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| **Radiocommunication Study Groups** |  |
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| Source: Document 5A/TEMP/77(Rev.1) | |  | | --- | | **Annex 16 to Document 5A/221-E** | | **23 November 2020** | |
| **English only** |
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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](https://www.itu.int/pub/R-QUE-SG05.261)

# 1 Introduction

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

There is a potential for CAVs to smooth traffic flows. This could 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. 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.

CAVs are being planned to be or are deployed in various regions encompassing various stages of automation involving different levels of human intervention and radiocommunications for CAVs may be implemented in frequency bands already allocated to the land mobile service.

This Report addresses overall objectives and radiocommunication requirements for CAVs, including the consideration of global or regional harmonization of frequency spectrum for CAVs.

# 2 Vocabulary

## 2.1 Vocabulary of terms

## 2.2 Acronyms and abbreviations

|  |  |
| --- | --- |
| CAV | Connected automated vehicle |
| ITS | Intelligent Transport System |

# 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](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.itu.int%2Fpub%2Fpublications.aspx%3Flang%3Den%26parent%3DR-HDB-49&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910806401&sdata=aQLHd7XEH9z6573nGh%2B%2BptYMuL9SYOs1BoRjw0wKLuw%3D&reserved=0).  
*[Editor’s Note: currently being revised by Working Party 5A* [*here*](https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fextranet.itu.int%2Frsg-meetings%2Fsg5%2Fwp5a%2FShare%2FForms%2FColumn%2520view.aspx%3FRootFolder%3D%252Frsg-meetings%252Fsg5%252Fwp5a%252FShare%252FLMH%2520review%252FLMH%2520vol4%2520ITS%26FolderCTID%3D0x012000FB880722B4622243913B1114C70648D5%26View%3D%257B627C3C95-CC37-49E0-8D8A-33AC93C6F497%257D&data=02%7C01%7CTom.Schaffnit%40dot.gov%7C813dcfdab2e54a26b34708d83219da81%7Cc4cd245b44f04395a1aa3848d258f78b%7C0%7C0%7C637314433910816391&sdata=aXKBPw9iLEdS%2BDAfGi7dAmv3UkHM%2BuCTftGWW5Hft%2Fw%3D&reserved=0)*]*

# 4 Connected automated vehicles in the context of ITS

*[Editors note: The following replacement Section 4 was developed as a compromise to include multiple overlapping contributions to this section, and now includes subsequently provided edits in turquoise highlight.]*

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.

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 autonomous driving applications are supported using both in-vehicle perception sensors and cooperative V2X connectivity.

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 Anything (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 applications.

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 2+ up to Level 5. The latter consists of a combination of advanced driver assistance system (ADAS) using sensors such radar, camera, and lidar (line-of-sight technologies). The V2X communication extends the awareness horizon of ADAS by charting both location and intention of other road users such as vehicles, and it has the ability to “see” beyond other objects in real-time (non-line-of-sight).*

Automated Vehicles (AVs), also sometimes referred to as driverless cars 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. “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.”[[1]](#footnote-1)

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[[2]](#footnote-2). 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 been as rapid 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.

As indicated in the definition of CAV, 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 is essential for bringing automated driving to the streets. V2X communication enables applications intended to improve road traffic safety and boost road traffic efficiency on all SAE levels.

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.

**Relationship for crash avoidance between short range ad hoc communication (V2V, V2I, V2P) and Advanced Driver Assistance Systems (ADAS) based on in-vehicle perception sensors:**

I) Vehicle versus vehicle crashes: when looking at vehicle versus vehicle crashes, different driving scenarios can be distinguished where ADAS can avoid certain percentages of such accidents. A BASt study[[3]](#footnote-3) 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 1.

Table 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% |

V2V, V2I and Vehicle-to-Pedestrian (V2P) or 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 BSM, CAM, CPM, MCM[[4]](#footnote-4) are used to communicate directly between V2X vehicles. Using direct V2X communication, there will be fewer restrictions due to LoS obscurations. Also, kinematics data and driver behavior information such as pedal actuation is exchanged.

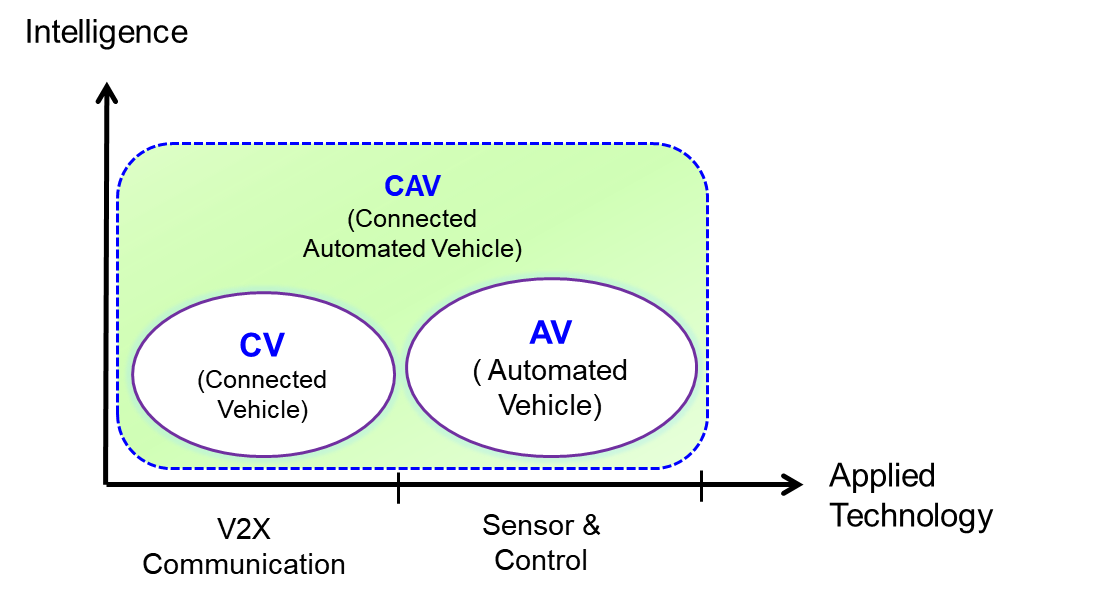
Short range ad hoc communication is able to close the gap and to address vehicle versus vehicle crashes which cannot be prevented by in-vehicle perception ADAS alone.

II) Vehicle versus Vulnerable Road User (VRU) crashes: The effectiveness of preventing vehicle vs VRU crashes using in-vehicle perception ADAS has been analyzed in PROSPECT D2.3 [x[[5]](#footnote-5)]. 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 to address vehicle versus VRU crashes which cannot be prevented by ADAS.

FIGURE 1

Relationship between applied technologies and vehicle intelligence level

**

*[Editor’s note: “Sensor & Control” label in Figure 1 requested to be changed to [“in-vehicle perception ADAS” or “in-vehicle sensors”]*

At a fundamental level, the ‘basic safety’ use cases; described, for example, in Report ITU-R [M.2445-0](https://www.itu.int/pub/R-REP-M.2445) (11/2018) - Intelligent transport systems (ITS) usage, 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.2084-1](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 capabilities necessary for Level 5 – full automation – by 2023.

## 4.1 Communication technologies

## 4.2 Types of communication

*[Editor’s note (J): texts need to elaborate for the following 3 types.]*

Three types of communication technologies are used for CAV communications.

### 4.2.1 Unicast

This technology is used for 1 to 1 communication.

### 4.2.2 Multicast

This technology is used for 1 to Multiple communication, e.g. group communication. The source of the transmission is always the same, so the 1 in 1 to n is always the same transmitter.

### 4.2.3 Broadcast

This technology is used for CAV communication among unspecified number of vehicles, e.g. traffic light information and/or road sign information to vehicles around there. The source of the transmission can be different, so it is n to m.

# 5 Radiocommunication elements for CAVs

There are two main radiocommunication elements for operation of CAVs – ad hoc wireless direct communication and cellular connectivity (requiring base station coverage). Ad hoc communication is essential for CAVs and cellular connectivity is important. Both technology families have their advantages and drawbacks but it should be noted that they are supporting different types of applications in the CAV domain.

Access layer technologies:

The ad hoc access layer V2X communication technologies are either:

• IEEE based, or

• 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[[6]](#footnote-6). 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 drafted in IEEE under the working name IEEE 802.11bd, which is not violating backward compatibility, coexistence nor interoperability. Both IEEE 802.11p and IEEE 802.11bd can use the same frequency channel in the same geographical area at the same time in a spectrum efficient manner.

3GPP based access layer technology supporting ad hoc communication is LTE-V2X (release 14) and 5G-NR V2X (release 16). These two radio technologies cannot talk to each other, are not backward compatible nor coexistent in the same channel and consequently cannot share the same frequency channel.

The cellular connectivity is based on 4G and 5G, requiring coverage by base stations and subscriptions to traditional operators.

Higher layer technologies for V2X above access layer are available at:

• ETSI ITS set of standards,

• CEN set of standards,

• IEEE 1609 set of standards,

• SAE set of standards.

# 6 Overall objectives and radiocommunication requirements for CAVs

CAV development is an evolution and not a revolution. CAVs will exist side-by-side with other non-automated road users 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 camera and radar. Ad hoc V2X communication based on IEEE 802.11p as part of IEEE 802.11-2016 are deployed in Road Side Units and serial 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). 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 step-by-step more functionalities. Once the ad hoc V2X sensor is included in the sensor set, new V2X enhanced ADAS features will be enabled 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). The only mature technology for ad hoc V2X communication is IEEE 802.11p (ITS-G5, WAVE, ITS-Connect). All proposed applications in the CAV domain (e.g., platooning, collective perception, maneuver coordination) are fully supported by IEEE 802.11p based V2X technologies. The applications, however, cannot be supported by one single radio on one frequency channel. The necessary exchange of data by direct, communication to support CAV applications is estimated to need at least 70 MHz of spectrum by automotive proponents[[7]](#footnote-7),[[8]](#footnote-8).

## 6.1 Higher layer including application layer requirements

CAV requirements (higher layer requirements):

Ad hoc V2X communication will be an essential part for CAVs. Nevertheless, there are many other parts in the CAV domain that needs 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 piece in this giant puzzle.

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, legal certainty is of utmost importance for vehicle manufacturers. For example, a sudden removal of spectrum resources cause much headache and creates insecurities resulting in unwillingness to make necessary investments for realizing certain technologies. Further, new technology for inclusion in vehicles needs to be mature when the product development starts and it needs to be available for the coming 15 years.

Cellular specific requirement for CAV:

• full road coverage with cellular communication.

• cross-border interoperability.

• cross-provider interoperability.

## 6.2 Radiocommunication requirements: sensors, interoperability, radio interfaces, data rate, latency, reliability

*[Editors note: For missing information, further input expected – topics on Interoperability / backward compatibility / coexistence are suggested.]*

Access layer requirements:

1) Communication topology

By nature, V2X communication is a many-to-many omnidirectional type of communication.

2) Dynamic channel:

The highly mobile environment of road traffic leads to much higher requirements on the V2X receiver. Consequently, CAV services using the ad hoc V2X sensor requires continuous adaption to the current channel status, which is affected by, e.g., severe multipath, doppler effect of the channel resources. V2X receivers need to comply with dynamic channel conditions as described in, e.g., ETSI EN 302 663 Annex A. Despite the reason for poorer wireless communication, CAV services need to have graceful performance degradation.

3) Dynamic number of participants

Dynamic load change in the channel 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. Vulnerable Road Users (VRU) like bicyclist and pedestrians can be V2X traffic participants and have to be calculated on top of that.

4) Dynamic use of channels:

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

5) Dynamic V2X message:

For most efficient use of spectrum V2X messages are generated only if required and necessary content is adapted by application layer to the minimum. 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*”[[9]](#footnote-9). Other CAV related messages such as CPM, MCM, PSM/VAM[[10]](#footnote-10), 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 applications intended to reduce traffic accidents in short range need 90% packet success rate at 150m in urban, suburban environment and at 500 m in highway environment or fast rural environment in combination with omnidirectional communication requirement.

7) Selection of V2X modulation characteristics:

The requirements for most, especially safety applications, CAV applications (V2X services 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 at least 500 m range with Packet Success Rate 90%.

These requirements lead to a preferred selection of low data rates and the choice of a robust modulation like QPSK ½ [[11]](#footnote-11). There are some CAV applications which can use higher order modulations and/or multiple/directional antenna systems, e.g. truck platooning.

8) Service layer latency:

Below 10 ms as in table “Technical characteristics on Advanced ITS and CAV”.

From the view of wireless connectivity, V2X communication technology for many new CAV applications need to support lower latency and higher reliability. The 3rd Generation Partnership Project (3GPP) specifications, ETSI, SAE, and IEEE standards provide the categories of enhanced V2X applications and technical requirements in terms of packet size, data latency, reliability, and data rate for currently-defined CAV applications. Based on these specifications and standards, the radio communication technology for CAV applications requires less than 10 msec in packet latency on the service / application level [x[[12]](#footnote-12)] and greater than 90% packet success rate. V2X applications intended to reduce traffic accidents in short range need 90% packet success rate at 150 m in urban, suburban environment and at 500 m in highway environment or fast suburban environment, in combination with omnidirectional communication requirement. Those safety applications like e.g. collective perception lead to lower data rates and the choice of a robust modulation. Other applications with much shorter communication range requirements or directional communication may choose an increased data rate. [1-4].

TABLE X

Technical characteristics on Advanced ITS and CAV

| Items | Advanced ITS | CAV |
| --- | --- | --- |
| Applications | Cooperative Awareness  Collective 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 1000m | Short range ad hoc and direct communication up to 1000 m |
| Packet size including necessary overheads and security certificate | 380 bytes – 1900 byte | 400 byte - 6000 bytes |
| End to End Service Level Latency | Less than 100 msec | less than 10 msec |
| Packet Success Rate | Greater than 90% in highway scenario within 500m communication range  Greater than 90% in suburban scenario within 150m communication range  Greater than 90% in urban scenario within 150m communication range | Greater than 90% |

The initial, and continuing, focus in most AV development has been upon onboard 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 onboard 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 onboard 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 onboard sensor data. These additional capabilities will greatly enhance the safety and efficiency of AV operations.

## 6.3 Use Cases

[Editor’s note (J): this section

– first describes CAV use cases and analyse them to derive CAV elements,

– Identifies their required types of radio links, e.g. V2V, V2N, V2N2V,

– Also identifies their requirements, e.g. throughput, latency, reliability, coverage area

– preferable frequency ranges, if any,

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 critically important for AVs. One of the first use cases in this category is platooning but coordinated merging and coordinated lane changing are also being developed.

[Editor’s note (J): The following texts need to move under section 7 since they address a radio communication system which support CAV.]

1) Platooning

Platooning involves multiple vehicles driving together in a convoy. The platoon is controlled as a unit by using inter-vehicle radiocommunication. Development to implement platooning is currently underway in several countries around the world. For example, in Japan, a field trials of truck platooning are underway[[13]](#footnote-13), as shown in Figure 6.3-1.

Figure 6.3-1

Truck platooning

|  |  |
| --- | --- |
| a) Rear view | b) Bird view |
|  |  |

Several social issues can be resolved through the use of truck platooning. Platooning can enable trucks to drive closer together to reduce wind resistance, which can reduce fuel consumption and reduce CO2 emissions. It has been shown that a platoon of three trucks travelling 4 m apart at 80 km/h consumes 15% less fuel[[14]](#footnote-14). 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 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 sub-use-cases in truck platooning, as shown in Figures 6.3-2 and 6.3-3.

Figure 6.3-2 shows radiocommunications between vehicles in truck platooning. There are two

Radiocommunication links in Figure 6.3-2; one is a link of Vehicle-to-Network-to-Vehicle (V2N2V), using cellular up- and down-link, i.e. a radio link via a cellular base station. Another is a direct radio link of Vehicle-to-Vehicle (Direct V2V) between two vehicles, which can be realized by using DSRC (Dedicated Short Range Communication) or Cellular-V2X Sidelink.

As described above, the direct, V2V radiocommunication is used, for example, for control messages to support coordinated braking, as well as basic safety use cases. Cellular network-based radiocommunication is used, for example, in geofencing, traffic congestion warning and road restriction violation warning use cases.

In the sub-use-case, three types of radiocommunication are required, (i) message communication for vehicle control, (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.

The above (i) requires small packet but [low latency communication]. 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.

Figure 6.3-2

Radiocommunications between vehicles in truck platooning

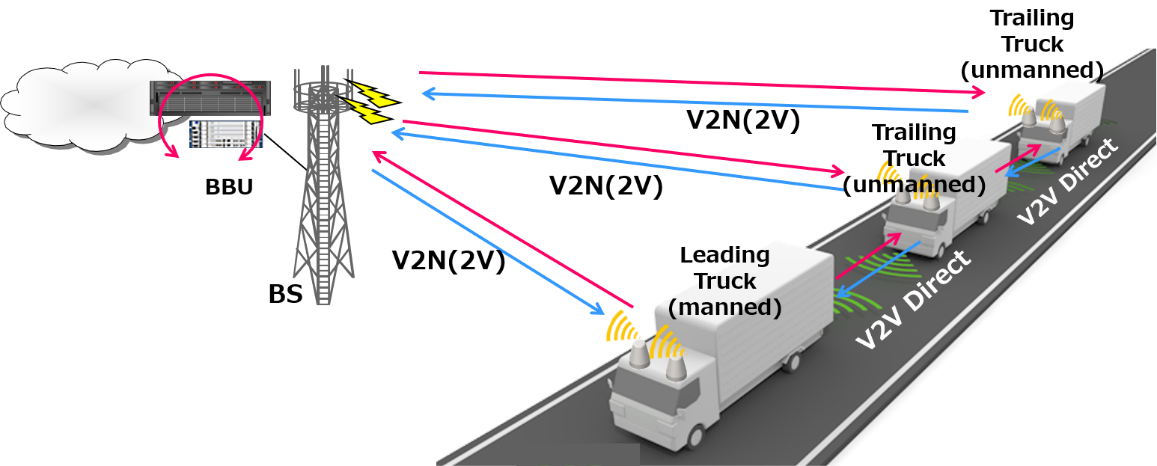
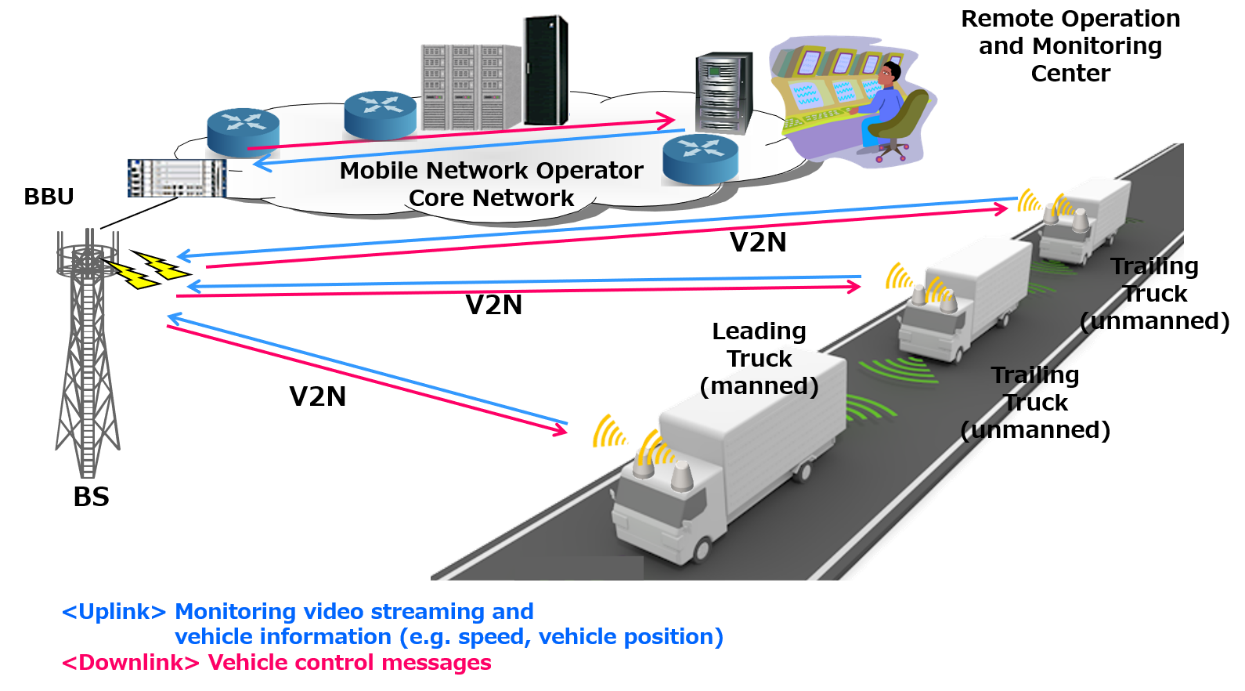


Figure 6.3-3

Radiocommunications between remote monitoring center (ground station) and   
moving vehicles in truck platooning



The above three radiocommunication may be provided by group communication among member vehicles, which would be provided by multiple of unicast or multicast V2V radiocommunications.

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 are preferable for the direct-V2V group communications in a platoon, since communication distances are relatively short. In case of V2N2V, i.e. via a base station, typical cellular communication, i.e. up- and down-link, can be used for the V2V communication, as well. In this sub-use-case, typical cellular coverage is required.

Figure 6.3-3 shows another sub-use-case of the platooning, in which radiocommunication is required between a remote operation and monitoring center, i.e. ground station, and a moving platoon of trucks.

In the sub-use-case, a human operator at remote operation and monitoring center, monitors a truck platoon by video monitoring over a radiocommunication link. If the operator recognizes something wrong with a platoon, he or she sends a control message, e.g. a message to safely stop a platoon on a highway. This sub-use-case requires the same requirements as discussed in (i) and (ii) above. In the sub-use-case, typical cellular coverage and its network are required.

2) Automated Valet Parking

*T.B.D.*

3) Urban Driving

*T.B.D.*

4) Advanced Driving

*T.B.D.*

5) Remote Driving

Remote Driving - 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.

6) Maneuver Coordination / Cooperative Driving / Advanced Driving

Maneuver Coordination Service also called Coordinated Driving or Advanced Driving enables e.g. coordinated merging, coordinated lane change of semi-automated or fully automated vehicles.

“Cooperative Automated Driving (CAD)[[15]](#footnote-15) 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. The IMAGinE[[16]](#footnote-16) [x] research project develops a CAD system based on collective perception and cooperative maneuver coordination, one example of CAD is a connected lane merge function”[[17]](#footnote-17) [x]. 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.

7) Object sharing / cooperative sensing driving / extended sensor sharing

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 communicate such identified objects to other V2X traffic participants with Collective Perception Messages (CPM). 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. Cameras, radars, LiDAR sense all object types (such as vehicles, pedestrians, bicycles, scooters, motorcycles or obstacles) in the Line-of-Sight environment and transmit the object data to all ITS traffic participants. Pedestrians are not equipped with camera, radar, LiDAR and cannot send CPM.

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 objects 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.

• Interaction with non CAVs such as VRUs and non-CAV vehicles.

All of 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 further improve ITS communication technologies and applications. However, there are additional advanced use cases emerging for automated driving, for which communication requirements have not yet been developed. These requirements are expected to become better defined by 2023 as the developments in both technology and regulation become better understood for Level 5 automated driving.

8) Raw perception data sharing

To guarantee the driving safety for Level 5 full automation of CAVs, autonomous 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 guarantee 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 Gbps and msec. As defined by 3GPP Release 16 specifications in the “Collective perception of environment” scenario [5], for high-level automatic driving vehicles, the delay requirement for collision prevention is as low as 3 ms, and the transmission rate is required to be more than 1Gbps. Therefore, related studies on new technologies should be considered to ensure the high data rate raw perception data sharing among CAVs with the low latency requirement.

## 6.4 Summary of the radiocommunication requirements to meet the CAV functionalities

# 7 Radiocommunication systems that support CAV

Wireless communication technologies are on an accelerating innovation cycle. For example, the 3GPP completed Release 16 Stage 3 specifications and froze the related ASN.1 in June 2020, incorporating the New Radio access technology, which is meant to satisfy the IMT-2020 performance requirements. In addition, 3GPP is currently working on Release 17, and intends to complete Release 17 by February 2022. In Release 17, 3GPP intends to extend the flexibility of the cellular technologies into an expanding number of vertical industries. For ad hoc technologies based on 3GPP technology such as LTE-V2X and 5G-NR V2X, it is still unclear if all CAV requirements as listed above are fulfilled since deployment has not started with the former and the latter has just been approved. Independent results from large field tests or pilots are missing.

IEEE 802.11p supports already today CAV requirements especially in terms of latency. Draft IEEE 802.11bd will enhance the robustness of the physical layer thereby increasing the reliability at longer distances (the information horizon will increase for the automated vehicle). IEEE 802.11p supports a latency below 1 ms[[18]](#footnote-18).

The IEEE 802.11p based ITS-G5 and WAVE communication technologies support the required performance criteria for CAV applications. This is now proven with Collective Perception and Maneuver Coordination Services which are successfully tested for CAV with IEEE 802.11p based ITS-G5 in IMAGinE[[19]](#footnote-19) [x].

This Report will provide further details of capabilities, technical demands and operational characteristics associated with C-V2X using the terrestrial component of IMT systems, as these capabilities become better known.

[Editor’s note (J): The following texts are moved from Section 6.3.]

The 3GPP Release 16 specifications are designed to support four categories of advanced use cases, including fully automated driving vehicle scenarios. These categories are:

– Vehicles Platooning – 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 pedestrians and V2X application servers.

– Advanced Driving – enables semi-automated or fully automated driving.

– Remote Driving – 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.

All of 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. However, there are additional advanced use cases emerging for automated driving, for which communication requirements have not yet been developed. These requirements are expected to become better defined during the next two or three years as the developments in both technology and regulation become better understood for Level 5 automated driving.

The IEEE has initiated IEEE P802.11-Task Group BD - “Enhancements for Next Generation V2X”[[20]](#footnote-20) 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.

Regarding V2N cellular connectivity, CAVs are more in need of better coverage of existing deployment of 4G networks then 5G and better cross-border/cross-operator functionality. OEMs design CAVs for surviving without network coverage.

# 8 Spectrum needs for CAV radiocommunication

## 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.2121-0](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 best be effectively supported in EHF (30‑300 GHz) bands. 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 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. 2121-0. 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. Table 1 summarizes spectrum needs for CAV direct communication. Table 1 does not address the spectrum needs for cellular network connectivity such as 4G/5G, which is subject to another spectrum regime.

Table 1

Current and future spectrum needs for CAVs

|  |  |  |  |
| --- | --- | --- | --- |
| Frequency band | Status/description | Current availability | Future requirements CAV |
| 5.9 GHz | Main spectrum today for deployment of road traffic safety and efficiency applications | 5.9 GHz is identified recommended for evolving ITS (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) | [As a minimum 70 MHz of spectrum is required for CAVs, see table x in present document, around 140 MHz is required as a typical need] |
| 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 in bandwidth for enabling high transfer rates] |
| < 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] |

70 MHz spectrum band for transportation safety

A spectrum study[[21]](#footnote-21) (2020) shows that deployed as well as planned applications for increasing road traffic safety towards cooperative automated driving may consume more than 70 MHz. This study only takes the applications’ needs of bandwidth in MHz into account and it is communication technology agnostic. Table x 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 show that the 7x10 MHz channels are required for existing and planned safety applications, thus preserved spectrum is a necessity.

Table x explains the different message types found in Table x, which are already well defined and specified in standardization bodies, such as ETSI.

Table x

Minimum Spectrum needs for different message types for direct, V2X communication



Applications 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 applications are intended to inform the driver about impending dangerous situation and the driver needs to react accordingly. Day two scenarios intend to increase the information horizon for the vehicle and day-two applications involve for example truck platooning and cooperative adaptive cruise control (CACC).

Figure x 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 applications 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 2, three phases of V2X deployment:

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

• sensing driving (CPM),

• cooperative automated driving (MCM, PCM).

Table x

Explanation of different message types

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Phases of V2X application roadmap2** | **Message types[[22]](#footnote-22)** | |  | **Examples of applications 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 |
|  | SPaT, MAP, IVI | SPaT, MAP, 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 1

C2C-CC roadmap for V2X application[[23]](#footnote-23)

|  |
| --- |
|  |
|  |

The following study[[24]](#footnote-24) 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 the minimum requirements to enable these CPM and MCM live-saving applications. For CAV it is recommended to choose at least the typical instead of the minimum values of the following parameters, because all values between best and worst case can occur in realistic scenarios.

| CPM |  | 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 | 1000 | 1900 | 1450 |
| Periodicity in Hz | Dynamic, up to 10 Hz |  |  |  |
| Periodicity | In Urban | 3 | 5 | 4 |
| Periodicity | In Suburban | 6 | 10 | 8 |
| Periodicity | In Highway | 10 | 10 | 10 |
| Communication range in m |  |  |  |  |
| Communication range | In Urban | 150 | 300 | 225 |
| Communication range | In Suburban | 150 | 500 | 325 |
| Communication range | 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 |  |  |  |  |
| **CPM** | **Urban** | **23** | **108** | **57** |
| **CPM** | **Suburban** | **26** | **122** | **65** |
| **CPM** | **Highway** | **24** | **68** | **45** |
| 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 | 1000 | 1300 | 1150 |
| Periodicity in Hz | Dynamic, up to 10 Hz |  |  |  |
| Periodicity | In Urban | 3 | 5 | 4 |
| Periodicity | In Suburban | 6 | 10 | 8 |
| Periodicity | In Highway | 10 | 10 | 10 |
| Communication range in m |  |  |  |  |
| Communication range | In Urban | 150 | 300 | 225 |
| Communication range | In Suburban | 150 | 500 | 325 |
| Communication range | 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** |
| **MCM** | **Suburban** | **26** | **83** | **51** |
| **MCM** | **Highway** | **24** | **46** | **36** |

# 9 Spectrum harmonization

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 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 applications.

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 Relevant provisions in the Radio Regulations

ITS applications are operated under mobile service allocations in Article **5** of the Radio Regulations. Specific frequency bands harmonized for ITS applications should be used for CAVs as noted in relevant ITU-R texts found in Section 2 of this report.

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[2] TTAK.KO-06.0505, “Vehicle Communication for Connected Automated Driving Stage 2: Architecture, December, 2019.

[3] 3GPP TS 22.185, “Service Requirements for V2X services; Stage 1(Rel.15)”, June, 2018.

[4] 3GPP TS 22.186, “Enhancement of 3GPP support for V2X scenarios; Stage 1(Rel.16)”, June, 2019.

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

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

**TS 22.186**:Service requirements for enhanced V2X scenarios:  
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**TS 23.285**: Architecture enhancements for V2X services:  
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<https://www.3gpp.org/DynaReport/37985.htm>

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– T-200111 TR C-V2X Use Cases and Service Level Requirements Vol I V3.0

– “[Study of spectrum needs for safety related intelligent transportation systems – day 1 and advanced use cases](https://5gaa.org/news/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.

– “[A Visionary Roadmap for Advanced Driving Use Cases, Connectivity Technologies, and Radio Spectrum Needs](https://5gaa.org/news/the-new-c-v2x-roadmap-for-automotive-connectivity/)” relates to Question 3 and introduces a timeline related to identified Use Cases.

– “[White Paper C-V2X Use Cases Volume II: Examples and Service Level Requirements](https://5gaa.org/news/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.

– ETSI GS MEC 030 V2.1.1 (2020-04), “Multi-access Edge Computing (MEC); V2X Information Service API”, Link: <https://www.etsi.org/deliver/etsi_gs/MEC/001_099/030/02.01.01_60/gs_MEC030v020101p.pdf>

*[Editor’s note: The material from ETSI ERM TGSRR in Document 5A/142 contains information on vehicular radar sensors which may be pertinent for CAVs.]*

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2. <https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic> [↑](#footnote-ref-2)
3. BASt, German Federal Highway Authority. “Requirements to ADAS from the road safety perspective”, 2007. https://www.bast.de/BASt\_2017/DE/Publikationen/Archiv/Infos/2007-2006/11-2007.html. [↑](#footnote-ref-3)
4. BSM Basic Safety Message; CAM Cooperative Awareness Message; CPM Collective Perception Message; MCM Maneuver Coordination Message. [↑](#footnote-ref-4)
5. European H2020 research project PROSPECT, PROactive Safety for PEdestrians and CyclisTs, analyse and tested in-vehicle perception ADAS to protect VRUs, finalized 2018. Deliverable D2.3, https://ec.europa.eu/inea/en/horizon-2020/projects/H2020-Transport/Safety/PROSPECT. [↑](#footnote-ref-5)
6. 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-6)
7. 5GAA TR S-200137: Working Group Standards and Spectrum, “Study of spectrum needs for safety related intelligent transportation systems - day 1 and advanced use cases”, https://5gaa.org/wp-content/uploads/2020/06/5GAA\_S-200137\_Day1\_and\_adv\_Use\_Cases\_Spectrum-Needs-Study\_V2.0-cover.pdf [↑](#footnote-ref-7)
8. Communication technology independent CAR-2-CAR Communication Consortium Spectrum Study for V2V and V2I safety message types defined in ETSI and SAE: “Road Safety and Road Efficiency Spectrum Needs in the 5.9 GHz for C-ITS and Cooperative Automated Driving” https://www.car-2-car.org/fileadmin/documents/General\_Documents/C2CCC\_TR\_2050\_Spectrum\_Needs.pdf [↑](#footnote-ref-8)
9. R. Molina-Masegosa, M. Sepulcre, J. Gozalvez, F. Berens and V. Martinez, "Empirical Models for the Realistic Generation of Cooperative Awareness Messages in Vehicular Networks," in IEEE Transactions on Vehicular Technology, Vol. 69, No. 5, pp. 5713-5717, May 2020, doi: 10.1109/TVT.2020.2979232. [↑](#footnote-ref-9)
10. PSM: Personal Safety Message, VAM: Vulnerable Road User VRU Awareness Message. [↑](#footnote-ref-10)
11. D. Jiang, Q. Chen, L. Delgrossi, “Optimal data rate selection for vehicle safety communications”, *Proc. ACM international workshop on VehiculAr Inter-NETworking (VANET)*, San Francisco, California, USA, pp. 30-38, 15 Sept. 2008. [↑](#footnote-ref-11)
12. 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-12)
13. M. Mikami and H. Yoshino, “Field Trial on 5G Low Latency Radio Communication System Towards Application to Truck Platooning,” pp. 1447-1457, IEICE Transactions on Communications Vol.E102-B, No.8, Aug. 2019. [↑](#footnote-ref-13)
14. K. Aoki, “Current Activities of Development on the Automated Truck Platoon,” pp. 303-309, IPSJ Journal, Vol. 54 No. 4, Apr. 2013 (in Japanese). [↑](#footnote-ref-14)
15. Note that CAD has the same meaning as CAV. [↑](#footnote-ref-15)
16. 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-16)
17. ] 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-17)
18. 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-18)
19. Research project IMAGinE; <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-19)
20. <http://www.ieee802.org/11/Reports/tgbd_update.htm> [↑](#footnote-ref-20)
21. 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-21)
22. 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-22)
23. Source C2C-CC: <https://www.car-2-car.org/fileadmin/downloads/PDFs/roadmap/CAR2CAR_Roadmap_Nov_2018.pdf> [↑](#footnote-ref-23)
24. Continental, July 10th 2020, published on US FCC website, <https://ecfsapi.fcc.gov/file/10710018216099/Ex-Parte%20-%20July%2010%202020.pdf> [↑](#footnote-ref-24)