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| **Radiocommunication Study Groups** |  |
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| Annex 16 to Working Party 5A Chairman’s Report | |
| WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW  REPORT ITU-R M.[CAV] | |
| Connected Automated Vehicles (CAV) | |

(Question ITU-R 261/5)

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Scope

This Report provides Connected Automated Vehicle (CAV) terminology, descriptions of communication methods and radiocommunication systems for CAV, as well as radiocommunication requirements and 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 [DN] Report ITU-R M.[IMT.C-V2X].

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

[Editor’s note: Add text that “ITS is an application in the land mobile service, and use cases represent specific functionalities within that application." Perhaps also add footnote to explain use case/application terminology in this document relative to others.]

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 communication requirements are a consideration for inclusion of coordinated automated driving maneuvers 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 3-5 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 ITS. ITS is an application operated under mobile service allocations in Article **5** of the Radio Regulations.

This Report addresses overall objectives and radiocommunication requirements for CAVs.

# 2 Vocabulary

[Editor’s note: Consensus reached to move CAV definitions in 4.1 to Section 2. Suggestion to consult with 5A on terms to be incorporated in vocabulary database.]

## 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 communication 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]](#footnote-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 communication 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 communication capability blended with automated functionality beginning at SAE Level ~~3~~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 communication 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) [IoT based CAV (referred to as IoT-CAV). Recently, a vehicle is labeled as IoT-CAV if the ultra-connectivity using IoT devices and platforms is applied for CAV.]

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

9) 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 communications connectivity between vehicles and between vehicles and transport infrastructure – is expected to significantly improve road safety through crash 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

[Editor’s Note: Consider adding “RSE” and “OBE” and creating consistency throughout document on RSE/OBE usage instead of RSU/OBU]

|  |  |
| --- | --- |
| 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 |
| MAP | Map message |
| MCM | Maneuver Coordination Message |
| PCM | Platooning Control Message |
| RSC | Roadside Coordination |
| RSM | Roadside Safety Message |
| RSI | Roadside Information |
| 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  V2VRU  VRU | Vehicle to Everything  Vehicle-to-Vulnerable Road User  Vulnerable Road User |

# 3 Related ITU-R Texts

[Recommendation ITU-R M.1452](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Frec%2FR-REC-M.1452%2Fen&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910756423&sdata=mSNLHbzn3tu1%2F974KmQS%2FHfkY%2FHHQH0KbAM14VOOLv4%3D&reserved=0) “Millimetre wave vehicular collision avoidance radars and radiocommunication systems for intelligent transport system application”

[Recommendation ITU-R M.1453](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Frec%2FR-REC-M.1453%2Fen&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910766419&sdata=1YbuWK4zmNu%2BpXJyvADVHaYMS3vVVHOafPx%2FlWNcjjM%3D&reserved=0) “Intelligent transport systems - Dedicated short range communications at 5.8 GHz”

[Recommendation ITU-R M.1890](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Frec%2FR-REC-M.1890%2Fen&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910776415&sdata=CBuOuYhEUdJNbQg4WHWI354uhqpyN%2FGZBKu3kiIG48A%3D&reserved=0) “Operational radiocommunication objectives and requirements for advanced Intelligent Transport Systems”

[Recommendation ITU-R M.2057](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Frec%2FR-REC-M.2057%2Fen&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910776415&sdata=5lDdQD1wB3Ruy2f3gccyRk2UKXun3dbsH518QBQWAes%3D&reserved=0) “Systems characteristics of automotive radars operating in the frequency band 76-81 GHz for intelligent transport systems applications”

Recommendation [ITU-R M.2084](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Frec%2FR-REC-M.2084%2Fen&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910786409&sdata=5zXuXWKV2DX4W%2BagKxKyLosbTS5D0nbUDZ36jHXJ%2FH4%3D&reserved=0) “Radio interface standards of vehicle-to-vehicle and vehicle-to-infrastructure two-way communications for Intelligent Transport System applications”

Recommendation [ITU-R M.2121](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Frec%2FR-REC-M.2121%2Fen&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910786409&sdata=e66gFradfU5rnXYvJk8rDM8Ez79C5kaeGjW2t2%2FwnJo%3D&reserved=0) “Harmonization of frequency bands for Intelligent Transport Systems in the mobile service”

Report [ITU-R M.2228](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Fpub%2FR-REP-M.2228&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910786409&sdata=NEEk3iq5MrQ5zmXaagnptqFSh0waqXwOUrOODnYOd8I%3D&reserved=0) “Advanced intelligent transport systems (ITS) radiocommunications”

Report [ITU-R M.2322](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Fpub%2FR-REP-M.2322&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910796403&sdata=nHkxl4IzfKtGh8Ub%2F3khDAwVgzaDN2wk8%2FU1hdgJYME%3D&reserved=0) “Systems characteristics and compatibility of automotive radars operating in the frequency band 77.5-78 GHz for sharing studies”

Report [ITU-R M.2444](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Fpub%2FR-REP-M.2444&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910796403&sdata=uMtOaYJrjtRq7JEUVKkYJ6jZ9i0QcPvvCuATrCXVMgw%3D&reserved=0) “Examples of arrangements for Intelligent Transport Systems deployments under the mobile service”

Report [ITU-R M.2445](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Fpub%2FR-REP-M.2445&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910806401&sdata=uRQauQmAtYyyXFXnBb2JmJTfREgW4RGPtPFngwh8Dtk%3D&reserved=0) “Intelligent transport systems (ITS) usage”

[Draft new] Report ITU-R M.[IMT.C-V2X] “Application of the Terrestrial Component of IMT for Cellular-V2X”

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 applications to improve the vehicle safety and comfortable driving. It uses onboard sensors and V2X communications in vehicle and infrastructure domain. The advanced ITS applications are described in ITS usage report ITU-R M.2445. The [cellular component of C-V2X] automated driving applications are described in [DN] Report ITU-R M.[IMT.C-V2X]. [Editor’s Note: Need reference link when available]

] [Editor’s Note: Review paragraph for clarity on report references. Final sentence included in Scope section as “The cellular network connectivity aspects are covered in more detail in [DN] Report ITU-R M.[IMT.C-V2X].”]

As indicated in the definition of CAV in Section 2.1, V2X communication is an essential component of CAVs. V2X communication 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 communication 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, 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 communication.

Figure 4-1 illustrates the relationship between CAV, CV and AV.

FIGURE 4-1

Relationship between CAV, CV and AV

Diagram

Description automatically generated

## 4.2 Relationship between increased crash avoidance capabilities and short range ad hoc communication 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 percentages of such accidents. A BASt study[[2]](#footnote-2) gives potential percentages of the total crash avoidance depending on different driving maneuvers. Overall, up to 50% of vehicle versus vehicle road traffic crashes can be addressed by ADAS, see Table 4-1.

Table 4-1

Driving maneuvers 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 communication among vehicles, or V2V, has the potential to address approximately 80 percent of unimpaired[[3]](#footnote-3) multi-vehicle crashes[[4]](#footnote-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]](#footnote-5). However, the combination of direct V2X communication 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) communication 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), Maneuver 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 communication, 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 communication 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 analyzed in PROSPECT D2.3[[6]](#footnote-6). An overall potential of 55% in fatality and injury reduction was determined for state of the art ADAS.

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

## 4.3 Transmission modes used for CAV communication

Three types of transmission methods are used for CAV communications.

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, i.e. one by one. There is some flexibility in selecting which type of transmission in communication to be used for implementing the V2V/V2I/V2N communications, depending on use cases.

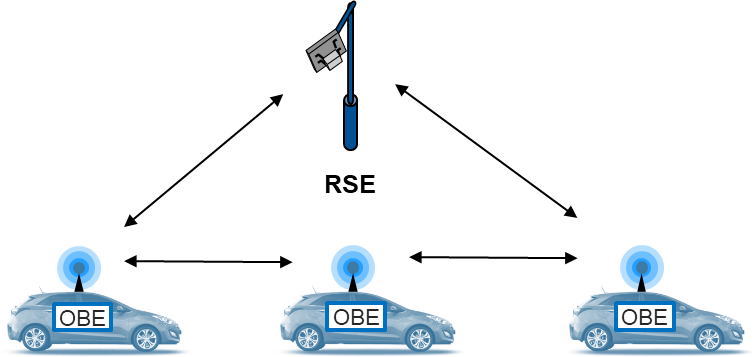
### 4.3.1 Unicast

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 communication. 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 4-2 shows unicast transmission mode.

Figure 4-2

Unicast transmission mode

[Editor’s Note: Two graphics are provided to consider in May 2023 meetings.]



[Editor’s Note: Alternative graphic below to be considered in May 2023 meetings.]

Graphical user interface, application

Description automatically generated

### 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 1 to multiple communication, e.g. group communication. The source of the transmission is the same, with more than one recipient. As an example, a OBE may send a message to a certain OBE in a selected group that satisfy the specified criteria (as shown in figure 4-3-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 figure 4-3-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. Figures 4-3-A and 4-3-B show groupcast transmission mode.

Figure 4-3-A

Groupcast transmission mode from an OBE to a group of OBEs

A picture containing diagram

Description automatically generated

Figure 4-3-b

Groupcast transmission mode from RSE to a group of OBEs

Diagram

Description automatically generated

### 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 communication 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 RSE may also transmit the speed-limit alert information which may be received by multiple OBEs. Figure 4-4 shows broadcast transmission mode.

Figure 4-4

Broadcast transmission mode

Diagram

Description automatically generated

[Editor’s Note: Alternative graphic below to be considered in May 2023 meetings.]

Diagram

Description automatically generated

## 4.4 Radiocommunications approaches for CAV

There are two main radiocommunication approaches for operation of CAVs – ad hoc wireless direct communication and cellular connectivity (requiring base station coverage). Ad hoc communication 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 [DN] Report ITU-R M.[IMT.C-V2X]. 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 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 [Editor’s Note: Consider replacing “radio access layers” with “radiocommunication layer” and to add text to explain “radiocommunication layer”.] enable to actual transfer of messages between the entities.

[Editor’s Note: Consider placement relative to Section 6.1]

The relationship between the different levels / layers can be visualized in the Figure A below:

Figure A

Framework for V2X communications and relationship between different layers

Graphical user interface, text, application

Description automatically generated

## 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]](#footnote-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](https://www.itu.int/pub/R-REP-M.2445) (11/2018) - Intelligent transport systems (ITS) usage (the terminology “applications” is used for “use cases” in Report ITU-R [M.2445](https://www.itu.int/pub/R-REP-M.2445) (11/2018)), provide the foundational safety-of-operation required for CAVs. These use cases also provide the rationale for the inclusion of wireless communication capabilities as a basis for the definition of CAVs. Therefore, the advanced ITS radio interface standards in Recommendation ITU-R [M.2084](https://www.itu.int/rec/R-REC-M.2084/en) (11/2019) - 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 communication 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 Section 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 communication. The automotive industry report provides a framework for grouping and classification of use cases[[8]](#footnote-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]](#footnote-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.

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, e.g. 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, e.g. 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, e.g. 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 maneuvers, Platooning, Automated Valet Parking. The communication system architecture of CAV is basically the same as that of Advanced ITS.

Coordinated automated driving maneuvers are one of the main reasons that wireless communications 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]](#footnote-10)

In this use case, Cooperative Awareness Message (CAM) is periodically sent by a vehicle to provide real-time information about its status, e.g., 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 vehicle stops at the traffic lights and signal request message by emergency vehicles.

Traffic signal information, including current traffic signal color 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.

### 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 radio communication, 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 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. 5.1-1. This abstraction can reduce the amount of radiocommunication data traffic and can ease the burden of radiocommunication.

Figure 5.1-1

Sensing driving by Collective Perception Messages [[11]](#footnote-11)

グラフィカル ユーザー インターフェイス, アプリケーション

自動的に生成された説明

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

In cases where direct V2V communication 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 communication. 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 communication between V2X-equipped participants and incorporates non-equipped V2X traffic participants. CPM can accelerate the effective V2X communication 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, RSUs, devices of pedestrians and V2X application servers. The raw data sharing is described in section 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 at the subsection 5.1.1) ‘Cooperative Awareness’ above.

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 maneuver.

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).

### 5.1.4 Remote Driving / Teleoperation

Remote Driving / Teleoperation 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.

## 5.2 Use cases specifically for CAVs

### 5.2.1 Coordinated Merging

[Editor’s Note: Add sentence that references 5.2.1 as an example of a specific function that may be included in this service.]

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. In this use case the merging vehicles coordinate their expected trajectories continuously upon approaching the merge point to negotiate necessary adjustments in operational control parameters (e.g., acceleration, braking, steering) to allow a safe merge maneuver. At an overall systems level, this use case must meet strict reliability requirements. However, in order to ensure the safe operation of this automated maneuver, crash-avoidance safety systems using both radiocommunication and onboard sensor inputs are expected to provide failsafe backup for this use case.

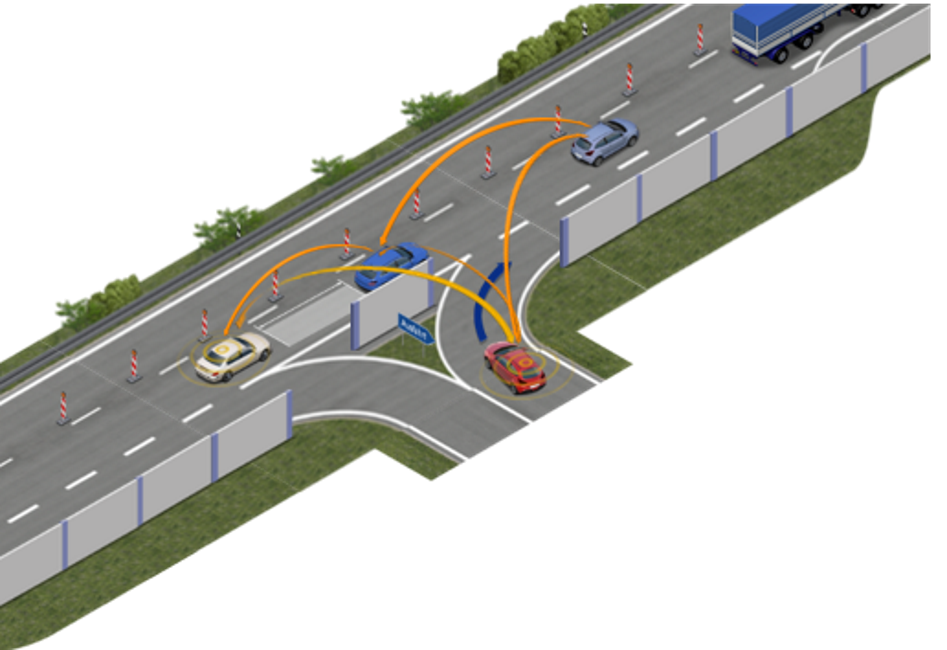
### 5.2.2 Cooperative Driving with Maneuver Coordination Service

[Editor’s Note: Add sentence that references 5.2.1 as an example of a specific function that may be included in this service.]

Cooperative Driving with Maneuver 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 Section 6.4, in detail.

Figure 5.2-1

Radiocommunications between vehicles in cooperative merging on highway



{Editor’s note: Relevant IPR information on all added graphical content to be checked}

Figure 5.2-2

Radiocommunications between vehicles in cooperative turning at junctions

A car driving on a road

Description automatically generated with low confidence

“Cooperative Automated Driving (CAD)[[12]](#footnote-12) brings together driving automation technology with V2X communication in order to enable vehicles to coordinate their driving maneuvers 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[[13]](#footnote-13) research project developed a CAD system based on collective perception and cooperative maneuver coordination, one example of CAD is a connected lane merge function”[[14]](#footnote-14). By exchanging maneuver 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[[15]](#footnote-15). 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 communication by adding functions to Japan’s ITS communication standard (ARIB STD-T109).

Cooperative merging and coordinated lane change are included as functional elements in Section 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 Figure 5.2-3.

Figure 5.2-3

Truck platooning

Inter-vehicle

distance

Inter-vehicle

distance

Lead truck

with a human driver

Following truck

without a human driver

Following truck

without a human driver

Moving direction

Development to implement platooning is currently underway in several countries around the world. For example, in Japan, field trials of truck platooning are underway[[16]](#footnote-16), as shown in Figure 5.2-4.

Figure 5.2-4

Field Trial of Truck platooning (CACC and automated steering) on a highway

|  |  |
| --- | --- |
| **a) Rear view** | **b) Bird view** |
| 道路を走っているトラック  自動的に生成された説明 | 高速道路を走る車  中程度の精度で自動的に生成された説明 |

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 CO2 emissions. It has been shown that a platoon of three trucks travelling 4 m apart at 80 km/h consumes 15% less fuel[[17]](#footnote-17). If the distance between trucks is reduced to 2 m, the fuel consumption would be reduced by 25%. Reducing the distance between vehicles can also increase the traffic capacity of roads, i.e. the number of vehicles per km, mitigating congestion. This could further reduce fuel consumption and CO2 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.

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, i.e. 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 communication which is carried out within a specific platoon, i.e. a group of trucks which forms platooning.

The direct radiocommunication needs to support three types of radiocommunication; (i) message communication for vehicle control, may require (ii) video communication for safety monitoring of rear and side views, being sent from the trailing vehicles to the lead vehicle human driver, and (iii) message communication for information of auxiliary equipment, e.g. fuel indicator, handbrake status, warning lamps and/or position of transmission gear. [Editor’s Note: Consider adding additional text on video messaging as a type of communication in a future contribution] The above (i) requires small packet but low latency communication, e.g. 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, i.e. 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, e.g. upper portion of microwave or mm-wave may be considered for the direct-V2V group communications in a platoon, since communication 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 sections 6.4.2.3 (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 communication via a base station.

### 5.2.4 Raw perception data sharing

Raw perception data of video, 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. The need for raw data sharing is still [in progress]. Failure sources like inaccurate sensors cannot be mitigated with raw data. In addition, wider spectrum bandwidth may be required for such broadband radio communication to convey raw perception data.

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 different sensors, such as video, radar, and lidar. 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 will be in the order of Gbit/s and msec. For example, as shown in the 3GPP Technical Report[[18]](#footnote-18) 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 1Gbit/s. Therefore, related studies on new technologies could be considered [Editor’s Note: Consider adding clause to ending of preceding sentence “, for example, joint communication and sensing in Section 7.4.1,”] [Editor’s note: if delete example on joint communication… can reference 5.2.4 in Section 7.4.1] to ensure the high data rate raw perception data sharing among CAVs with the low latency requirement.

Figure 5.2-5

Typical scenario of raw perception data sharing among CAVs.

[Editor’s Note: Change “5G NR” to “RSE” in Figure]

图示, 工程绘图

已生成极高可信度的说明

Figure 5.2-5 depicts typical scenario of raw perception data sharing among CAVs. There are multiple sensors in CAV, such as radar, video camera, lidar and other on-board sensors. Both low-frequency and high-frequency bands need to be considered to provide broadband communication ability among CAVs and roadside units. In the Figure, it is assumed that vehicles B, D and E are the targets that can be directly detected by the radar of vehicle A. 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 communication 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. [1] [Editor’s Note: Turn reference into footnote.] However, in some cases, V2V communication links are limited. The raw perception data needs to be shared through the RSU. Therefore, V2I communication 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[[19]](#footnote-19) (e.g. six cameras with a resolution of 1280 x 720, 24 bit per pixel, 30 frames per second), which will rely on vendors’ specific classifiers[[20]](#footnote-20),[[21]](#footnote-21). The raw data rate will reach gigabit-class because raw perception data sharing is real-time data sharing, which requires low latency transmission. [5] [Editor’s Note: Turn into footnote] Extended sensing for high-level autonomous 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 Figure 6.3-4, 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 [9] [Editor’s Note: Translate [9] into footnote]. Therefore, by sharing the raw perception data among vehicles, the traffic accidents caused by incorrect decision propagation may be extensively minimized.

[Editor’s Note: Japan’s comments: The URL referred to in [9] should be updated to refer the web site of US National Transportation Safety Board, as it is document cloud.] [Editor’s Note: USA to provide]

Large-bandwidth, low-latency services such as collective environmental awareness and extended sensing will promote the evolution of CAV communication systems to higher frequency bands (e.g., millimeter-wave band) to meet their ultra-gigabit-level data rate requirements.

[1] 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.

[2] 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.

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

[4] 3GPP TR 22.886, “Study on enhancement of 3GPP Support for 5G V2X Services (Rel.16)”, December 2018.

[9] VEHICLE AUTOMATION REPORT Tempe, AZ HW Y18MH010 <https://www.documentcloud.org/documents/6540547-629713.html>

### 5.2.5 Remote Driving / Teleoperation

Remote Driving / Teleoperation 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.

### 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 Figure 5-x, 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 5-7

Automated Valet Parking Sequence

Graphical user interface, application

Description automatically generated

# 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, e.g., 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, e.g., 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 communication can be considered as an additional sensor providing data to the CAV.

Ad hoc V2X communication based on IEEE 802.11p as part of IEEE 802.11-2016 are deployed in Road Side Units 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 Units 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 communication and include the ad hoc V2X communication 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 maneuvers 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 communication include IEEE 802.11p (ITS-G5, WAVE, ITS-Connect) that has been proven for safety-related communications through extensive testing, and deployment; and, 3GPP LTE V2X that has demonstrated safety-related communications 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[[22]](#footnote-22). 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 (e.g., 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 communication to support CAV use cases is estimated by automotive and other industry proponents to need at least70-75 MHz of spectrum,[[23]](#footnote-23),[[24]](#footnote-24). 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[[25]](#footnote-25).

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 Section 7.1]) are tested for IEEE 802.11p based V2X technologies.

## 6.1 Higher layer requirements for CAV

CAV requirements (higher layer including application layer requirements):

Ad hoc V2X communication 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, communication is just one element in this complex system.

[Editor’s Note: Potentially develop language on higher-layer requirements in Section 6.1 to relate to Table 6-1]

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 Section 7.5 of Report ITU-R M.2445-0 (11/2018) Intelligent transport systems (ITS) usage.

V2N network specific requirement for CAV are being considered for:

– full road coverage with cellular communication.

– cross-border interoperability (e.g., session continuity via Edge Computing).– cross-MNO interoperability.

## 6.2 Security Requirements

Security requirements for V2X communication, pertinent to CAV communication, are presented in ITU-T Recommendation X.1372 (03/2020), Security guidelines for vehicle-to-everything (V2X) communication.

## 6.3 Radiocommunication requirements for CAV

1) Transmission topology

By nature, V2X communication is a many-to-many omnidirectional type of transmission in communication~~.~~ 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, e.g., 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, e.g., ETSI EN 302 663 Annex A. 3GPP V2X receivers need to comply with dynamic channel conditions as described in e.g., 3GPP TS 36.101 and 38.101 for LTE V2X and NR V2X respectively. Despite the reason for wireless communication 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 communication range of ITS stations. High density scenarios show that 100-800 vehicles can be in the functional relevant distance of the communications 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”[[26]](#footnote-26). Other CAV related messages such as Collective Perception Messages (CPM), Maneuver 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) Communication 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 communication requirement[[27]](#footnote-27). Automotive 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[[28]](#footnote-28).

7) Selection of V2X modulation characteristics:

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

– dynamic radio channel changes, e.g. mobile environment,

– dynamic message generation, e.g. dynamic changes in Tx rate and message size from message to message,

– omnidirectional communication,

– dynamic channel load at up to “99.9% Service Level Reliability at 300 m range”[[29]](#footnote-29), 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 QPSK ½ [[30]](#footnote-30). There are some CAV use cases which can use higher order modulations and/or multiple/directional antenna systems, e.g. truck platooning.

8) Service layer latency:

Service layer latency is below 10 ms as shown in Table 6.3-1 “Technical characteristics of radiocommunication for Advanced ITS and CAV”.

From the view of wireless connectivity, V2X communication 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 msec in packet latency at the service / application level[[31]](#footnote-31) and greater than 90% packet success rate. While Packet Success Rate has been a generic metric in V2X communications 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.

TABLE 6.3-1

Technical characteristics of radiocommunication for Advanced ITS and CAV

[Editor’s note: Ensure the information presented in the table is consistent with the text above]

| Items | Advanced ITS | CAV |
| --- | --- | --- |
| Use cases | Cooperative Awareness  Cooperative Perception | Cooperative Driving with Maneuver Coordination Service  Platooning  Automated Valet Parking |
| ITS Connectivity Scope | V2V, V2I, V2N\*,V2P | V2V, V2I, V2N\*, V2P |
| **Radio Performance** | | |
| Typical Coverage Range | Short range ad hoc and direct communication up to 1 000 m | Short range ad hoc and direct communication up to 1000 m  Short range communication also may include hybrid use of cellular communication\* |
| Packet size including necessary overheads and security certificate | 380 bytes – 1 900 byte | 400 bytes - 6 000 bytes |
| End to End Service Level Latency | Less than 100 msec | less than 10 msec |
| Packet Success Rate[[32]](#footnote-32) | Greater than 90% in highway scenario within 500 m communication range  Greater than 90% in suburban scenario within 150 m communication range  Greater than 90% in urban scenario within 150 m communication range | Greater than 90% |
| Service Level Reliability\*\*[[33]](#footnote-33) | “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” |

\* V2N communication has performance characteristics that are very different from direct communications used for V2V, V2I, and V2P. The cellular network connectivity aspects for V2N communications are described in [DN] Report ITU-R M.[IMT.C-V2X].

*\*\** 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 communication, 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 communication can allow AVs to share driving intentions, collectively negotiate and execute maneuvers 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 Connected Automated Vehicles 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 (e.g., traffic signal phase and timing information)

c) Statistical prediction information (e.g., 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 communication by using V2I and V2V

Mutual communication by using V2I and V2V refers to communication 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 communication between an automated vehicle and vehicles around it (specified or unspecified)

c) Provision of information from external stakeholders related to a vehicle’s driving (e.g., road administrators, traffic managers) to the vehicle or vice versa

d) Driving behavior instructions from external stakeholders related to a vehicle’s driving (e.g., 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 section 5.Those functional elements compiled based on classification by function are listed in Table 6.4-1 below, details of which are presented in Annex 1.

TABLE 6.4-1[[34]](#footnote-34)

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 (e.g., 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. |
| b. Traffic signal information | b-1. Driving assistance by using traffic signal information | Current traffic signal color and traffic signal phase and timing information (the next traffic signal color 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 (e.g., 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. |
| 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. |

(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 (e.g., 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 analyze 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 (e.g., location, speed) of vehicles driving on certain range of main lane is provided by the infrastructure to merging vehicles. Meanwhile, instructions (e.g., 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 | During merging to a main lane with heavy traffic, vehicles on the main lane communicate with merging vehicles (e.g., 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

[Editor’s note: summary text to be further developed]

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 Maneuver Coordination / Cooperative Driving / Advanced Driving.

This report provides a list of functional elements for the Connected Automated Vehicles as a basis for identifying radiocommunication requirements in Table 6.5-1.

[Editor’s note (Japan): Some parameters or the elements of them which are used to calculate “**Table X Minimum Spectrum needs for different message types for direct, V2X communication”** in Section 8.2 need to be inserted in the Table 6.5-1 below to derive spectrum needs in Chapter 8, e.g. CAM, DENM, SPATEM , VAM, PCM, CPM(Collective Perception Message) and MCM(Maneuver Coordination Message)]

[Editor’s Note: Additional detail on functional elements will be provided in a future meeting]

[Editor’s Note: Discuss if message size includes the size of the security certificate, or if it should]

Table 6.5-1

Functional elements of radiocommunication for CAV

| Functional element | Description | Message set example (Note1) | Connection Mode (Note 2) | Transmission Interval in Hz (min/max/static or dynamic (Note 3) | Message Size in Byte (min/max/typical) [Editor’s Note: Consider using average] (Note 4) | Bit Rate | Communication  Latency in ms [Editor’s Note: Provide reference to values in table to help identify what latency includes. Note Section 7 definition of “Communication Latency.”] |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Merging/lane change assistance (a) | - Merging assistance by  - preliminary acceleration and deceleration  - targeting the gap on the main lane Cooperative merging assistance with vehicles on the main lane by roadside control | ETSI MCM,  SAE MSCM, CSAE, VIR | V2I | 10/static | 1000/1300/1150 | [XXX kbit/s] | 10 |
| - Merging assistance based on negotiations between vehicles / Decentral path coordination and decision between multiple CAV  - Lane change assistance when the traffic is heavy  - Entry assistance from non-priority roads to priority roads during traffic congestion | ETSI MCM,  SAE MSCM, CSAE, VIR | V2V | 1/10/dynamic | 1000/1300/1150 | [T.B.D.] | 10 |
| Traffic signal information (b) | - Driving assistance by using traffic signal information, traffic light | ISO SPaTEM,  SAE SPAT,  CCSA SPAT | V2I, | 2/10/static | 1200 | [T.B.D.] | 100 |
| Traffic signal information (b) | - Driving assistance by using traffic signal information, intersection/road construction map | ISO MAPEM,  SAE MAP | V2I | 2/10/static | 1200 |  | 100 |
| Traffic signal information (b) | Driving assistance by using traffic signal information, traffic signs | ISO IVI, CCSA, RSI | V2I | 2/10/static | 1200 |  | 100 |
| Lookahead information: collision avoidance (c) | Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly | ETSI DENM,  SAE BSM, CCSA BSM | V2V | 10/static | 1000 |  | 100 |
| Lookahead information: collision avoidance (c) | Driving assistance based on intersection information | ETSI CAM, SAE BSM, CCSA BSM, CSAE SSM | V2V | 1/10/dynamic | 400/700/550 |  | 100 |
| Lookahead information: collision avoidance (c) | Driving assistance based on intersection information | ETSI, CPM, SAE SDSM  CCSA RSM,  CSAE SSM | V2I | 1/10/dynamic | [1000/1900/1450]  250/4000/1000  [400/700/550] |  | 100 |
| Lookahead information: collision avoidance (c) | - Collision avoidance assistance by using hazard information | ETSI DENM, SAE BSM, ETSI CPM, SAE SDSM, CCSA BSM, CSAE SSM | V2V |  |  |  |  |
| Lookahead information: collision avoidance (c) | 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 |
| Lookahead information: collision avoidance (c) | - Collision avoidance assistance at intersections | ETSI CAM, SAE BSM | V2V | 1/10/dynamic | 400/700/550 | [T.B.D.] | 100 |
| Lookahead information: trajectory change (d) | - Driving assistance by  - notification of abnormal vehicles  - by notification of wrong-way vehicles  - based on traffic congestion information  - Traffic congestion assistance at branches and exits  - based on hazard information | ETSI MCM,  SAE MSCM, CCSA RSM | V2I | 10/static | 1000/1300/1150 | [T.B.D.] | 10 |
| Lookahead information: emergency vehicle notification (e) | - Driving assistance based on emergency vehicle information | ETSI DENM,  SAE BSM, CCSA BSM | V2V | 10/static | 1000 | [T.B.D.] | 100 |
| Lookahead information: emergency vehicle notification (e) | - Driving assistance based on emergency vehicle information | ETSI CPM, SAE SDSM, CCSA RSM, CSAE SSM | V2I | 10/static | 1000/1900/1450 |  | 100 |
| Lookahead information: emergency vehicle notification (e) | - Driving assistance based on emergency vehicle information, note 3 | - | V2I,  V2N | - | - | - | - |
| Information collection/ distribution by infrastructure (f) | Request for rescue (e-Call)  Collection of information to optimize the traffic flow | - | V2N | - | - | - | - |
| Information collection/distribution by infrastructure (f) | Collection of information to optimize the traffic flow (note: receive only) | ETSI CAM, SAE BSM | V2I |  |  |  |  |
| Information collection/ distribution by infrastructure (f) | Update and automatic generation of maps | - | V2N | - | - | - | - |
| Information collection/ distribution by infrastructure (f) | - Distribution of dynamic map information | ISO MAPEM,  SAE MAP, CCSA MAP | V2N | 2/10/static | 1200 |  | 100 |
| Platooning/ adaptive cruise control (g) | - Platooning of driverless follower vehicles by electronic towbar  - Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control | ETSI PCM,  SAE CCM, CSAE CLPMM | V2V | 20/50 | 1400 | [T.B.D.] | 10 |
| Teleoperation (h) | - Operation and management of mobility service cars | - | V2N | - | - | - | - |
| Pedestrian, Bicyclist protection | Integration of Vulnerable Road Users into V2X communication | ETSI VAM, SAE PSM | V2P | 1/10/dynamic | 350 |  | 100 |

Note 1: message sets may enable multiple use cases

Note 2: V2N is not in scope of this report

Note 3: static: Tx rate constant; dynamic: may vary depending on e.g. vehicle speed, steering dynamic, acceleration

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

# 7 Radiocommunication technologies that support CAV

[Editor’s Note: The drafting group might develop introductory language after consolidating text]

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

Access layer technologies:

The ad hoc access layer V2X communication 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[[35]](#footnote-35). 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. A successor to IEEE 802.11p is currently being developed in IEEE under the working name IEEE 802.11bd.

3GPP based access layer technology is an enhancement on the initial work on D2D communications defined as part of ProSe services (in Release 12 and Release 13 specifications) for supporting ad hoc communication 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 & 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

[Editor’s Note: Encourage contributions to the next WP5A meeting regarding the structure of this sub-section and whether additional material is appropriate, such as KPIs and channel frequency explanation. Encourage improved organization of this section to separate specifications from service-layer views]

IEEE 802.11p supports already today CAV requirements especially in terms of latency. Draft IEEE 802.11bd [Editor´s note: Reference to published 11bd to be delivered May 2023] 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).

The IEEE has initiated IEEE P802.11-Task Group BD - “Enhancements for Next Generation V2X”[[36]](#footnote-36) 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[[37]](#footnote-37)

− Cooperative Perception Service, a.k.a. Collective Perception Service or Sensor Sharing, was implemented with ITS-G5 in IMAGinE[[38]](#footnote-38)

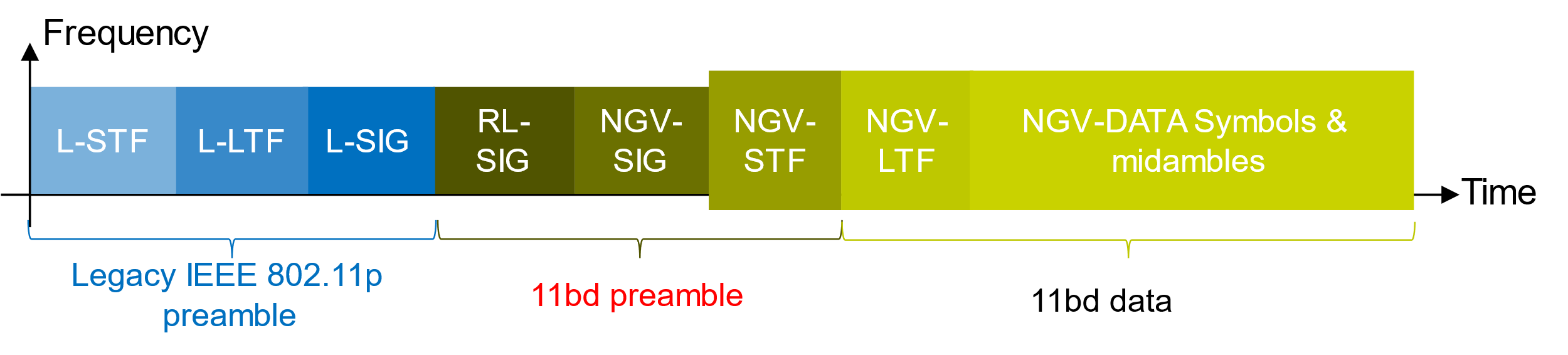
− Cooperative Maneuver Coordination, a.k.a. Cooperative Driving, with cooperative merging on highways, cooperative longitudinal control on highways, cooperative overtaking on rural roads, cooperative strategic traffic distribution, cooperative turning at junctions, cooperative overtaking by heavy-goods vehicles on highways was implemented with ITS-G5 in IMAGinE.

IEEE 802.11p may support the necessary End to End Service Level Latency given in table 6-3-1 of 10 ms for CAV with a sufficient low communication latency [[39]](#footnote-39) [[40]](#footnote-40) [[41]](#footnote-41) for typical network load assumed in this report, see clause 8. [Editor’s Note: Consider whether the following text is still necessary and how it relates to the “communication latency” definition provided in Section 6]. [A communication latency covers the time for sending an ITS message from OSI-Layer 1 and 2 of ITS device 1 plus air time plus time OSI-Layer 1 and 2 (ITS device 2). This corresponds in IEEE to input Mac-layer to output Mac-layer. In addition to the communication 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.]]

Both IEEE 802.11p and IEEE 802.11bd can use the same frequency channel in the same geographical area at the same time. 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 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 IEEE802.11bd can fully decode the data content of frames transmitted using the legacy IEEE802.11p based encoding. The frame format of IEEE802.11bd is depicted in Figure 1.

Figure 1

IEEE 802.11bd packet format with legacy preamble, repeated SIG and new DATA symbols



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 (e.g. IEEE WAVE, ETSI ITS-G5 Multi-Channel Operation) entities based on application requirements and the known capabilities of the ITS devices in the vicinity.

[Editor’s Note: Need to consider how IEEE 802.11bd device would switch to new data format once it enters legacy mode, and switches back to NGV as soon as 802.11p is no longer available.]

## 7.2 3GPP - Sidelink

[Editor’s Note: Encourage contributions to the next WP5A meeting regarding the structure of this sub-section and whether additional material is appropriate, such as KPIs and channel frequency explanation. Encourage improved organization of this section to separate specifications from service-layer views]

LTE V2X supports the Day 1 use cases which are covered in the 5GAA reports [Editor’s Note: Consider adding reference to specific reports; reference might already exist in this report somewhere] 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.[[42]](#footnote-42) [[43]](#footnote-43) [Editor’s Note: Need to update to appropriate Annex once section locations are finalized.]

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 communications 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 [Editor’s Note: Clarify KPIs are for Release 14 and Release 15, provide references]for the use cases were utilized to show the capability of LTE V2X.

3GPP Release 16 specification work was completed in June 2020, supporting advanced V2X use cases based on multiple technologies; e.g., NR V2X complements LTE V2X for advanced V2X use cases, including connected and automated driving, and also is 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.

– Extended Sensors – enables the exchange of raw or processed data gathered through local sensors or live video data among vehicles, RSUs, 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, e.g. 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, e.g. 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[[44]](#footnote-44). 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 communication 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 [DN] Report ITU-R M.[IMT.C-V2X].

## 7.4 Future technical enablers

There are additional advanced use cases emerging for automated driving, for which possible communication 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 ability

[Editor’s Note: Provide contributions on definition of JCAS in reference to usage in this document]

In CAV, the necessity of joint communication and sensing (JCAS) [Editor’s Note: Add definition and refer to ITU report on this topic, and add acronym to acronym section] technology is mainly reflected in the scenario requirements and standard requirements. [3GPP defines [Editor’s note: Clarify whether the 3GPP use cases involve reception data sharing (possibly in “TR” report)] four categories of enhanced V2X scenarios in Rel-15[6] [Editor’s Note: Convert reference to footnote]], and in the use cases for collective perception, object sharing, cooperative perception driving, and extended sensor sharing in Section 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.

The joint communication and sensing (JCAS) capability within the CAV network can reduce the cost of sensor deployment and improve the sensing capability of communication systems. For example, with the joint design of communication and sensing systems, a large number of signal processing processes and hardware modules such as base-band units, RF, and antennas, can be shared within the JCAS system[[45]](#footnote-45). Besides, JCAS system can reduce the interaction latency between communication and sensing systems, which could benefit use cases with low latency requirements for sensing information sharing among CAVs, such as the raw perception data sharing use case.

In highly dynamic CAV networks, for sensory sharing services such as extended sensing and raw perception data sharing, the JCAS system will bring more obvious advantages[[46]](#footnote-46): e.g., lower inter-system interaction overhead; sensing results to assist millimeter wave antenna alignment; and sensing side to provide multi-state channel estimation feedback to assist the communication side in the equalization process.

[6] 3GPP. TS 22.186. Service requirements for enhanced V2X scenarios[S]. 3GPP, 2018. [Editor’s Note: Find the appropriate reference to JCAS; likely starts with “TR”]

]

# 8 Initial Spectrum needs for CAV radiocommunication

[Editor’s Note: Consensus reached on including initial spectrum needs for CAV radiocommunication based on the information provided in this document. If more detailed spectrum needs analysis is needed, it can be discussed at a later time in a separate document.]

The spectrum needs for CAV radiocommunication identified in Section 8 of this document 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 communication was included in Recommendation [ITU-R](https://www.itu.int/rec/R-REC-M.2121/en) [M.2121](https://www.itu.int/rec/R-REC-M.2121/en) (01/2019) – 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 communication requirements become better known.

Spectrum other than that previously recommended for ITS may be desirable for CAV communications. For example, it may be possible that platooning and/or other very close range cooperative maneuvering communications 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 communication, which could be specifically used for CAV use cases.

## 8.2 Spectrum bandwidth needed

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](https://www.itu.int/pub/R-QUE-SG05.261) is to determine the spectrum needs for CAV Radiocommunication, including suitable bands and spectrum bandwidth needed.

CAVs require spectrum dedicated to safety-related communication. Spectrum may need to be physically uncorrelated to provide fully redundant communication conditions. Tables 8.2-1 (1A, 1B & 1C) summarize estimated spectrum needs and plans for CAV direct communication in different countries and regions. Tables 8.2-1A, B and C 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 *draft new Report* ITU-R M.[IMT.C-V2X].

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 8.2-1 only represents the potential spectrum needs for CAVs in specific regions and countries.

Table 8.2-1A

Current and future spectrum needs for CAVs in 5.9 GHz band

|  |  |  |  |
| --- | --- | --- | --- |
| Frequency band | Status/description | Current availability | CAV current & 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) | [Region 1 – As a minimum 70 MHz of spectrum is required for CAVs, see Table 8.2-4 in present document, around 140 MHz is required as a typical need]  [Spectrum designated in the 5.9 GHz band for ITS use cases varies by country within Region 1.] |
| Regional and Country notes on use of 5.9 GHz band for CAV  The United States of America has identified 5 895 – 5 925 MHz to ITS generally, not specific to CAV | | | |

Table 8.2-1B

Current and future spectrum needs for CAVs in mm Wave bands

|  |  |  |  |
| --- | --- | --- | --- |
| Frequency band | Status/description | Current availability | CAV current & future Spectrum needs |
| mmWave | Short-range, high-capacity and low-latency communication potentially combined with radio location capabilities | Europe has an allocation of mmWave for ITS at 60 GHz | [At least 2 GHz bandwidth is needed for enabling high transfer rates] |
| Regional and Country notes on use of mmWave bands for CAV | | | |

Table 8.2-1c

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

|  |  |  |  |
| --- | --- | --- | --- |
| Frequency band | Status/description | Current availability | CAV current & foreseen Spectrum needs |
| < 1 GHz | For long range strategic control information between CAVs, redundant communication channel to enable certain functional safety levels | Japan has an allocation at 760 MHz band for road traffic safety | [At least 10 MHz] |
| Regional and Country notes on use of <1 GHz band for CAV: | | | |

### 8.2.1 Estimated spectrum needs for CAV radiocommunication [Editor’s Note: Include where the estimated spectrum needs come from in the title]

[Editor’s Note: Detailed language moved to Annex 2. Need to provide summary language for the section remaining in the body of the report.]

### 8.2.2 C2C-CC estimated spectrum needs for transportation safety

[Editor’s Note: Detailed language moved to Annex 2. Need to provide summary language for the section remaining in the body of the report.]

### 8.2.3 5GAA estimated Spectrum needs for safety related ITS – day 1 and advanced use cases

[Editor’s Note: Detailed language moved to Annex 2. Summary language for this section is provided below.]

A 5GAA white paper[[47]](#footnote-47) 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 communications 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 the Annexure A.2.3.

# 9 CAV Interoperability Requirements

Interoperability is of critical importance for safety-related CAV functions. This is especially true for direct ad hoc wireless communications among CAVs and between CAVs and infrastructure, since these types of transmission in communications 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 communications, 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 communications 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

[Editor’s Note: Provide 1-2 page summary of detailed information moved to the Annex 3.]

# 11 References

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3GPP TR 37.985: Overall description of Radio Access Network (RAN) aspects for Vehicle-to-everything (V2X) based on LTE and NR,<https://www.3gpp.org/DynaReport/37985.htm>

3GPP TS 22.185: Service requirements for V2X services:<https://www.3gpp.org/DynaReport/22185.htm>

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

3GPP TS 23.286: Application layer support for Vehicle-to-Everything (V2X) services; Functional architecture and information flows,<https://www.3gpp.org/DynaReport/23286.htm>

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3GPP TS 36.300: Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2,<https://www.3gpp.org/DynaReport/36300.htm>

3GPP TS 38.300: NR; NR and NG-RAN Overall description; Stage-2,<https://www.3gpp.org/DynaReport/38300.htm>

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

# A.1 The functional elements of CAV

[Editor’s Note: Consider clarifying in footnote to title that these are the functional elements of CAV “considered by WP5A”. Also consider adding CCSA messages.]

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.

Figure A.1-1

How to read the diagrams



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

Table A.1-1

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 communication 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 communication in respective categories (message, sensor data, rich contents) |
| Rich contents | Information of photos, images, etc. (e.g., 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 communication |

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.

## A.1.1 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-1-1. Merging assistance by preliminary acceleration and deceleration

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ***Classification by function*** | | **a. Merging/lane change assistance** | | | | |
| ***Name of the functional element*** | | **a-1-1. Merging assistance by preliminary acceleration and deceleration** | | | | |
| ***Target areas*** | | **Expressways and General roads** | | | | |
| ***Overview*** | | **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.** | | | | |
| **Image of the functional element** | | | | | | |
| Graphical user interface  Description automatically generated | | | | | | |
| ***Remarks (communication requirements, etc.)*** | **Connection mode** | | **V2I** | **Data category/**  **content of information** | **Message** | **Predicted time to arrive at a merging section (vehicles on the main lane)** |
| **Message recipient(s)** | | **Multiple recipients** | **Sensor data** | **Speed (spot measurement of vehicles on the main lane), vehicle length** |
| **Vehicle action** | | **Preliminary acceleration and deceleration** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Small** |

a-1-2. Merging assistance by targeting the gap on the main lane

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **a. Merging/lane change assistance** | | | | |
| **Name of the functional element** | | **a-1-2. Merging assistance by targeting the gap on the main lane** | | | | |
| **Target areas** | | **Expressways and General roads** | | | | |
| **Overview** | | **Continuous measurement information (e.g., 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.** | | | | |
| **Image of the functional element** | | | | | | |
| **Graphical user interface  Description automatically generated** | | | | | | |
| **Remarks (communication requirements, etc.)** | **Connection mode** | | **V2I** | **Data category/**  **content of information** | **Message** | **Predicted time to arrive at a merging section (vehicles on the main lane)** |
| **Message recipient(s)** | | *Multiple recipients* | **Sensor data** | **Speed, location (continuous measurement of vehicles on the main lane), vehicle length** |
| **Vehicle action** | | **Speed adjustment** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Small** |

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 color and traffic signal phase and timing information (the next traffic signal color 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** | | | | | | |
| **Graphical user interface, diagram  Description automatically generated with medium confidence** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2I, V2N** | **Data category/**  **content of information** | **Message** | **Current traffic signal color, 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** | | | | | | |
| **Graphical user interface  Description automatically generated** | | | | | | |
| **Remarks (communication 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** |
| **Message Set Example** | | **ETSI DENM, SAE BSM** |

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** | | | | | | |
| **Chart  Description automatically generated with medium confidence** | | | | | | |
| **Remarks (communication 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** |
| **Message set example** | | **ETSI CAM, SAE BSM** |

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 (communication 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** |
| **Message set example** | | **ETSI CPM, SAE SDSM** |

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** | | | | | | |
| **Timeline  Description automatically generated with low confidence** | | | | | | |
| **Remarks (communication 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** |
| **Message set example** | | **ETSI DENM, SAE BSM, ETSI CPM, SAE SDSM** |

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **c. Lookahead information: collision avoidance** | | | | |
| **Name of the functional element** | | **c-4. Provision of blind spot information ahead (see-through)** | | | | |
| **Target areas** | | **Expressways and General roads** | | | | |
| **Overview** | | **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.** | | | | |
| **Image of the functional element** | | | | | | |
| **Graphical user interface  Description automatically generated** | | | | | | |
| **Remarks (communication requirements, etc.)** | **Connection mode** | | **V2V** | **Data category/**  **content of information** | **Message** | **Object list consisting all detected road users** |
| **Message recipient(s)~~Connection mode~~** | | **Multiple recipients** | **Sensor data** | **Positions and speed of the detected objects, object identification** |
| **Vehicle action** | | **Speed adjustment, stop** | **Rich contents** |  |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Medium** |
|  |  | |  | **Message set example** | | **ETSI CPM, SAE SDSM** |

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 (communication requirements, etc.)** | **Connection mode** | | **V2V** | **Data category/**  **content of information** | **Message** | **–** |
| **Message recipient(s)~~Connection mode~~** | | **Multiple recipients** | **Sensor data** | **Location, speed** |
| **Vehicle action** | | **Speed adjustment, stop, right and left turns** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Small** |
| **Message set example** | | **ETSI DENM, SAE BSM** |

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 (e.g., 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 (communication 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** | | **Medium** |
| **Message set example** | | **ETSI MCM, ETSI DENM** |

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **d. Lookahead information: trajectory change** | | | | |
| **Name of the functional element** | | **d-2. Driving assistance by notification of wrong-way vehicles** | | | | |
| **Target areas** | | **Expressways and General roads** | | | | |
| **Overview** | | **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.** | | | | |
| **Image of the functional element** | | | | | | |
| **A screenshot of a computer  Description automatically generated with medium confidence** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2I, V2N** | **Data category/**  **content of information** | **Message** | **Presence of wrong-way vehicles** |
| **Message recipient(s)** | | **Multiple recipients** | **Sensor data** | **Location, speed, and lane category of wrong-way vehicles** |
| **Vehicle action** | | **Lane change, trajectory change, pulling over** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Not required** | **Data amount** | | **Small to Medium** |
| **Message set example** | | **ETSI DENM, ETSI MCM** |

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** | | | | | | | |
| **A screenshot of a computer  Description automatically generated with medium confidence** | | | | | | | |
| **Remarks (communication 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** | | | | | | |
| **Graphical user interface  Description automatically generated** | | | | | | |
| **Remarks (communication 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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **d. Lookahead information: trajectory change** | | | | | |
| **Name of the functional element** | | **d-5. Driving assistance based on hazard information** | | | | | |
| **Target areas** | | **Expressways and General roads** | | | | | |
| **Overview** | | **Information about obstacles, construction work, traffic congestion, etc. is provided by the infrastructure to the surrounding vehicles to assist driving.** | | | | | |
| **Image of the functional element** | | | | | | | |
| **A picture containing graphical user interface  Description automatically generated** | | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2I, V2N** | **Data category/**  **content of information** | **Message** | **Obstacle information** |
| **Message recipient(s)** | | **Multiple recipients** | **Sensor data** | **Location** |
| **Vehicle action** | | **Trajectory change, lane change, automated driving control assistance level change** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Not required** | **Data amount** | | **Small** |

e. Lookahead information: emergency vehicle notification

e-1. Driving assistance based on emergency vehicle information

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **e. Lookahead information: emergency vehicle notification** | | | | |
| **Name of the functional element** | | **e-1. Driving assistance based on emergency vehicle information** | | | | |
| **Target areas** | | **Expressways and General roads** | | | | |
| **Overview** | | **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.** | | | | |
| **Image of the functional element** | | | | | | |
| **Graphical user interface, application, website  Description automatically generated** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2V, V2I, V2N** | **Data category/**  **content of information** | **Message** | **Information about approaching emergency vehicles** |
| **Message recipient(s)** | | **Multiple recipients** | **Sensor data** | **Location, speed** |
| **Vehicle action** | | **Speed adjustment, lane change, stop (shoulder)** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Not required** | **Data amount** | | **Small to medium** |
| **Message set example** | | **ETSI DENM, ETSI CPM, SAE BSM, SAE SDSM** |

(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)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **f. Information collection/distribution by infrastructure** | | | | |
| **Name of the functional element** | | **f-1. Request for rescue (e-Call)** | | | | |
| **Target areas** | | **Expressways and General roads** | | | | |
| **Overview** | | **Rescue information is transmitted from abnormal vehicles (e.g., vehicles in accidents) to the infrastructure to request rescue.** | | | | |
| **Image of the functional element** | | | | | | |
| **Graphical user interface  Description automatically generated** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2N** | **Data category/**  **content of information** | **Message** | **Request for rescue** |
| **Message recipient(s)** | | **One recipient** | **Sensor data** | **Location** |
| **Vehicle action** | | **Notification** | **Rich contents** | **–** |
| **Quick responsiveness** | | **ー** | **Data amount** | | **Small** |

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **f. Information collection/distribution by infrastructure** | | | | |
| **Name of the functional element** | | **f-2. Collection of information to optimize the traffic flow** | | | | |
| **Target areas** | | **Expressways and General roads** | | | | |
| **Overview** | | **Information about the location and speed of driving vehicles is collected via the infrastructure to analyze and optimize the traffic flow.** | | | | |
| **Image of the functional element** | | | | | | |
| **Graphical user interface, diagram  Description automatically generated with medium confidence** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2I, V2N** | **Data category/**  **content of information** | **Message** | **–** |
| **Message recipient(s)** | | **One recipient** | **Sensor data** | **Location, speed** |
| **Vehicle action** | | **–** | **Rich contents** | **–** |
| **Quick responsiveness** | | **–** | **Data amount** | | **Small** |
| **Message set example** | | **ETSI DENM, SAE BSM** |

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** | | | | | | |
| **Graphical user interface  Description automatically generated** | | | | | | |
| **Remarks (communication 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 e.g. road constructions, mobile road works, lane closures** | | | | |
| **Image of the functional element** | | | | | | |
| **Graphical user interface  Description automatically generated** | | | | | | |
| **Remarks (communication 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** | | **ー** | **Data amount** | | **Large** |
| **Message set example** | | **ISO MAPEM** |

(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 (e.g., location, speed) of vehicles driving on certain range of main lane is provided by the infrastructure to merging vehicles. Meanwhile, instructions (e.g., 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** | | | | | | |
| **Diagram  Description automatically generated** | | | | | | |
| **Remarks (communication 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** |
| **Message set example** | | **ETSI MCM** |

a-1-4. Merging assistance based on negotiations between vehicles

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **a. Merging/lane change assistance** | | | | |
| **Name of the functional element** | | **a-1-4. Merging assistance based on negotiations between vehicles / Decentral path coordination and decision between multiple CAV** | | | | |
| **Target areas** | | **Expressways and General roads** | | | | |
| **Overview** | | **During merging to a main lane with heavy traffic, vehicles on the main lane communicate with merging vehicles (e.g., 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.** | | | | |
| **Image of the functional element** | | | | | | |
| **Diagram  Description automatically generated with low confidence** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2V** | **Data category/**  **content of information** | **Message** | Requests for entry, permission for acceptance; **Plan trajectory, requested trajectory** |
| **Message recipient(s)** | | **Multiple recipients → One recipient** | **Sensor data** | **Speed, location, acceleration, heading** |
| **Vehicle action** | | **Speed adjustment, gap adjustment** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Medium** |
| **Message set example** | | **ETSI MCM** |

Note: please also see Section 5 and <https://imagine-online.de/en/home/>

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

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **a. Merging/lane change assistance** | | | | |
| **Name of the functional element** | | **a-2. Lane change assistance when the traffic is heavy** | | | | |
| **Target areas** | | **Expressways and General roads** | | | | |
| **Overview** | | **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.** | | | | |
| **Image of the functional element** | | | | | | |
| **Graphical user interface, application  Description automatically generated** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2V** | **Data category/**  **content of information** | **Message** | **Requests for gap adjustment, permission for acceptance** |
| **Message recipient(s)** | | **Multiple recipients → One recipient** | **Sensor data** | **Speed, location** |
| **Vehicle action** | | **Gap adjustment, lane change** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Medium** |
|  |  | |  | **Message set example** | | **ETSI MCM** |

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **a. Merging/lane change assistance** | | | | | |
| **Name of the functional element** | | **a-3. Entry assistance from non-priority roads to priority roads during traffic congestion** | | | | | |
| **Target areas** | | **General roads** | | | | | |
| **Overview** | | **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.** | | | | | |
| **Image of the functional element** | | | | | | | |
| **A picture containing graphical user interface  Description automatically generated** | | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2V** | **Data category/**  **content of information** | **Message** | **Requests for entry, permission for acceptance; plan trajectory, requested trajectory, ETSI MCM** |
| **Message recipient(s)** | | **Multiple recipients → One recipient** | **Sensor data** | **Location, speed, acceleration, heading** |
| **Vehicle action** | | **Right and left turns, gap adjustment** | **Rich contents** | **–** |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Small, medium** |

g. Platooning/adaptive cruise control

g-1. Driverless platooning of following vehicles by electronic towbar

[Editor’s Note: The data amount is updated to include the case for transmission of the image from the second truck to the first truck by using an electronic mirror.]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **g. Platooning/adaptive cruise control** | | | | |
| **Name of the functional element** | | **g-1.** P**latooning of driverless follower vehicles by electronic towbar** | | | | |
| **Target areas** | | **Expressways** | | | | |
| **Overview** | | **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.** | | | | |
| **Image of the functional element** | | | | | | |
| **Graphical user interface  Description automatically generated with low confidence** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2V** | **Data category/**  **content of information** | **Message** | **Speed, acceleration, braking, steering operation, information about follower vehicles** |
| **Message recipient(s)** | | **Multiple recipients** | **Sensor data** | **Location, speed, gap/heading, acceleration/deceleration speed** |
| **Vehicle action** | | **Keeping distance, platoon maintenance** | **Rich contents** | **Transmission of video image from the follower truck to the lead vehicle for Surrounding Monitoring (SM) and/or Driver Status Monitoring (DSM)** |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Small (ETSI PCM), large\***  *\*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.* |
|  |  | |  | **Message set example** | | **ETSI PCM** |

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)**  **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** | | | | | | |
| **Graphical user interface  Description automatically generated** | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2V** | **Data category/**  **content of information** | **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** |
| **Message set example** | | **ETSI PCM** |

h. Teleoperation

h-1. Operation and management of mobility service cars

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Classification by function** | | **h. Teleoperation** | | | | | |
| **Name of the functional element** | | **h-1. Operation and management of mobility service cars** | | | | | |
| **Target areas** | | **Expressways and General roads** | | | | | |
| **Overview** | | **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.** | | | | | |
| **Image of the functional element** | | | | | | | |
| **Diagram  Description automatically generated** | | | | | | | |
| **Remarks (communication requirements, etc.)** | ***Connection mode*** | | **V2N** | **Data category/**  **content of information** | **Message** | **Teleoperation instructions** |
| **Message recipient(s)** | | **One recipient** | **Sensor data** | **Location, speed** |
| **Vehicle action** | | **Teleoperation** | **Rich contents** | **Image captured by on-board cameras** |
| **Quick responsiveness** | | **Required** | **Data amount** | | **Large** |

ANNEX 2

# A.2 Estimated Spectrum Needs

## A.2.1 Estimated spectrum needs for CAV radiocommunication [Editor’s Note: Include where the estimated spectrum needs come from in the title]

[Editor’s Note: Encourage contributions on how these estimated spectrum needs are derived. Identify source of estimated spectrum needs.]

Taking into account the radio communication parameters for different functional elements from table 6-5-1 in combination with spectrum efficiencies[[48]](#footnote-48) the following minimum, maximum and typical spectrum needs can be calculated, following the formula in chapter 8-2-3.

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 8.2.1

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 communication 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 communication 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 communication 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 communication 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 communication 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** |
|  |  |  |  |  |
| CAM (Highway) V2V | message size in Byte | 400 | 700 | 550 |
| equivalent BSM | transmission interval in Hz | 10 | 10 | 10 |
|  | number of ITS stations in communication 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 communication 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 communication 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 communication 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 communication 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** |
|  |  |  |  |  |
| 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 communication 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 communication 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 communication 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 communication 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 communication 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** |
|  |  |  |  |  |
| 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 communication 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 communication 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 communication 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 communication 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 communication 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** |
|  |  |  |  |  |
| VAM (Urban) V2P | message size in Byte | 350 | 350 | 350 |
| equivalent PSM | transmission interval in Hz | 1 | 3 | 2 |
|  | number of ITS stations in communication 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 communication 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

### A.2.2 C2C-CC estimated spectrum needs for transportation safety

A spectrum study[[49]](#footnote-49) (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 communication technology agnostic. Table 8.2-2 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 7x10 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 8.2-3 also explains the different message types found in Table 8.2.2, which are already well defined and specified in standardization bodies, such as ETSI.

Table 8.2-2

Minimum Spectrum needs for different message types for direct, V2X communication Spectrum Need (MHz).



Use cases based on V2X communication 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 8.2-1 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 8.2-3, three phases of V2X deployment:

– awareness driving (day-1) (BSM, I2V, PSM),

– sensing driving (CPM),

– cooperative automated driving (MCM, PCM).

Table 8.2-3

Explanation of different message types

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Phases of V2X application roadmap2 | Message types[[50]](#footnote-50) | |  | Examples of use cases based on the message types |
| Europe | USA | Abbreviations explained |
| **Awareness driving** | CAM, DENM | BSM | Cooperative Awareness message, Decentralized Environmental Notification Message, Basic Safety Message | Intersection Collision Warning  Emergency Vehicle Warning  Dangerous Situation Warning  Stationary Vehicle Warning  Traffic Jam warning  Pre-/Postcrash Warning |
|  | SPaTEM, MAPEM, IVIM | SPaTEM, MAPEM, IVI | Signal Phase and Time, MAP message, In-Vehicle-Information message | Enabling Infrastructure-to-Vehicle Communication at e.g. traffic lights |
|  | VAM | PSM | VRU Awareness Message, Personal Safety Message | VRU warning for (C-ITS) equipped Vulnerable Road Users |
| **Sensing Driving** / sensor sharing | CPM | CPM | Collective Perception Message | Overtaking Warning  Extended Intersection Collision Warning  Vulnerable Road User Warning for non-equipped VRU´s  Cooperative Adaptive Cruise Control  Long-term Road Works Warning  Special Vehicle Prioritisation |
| **Cooperative Driving** with Coordinated maneuvering and cooperative automated driving | MCM, PCM | MCM, PCM | Maneuver Coordination Message, Platooning Control Message | (Static or dynamic) Platooning  Area reservation  Cooperative Merging  Cooperative Lane Change  Cooperative Overtaking |

Figure 8.2-1

C2C-CC roadmap for V2X evolution[[51]](#footnote-51)

|  |
| --- |
| Table  Description automatically generated |

Table 8.2-4, based on a C2C-CC study[[52]](#footnote-52), details the spectrum needs for CPM and MCM:

The parameters to calculate the spectrum needs were briefly described in the study. 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, and only the higher end for parameters in the denominator of the spectrum calculation formula, were chosen to calculate the spectrum needs (see last column), which means that the spectrum needs shown are suggested as the minimum requirements to enable these CPM and MCM 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.

Table 8.2-4

C2C-CC Estimated Spectrum Needs for CPM and MCM Use cases

| CPM  (Collective Perception Message) |  | Min = current parameter setting | Max = future estimation | Typical parameter setting |
| --- | --- | --- | --- | --- |
| Packet Size (Including security, payload, overhead) in Bytes | Message size changes depending on number of detected objects, including vehicles, pedestrians, cyclists, all seen by the in-vehicle-perception sensors such as cameras and radars | 1 000 | 1 900 | 1 450 |
| Periodicity in Hz | Dynamic, up to 10 Hz |  |  |  |
| Periodicity | In Urban | 3 | 5 | 4 |
| In Suburban | 6 | 10 | 8 |
| In Highway | 10 | 10 | 10 |
| Communication range in m |  |  |  |  |
| In Urban | 150 | 300 | 225 |
| In Suburban | 150 | 500 | 325 |
| In Highway | 500 | 1 000 | 750 |
| ITS stations in communication range |  |  |  |  |
|  | In Urban | 320 | 640 | 480 |
|  | In Suburban | 180 | 360 | 270 |
|  | In Highway | 100 | 200 | 150 |
| Spectrum efficiency |  | 0.55 | 0.6 | 0.575 |
| Max allowed channel load |  | 0.6 | 0.75 | 0.675 |
| Spectrum efficiency x max allowed channel load |  | 0.33 | 0.45 | 0.39 |
| Spectrum needs in MHz: |  |  |  |  |
| **CPM** | **Urban** | **23** | **108** | **57** |
| **Suburban** | **26** | **122** | **65** |
| **Highway** | **24** | **68** | **45** |

| MCM  (Maneuver Coordination Message) |  | Min = current parameter setting | Max = future estimation | Typical parameter setting |
| --- | --- | --- | --- | --- |
| Packet Size (Including security, payload, overhead) in Bytes | Message size changes depending on number of detected objects, including vehicles, pedestrians, cyclists, all seen by the in-vehicle-perception sensors such as cameras and radars | 1 000 | 1 300 | 1 150 |
| Periodicity in Hz | Dynamic, up to 10 Hz |  |  |  |
| In Urban | 3 | 5 | 4 |
| In Suburban | 6 | 10 | 8 |
| In Highway | 10 | 10 | 10 |
| Communication range in m |  |  |  |  |
| In Urban | 150 | 300 | 225 |
| In Suburban | 150 | 500 | 325 |
| In Highway | 500 | 1000 | 750 |
| ITS stations in communication range |  |  |  |  |
|  | In Urban | 320 | 640 | 480 |
|  | In Suburban | 180 | 360 | 270 |
|  | In Highway | 100 | 200 | 150 |
| Spectrum efficiency |  | 0.55 | 0.6 | 0.575 |
| Max allowed channel load |  | 0.6 | 0.75 | 0.675 |
| Spectrum efficiency x max allowed channel load |  | 0.33 | 0.45 | 0.39 |
| Spectrum needs in MHz: |  |  |  |  |
| **MCM** | **Urban** | **23** | **74** | **46** |
| **Suburban** | **26** | **83** | **51** |
| **Highway** | **24** | **46** | **36** |

### A.2.3 5GAA estimated Spectrum needs for safety related ITS – day 1 and advanced use cases

The white paper sets out a consolidated view of the automotive and telecommunications industries on the evolution of communication 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, i.e. on-board units (OBUs), road-side units (RSUs), 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 communications. 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 communications, 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 (e.g. message types and protocols), as well as equipment availability, testing and interoperability. The report shows that some advanced driving use cases will require direct communication for their implementation.

The spectrum needs for basic and advanced driving use cases are highlighted in the report. For direct communication, 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 communications for use by mobile operators in delivering advanced driving capabilities in rural and urban environments.

As indicated in Figure 8.2-2, the use case timelines can be segmented into four phases which reflect increasing complexity and technical requirements.

Figure 8.2-2

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

Timeline

Description automatically generated

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 communications 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 communication) and Sensor Sharing to support cooperative perception – both basic functionalities for automated driving, e.g. 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 communications – 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 communications.

**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 communications 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 Figure 8.2-3.

Figure 8.2-3

Message categories

Diagram

Description automatically generated

The study identified a total of 44 diverse use cases that utilize different modes of communication (V2V, V2P, V2I and V2N) and message categories. These are summarised in the tables below:

Table 8.2-5

Day-1 use cases

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

Table 8.2-6

Advanced use cases

| Messages per link | Use case |
| --- | --- |
| Continual repetitive messages  (V2V)(broadcast) | (9a) Sensor Sharing for Autonomous Vehicles  (9b) High-Definition Sensor Sharing |
| Event triggered messages  (V2V)(broadcast/groupcast/unicast) | (10) See Through for Passing  (43) Vehicle Decision Assist |
| *Trajectory information sharing:*  (1) Cross-Traffic Turn Assist  (18) Cooperative Manoeuvres in Emergency Situations  (28) Cooperative Lane Merging  (38) Coordinated Cooperative Driving Manoeuvre  (40) Interactive VRU Crossing  (41) Cooperative Lateral Parking  (42) Cooperative Traffic Gap |
| Continual repetitive messages  (V2V)(broadcast/groupcast) | (12) Vulnerable Road User |
| Continual repetitive messages  (V2V/V2I)(broadcast/groupcast)  Event triggered messages  (V2V/V2I)(broadcast/groupcast/unicast) | (13) Group Start  (22) Automated Intersection Crossing/Manager  (27) Vehicles Platooning in Steady State  (17) Obstructed View Assist  (20) Remote Automated Driving Cancellation  (30) Law Enforcement Messaging  (25) Vehicle Shares Information on Road Hazards/Events  (37) Awareness Confirmation |
| Event triggered messages  (V2I)(broadcast/groupcast/unicast) | (8) Speed Harmonisation  (33) Infrastructure Assisted Environment Perception |
| Delay sensitive  Continual  or event triggered messages  (V2N)(broadcast/groupcast/unicast) | (12) Vulnerable Road User (VRU)  (14) Tele-Operated Driving  (15) Tele-Operated Driving Support  (16) Tele-Operated Driving for Automated Parking  (17) Obstructed View Assist  (19) Continuous Traffic Flow via Green Lights Coordination  (20) Remote Automated Driving Cancellation  (21) High-Definition Map Collecting and Sharing  (27) Vehicles Platooning in Steady State  (30) Law Enforcement Messaging  (31) Patient Transport Monitoring  (34) Infrastructure Based Tele-Operated Driving  (44) Bus Lane Sharing Request and Revoke |
| Delay non-sensitive  Event triggered messages  (V2N)(unicast) | (5) Software Update  (23) In-Vehicle Entertainment (IVE)  (26) Software Update of Reconfigurable Radio System  (29) Autonomous Vehicle Disengagement Report  (32) Accident Report  (35) Automated Valet Parking:  Joint Authentication and Proof of Localisation  (36) Automated Valet Parking: Wake-up  (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 communication given the spectral efficiency of the communications system.

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

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 communications 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 (Hz) of the event triggered communications are calculated as

|  |  |  |
| --- | --- | --- |
|  |  |  |

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 communications use cases (using the 3GPP-specified PC5/sidelink interface) are calculated and are summarised Table 8.2-7.

Table 8.2-7

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) |
| Event Triggered | |
| Advanced use cases (PC5/sidelink) |  |
| Group Start | ~ 890 kHz + CAM/BSM |
| Cooperative Lane Merging | ~ 150 kHz+ CAM/BSM |
| Trajectory Information Sharing\* | ~ 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 |
| \* 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 communications (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 communications.

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 communications.

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 (e.g. 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 (e.g., 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 communication 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) communications for the delivery of advanced driving use cases by mobile network operators.

ANNEX 3

Research projects on connected automated vehicle

[Editor’s Note: Placeholder if decision is made to move portions of Chapter 10 to Annex 2]

# A.3 Status of global CAV development

[Editor’s note: Decision carried forward on whether to move detailed text from Chapter 10 into Annex 2, which would require summaries of the detailed sections moved. Suggestion: review language to identify how to create 1-2 page summary, with more detailed descriptions possibly moving to Annex 2]

## A.3.1 Region 1 – Europe, Africa and Middle East

### A.3.1.1 Europe

Project overview

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

• 5G NETMOBIL[[53]](#footnote-53)

• ADAS&ME[[54]](#footnote-54)

• AdaptIVe[[55]](#footnote-55)

• AutoNet2030[[56]](#footnote-56)

• Fraunhofer FOKUS CMP[[57]](#footnote-57)

• ICT4CART[[58]](#footnote-58)

• iKoPA[[59]](#footnote-59)

• IMAGinE[[60]](#footnote-60)

• MAVEN[[61]](#footnote-61)

• MEC-View[[62]](#footnote-62)

• PRoPART[[63]](#footnote-63)

• SecForCARs[[64]](#footnote-64)

• TransAID[[65]](#footnote-65)

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

Different automation levels according to SAE J3016 have been tackled by the different projects. Even though cooperation and communication have a high impact on automated driving, 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 1. While in most projects actual driving is performed, PRoPART and 5G NETMOBIL use simulation for evaluation.

Table A.2.1-1

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 |

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

In the scope of the new Horizon Europe [REF] and CEF [REF] project framework of the European commission several additional projects will be realized towards a more deployment oriented approach.

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 communication infrastructure for tactile connected driving and to demonstrate the advantages of tactile connected driving in terms of traffic safety, traffic efficiency and environmental impact compared to autonomous driving based solely on local sensor data.

While autonomous driving already promises more comfort and safety, tactile networked driving enables new driving strategies that further increases road traffic safety, significantly 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 (e.g. 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 communication 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 maneuver coordination using a basic MCM.

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

The main passenger vehicle use case of ADAS&ME was “Non-Reacting Driver Emergency Maneuver”. 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 maneuver, e.g.

• Coordinated safe stop: the vehicle makes a safe stop by coordinating with neighboring vehicles to make space

• e-towing: the vehicle agrees with a neighboring 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 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 maneuvering 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 maneuvering 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 Maneuver Protocol

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

The content of a state determines vehicle behavior in a defined function, e.g. the state of a platoon can be “forming”, “disband”, or “lane change”. Each transition to follow-up states passes through another vote round. 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, e.g. which have left the session without notification or are no longer within communication range, can be detected. Furthermore, each transition is synchronized with the Turquoise algorithm.

The aim of CMP is to form a robust cooperation protocol specifically designed for adverse network conditions[[66]](#footnote-66).

ICT4CART

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

iKoPA

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

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

A major aspect of iKoPA is the secure communication and authentication in vehicular networks. Therefore, a set of messages is developed that allow for secure authentication at parking garages or charging infrastructure[[67]](#footnote-67). 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 Maneuver Automation – cooperative hazard avoidance in real time) project develops innovative driver assistance systems for cooperative driving, i.e. road traffic behavior in which road users cooperatively plan and execute driving maneuvers. Individual driving behavior is coordinated with other road users and the overall traffic situation based on automatic information exchange between vehicles and infrastructure. Critical situations can be avoided or mitigated, thereby making driving safer and more efficient.

Communication technologies enable vehicles to exchange information with other vehicles about objects detected by onboard sensors in real time, thus providing the technological basis for collective environmental perception. Intuitive human-machine interaction concepts ensure high user acceptance of these technologies. IMAGinE employs advanced simulation systems to analyze to what extent cooperative driving maneuvers 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 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 maneuver 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 modeling for impact assessment. It contributes the development of enablers, e.g. standards and high precision maps. MAVEN also provides ADAS techniques for vulnerable road users (VRU). The goal of MAVEN is the development of a roadmap for introduction of vehicle-road automation to support road authorities in the changes of their role and in the tasks of traffic management systems[[68]](#footnote-68).

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, e.g. 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. 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 mergings, etc.) in future mixed traffic scenarios where automated, cooperative, and conventional vehicles will coexist. In this context, V2X is used by the C-ITS road infrastructure to inform about warnings (presence of a non-AD area) and suggest maneuvers (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 Maneuvering

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 (e.g. other vehicles, pedestrians and motorcyclists) to/from neighboring 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 (e.g. 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 (e.g. 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[[69]](#footnote-69).

IMAGinE

In the IMAGinE system, cooperative vehicles use the Collective Perception Service (CPS) to exchange information about their environment perceived by the onboard sensors (e.g. detected objects and free space areas). To enable this service, the Collective Perception Message (CPM) in standardization by ETSI is used. The service receives an object list provided by the IMAGinE environmental model and fills the CPM accordingly for transmission. After decoding 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 A.2.1-1 represents an example of CPS usage for this purpose.

Figure A.2.1-1

MAVEN application of CPS at intersection scenarios

A picture containing text, indoor, computer

Description automatically generated

Isolated cooperative automated vehicles (CAVs) and/or CAVs organized in a Cooperative Adaptive Cruise Control (CACC) string (in red) are heading towards the same intersection equipped with C-ITS and detection capabilities. Conventional traffic or VRU in dangerous positions can be detected only by a subset of the approaching CAVs and by the intersection sensors. On the contrary, other CAVs cannot detect the risk (e.g. in Figure 1, the string of red CAVs is not capable to detect the pedestrians since they are hidden around the corner). Knowing about the presence of hidden obstacles would give CAVs more information for planning paths in a safer way (e.g., in Figure 1, if the platoon needs to turn right). In fact, with this additional information, CAVs might decide to slow down preventively before getting in 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 (e.g. different sensing capabilities, distinct coordinate systems, etc.)[[70]](#footnote-70). The above-mentioned CPS application 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 (e.g. how many vehicles, and of what categories are heading the transition areas). The estimation of traffic demands is achieved by the TransAID road infrastructure through analysis or received CAMs and CPM messages. In particular, receiving CPMs is of special relevance in a mixed traffic scenario where conventional and cooperative (automated) vehicles coexist. This information can be employed to detect conventional vehicles that cannot share their presence due to lack of connectivity. As a result, the road infrastructure can employ this information, together with the information about the ego vehicle (CAMs), to estimate the status and composition of the traffic stream (see Figure A.2.1-2).

Figure A.2.1-2

Typical example of CPS application in TransAID: cooperative (automated) vehicles supporting CPS (in blue) inform the road infrastructure about presence of non-connected vehicles[[71]](#footnote-71)

Graphical user interface, text, application

Description automatically generated

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 neighbors. 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[[72]](#footnote-72). Specifically, Misbehavior Detection in that context is considered because relying on potentially false perception data from untrusted sources can lead to severe safety risks.

Maneuver Coordination with Intention Sharing

Intention sharing will share abstract representation of driving states which do not require a negotiation or 2-way communication (e.g. emergency braking, Transition of Control, minimum risk maneuver, in-out maneuver 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 Figure A.2.1-3, two separate extended CAMs are defined (the MAVEN extensions are highlighted in light grey). Some of the content of these extensions can be seen as information related to intention sharing, because the content of those extensions does not necessarily imply the establishment of negotiation sessions with other vehicles or infrastructure units. In particular, the Extended CAM on SCH0 carries, besides other information, CAV and/or platoon features (planned route, platoon ID, participants, etc.) usable by cooperative intersections to perform traffic light signal timing optimization. As indicated in Figure 3, this information is contained in an optional special vehicle container called MAVENAutomatedVehicleContainer, better detailed in Table A.2.1-2.

Figure A.2.1-3

MAVEN CAM extensions



Table A.2.1-2

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) |

Maneuver Coordination with Trajectory Sharing

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

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[[73]](#footnote-73). 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 [[74]](#footnote-74).

Table A.2.1-3

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 |

Maneuver 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 Maneuver Coordination Service realizes the exchange and negotiation of prospective trajectories between neighboring vehicles. This allows a group of vehicles to find a common joint maneuver 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 "Maneuver Coordination Messages (MCM)" is specified and implemented in IMAGinE. The MCM essentially contains a list of attributed trajectories of the ego vehicle which are generated in the system module “maneuver planning and coordination”.

Maneuver Coordination and Cooperative Maneuver planning

Cooperative Maneuver planning will share V2V short-term strategic coordination of maneuvers (e.g. lane-changes) implying 2-way communication of abstract maneuver 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 (e.g. platoon) in collaboration with surrounding cooperative vehicles. Figure A.2.1-4 illustrates a situation where two subject vehicles intend to perform a cooperative lane change.

Figure A.2.1-4

Planned lane change maneuver

Diagram

Description automatically generated

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 communication 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 maneuver phase. Further information about the Cooperative Lane Change Service is available[[75]](#footnote-75).

ADAS&ME

For its passenger vehicle use cases, the ADAS&ME project uses very basic maneuver coordination. In case the host vehicle can’t drive automated, for example due to a construction site, and the driver is not taking over the control, the vehicle sends out a coordinated maneuver 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

[Editor’s Note: To be added when available]

🡪 CCAM Partnership

🡪 CEF calls in Move and Connect

### A.3.1.2

[T.B.D.]

## A.3.2 Region 2 – Americas

### A.3.2.1 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 communication 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) communication 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](file:///C:\Users\KhademJ\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\GESLEDHI\www.AreaXO.com) and [www.investottawa.ca](http://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 vehicles. The test bed is managed by the University of Alberta and includes 51 roadside units (RSUs) deployed within the City of Edmonton, and an additional 15 RSUs deployed on private roads inside University of Alberta South Campus. There are two additional C-V2X RSUs installed on South Campus, positioned alongside DSRC RSUs. 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 OBUs.

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 applications 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](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 OBU-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 communication 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) RSUs. The primary focus of the project was to test emergency vehicle preemption and 4 fire department vehicles were equipped with OBUs 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 behavior 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/>.

### A.3.2.2 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.[[76]](#footnote-76)

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.”[[77]](#footnote-77) At this time, the regulator also notes “…that 5G is not backwards compatible with LTE.”[[78]](#footnote-78) The U.S. regulator also concluded that “DSRC-based ITS has not lived up to the original promise of achieving the ITS goals identified”[[79]](#footnote-79). Current ITS deployments “… authorizations granted prior to July 2, 2021 may remain on existing frequencies in the 5 850-5 895 MHz band until July 5, 2022, at which time they may only operate in the 5 895-5 925 MHz band.”[[80]](#footnote-80)

## A.3.3 Region 3 – Asia-Pacific

### A.3.3.1 China, Peoples Republic of

China has planned 20 MHz (5 905~5 925 MHz) of spectrum for LTE V2X communication 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 communication 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 communication 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

In order to further verify the C-V2X application of multiple venders in the real road environment, the C-V2X Working Group of the IMT-2020 (5G) Promotion Group organized the large-scale C-V2X interoperability test activities in 2021. The C-V2X Phase I Application Verification Demonstration is oriented to support the basic road safety applications with mass production, and the Phase II Application Verification Demonstration contains the CAV applications. The Phase I Application Verification Demonstration was held in Shanghai International Automobile City. The Phase II Application Verification Demonstration was held in Suzhou, CAV applications, such as cooperative lane change, cooperative vehicle merge, and sensor sharing, have been tested, verified and demonstrated in the open road.

### A.3.3.2 Japan

SIP-adus Programme in Japan

The Government of Japan initiated SIP-adus (SIP[[81]](#footnote-81)’s Automated Driving for Universal Services) programme[[82]](#footnote-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. This programme started in Fiscal Year 2014 and entered its 2nd Phase in Fiscal Year 2018. In the 2nd Phase the scope has been extended to include automated driving on general public roads and application to logistics and transportation services, as shown in Figure SIP.

Figure SIP

Overview of the 2ndPhase SIP-adus

Text

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The programme envisions a scenario for the commercialization and service of fully automated driving by 2025. For this, it has 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 government.

In October 2019, FOTs started in the Tokyo waterfront city area (general roads and Metropolitan Expressway / Haneda area) with wide participations. The program has undergone 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[[83]](#footnote-83). Based on the results, the study is now moving to the next phase on the subject of communication technology requirements and new communication protocols.

### A.3.3.3 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 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 communications 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 communication 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 communication: high data rate, the low latency and high reliability. The use cases of 5G communication are automated shuttle bus, remote control and entertainment.

Platooning is tested on highway based on C-ITS digital infrastructure and V2X communication 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 communication 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 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. Table A.2.3-1 shows CAV use cases in Korea.

Table A.2.3-1

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 GHz1 |
| Remote Control | IEEE 802.11 WAVE, LTE V2X, | 5.855~5.925 GHz | 2018 ~ 2020 |
| 5G NR | 3.5 GHz, 28 GHz1 |
| Entertainment | IEEE 802.11 WAVE, LTE V2X, | 5.855~5.925 GHz | 2018 ~ 2020 |
| 5G NR | 3.5 GHz, 28 GHz1 |

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 A.2.3-1 shows the CAV system architecture.

Figure A.2.3-1

CAV system architecture

Diagram

Description automatically generated

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3. Unimpaired motor vehicle crashes refer to crashes in which the driver was not impaired by alcohol or drugs. [↑](#footnote-ref-3)
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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. [↑](#footnote-ref-10)
11. C-ITS in Europe, Niels Peter Skov Andersen, SIP-adus workshop 2021, 29 October 2021. [↑](#footnote-ref-11)
12. Note that CAD has the same meaning as CAV. [↑](#footnote-ref-12)
13. IMAGinE is a German research project implementing Collective Perception Service and Maneuver Coordination Service into passenger cars, <https://imagine-online.de/en/home/>:

    “The IMAGinE (Intelligent Maneuver Automation – cooperative hazard avoidance in realtime) project is developing innovative driving assistance systems for cooperative driving. Cooperative driving refers to road traffic behaviour in which road users cooperatively plan and execute driving maneuvers. Individual driving behaviour is coordinated with other road users and the overall traffic situation based on automatic information exchange between vehicles and infrastructure. Critical situations can be avoided or mitigated, thereby making driving safer and more efficient.” [↑](#footnote-ref-13)
14. 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. [↑](#footnote-ref-14)
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31. 5GAA white paper “C-V2X Use Cases Volume II: Examples and Service Level Requirements” Service Level Latency definition:

    • Measurements of time from the occurrence of the event in a scenario application zone to the beginning of the resulting actuation. Depending on implementation, this includes one or more of the following:

    • Processing of the event into information by the information generator;

    • Communication of the information to end-user;

    • Processing of the information by the end-user;

    • Time to actuation driven by the result of processing of the information. [↑](#footnote-ref-31)
32. 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 [↑](#footnote-ref-32)
33. 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> [↑](#footnote-ref-33)
34. https://en.sip-adus.go.jp/rd/rddata/usecase.pdf. [↑](#footnote-ref-34)
35. 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)”. [↑](#footnote-ref-35)
36. <http://www.ieee802.org/11/Reports/tgbd_update.htm>. [↑](#footnote-ref-36)
37. The ENSEMBLE “ENabling SafE Multi-Brand pLatooning for Europe” consortium implemented and demonstrated multi-brand truck platooning on European roads 2018-2022 in serial trucks and in collaboration of six European truck manufacturers DAF, DAIMLER, IVECO, MAN, SCANIA and VOLVO Group. <https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/automated-road-transport/ensemble>; https://platooningensemble.eu/ [↑](#footnote-ref-37)
38. IMAGinE “(Intelligent Maneuver Automation – cooperative hazard avoidance in realtime)” implemented Collective Perception in serial vehicles and in collaboration of five German vehicle manufacturers Opel, BMW, Mercedes-Benz, MAN, Volkswagen in 2016-2022. <https://www.imagine-online.de/en/home>. [↑](#footnote-ref-38)
39. 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). [↑](#footnote-ref-39)
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41. “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. [↑](#footnote-ref-41)
42. Project Convex [tested use cases using “CAM DENM messages”, and others [Editor’s Note: Possibly list of additional messages tested]]. Deliverable D7.1: Final Report on Field Test and Evaluation Results https://convex-project.de/onewebmedia/D7.1\_Final\_Report\_Field.pdf [↑](#footnote-ref-42)
43. 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. [↑](#footnote-ref-43)
44. Note: This use case category appears to be one that requires ubiquitous cellular network connectivity. [↑](#footnote-ref-44)
45. 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. [↑](#footnote-ref-45)
46. 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. [↑](#footnote-ref-46)
47. 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>. [↑](#footnote-ref-47)
48. 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). [↑](#footnote-ref-48)
49. 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)” [↑](#footnote-ref-49)
50. 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 maneuver 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](https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=53495&curItemNr=1&totalNrItems=1&optDisplay=10&titleType=all&qSORT=HIGHVERSION&qETSI_ALL=&SearchPage=TRUE&qINCLUDE_SUB_TB=True&qINCLUDE_MOVED_ON=&qSTOP_FLG=N&qKEYWORD_BOOLEAN=OR&qCLUSTER_BOOLEAN=OR&qFREQUENCIES_BOOLEAN=OR&qTITLE=collective&qSTOPPING_OUTDATED=&butExpertSearch=Search&includeNonActiveTB=FALSE&includeSubProjectCode=FALSE&qREPORT_TYPE=SUMMARY)

    MCM Manoeuvre Coordination Message, according to ETSI TR 103 578 (draft) “Informative report for the Manoeuvre Coordination Service”; <https://imagine-online.de/en/home/> [↑](#footnote-ref-50)
51. Source C2C-CC: <https://www.car-2-car.org/fileadmin/downloads/PDFs/roadmap/CAR2CAR_Roadmap_Nov_2018.pdf> [↑](#footnote-ref-51)
52. *See* Attachment 1 to *Ex Parte* Letter from Continental Automotive Systems to U.S. Federal Communications Commission, ET Docket No. 19-138 (filed July 10, 2020) (citing Car 2 Car Communication Consortium, Road Safety and Efficiency Spectrum Needs in 5.9 GHz for C-ITS and Cooperative Automated Driving (2020); and 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)). [↑](#footnote-ref-52)
53. <https://5g-netmobil.de/> [↑](#footnote-ref-53)
54. <https://www.adasandme.com/> [↑](#footnote-ref-54)
55. <http://www.adaptive-ip.eu/> [↑](#footnote-ref-55)
56. <http://www.autonet2030.eu/> [↑](#footnote-ref-56)
57. <https://ieeexplore.ieee.org/abstract/document/8375118> [↑](#footnote-ref-57)
58. <https://www.ict4cart.eu/> [↑](#footnote-ref-58)
59. <https://ikopa.de> [↑](#footnote-ref-59)
60. <https://imagine-online.de/en/home/> [↑](#footnote-ref-60)
61. <http://maven-its.eu/> [↑](#footnote-ref-61)
62. <http://www.mec-view.de/> [↑](#footnote-ref-62)
63. <http://propart-project.eu/about/> [↑](#footnote-ref-63)
64. <https://www.secforcars.de> [↑](#footnote-ref-64)
65. <https://www.transaid.eu/> [↑](#footnote-ref-65)
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67. O. Sawade et al., “Autonomous driving in enclosed car-parks using heterogeneous communication,” 2019. [↑](#footnote-ref-67)
68. “Managing Automated Vehicles Enhances Network.” [Online]. Available: <https://cordis.europa.eu/project/id/690727/de>. [↑](#footnote-ref-68)
69. AutoNet2030, “Deliverable D3.2 – ‘Specifications for the enhancement to existing LDM and cooperative communication protocol standards,’” 2015. [↑](#footnote-ref-69)
70. MAVEN consortium, “Deliverable D5.1: V2X communications for Infrastructure assisted automated driving,” February 2018. [↑](#footnote-ref-70)
71. TransAID Consortium, “Deliverable D5.1 : Definition of V2X message sets,” 2020. [↑](#footnote-ref-71)
72. 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. [↑](#footnote-ref-72)
73. ETSI, “Intelligent Transport Systems ( ITS ); Cooperative Adaptive Cruise Control (CACC); Pre-standardization study,” vol. 1, pp. 1–45, 2019. [↑](#footnote-ref-73)
74. MAVEN consortium, “Deliverable D5.1: V2X communications for Infrastructure assisted automated driving,” February 2018. [↑](#footnote-ref-74)
75. AutoNet2030, “Deliverable D3.2 – ‘Specifications for the enhancement to existing LDM and cooperative communication protocol standards,’” 2015. [↑](#footnote-ref-75)
76. <https://www.transportation.gov/sites/dot.gov/files/docs/policy-initiatives/automated-vehicles/360956/ensuringamericanleadershipav4.pdf>. [↑](#footnote-ref-76)
77. Federal Register / Vol. 86, No. 83 / Monday, May 3, 2021 / Proposed Rules, 23328 [↑](#footnote-ref-77)
78. Federal Register / Vol. 86, No. 83 / Monday, May 3, 2021 / Proposed Rules, 23328 [↑](#footnote-ref-78)
79. Federal Register / Vol. 86, No. 83 /Monday, May 3, 2021 / Rules and Regulations, 23281 [↑](#footnote-ref-79)
80. Federal Register /Vol. 86, No. 83 /Monday, May 3, 2021 /Rules and Regulations, 23297 [↑](#footnote-ref-80)
81. 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. [↑](#footnote-ref-81)
82. For further information, see <https://en.sip-adus.go.jp/>. [↑](#footnote-ref-82)
83. <https://en.sip-adus.go.jp/rd/rddata/usecase.pdf>. [↑](#footnote-ref-83)