urban | Suburban | Highway |
|---|---|---|---|
| CAM – cooperative awareness message | 9 | 10 | 10 |
| DENM – decentralized environmental notification message | 4 | 2 | 1 |
| SPATEM – signal phase and timing,<br>MAPEM – road/lane topology and traffic manoeuvre,<br>IVI – in-vehicle-information and other I2V messages | 1 | 1 | 1 |
| VAM – VRU awareness message | 4 | 0.2 | 2 |
| PCM – platooning control message | 3 | 6 | 10 |
| CPM – collective perception message | 23 | 26 | 24 |
| MCM – manoeuvre coordination message | 23 | 26 | 24 |
| Minimum basic spectrum needs (MHz) | 67 | 72 | 72 |
| Total number of 10 MHz channels required | 7 | 7 | 7 |

Use cases based on V2X radiocommunication are introduced in steps, where so-called day one scenarios increasing the information horizon for the driver are introduced first. Day one scenarios or basic safety use cases are intended to inform the driver about impending dangerous situations and the driver needs to react accordingly. Day two scenarios intend to increase the information horizon for the vehicle and day-two use cases involve for example truck platooning and cooperative adaptive cruise control (CACC).

Figure A2-1 shows the roadmap C2C-CC has developed to plan for reaching true cooperative automated driving with reduced number of accidents, increased road traffic efficiency with decreased environmental footprint. The roadmap shows V2X use cases starting with awareness driving over sensing driving with CPM towards higher levels of cooperative automation including the message types MCM and PCM detailed in Table A2-3, three phases of V2X deployment:

– awareness driving (day-1) (BSM, CAM, I2V/V2I, PSM/VAM, SPATEM, MAPEM),

– sensing driving (SDSM/CPM),

– cooperative automated driving (MCSM/MCM, PCM).

TABLE A2-3

**Explanation of different message types**

| **Phases of V2X use case roadmap** | **Message types**[87] | | **Abbreviations explained** | **Examples of use cases based on the message types** |
|---|---|---|---|---|
| | **Europe** | **USA** | | |
| **Awareness driving** | CAM, DENM | BSM | Cooperative Awareness message, Decentralized Environmental Notification Message, Basic Safety Message | Intersection Collision Warning<br>Emergency Vehicle Warning<br>Dangerous Situation Warning<br>Stationary Vehicle Warning<br>Traffic Jam warning<br>Pre-/Postcrash Warning |
| | SPaTEM, MAPEM, IVIM | SPaTEM, MAPEM, IVI | Signal Phase and Time, MAP message, In-Vehicle-Information message | Enabling Infrastructure-to-Vehicle Radiocommunication at for example, traffic lights |
| | VAM | PSM | VRU Awareness Message, Personal Safety Message | VRU warning for (C-ITS) equipped Vulnerable Road Users |
| **Sensing Driving**/ sensor sharing | CPM | SDSM | Collective Perception Message, Sensing Data Sharing Message | Overtaking Warning<br>Extended Intersection Collision Warning<br>Vulnerable Road User Warning for non-equipped VRU´s<br>Cooperative Adaptive Cruise Control<br>Long-term Road Works Warning<br>Special Vehicle Prioritisation |
| **Cooperative Driving** with Coordinated manoeuvring and cooperative automated driving | MSCM, PCM | MCM, PCM | Manoeuvre Coordination Message, Manoeuvre Sharing and Coordination Message, Platooning Control Message | (Static or dynamic) Platooning<br>Area reservation<br>Cooperative Merging<br>Cooperative Lane Change<br>Cooperative Overtaking |

[87] CAM, Cooperative Awareness Message, specified in ETSI EN 302 637-2.

DENM, Decentralized Environmental Notification Message, specified in ETSI EN 302 637-3.

SPATEM, Signal, Phase, and Timing, ISO/TS 19091:2017.

MAPEM, road/lane topology and traffic manoeuvre ISO/TS 19091:2017.

VAM, Vulnerable Road User (VRU) Awareness Message ETSI TS 103 300-3, Pedestrian protection with Personal Safety Messages (PSM) according to SAE J2735, SAE J2945/9_201703 https://www.sae.org/standards/content/j2945/9_201703/.

PCM, Platooning Control Message draft specification in ETSI TR 103 298, currently being drafted in the European H2020 project ENSEMBLE (multi-brand truck platooning) https://platooningensemble.eu/.

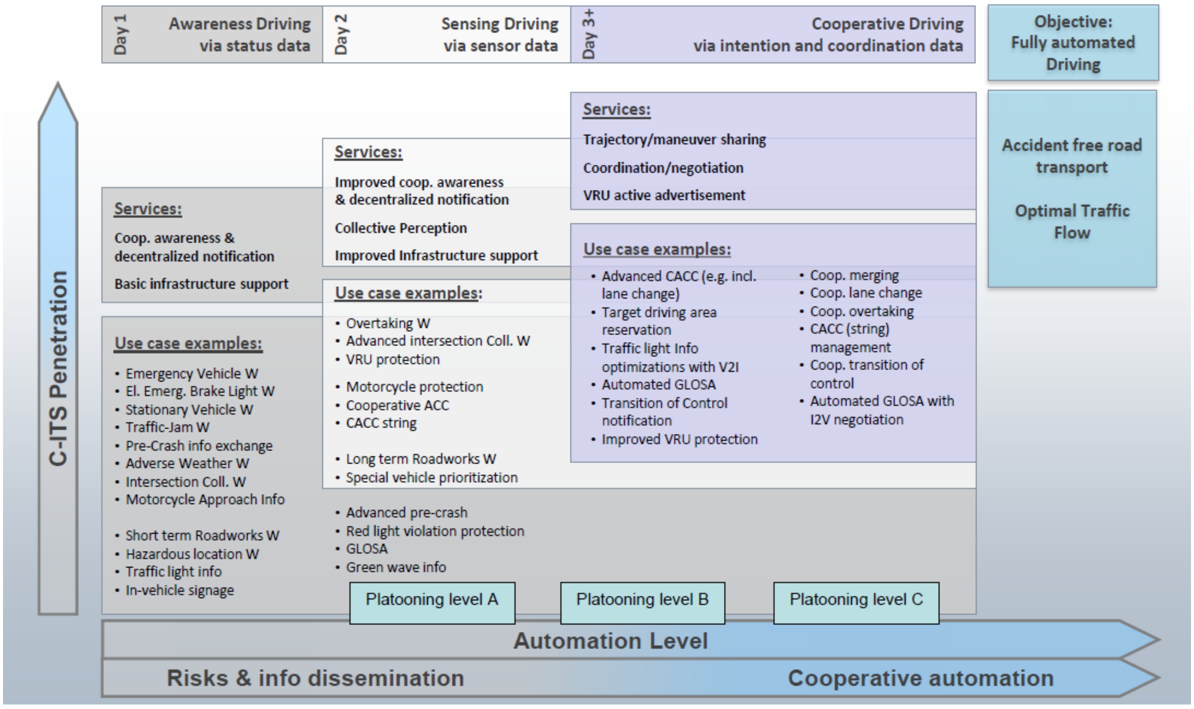
https://platooningensemble.eu/news/using-its-g5-for-efficient-truck-platooning5c1a203e7a226.

CPM Collective Perception Message, draft ETSI TS 103 324, ETSI TR 103 562.

MCM Manoeuvre Coordination Message, according to ETSI TR 103 578 (draft) "Informative report for the Manoeuvre Coordination Service"; https://imagine-online.de/en/home/.

FIGURE A2-1

**C2C-CC roadmap for V2X evolution**[88]




## A2.3 Estimate – C

The white paper sets out a consolidated view of the automotive and telecommunications industries on the evolution of radiocommunication technologies, their application to automotive connectivity, and the deployment of advanced driving use cases up to 2030, which include advanced safety and automated driving (AD).

Many so-called day-1 basic safety use cases have been widely analysed in the past, and several of these have already been deployed. Some of the advanced driving use cases would pave the way to automated driving, and thereby contribute to global safety and traffic efficiency goals, as well as environmental benefits for citizens and consumers.

The Report also identifies the most promising advanced driving use cases such as Cooperative Manoeuvres and Sensor Sharing, in conjunction with the adoption of the Cellular Vehicle-To-Everything (C-V2X) application in IMT specifications, as well as availability of required technologies and devices, that is, on-board equipment (OBEs), road-side equipment (RSEs), and smartphones, integrating the latest chipsets and modules. The market trajectory of the identified use cases is described along with the expected timeline for their mass market deployment.

The report notes that many advanced driving use cases will require 5G V2X radios. 5G V2X is considered for advanced driving and LTE V2X is considered for basic safety use cases, each encompassing both network and direct radiocommunications. Mobile network operators around the world have started to deploy 5G, building on current 4G networks. In the meantime, the planned releases of the 3GPP specifications include new features for direct radiocommunications, such as low power consumption in handheld devices, enabling additional use cases. The roadmap also accounts for the work currently undertaken on the upper application layers (for example, message types and

[88] Source C2C-CC: https://www.car-2-car.org/fileadmin/downloads/PDFs/roadmap/CAR2CAR_Roadmap_Nov_2018.pdf

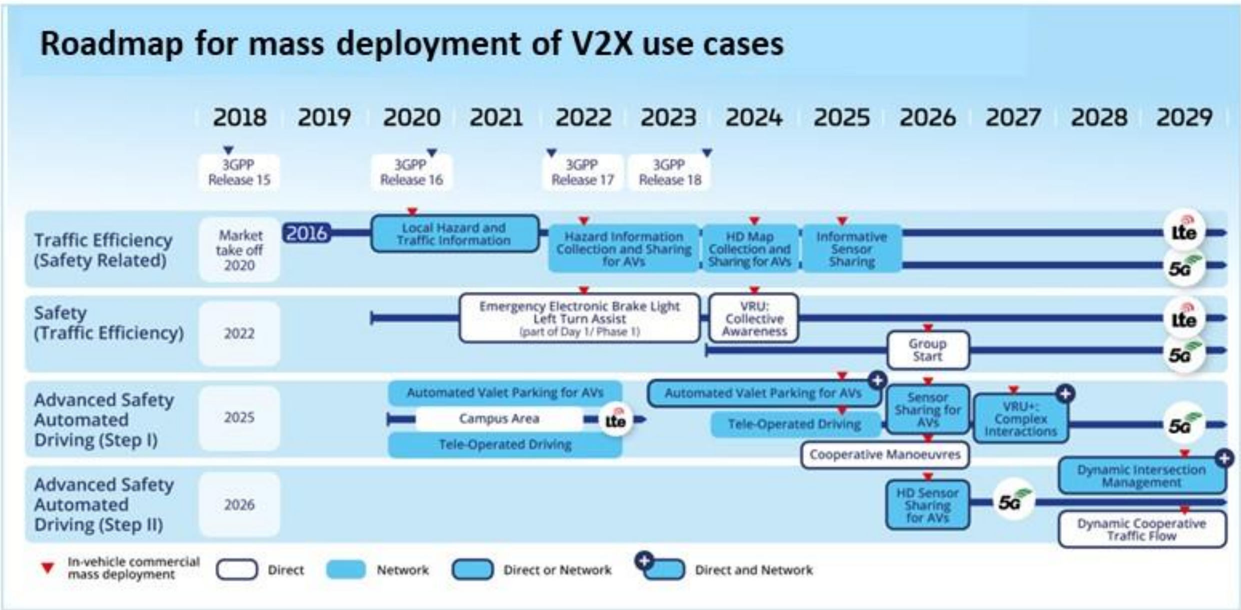
protocols), as well as equipment availability, testing and interoperability. The report shows that some advanced driving use cases will require direct radiocommunication for their implementation.

The spectrum needs for basic and advanced driving use cases are highlighted in the report. For direct radiocommunication, this corresponds to between 10 and 20 MHz at 5.9 GHz for basic safety, and an additional 40 MHz or more at 5.9 GHz for advanced driving. The report also highlights the need for additional spectrum for network-based radiocommunications for use by mobile operators in delivering advanced driving capabilities in rural and urban environments.

As indicated in Fig. A2-2, the use case timelines can be segmented into four phases which reflect increasing complexity and technical requirements.

FIGURE A2-2

**Roadmap for mass deployment of V2X use cases.**
**“Direct” means direct radiocommunications, for example, via 3GPP technologies (PC5/sidelink interface) at 5.9 GHz.**
**“Network” means cellular network-based radiocommunications in mobile bands**




From 2020, the 5GAA White Paper expects that use cases such as Traffic Information and Local Hazard will be complemented with PC5/sidelink direct communication and will lay the foundations for road safety and traffic efficiency. From 2022 onwards, advanced use cases such as Hazard Information Sharing for Automated Vehicles (AVs) and HD Map Sharing for AVs will gradually contribute to the building blocks required for automated driving.

Initial versions of certain advanced V2N use cases, such as Tele-Operated Driving and Automated Valet Parking, can already be implemented today by individual OEMs with LTE V2X network-based radiocommunications and on-board sensors in controlled environments, such as on private campuses. By 2025/26, it is expected that these use cases will be extended to operate in more complex environments and scenarios, such as on public roads and in parking garages, leveraging 5G V2X.

Cooperative Manoeuvres (via direct radiocommunication) and Sensor Sharing to support cooperative perception – both basic functionalities for automated driving, for example, Highway Pilot – are supported by 5G V2X. The report predicts that all new AD vehicles will be equipped with 5G V2X from 2026, in line with their mass production and entry to the market. Complex interactions between vehicles and VRUs via mobile phones – through both direct (PC5) and network-based (Uu) C-V2X radiocommunications – are foreseen to start by 2027.

High-Definition Sensor Sharing, based on 5G V2X will support the development of further automated driving levels in the future, with first pilots expected after 2026. Enhanced urban and highway pilots are expected to start in 2029 in dedicated areas allowing Dynamic Cooperative Traffic Flow and Dynamic Intersection Management.

**Spectrum needs**

The report by an automotive and mobile industry association further provides a study on the spectrum needs of a number of use cases for intelligent transport systems (ITS) as implemented by 3GPP-specified V2X technologies.

The study considers a mapping of messages to use cases to meet the demands. A message may be categorised as those which occur continually and those which are event triggered:

– Continual messages – These are used where the road users, infrastructure or network continually share information with other entities. This may include information about the location and movements of the road users, sensor data, or information about objects on the road. These continual messages are typically also repetitive (such as CAM/BSM) and tend to support broadcast radiocommunications.

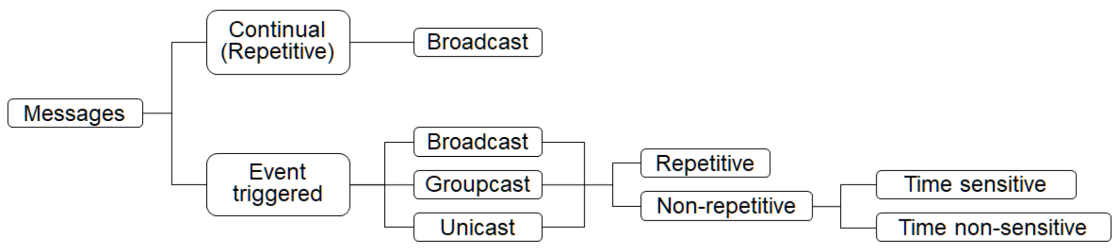
– Event triggered messages – These are only used in special circumstances. This might be when a road user intends to perform a special manoeuvre and wishes to inform (or seek the cooperation of) other users, or when a road user requests specific information from an infrastructure or network, or where an infrastructure or network wishes to provide specific information to a road user. Depending on the use case, these messages may be repetitive (during the event) or non-repetitive, and in the latter case, they might be delay sensitive or delay non-sensitive (best effort). Event triggered messages may support broadcast, groupcast or unicast radiocommunications depending on the use case.

Continual repetitive messages define a relatively deterministic baseline for the ITS spectrum needs. This is because road users transmit such messages regularly and at all times when active. The contribution of event triggered messages to the overall ITS spectrum needs is, on the other hand, more stochastic, in the sense that use cases which employ such messages may or may not occur at the same time at any given location, and this can result in a highly variable demand for spectrum.

The above message categories are illustrated in Fig. A2-3.

FIGURE A2-3

**Message categories**



The study identified a total of 44 diverse use cases that utilize different modes of radiocommunication (V2V, V2P, V2I and V2N) and message categories. These are summarised in Tables A2-4 and A2-5.

TABLE A2-4

**Day-1 use cases**

| **Messages per link** | **Use case** |
|---|---|
| Continual repetitive messages<br>(V2V) (broadcast) | (1) Cross-Traffic Turn Assist<br>(2) Intersection Movement Assist<br>(3) Emergency Brake Warning<br>(4) Traffic Jam Warning<br>(7) Real-Time Situational Awareness<br>(11) Lane Change Warning<br>(22) Automated Intersection Crossing<br>*Supported by the same messages.* |
| Continual repetitive messages<br>(V2I) (broadcast) | (22) Automated Intersection Crossing |
| Event triggered messages<br>(V2N) (groupcast/unicast) | (4) Traffic Jam Warning<br>(5) Software Update<br>(6) Vehicle Health Monitoring<br>(7) Real-Time Situational Awareness<br>(19) Continuous Traffic Flow via Green Lights Coordination<br>(24) Security Credentials<br>*Supported by different messages* |

TABLE A2-5

**Advanced use cases**

| **Messages per link** | **Use case** |
|---|---|
| Continual repetitive messages<br>(V2V) (broadcast) | (9a) Sensor Sharing for Autonomous Vehicles<br>(9b) High-Definition Sensor Sharing |
| Event triggered messages<br>(V2V) (broadcast/groupcast/unicast) | (10) See Through for Passing<br>(43) Vehicle Decision Assist |
| | *Trajectory information sharing:*<br>(1) Cross-Traffic Turn Assist<br>(18) Cooperative Manoeuvres in Emergency Situations<br>(28) Cooperative Lane Merging<br>(38) Coordinated Cooperative Driving Manoeuvre<br>(40) Interactive VRU Crossing<br>(41) Cooperative Lateral Parking<br>(42) Cooperative Traffic Gap |

TABLE A2-5 (*end*)

| **Messages per link** | **Use case** |
|---|---|
| Continual repetitive messages<br>(V2V) (broadcast/groupcast) | (12) Vulnerable Road User |
| Continual repetitive messages<br>(V2V/V2I) (broadcast/groupcast)<br><br>Event triggered messages<br>(V2V/V2I) (broadcast/groupcast/unicast) | (13) Group Start<br>(22) Automated Intersection Crossing/Manager<br>(27) Vehicles Platooning in Steady State<br><br>(17) Obstructed View Assist<br>(20) Remote Automated Driving Cancellation<br>(30) Law Enforcement Messaging<br><br>(25) Vehicle Shares Information on Road Hazards/Events<br>(37) Awareness Confirmation |
| Event triggered messages<br>(V2I) (broadcast/groupcast/unicast) | (8) Speed Harmonisation<br>(33) Infrastructure Assisted Environment Perception |
| Delay sensitive<br><br>Continual or event triggered messages<br>(V2N) (broadcast/groupcast/unicast) | (12) Vulnerable Road User (VRU)<br>(14) Tele-Operated Driving<br>(15) Tele-Operated Driving Support<br>(16) Tele-Operated Driving for Automated Parking<br>(17) Obstructed View Assist<br>(19) Continuous Traffic Flow via Green Lights Coordination<br>(20) Remote Automated Driving Cancellation<br>(21) High-Definition Map Collecting and Sharing<br>(27) Vehicles Platooning in Steady State<br>(30) Law Enforcement Messaging<br>(31) Patient Transport Monitoring<br>(34) Infrastructure Based Tele-Operated Driving<br>(44) Bus Lane Sharing Request and Revoke |
| Delay non-sensitive<br><br>Event triggered messages<br>(V2N) (unicast) | (5) Software Update<br>(23) In-Vehicle Entertainment (IVE)<br>(26) Software Update of Reconfigurable Radio System<br>(29) Autonomous Vehicle Disengagement Report<br>(32) Accident Report<br>(35) Automated Valet Parking:<br>Joint Authentication and Proof of Localisation<br>(36) Automated Valet Parking: Wake-up<br>(39) Curbside Management |

For the scenarios involving continual repetitive messages, the spectrum needs are calculated by accumulating the total offered data traffic and deriving the total amount of bandwidth required for its reliable radiocommunication given the spectral efficiency of the radiocommunications system.

Specifically, the spectrum needs $B$ (Hz) for continual repetitive messages can be calculated as:

$$B = \frac{M\,N\,F\,a}{e\,u}$$

where:

$B$ : spectrum needs (Hz)
$M$ : number of vehicles within range
$N$ : bits per message
$F$ : repetition rate of message (Hz)
$A$ : fraction of vehicles transmitting
$e$ : spectral efficiency (bit/s/Hz)
$u$ : channel utilisation factor.

In other use cases, event triggered radiocommunications are employed when a vehicle intends to cooperate with other road users to change lanes, navigate an intersection, join a freeway, exploit a gap in the traffic or among parked vehicles, form a group or platoon, or a range of other special manoeuvres. The event triggered use cases appear to vary widely in nature, as a result the number of steps vary from one use case to another and are also dependent on the implementation. Broadly, the sequence involves:

1) Notification and trajectory information
2) Feedback (confirmation/rejection)
3) Decision and feedback
4) Termination.

The spectrum needs $B$ (Hz) of the event triggered radiocommunications are calculated as:

$$B = \frac{N}{(e.u)\,T}$$

where:

$B$ : spectrum needs (Hz)
$N$ : total number of bits
$T$ : delivery time (s)
$e$ : spectral efficiency (bit/s/Hz)
$u$ : channel utilisation factor.

Based on the above, the spectrum needs of a number of important Day-1 and advanced direct radiocommunications use cases (using the 3GPP-specified PC5/sidelink interface) are calculated, and are summarised Table A2-6.

TABLE A2-6

**Spectrum needs for PC5/sidelink interface day-1 and advanced use cases**

| **Continual (repetitive)** | |
|---|---|
| Day-1 use cases (PC5/sidelink) | |
| CAM/BSM | ~ 10 – 20 MHz |
| Advanced use cases (PC5/sidelink) | |
| Cooperative perception | ~ 6 – 220 MHz |
| Vulnerable road user | ~ 2 – 5 MHz (40 – 100 kHz) |

TABLE A2-6 (*end*)

| Event triggered | |
|---|---|
| Advanced use cases (PC5/sidelink) | |
| Group start | ~ 890 kHz + CAM/BSM |
| Cooperative lane merging | ~ 150 kHz+ CAM/BSM |
| Trajectory information sharing [(1)] | ~ 100-200 kHz + CAM/BSM |
| Advanced use cases (miscellaneous) (PC5/sidelink) | |
| Platooning in steady state | ~ 10s of kHz + CAM/BSM |
| Vehicle decision assist | ~ 100 kHz |
| See-through for passing | ~ See-through for Passing |
| Speed harmonisation | ~ 10 kHz |
| Automated intersection crossing | ~ 1 MHz + CAM/BSM |

[(1)] Trajectory Information sharing use cases include: “Cross-Traffic Left-Turn Assist”, “Cooperative Manoeuvres in Emergency Situations”, “Cooperative Lane Merging”, “Coordinated Cooperative Driving Manoeuvre”, “Interactive VRU Crossing”, “Cooperative Lateral Parking”, and “Cooperative Traffic Gap”.

Based on the results of industry studies of the spectrum needs of PC5/sidelink direct radiocommunications (V2V/I/P), the following conclusions are drawn:

a) It is expected that the delivery of day-1 use cases via LTE V2X for the support of basic safety ITS services will require between 10 and 20 MHz of spectrum at 5.9 GHz for V2V/I radiocommunications.

b) It is expected that the delivery of advanced use cases via LTE V2X and NR V2X for the support of advanced driving services will require an additional 40 MHz or more of spectrum at 5.9 GHz for V2V/I/P radiocommunications.

With respect to the advanced use cases, the following is also highlighted:

- “Sensor Sharing for Autonomous Vehicles” is an important advanced driving use case which involves the ability of road users to share their processed sensor data with other road users on a continual basis for what is known as cooperative perception, to provide advanced driver assistance and to facilitate autonomous driving. The appropriate amount of sensor data which should be shared is an open question for the industry, and directly impacts the required spectrum. The analysis also indicates that, depending on the extent of required redundancy in the sharing of sensor information for the implementation of automated driving, the spectrum needs can be as high as a few tens of MHz or even more.
- For advanced “Vulnerable Road User” use case, whereby vulnerable road users (VRUs) such as pedestrians or cyclists share information about themselves by broadcasting continual repetitive messages to other road users. The analysis of this use case for pedestrian VRUs indicates that, depending on the extent of clustering among the VRUs, the spectrum needs in dense urban environments can be up to several MHz.
- Many other advanced driving use cases are event triggered (for example, Cooperative Manoeuvres), that is to say, messages are exchanged over the air only in response to a desire by a road user to undertake a specific manoeuvre (for example, crossing an intersection, changing lanes, joining a freeway, or the like). Here, the road user shares its intended trajectory with other road users as part of a handshake exchange of information, in order to provide advanced driver assistance and to facilitate autonomous driving. Specifically, the analysis indicates that spectrum needs for “Group Start” are of the order of several

hundred kHz (approaching 1 MHz), whereas the spectrum needs for "Cooperative Lane Merging" (and other similar trajectory information sharing use cases) are of the order of around 150 kHz, and in any case both considerably lower than the spectrum needs of the "Cooperative Perception" use case. Notably, the contribution of these event triggered use cases to the overall ITS spectrum needs is stochastic, in the sense that such use cases may or may not occur at the same time and place, and this can result in a highly time variable demand for spectrum at any given location.

- The study has also examined a number of miscellaneous advanced use cases which do not fall under the above categorisations (including "Platooning", "Vehicle Decision Assist", "See Through for Passing", "Speed Harmonisation", and "Automated Intersection Manager"). The analysis indicates that with the exception of "See Through for Passing" which may require several MHz for the radiocommunication of high definition video, the spectrum needs of each of the remaining use cases is unlikely to exceed at most several hundred kHz. Again, the contribution of these use cases to the overall ITS spectrum needs depends on the extent to which they might occur at the same time and place.

The industry report concluded that 70-75 MHz of ITS spectrum in the 5.9 GHz band is needed to support the basic safety and advanced use cases under consideration today.

Furthermore, the report also recognizes and estimates the need for additional spectrum in mobile bands to support cellular network-based (V2N) radiocommunications for the delivery of advanced driving use cases by mobile network operators.

# Annex 3

# Global CAV development

## A3 Status of global CAV development

### A3.1 Region 1 – Europe, Africa and Middle East

#### A3.1.1 Europe

**Project overview**

**Detailed project description**

**5GNetMobil**

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

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

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

**ADAS&ME**

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

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

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

The messages CAMs, CPMs and MCMs were exchanged over standard ITS G5 technology. Additionally, cellular radiocommunication was used to obtain information (such as driving difficulty from a road-layout point of view) from a cloud-based entity.

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

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

**AutoNet2030**

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

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

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

**CMP – Collaborative manoeuvre protocol**

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

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

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

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

The aim of CMP is to form a robust cooperation protocol specifically designed for adverse network conditions[89].

**ICT4CART**

ICT4CART, in alignment with the EU vision, is providing an ICT infrastructure to enable the transition towards road transport automation. To meet this high-level objective ICT4CART is bringing together, adapting and improving technological advances from different industries, mainly telecom, automotive and IT. It adopts a hybrid radiocommunication approach where all the major wireless technologies, that is, cellular and ITS G5, are integrated under a flexible network architecture. This architecture will ensure performance and resilience for different groups of use cases according to the needs of higher levels of automation (L3 and L4). On top of that, a distributed IT environment for data aggregation and analytics is implemented. This offers seamless integration and exchange of data and services between all the different actors, allowing third parties to develop, deliver and provide innovative services, thus creating new business opportunities. Cyber-security and data privacy aspects are considered thoroughly throughout the whole ICT infrastructure. In addition, novel accurate localization services, exploiting the cellular network and information from other sources, such as on-board sensors, especially in complex areas (for example, urban), are addressed.

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[89] O. Sawade, M. Schulze, and I. Radusch, "Robust Communication for Cooperative Driving Maneuvers," IEEE Intell. Transp. Syst. Mag., vol. 10, no. 3, pp. 159-169, Sep. 2018.

To achieve its objectives, ICT4CART, instead of working in generic solutions with questionable impact, builds on four specific high-value use cases (urban and highway) which are demonstrated and validated under real-life conditions at the test sites in Austria, Germany, Italy and across the Italian-Austrian borders.

**iKoPA**

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

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

A major aspect of iKoPA is the secure radiocommunication and authentication in vehicular networks. Therefore, a set of messages is developed that allow for secure authentication at parking garages or charging infrastructure[90]. One outcome of iKoPA is a system that allows automated vehicles to charge in a fully automated manner, in which all aspects of the charging process are considered. The iKoPA platform allows an automated electric vehicle to access a parking area with charging infrastructure, drive to a free charging spot and perform the charging process including the billing process.

**IMAGinE**

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

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

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

**MAVEN**

The objective of MAVEN (Managing Automated Vehicles Enhances Network) is to deliver C-ITS-assisted solutions for managing Cooperative Automated Vehicles (CAVs) at signalized intersections and intersection corridors with the aim of increasing traffic efficiency and safety. MAVEN develops

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[90] O. Sawade *et al*., “Autonomous driving in enclosed car-parks using heterogeneous communication”, 2019.

infrastructure-assisted platoon organization and negotiation algorithms. These help in the management of automated vehicles at signalized intersections and corridors. Thereby, vehicle systems for trajectory and manoeuvre planning and infrastructure systems for adaptive traffic light optimization are extended and connected.

In MAVEN, traffic lights that adapt their signal timing are investigated. These traffic lights facilitate the movement of organized platoons and allow for better utilization of infrastructure capacity. Thereby the vehicle delay and emission are reduced. MAVEN develops a prototype for field tests and extensive modelling for impact assessment. It contributes the development of enablers, for example, standards and high precision maps. MAVEN also provides ADAS techniques for vulnerable road users (VRU). The goal of MAVEN is the development of a roadmap for introduction of vehicle-road automation to support road authorities in the changes of their role and in the tasks of traffic management systems[91].

**MECView**

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

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

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

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

**SecForCARs**

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

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

Within the framework of SecForCARs, the partners are jointly investigating the weaknesses and vulnerabilities of modern vehicles. To this end, they develop a security architecture as well as tools and test methodologies to incorporate both safety and security into the future development process.

[91] "Managing Automated Vehicles Enhances Network." Available: https://cordis.europa.eu/project/id/690727/de; MAVEN project description http://maven-its.eu/.

In addition, security mechanisms are developed based on a vulnerability assessment in order to detect and prevent attacks against the vehicle from inside and outside.

**TransAID**

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

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

**Selected projects on CAV with focus on Collective Perception and Cooperative Manoeuvring**

**Collective perception**

For collective perception, an abstract representation of detected objects is shared via V2X. The originators of the information can be other vehicles, or road infrastructure, or both.

**AutoNet2030**

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

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

Further information about the Cooperative Sensing Service can be found in the deliverable of the AutoNet2030 project[92].

**IMAGinE**

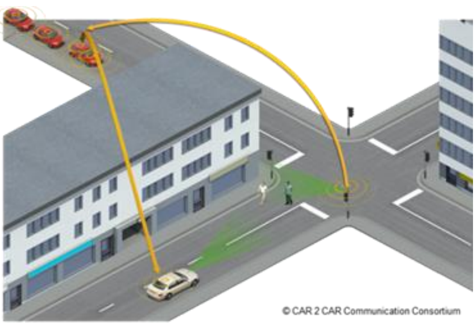
In the IMAGinE system, cooperative vehicles use the Collective Perception Service (CPS) to exchange information about their environment perceived by the onboard sensors (for example, detected objects and free space areas). To enable this service, the Collective Perception Message (CPM) in standardization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

**MAVEN**

MAVEN deals with I2V-assisted automated driving solutions at C-ITS equipped signalized intersections and corridors. Therefore, it applies CPS for protection of VRUs and drivers in such scenarios. Figure A3-1 represents an example of CPS usage for this purpose.

FIGURE A3-1

**MAVEN application of CPS at intersection scenarios**




Isolated cooperative automated vehicles (CAVs) and/or CAVs organized in a Cooperative Adaptive Cruise Control (CACC) string (in red) are heading towards the same intersection equipped with C-ITS and detection capabilities. Conventional traffic or VRU in dangerous positions can be detected only by a subset of the approaching CAVs and by the intersection sensors. On the contrary, other CAVs cannot detect the risk (for example, in Fig. A3-1, the string of red CAVs is not capable to detect the pedestrians since they are hidden around the corner). Knowing about the presence of hidden obstacles would give CAVs more information for planning paths in a safer way (for example, in Fig. A3-1, if the platoon needs to turn right). In fact, with this additional information, CAVs might decide to slow down preventively before getting in proximity of the stop line and checking with on-board sensors if the obstacle still represents a risk. In order to let CAVs aware of VRUs and other unequipped vehicles that cannot be locally detected at road intersections, collective perception is used at both vehicles and infrastructure side. For this purpose, MAVEN contributed to CPS pre-standardization at ETSI TC ITS by proposing adaptation of the CPM message format to convey information suitable for describing and handling object detections performed by the road infrastructure (for example, different

[92] AutoNet2030, Deliverable D3.2 – Specifications for the enhancement to existing LDM and cooperative communication protocol standards, 2015.

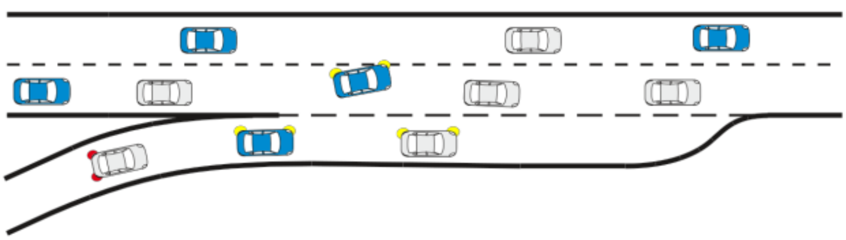
sensing capabilities, distinct coordinate systems, etc.)[93]. The above-mentioned CPS use case scenario has been tested by MAVEN with proving ground tests using a CAV prototype vehicle.

**TransAID**

To optimally calculate traffic management decisions, the C-ITS infrastructure needs to achieve a more precise and real-time assessment of traffic demands and stream (for example, how many vehicles, and of what categories are heading the transition areas). The estimation of traffic demands is achieved by the TransAID road infrastructure through analysis or received CAMs and CPM messages. In particular, receiving CPMs is of special relevance in a mixed traffic scenario where conventional and cooperative (automated) vehicles coexist. This information can be employed to detect conventional vehicles that cannot share their presence due to lack of connectivity. As a result, the road infrastructure can employ this information, together with the information about the ego vehicle (CAMs), to estimate the status and composition of the traffic stream (see Fig. A3-2).

FIGURE A3-2

**Typical example of CPS application in TransAID: cooperative (automated) vehicles supporting CPS (in blue) inform the road infrastructure about presence of non-connected vehicles**[94]



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

**SecForCARs**

SecForCARs investigates security implications of Collective Perception as standardized by the ETSI[95]. Specifically, Misbehaviour Detection in that context is considered because relying on potentially false perception data from untrusted sources can lead to severe safety risks.

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93 MAVEN consortium, "Deliverable D5.1: V2X communications for Infrastructure assisted automated driving," February 2018.

94 TransAID Consortium, "Deliverable D5.1: Definition of V2X message sets," 2020.

95 ETSI, "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Analysis of the Collective Perception Service (CPS)," *Draft TR 103 562 V0.0.16*, vol. 1, pp. 1-119, 2019.

**Manoeuvre Coordination with Intention Sharing**

Intention sharing will share abstract representation of driving states which do not require a negotiation or 2-way radiocommunication (for example, emergency braking, Transition of Control, minimum risk manoeuvre, in-out manoeuvre at an intersection).

**MAVEN**

MAVEN deals with I2V-assisted automated driving solutions at C-ITS equipped signalized intersections and corridors including platoon driving through those intersections and corridors. For this, MAVEN supports CAVs' interactions in an efficient and backward compatible way by defining ETSI ITS CAM extensions: MAVEN CAVs and cooperative intersections will be able to process the whole extended message, pre-MAVEN cooperative vehicles and infrastructure will discard the extensions yet process the rest of the received message. As indicated in Fig. A3-3, two separate extended CAMs are defined (the MAVEN extensions are highlighted in light grey). Some of the content of these extensions can be seen as information related to intention sharing, because the content of those extensions does not necessarily imply the establishment of negotiation sessions with other vehicles or infrastructure units. In particular, the Extended CAM on SCH0 carries, besides other information, CAV and/or platoon features (planned route, platoon ID, participants, etc.) usable by cooperative intersections to perform traffic light signal timing optimization. As indicated in Fig. A3-3, this information is contained in an optional special vehicle container called MAVENAutomatedVehicleContainer, better detailed in Table A3-1.

FIGURE A3-3

**MAVEN CAM extensions**

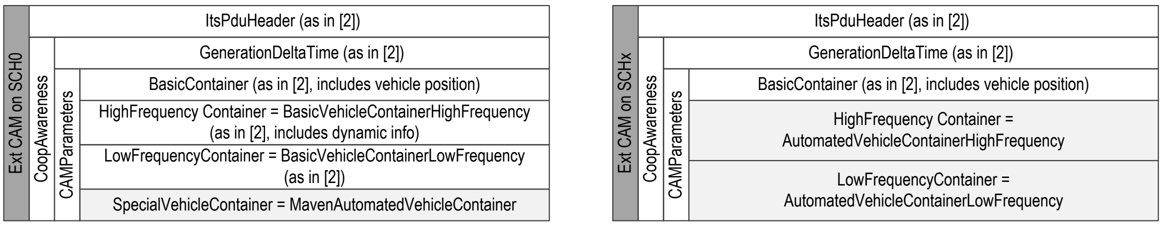



TABLE A3-1

**Content of the MAVEN Automated Vehicle container**

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

**Manoeuvre Coordination with Trajectory Sharing**

Trajectory sharing will share a short-term planned trajectory implying one-way radiocommunication.

**MAVEN**

MAVEN addresses urban platooning in a very different way compared to other developments targeting highways. Based on a common distributed algorithm and V2V exchanged information, individual CAVs shall form platoons, manage their operation (joining, leaving, etc.), and control their motion. In this sense, MAVEN platooning can be seen as an extended Cooperative ACC[96]. The C-ACC-like vehicle control and platoon management is executed independently at each individual vehicle following a common distributed protocol. Adopting dedicated messages instead of small extensions of already deployed messages would imply additional channel load (due to the overhead of lower layers' protocol headers). A complete description of the ASN1 definitions for the different data elements of the MAVEN extended CAMs (including the representation of the planned trajectory) is provided[97].

TABLE A3-2

**Content of the Automated Vehicle containers in the MAVEN extended CAM on the SCHx**

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

**Manoeuvre coordination and cooperative trajectory planning**

Cooperative trajectory planning will share a V2V short-term local coordination including planned and desired trajectory implying adaptation of ego-trajectory to other cars trajectory.

**IMAGinE**

In the IMAGinE-System, the Manoeuvre Coordination Service realizes the exchange and negotiation of prospective trajectories between neighbouring vehicles. This allows a group of vehicles to find a common joint manoeuvre that optimizes their global benefit. Since currently there is no standardized V2X message type for the exchange of prospective trajectories, a new message type called "Manoeuvre Coordination Messages (MCM)" is specified and implemented in IMAGinE. The MCM

[96] ETSI, "Intelligent Transport Systems (ITS); Cooperative Adaptive Cruise Control (CACC); Pre-standardization study", vol. 1, pp. 1-45, 2019.

[97] MAVEN consortium, "Deliverable D5.1: V2X communications for Infrastructure assisted automated driving", February 2018.

essentially contains a list of attributed trajectories of the ego vehicle which are generated in the system module "manoeuvre planning and coordination".

**Manoeuvre Coordination and Cooperative Manoeuvre planning**

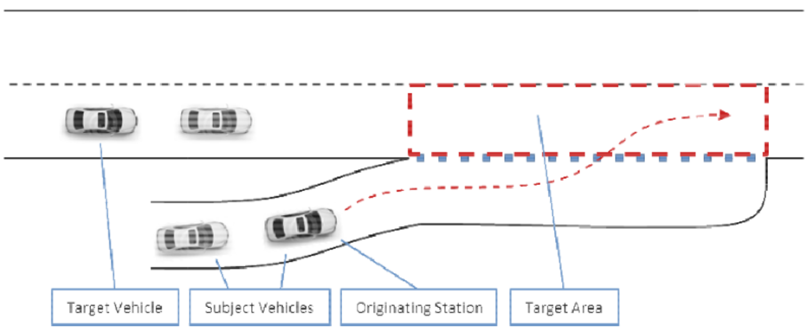
Cooperative Manoeuvre planning will share V2V short-term strategic coordination of manoeuvres (for example, lane-changes) implying 2-way radiocommunication of abstract manoeuvre representations.

**AutoNet2030**

In AutoNet2030, the Cooperative Lane Change Service (CLCS) supports the planning and execution of a lane change of a single vehicle or a group of vehicles (for example, platoon) in collaboration with surrounding cooperative vehicles. Figure A3-4 illustrates a situation where two subject vehicles intend to perform a cooperative lane change.

FIGURE A3-4

**Planned lane change manoeuvre**




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

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

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

The CLCS is executed by exchanging Cooperative Lane Change Messages (CLCM). There are four types of CLCM: laneChangeRequest, laneChangeResponse, laneChangeAbort and laneChangePrepared. Each of these message types contains the relevant information that is exchanged by the involved vehicles for every manoeuvre phase. Further information about the Cooperative Lane Change Service is available[98].

**ADAS&ME**

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

**EU commission Horizon Europe and CEF2 calls**

→ CCAM Partnership

→ CEF calls in Move and Connect.

## A3.2 Region 2 – Americas

### A3.2.1 Canada

This section details a few examples of pilot deployments and research facilities in Canada.

*Area X.O*

Established and operated by Invest Ottawa, Area X.O enables and accelerates the safe and secure development, testing, and application of next generation technologies in smart mobility, autonomy and connectivity for sectors that span telecom; smart agriculture; defence, security, and public safety; unmanned aerial vehicles; and smart cities. This 1 866-acre facility offers:

1) V2X (vehicle-to-everything) testing, validation and demonstration in a four-season climate with temperatures from −39 to +39 degrees Celsius (−38 to +102 degrees Fahrenheit).
2) Integrated test facilities with GPS systems, terrestrial wireless systems, and satellite radiocommunication systems; networking infrastructure; cybersecurity solutions; and industry-leading data gathering, analysis and cloud capabilities.

In CAVs and smart mobility, Area X.O enables innovation in:

1) Vehicle-to-Vehicle (V2V) radiocommunication use cases and systems
2) Vehicle-to-Infrastructure (V2I) technologies and systems
3) Next-generation networks that underpin V2V and V2I innovation and use cases
4) Software, hardware, and associated cybersecurity technologies required to integrate these capabilities into automated vehicles and municipal infrastructure
5) CAV operations in inclement weather, including systems that pinpoint the location of hidden objects, cybersecurity, interoperability and use of CAV-generated data.

For additional information, please visit www.AreaXO.com and www.investottawa.ca.

**Alberta Cooperative Transportation Infrastructure and Vehicular Environment (ACTIVE)**

The Alberta Cooperative Transportation Infrastructure and Vehicular Environment (ACTIVE) test bed was launched in 2014 as a collaborative effort between the Government of Canada, Government of Alberta, City of Edmonton, the University of Alberta’s Centre for Smart Transportation (CST) and the University of British Columbia and is part of Canada’s first network of test beds for connected

[98] AutoNet2030, “Deliverable D3.2 – Specifications for the enhancement to existing LDM and cooperative communication protocol standards,” 2015.

vehicles. The test bed is managed by the University of Alberta and includes 51 roadside equipment (RSEs) deployed within the City of Edmonton, and an additional 15 RSEs deployed on private roads inside University of Alberta South Campus. There are two additional C-V2X RSEs installed on South Campus, positioned alongside DSRC RSEs. Many of the connected intersections also include microwave or radar sensors for classifying vehicles, or traffic cameras with the ability to stream video remotely. The ACTIVE test bed also contains a number of vehicles equipped with OBEs.

The test bed focuses on research to explore how connected technology can enhance safety and increase traffic capacity. Demonstrated use cases include MAP and SPaT messages at connected intersections, pedestrian alerts, demonstrations of trusted vs untrusted messages (secured using credentials issued by a Security Credential Management System), red light and speed violation warnings, and a variety of standardized use cases using the messages defined in SAE J2735. Additionally, the location of the test bed makes it ideal to provide an environment to test CV systems in harsh winter conditions.

For more information on this test bed, please visit https://www.ualberta.ca/engineering/research/groups/smart-transportation/research/projects/connected-vehicles.html.

**Automotive testbed for Reconfigurable and Optimized Radio Access (AURORA)**

The Automotive testbed for Reconfigurable and Optimized Radio Access (AURORA) was launched in 2014 as a collaborative effort between the Government of Canada, Government of Alberta, City of Edmonton, the University of Alberta's Centre for Smart Transportation (CST) and the University of British Columbia. It is administered by the University of British Columbia (UBC) and is part of Canada's first network of connected vehicle test beds. The current deployment consists of 3 connected intersections, each with a traffic camera, roadside unit, Wi-Fi access point for backhaul connection, and a connection to a traffic signal controller. An OBE-equipped vehicle is available to send and receive messages (mock BSMs and SPaT messages) and additional devices are being bench-tested in a lab setting as well.

The AURORA test bed is heavily focused on the physical radiocommunication layer and has produced results that allow for the detection of interference or misuse of the DSRC spectrum.

For additional information on this test bed, please visit http://rsl.ece.ubc.ca/Aurora.html.

**Automated shuttles deployments (City of Montreal, Candiac, ELA project, Transport Canada)**

Multiple automated shuttle pilots have been conducted throughout Canada in recent years.

– The City of Montreal has previously tested a 12-passenger automated bus to help tourists travel between three major tourist attractions and another 15-passenger fully electric automated shuttle to ferry passengers around a shopping plaza.
– (For more information, please visit: https://montreal.ca/en/articles/automated-electric-shuttles-plaza-saint-hubert-19054).
– The City of Candiac, Keolis Canada, NAVYA, Propulsion Québec and the Technopôle IVÉO have piloted a fully electric autonomous shuttle on public roads. The route in Candiac was 2 km long, running between a large public transit hub, city hall and local businesses. (For more information, please visit: https://space.uitp.org/initiatives/candiac-av-canada).
– The Electric Autonomous shuttle (ELA) has been tested in various cities across western Canada. The project used a fully electric 12-passenger shuttle to collect feedback from residents on their experience using an automated vehicle and facilitate cold weather testing. (For more information, please visit: https://www.ridewithela.ca/).

– Transport Canada tested a 6-passenger fully electric shuttle to better understand the driving abilities of low-speed automated shuttles. The tests included closed-track testing and on-road trial in Ottawa, with the vehicle being exposed to winter conditions during the trial. (For more information, please visit: https://tc.canada.ca/en/corporate-services/transport-canada-s-annual-research-development-deployment-highlights#highlight6).

**Automotive Centre of Excellence (ACE) – University of Ontario Institute of Technology**

The Automotive Centre of Excellence (ACE) is the first independent testing and research centre of its kind in Canada, owned and operated by the University of Ontario Institute of Technology (UOIT). It is a multi-purpose centre divided into two sections: a core research facility, and an integrated research and training facility. It was developed in partnership with UOIT, General Motors of Canada, the Government of Ontario, the Government of Canada and the Partners for the Advancement of Collaborative Engineering Education (PACE). It is a suitable place to test alternative fuel and hybrid and electric vehicles.

Please visit https://ace.ontariotechu.ca/index.php for additional information.

**City of Calgary V2I Test Bed**

The City of Calgary was awarded funding by Transport Canada to establish a connected vehicle corridor on 16th Avenue North, comprised of 16 dual mode (DSRC and C-V2X) RSEs. The primary focus of the project was to test emergency vehicle preemption and 4 fire department vehicles were equipped with OBEs for testing. Additionally, the corridor was used to test an application to help visually impaired pedestrian navigate the crosswalk, in partnership with the Canadian National Institute for the Blind (CNIB).

More information is available here: https://www.calgary.ca/roads/connected-vehicles.html

**Cooperative Truck Platooning Systems (CTPS) Testing and Guidance**

Transport Canada has conducted track-testing of cooperative truck platooning to test fuel consumption and behaviour of platooning trucks at the Motor Vehicle Test Center in Blainville, Québec. Tests scenarios included hard braking events and vehicle cut-ins. The testing results helps Transport Canada define the conditions for safe operation of a platoon.

Additionally, the Alberta Motor Transport Association is running an on-road trial using an existing Canadian trucking fleet with professional drivers for Transport Canada. The pilot is looking at human factors (driver fatigue, vigilance, etc.) as well as vehicle analytics (fuel consumption, traffic interactions, etc.). The results will be used to advance national platooning guidance, best practices, and standards for Canada.

For additional information, please visit https://tc.canada.ca/en/corporate-services/transport-canada-s-annual-research-development-deployment-highlights#highlight3

**Motor Vehicle Test Center (MVTC)**

The Motor Vehicle Test Centre (MVTC) is a world-class facility that supports transportation-related research, development and demonstration. Transport Canada and PMG Technologies have partnered to test crash avoidance systems – such as lane-keeping assist, automatic emergency braking and pedestrian detection – in various environments, as well as vehicle-to-vehicle (V2X) technologies. The site features environmental chambers, low-speed, high-speed and dynamic test tracks and an intersection equipped with traffic control devices.

More information is available here: https://www.tc.gc.ca/en/services/road/innovative-technologies/automated-connected-vehicles/testing-research.html.

**Regional Technology Development Sites (RTDS)**

The Ontario Vehicle Innovation Network (OVIN) is an initiative from the Government of Ontario to accelerate the development and commercialization of electric, connected and autonomous vehicle, and mobility technologies. It has seven Regional Technology Development Sites (RTDS) that each focus on a unique aspect of the automotive and smart mobility sector, such as hardware, security, and data analytics. The RTDS are located in Waterloo, Ottawa, Hamilton, Durham, Windsor-Essex, Toronto and a Northern RTDS that includes Greater Sudbury, Thunder Bay, Timmins, Temiskaming Shores, Sault Ste. Marie and North Bay.

The development sites are used to bring together stakeholders to support testing, validation and commercialization of automotive technologies. Additionally, these sites provide access to specialized equipment and support regional testing and piloting of technologies.

For more information on the development sites, please visit https://www.ovinhub.ca/ecosystem/regional-technology-development-sites/.

### A3.2.2 United States of America

The U.S. Government is actively pursuing a range of regulatory and non-regulatory activities that will enable the adoption of AVs, with the overall goal to facilitate the safe and full integration of AV technologies into the national surface transportation system. Integration would help realize the great potential AV technologies have for enhancing public safety, making systems more efficient, and facilitating economic vitality.[99]

The United States has not identified any spectrum specific to CAV. In 2020, the U.S. regulator decided to reduce the 75 MHz of spectrum previously assigned for ITS to 30 MHz at 5 895-5 925 MHz and specified the use of 3GPP Cellular-Vehicle to Everything Technology. The U.S. regulator decided that with the availability of cellular networks and other technologies such as ultrasonic sensors, lidar, perceptive sensors, optical cameras and automotive radar, 30 MHz in the 5.9 GHz band was sufficient for currently defined safety-related use cases. The United States has made 76-81 GHz available for automotive radar applications that support road safety, including long-range radar useful for automated emergency braking and adaptive cruise control systems. The U.S. regulator has not specified the particular Cellular-Vehicle to Everything radio access technology to be used – "Release 14 which is based on LTE technology or Release 16 which incorporates 5G technology."[100] At this time, the regulator also notes "…that 5G is not backwards compatible with LTE."[100] The U.S. regulator also concluded that "DSRC-based ITS has not lived up to the original promise of achieving the ITS goals identified"[101]. Previous DSRC-based ITS deployments have sunset or are in the process of transitioning under new waiver rules to operate in the 5 895-5 925 MHz band. As of July 2023, initial waivers are being reviewed for LTE-based C-V2X deployment. Final rules and operating parameters are still being finalized by the Federal Communications Commission.

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99 https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/360956/ensuringamericanleadershipav4.pdf.

100 Federal Register / Vol. 86, No. 83 / Monday, May 3, 2021 / Proposed Rules, 23328.

101 Federal Register / Vol. 86, No. 83 /Monday, May 3, 2021 / Rules and Regulations, 23281.

**CARMA[102]**

The Federal Highway Administration (FHWA) developed the innovative CARMA$^{SM}$ Platform to encourage collaboration with the goal of improving transportation efficiency and safety. FHWA's interest in advancing Transportation Systems Management and Operations (TSMO) strategies with automated driving technology is focused on how infrastructure can move traffic more efficiently.

CARMA enables Automated Driving Systems (ADS) to navigate more safely and efficiently with other vehicles and roadway infrastructure though communication and cooperation. CARMA was designed using open source software (OSS) and is available on GitHub. The unique platform was created to work collaboratively with any vehicle, hardware, or control system. By simplifying software development and providing access to increased functionality and a community of developers, CARMA enables the research and development (R&D) of cooperative automated driving system (CADS) capabilities to support TSMO.

CARMA also will develop a concept of operations for new TSMO strategies, such as identifying Traffic Incident Management (TIM) scenarios that provide new strategies for first responder use cases interacting with ADS. This research will accelerate market readiness and the deployment of cooperative automated driving technology, while advancing safety, security, data, and artificial intelligence.

Beyond reducing traffic congestion and improving transportation safety, CARMA will support industry collaboration and expand on existing automation capabilities to reduce R&D time and advance cooperative automated driving technology. CARMA promotes collaboration and participation from communities of engineers and researchers to advance the understanding of cooperative automated driving using OSS and agile project management practices.

**Vehicle Platooning[103]**

In June 2018, FHWA tested a cooperative automation system on the Virginia I-95 express lanes in cooperation with the Virginia DOT and TransUrban, the operator of the express lanes. FHWA previously had conducted Human Factors studies and controlled testing of cooperative adaptive cruise control, but the Virginia tests happened in a real-world situation on an open road. The research project represented the next step in assessing the potential of CDA to reduce traffic congestion.

**Truck Platooning[104]**

In collaboration with the Intelligent Transportation Systems (ITS) Joint Program Office (JPO) and the Federal Motor Carrier Safety Administration (FMCSA), FHWA is managing the Truck Platooning Early Deployment Assessment project to understand how truck platoons will operate in a realistic, operational environment. This project will assess various aspects of inservice truck platoons that deliver commercial goods by a fleet operator on their common delivery routes over an extended period. Previous research resulted in the development of truck platooning technology with only limited testing and demonstration in a real-world environment.

102 https://highways.dot.gov/research/research-programs/operations/carma-overview.

103 https://highways.dot.gov/automation.

104 https://www.youtube.com/watch?v=iNTKqh7i5jQ & https://highways.dot.gov/automation.

**Eco-Approach and Departure**[105]

FHWA is working with the automotive industry to evaluate concepts to improve traffic flow through intersections. Initial tests indicate that cooperative automation on signalized arterials can reduce and smooth the flow of traffic through intersections while reducing fuel consumption and emissions.

## A3.3 Region 3 – Asia-Pacific

### A3.3.1 China (People's Republic of)

The Government of China has carried out top design, strategic layout and development planning for CAV, and has formed a systematic organizational and working system.

**Standardization**

In 2018, Ministry of Industry and Information Technology (MIIT) and the Standardization Administration of China have jointly issued a series of documents of "Guidelines for Construction of National V2X Industrial Standard system" from several aspects, such as the general requirements, Intelligent Connected Vehicles (ICV), Information and Communication Technologies, electronic products and services, and intelligent vehicle management. Among them, CAV in this report is corresponding to ICV. In July 2023, the part of ICV of the National V2X Industrial Standard System was updated to adapt to the new needs and trends of CAV, a more complete standard framework, more comprehensive content, and clearer standard system guideline has been formed, laying a solid foundation for the high-quality development of the intelligent connected vehicle industry. The typical CAV related use cases in § 5.2 have been formulated in "T/CSAE 157-2020 Cooperative Intelligent Transportation System: Vehicular Communication Application Layer Specification and Data Exchange Standard Phase II" with the consideration of the realistic conditions in China.

**CAV Related Spectrum Regulations**

In order to promote the application and development of intelligent connected vehicles based on C-V2X in China, the 5 905-5 925 MHz is specified by the Bureau of Radio Regulation of MIIT of China as the operating frequency band for the LTE-V2X direct communication. Under the leadership of the radio regulatory authority of the state and the people's government of the province, autonomous region or municipality directly under the Central Government, the radio regulatory authority of the province, autonomous region or municipality is responsible for radio regulation in fields of exercise the licensing for the use of radio frequencies of LTE-V2X direct communication. The installation and using of LTE-V2X devices (e.g., RSU, OBU, etc.) by the qualified applicant companies should apply for the licenses with the granted approval from the related radio regulatory authority.

**Large-Scale Applications of CAV Related Spectrum Regulations**

The clear spectrum policy of China plays an important and positive role in promoting large-scale applications and the progress of CAV related tests, verifications and demonstrations.

In order to promote CAV based on C-V2X related ICV, Intelligent Transportation System (ITS) and Smart Cities research and development, China has carried out strategic layout and approved development planning for three types of Pilot and Demonstration Areas:

(1) National Pilot Areas: China has built seven National Pilot Areas, including Wuxi City in Jiangsu Province, Xiqing District in Tianjin Municipality, Changsha City in Hunan Province, Liangjiang District in Chongqing Municipality, Deqing County in Zhejiang Province, Liuzhou City in Guangxi Province, and Xiangyang City in Hubei Province.

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105 https://www.youtube.com/watch?v=I753gGLJAcg and https://highways.dot.gov/automation.

(2) Demonstration Areas: Ministry of Industry and Information Technology (MIIT), Ministry of Transport (MOT), and Ministry of Public Security (MPS) have actively promoted and cooperated with local governments to support the construction of 17 ICV Demonstration Areas in Beijing, Shanghai, etc. Different climatic conditions and geomorphic characteristics are considered in order to carry out tests under diverse conditions.

(3) Pilot Cities of "Smart Cities and ICV": The Ministry of Housing and Urban-Rural Development (MoHURD) and MIIT approved two batches of 16 Pilot Cities, including Beijing, Shanghai, and Guangzhou, etc., for the coordinated development of infrastructures of "Smart Cities and ICV".

The series of large-scale C-V2X interoperability test activities from 2018 to 2023 have been organised by the C-V2X Working Group of the IMT-2020 (5G) Promotion Group and the China Industry Innovation Alliance for the Intelligent and Connected Vehicles (CAICV). From "Three Layers", "Four Layers" and "New Four Layers", the interoperability among diverse chipsets, terminals, OEMs, and security platforms is tested and verified. The typical CAV applications, such as Cooperative Vehicle Merge, Cooperative Lane Change, Sensor Data Sharing, etc., have been tested based on LTE-V2X in the series of large-scale C-V2X interoperability test activities.

### A3.3.2 Japan

**Study Group on Next-Generation ITS Communications for Cooperative Automated Driving**

The Ministry of Internal Affairs and Communications (MIC) of Japan held a Study Group on Next-Generation ITS Communications for Cooperative Automated Driving to consider approaches to such communications and published an Interim Report in 2023. The key issues studied were use cases for the next-generation of ITS communications, measures to interwork between V2X and V2N communications, draft allocation policy and deployment roadmap for 5.9 GHz band V2X communications. The Interim Report stated that consideration should be firstly given to allocating up to 30 MHz of bandwidth in the 5 895-5 925 MHz frequency band for V2X communications, and that towards the target of introducing 5.9 GHz-band V2X communication equipment around 2030 and deploying cooperative automated driving such as mediated and negotiated merging assistance around 2040, the roadmap should be specified with use cases to be demonstrated and verified and environmental improvements.

**SIP-adus Programme in Japan**

The Government of Japan worked SIP-adus (SIP's[106] Automated Driving for Universal Services) programme[107] aiming to solve issues of concern in today's society through realizing automated driving, including reducing traffic accidents, alleviating traffic congestion and securing a means of transportation for people with limited mobility, such as the elderly living in remote regions, among other issues. This programme started in Fiscal Year 2014 and entered its 2nd Phase in Fiscal Year 2018 and ran until FY 2022. In the 2nd Phase the scope was extended to include automated driving on general public roads and application to logistics and transportation services, as shown in Fig. A3-5.

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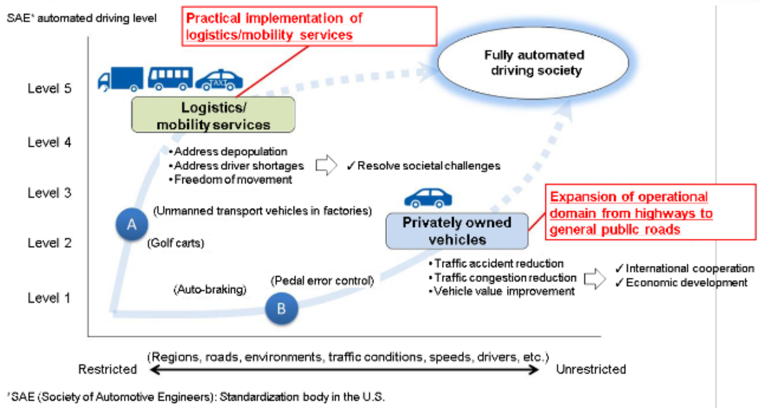
[106] SIP stands for The Cross-Ministerial Strategic Innovation Promotion Program (SIP) and is a group of R & D programmes for achieving science, technology and innovation as a result of the Council for Science, Technology and Innovation exercising its headquarters function to accomplish its role in leading science, technology and innovation beyond the framework of government ministries and traditional disciplines. SIP-adus is one of SIP programmes.

[107] For further information, see https://en.sip-adus.go.jp/.

FIGURE A3-5

**Overview of the 2nd Phase SIP-adus**




The programme envisioned a scenario for the commercialization and service of fully automated driving by 2025. For this, it targeted to establish the cooperative areas technologies essential for implementation by 2023 and to create multiple example cases for commercialization through Field Operational Test (FOTs) by involving various businesses and local governments.

In October 2019, FOTs started in the Tokyo waterfront city area (general roads and Metropolitan Expressway / Haneda area) with wide participations. The program underwent testing to provide signal display and change timing information to vehicles, even in environments where recognition is difficult using in-vehicle cameras; to assist vehicles merge onto the main lane of highways; and to operate public transport system (self-driving buses) by using automated driving technology in mixed traffic flow.

Under SIP-adus programme, a study was conducted regarding cooperative driving automation and advanced safety driver assistance. Firstly, in the study, as many use cases as possible were collected from projects in Europe, the United States and Asia, including those studied by the Japan Automobile Manufacturers Association, Inc. (JAMA). The use cases collected varied in terms of the expected time frame of the launch. Instead of securing all the use cases, the study decided to focus on those cases with certain assumptions. Firstly, the study assumed that all traffic participants would comply with the law and regulations in principle. Secondly, the study excluded from the scope, functional elements that can be realized by autonomous automatic driving systems. Lastly, three features were taken into account as those that characterize cooperative automated vehicles: that vehicles 1) obtain information beyond the detection range of on-board sensors, 2) provide information of one's own vehicle, and 3) interact with other vehicles or infrastructure with V2V and V2I connectivity. Consequently, eight (8) functional elements of use cases are selected for consideration. In September 2020, the results of this study were documented as the first output[108]. Based on the results, the study moved to the next phase on the subject of radiocommunication technology requirements and new radiocommunication protocols.

### A3.3.3 Korea, Republic of

MOLIT (Ministry of Land, Infrastructure and Transport) has a long term plan to deploy C-ITS applications in Korea. In 2014, a pilot test site for C-ITS applications was chosen in Sejong city, and the pilot test was performed to validate C-ITS applications. In 2018, the C-ITS system was deployed on Jeju island and Seoul metropolitan city. The C-ITS digital infrastructure was designed to support unexpected road situations, traffic signal information and location error compensation data for accurate positioning. The platooning and urban driving use cases of automated driving are tested to

108 https://en.sip-adus.go.jp/rd/rddata/usecase.pdf.

validate the usefulness of C-ITS digital infrastructure. The urban driving use case is focused on intersection safety.

MOTIE (Ministry of Trade, Industry and Energy) has conducted a pilot test on FCEV (Fuel Cell Electric Vehicle) automated bus for BRT (Bus Rapid Transit) route in Sejong city by the end of 2021. The C-ITS digital infrastructure supports hybrid radiocommunications using both IEEE 802.11 WAVE and LTE with the SAE J2735 compliance.

MSIT (Ministry of Science and ICT) has launched the Giga KOREA project to achieve 5G radiocommunication technology and applications since 2014. Along the 5G service demonstration in 2018 PyeongChang Winter Olympic Games, the 5G service are commercialized in 2019. And there were field trials to apply for CAV use cases in Seoul and Daegu city. CAV use cases are tested by using the merits of the key technical characteristics of 5G radiocommunication: high data rate, the low latency and high reliability. The use cases of 5G radiocommunication are automated shuttle bus, remote control and entertainment.

Platooning is tested on highway based on C-ITS digital infrastructure and V2X radiocommunication technologies (example, IEEE 802.11p and LTE) are used to form or deform vehicle groups, share the leading vehicle’s control and location error compensation information. The typical use case in urban driving is intersection safety warning. This use case uses traffic signal information which is transformed into LDM (Local Dynamic Map) and transmitted to the automated vehicle. This use case also needs V2X radiocommunication with low latency and high reliability. The service functions of FCEV automated bus include getting on and off at a stop station, recognizing signal intersections and pedestrian cross-walking, and sharing the BRT route with a manual driving.

Automated shuttle bus drives the test route by using 5G NR radiocommunication technology. This use case needs high accurate positioning, traffic signal timing and status and blind spot information. 5G radiocommunication can support the required information and supports automated driving. Remote control can monitor the vehicle and road status by sending on-board sensors data to the server, and control the vehicle driving remotely. The remote control may be applied for vehicle emergency rescue operation. Entertainment use cases are UHD (Ultra High Definition) display and augmented reality for passengers. These use cases are enabled to use gigabit rate performance of 5G radiocommunication technology. Table A3-3 shows CAV use cases in Korea.

TABLE A3-3

**CAV status in Korea**

| Use cases | Technology/Standard | Frequency band | Pilot project |
|---|---|---|---|
| Platooning | IEEE 802.11 WAVE | 5.855~5.925 GHz | 2018 ~ 2020 |
| | LTE | LTE frequency band | |
| Urban driving | IEEE 802.11 WAVE | 5.855~5.925 GHz | 2016 ~ 2020 |
| | LTE | LTE frequency band | |
| FECV(fuel cell electric vehicles) automated bus | IEEE 802.11 WAVE | 5.855~5.925 GHz | 2019 ~ 2021 |
| | LTE | LTE frequency band | |
| Automated shuttle bus | IEEE 802.11 WAVE, LTE V2X, | 5.855~5.925 GHz | 2018 ~ 2020 |
| | 5G NR | 3.5 GHz, 28 GHz (1) | |

TABLE A3-3 (*end*)

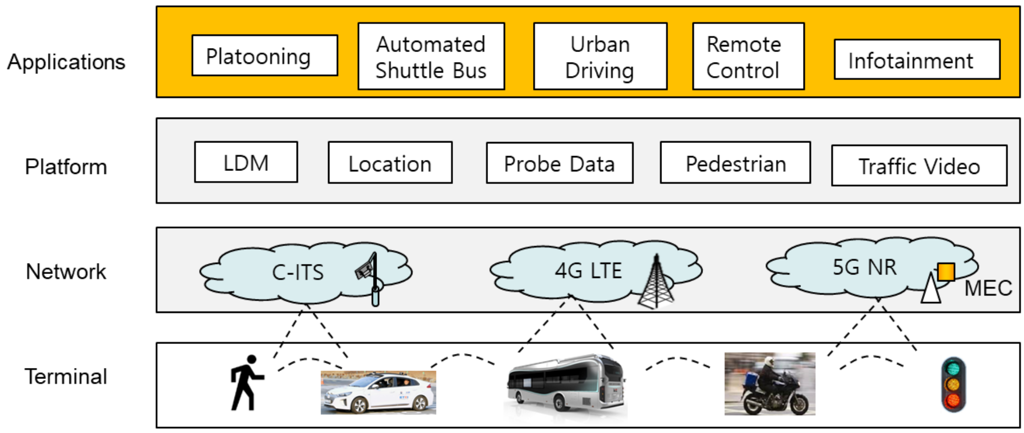
| Use cases | Technology/Standard | Frequency band | Pilot Project |
|---|---|---|---|
| Remote Control | IEEE 802.11 WAVE, LTE V2X, | 5.855~5.925 GHz | 2018 ~ 2020 |
| | 5G NR | 3.5 GHz, 28 GHz [(1)] | |
| Entertainment | IEEE 802.11 WAVE, LTE V2X, | 5.855~5.925 GHz | 2018 ~ 2020 |
| | 5G NR | 3.5 GHz, 28 GHz [(1)] | |

[(1)] Field experiment on 5G communication based mobile edge computing has been performed.

The CAV system has functional elements of use cases, platform, radio communication network and terminal from the aspects of layered architecture. Radio communication network includes C-ITS digital infrastructure system, 4G LTE and 5G NR cellular system with mobile edge computing. Figure A3-6 shows the CAV system architecture.

FIGURE A3-6

**CAV system architecture**

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