



Report ITU-R M.2520-0
(11/2022)

The use of the terrestrial component of International Mobile Telecommunications for the Cellular-Vehicle-to-Everything

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Note: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.

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REPORT ITU-R M.2520-0

The use of the terrestrial component of International Mobile Telecommunications for the Cellular-Vehicle-to-Everything

(Question ITU-R 262/5)

(2022)

TABLE OF CONTENTS

	<i>Page</i>
Policy on Intellectual Property Right (IPR).....	ii
1 Introduction	3
2 Relevant ITU-R Recommendations and Reports	4
3 Acronyms	4
4 C-V2X as a specific ITS application supported by IMT technologies in terrestrial networks	6
4.1 Overview on Usage of IMT technologies in the C-V2X application	6
4.2 Use cases classification.....	9
4.3 SDO use cases.....	11
4.4 Additional use cases	18
5 Relationship between IMT and C-V2X.....	21
6 The characteristics and capabilities of the C-V2X application supported by IMT mobile networks	21
6.1 Necessary capabilities.....	21
6.2 IMT capabilities.....	26
6.3 Operational spectrum.....	31
7 Case study.....	32
Annex 1 – Case studies from China.....	32
A1.1 Typical C-V2X use cases.....	32
A1.2 Advanced C-V2X use cases necessary capability	34
A1.3 C-V2X spectrum.....	36
A1.4 C-V2X Standards.....	36
A1.5 Industrial activities.....	37
A1.6 Demonstration zone and pilot zone construction.....	38

	<i>Page</i>
Annex 2 – ITS use cases included in Report ITU-R M.2445 “ITS usage”.....	38
A2.1 Applications.....	39

Scope

This Report contains the mutual relationship between IMT technologies in terrestrial networks and the Cellular-Vehicle-to-Everything (C-V2X), which supports various V2X use cases, as well as elements of functions in IMT technologies that are used to realize the C-V2X application. The focus of this Report is on the aspects of IMT technologies available for use by subscribers to mobile networks that are used to support V2X use cases, and also the description of provisions in these technologies that have been designed to address the common out-of-network coverage situations.

This Report provides details on:

- V2X use cases being considered to be supported by IMT technologies in terrestrial networks;
- Characteristics and capabilities of terrestrial networks necessary to support appropriate V2X use cases;
- Relationship between the IMT technologies and “the C-V2X application”; and,
- In an Annex, a Case Study associated with V2X use cases in various scenarios supported by Enhanced Mobile Broadband (eMBB), Massive Machine-Type Communications (mMTC), and Ultra-Reliable Low-Latency Communication (URLLC) of the terrestrial component of IMT.

1 Introduction

This Report provides information on the use of the terrestrial component of IMT as a specific application called “Cellular- vehicle to everything (C-V2X)” under Question ITU-R 262/5 – Usage of the terrestrial component of IMT systems for specific applications.

V2X use cases relevant to vehicle communication are also included in Report ITU-R M.2445 – ITS usage. These V2X use cases are attached as Annex 2 of this Report. Some of these use cases that could be supported by IMT radio interface technologies are also listed in § 4 of this Report. The terminology in the main body of this Report refers to the entirety of ‘C-V2X’ as an ‘application’, while the functions to perform a specific purpose are called ‘use cases’.

This Report addresses C-V2X as a specific ITS application supported by IMT technologies in terrestrial networks, and describes V2X use cases which are supported as 5G V2X by various IMT technologies¹ in terrestrial networks.

Further, this Report also describes the various IMT systems that are designed to support the C-V2X application, and then provides details on a number of V2X use cases, including which IMT systems are likely to support specific use cases.

IMT based 5G V2X currently uses cellular communication to directly carry the V2X messages through the IMT system, and/or for the IMT system to control peer-to-peer message exchange among vehicles affiliated with terrestrial networks.

Also, this Report provides information on characteristics and capabilities of the C-V2X application in terrestrial networks supported by IMT systems. Some case studies for the C-V2X application are introduced.

¹ The 5th Generation system (5GS) is able to accommodate V2X operations in both NR and LTE radio access technologies of IMT technologies. Although LTE V2X and NR V2X, as well as E-UTRA Uu and NR Uu, use different radio access technologies, 5G V2X includes 5G network control of LTE V2X, NR V2X, E-UTRA Uu and NR Uu.

2 Relevant ITU-R Recommendations and Reports

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

Recommendation ITU-R M.2083 – IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond

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

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

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

Report ITU-R M.2441 – Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT)

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

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

Handbook on Land Mobile (including Wireless Access) – Volume 4: Intelligent Transport System

3 Acronyms

3GPP	3 rd Generation Partnership Project
5GC	5G core network
5GS	5G system
5QI	5G QoS identifier
ADAS	Advanced driver assistance systems
BSM	Basic safety message
BSR	Buffer status report
CA	Carrier aggregation
CCSA	China Communications Standards Association
CEN	Comité Européen de Normalisation (European Committee for Standardization)
C-ITS	Cooperative intelligent transport systems
CS	Charge station
C-SAE	China-Society of Automotive Engineers
CV	Connected vehicle
C-V2X	Cellular vehicle to everything
DENM	Decentralized environmental notification message
DSRC	Dedicated short-range communications
eMBB	Enhanced mobile broadband
eNB	evolved Node B
EPS	Evolved packet system
EV	Electric vehicle

eV2X	Enhanced V2X
gNB	next Generation node B
HARQ	Hybrid automatic repeat request
HV	Host vehicle
ICV	Intelligent Internet connected vehicle
ITS	Intelligent transport systems
MBMS	Multimedia broadcast multimedia service
MEC	Multiple-access edge computing
mMTC	Massive machine-type communications
OBU	On-board Unit
OTA	Over The Air
PC5	Proximity-based Communication (Interface) 5 interface between the ITS stations used for V2X sidelink communication
PDB	Packet delay budget
PLMN	Public land mobile network
PPPP	ProSe per packet priority
ProSe	Proximity-based Services
P-UE	Pedestrian UE
QoS	Quality of service
RSI	Road side information
RSM	Road safety message
RSU	Road side unit
RV	Remote vehicle
SAE	SAE International, formerly named the Society of Automotive Engineers
SDO	Standards Development Organization
Sidelink	radio link between the ITS stations for direct communication
SPAT	Signal phase and timing message
S-SSB	Sidelink synchronization signal block
UE	User equipment
URLLC	Ultra-reliable low-latency communication
V2I	Vehicle to infrastructure
V2N	Vehicle to network
V2P	Vehicle to pedestrian
V2V	Vehicle to vehicle
V2X	Vehicle to everything
VAE	V2X application enabler

VRU Vulnerable road user

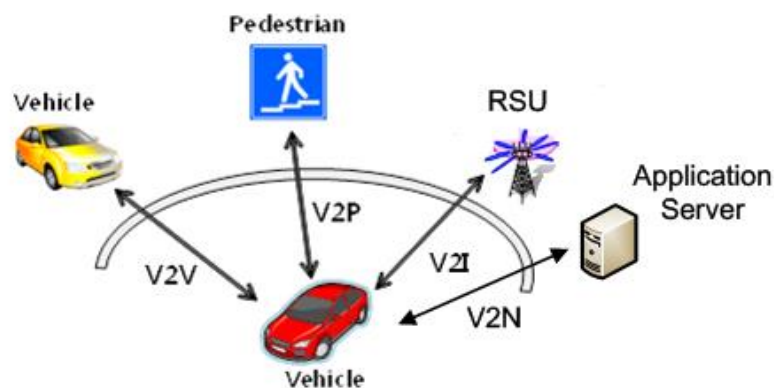
4 C-V2X as a specific ITS application supported by IMT technologies in terrestrial networks

4.1 Overview on Usage of IMT technologies in the C-V2X application

The use cases referred to as Vehicle-to-Everything (V2X) may be sub-categorized into the following four different types², among others:

- Vehicle-to-Vehicle (V2V).
- Vehicle-to-Infrastructure (V2I).
- Vehicle-to-Network (V2N).
- Vehicle-to-Pedestrian (V2P).

FIGURE 1
Types of V2X use cases (V2V, V2P, V2N and V2I)



V2X use cases can use “co-operative awareness” to provide more intelligent benefits for end-users. This means that entities such as vehicles, roadside infrastructure, use case servers and pedestrians, can collect knowledge of their local environment (e.g. information received from vehicles or other entities with sensor equipment in proximity) to process and share that knowledge in order to support more intelligent safety-critical use cases, such as cooperative collision warning.

Intelligent transport systems and the message sets associated with V2X use cases have been defined in automotive and related SDOs, and can typically be supported by any wireless communication technology which has the necessary characteristics to effectively transport these messages associated with the specific V2X use cases.

The 3rd Generation Partnership Project (3GPP) has developed specifications for cellular telecommunications technologies which are standardized through seven regional SDOs – ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC. V2X communication capabilities have been explicitly designed into 3GPP cellular technology specifications starting with Release 14 specifications.

² 3GPP TS 22.185 – “Service requirements for V2X services”.

The 3GPP specifications take into account the work by automotive and related SDOs to design and standardize the upper layer protocols, and handle the transport of these V2X message sets to support different types of V2X use cases.

4.1.1 LTE V2X

V2V, V2P, V2I are supported using the PC5 interface, and V2N is supported over the Uu interface in the 3GPP LTE V2X Specifications. Two different modes of operation are specified for the PC5 interface: PC5 Mode 3 and PC5 Mode 4³.

In PC5 Mode 3, the LTE cellular infrastructure (eNB (evolved Node B)) manages the V2X communications over the PC5 interface. This includes selecting and configuring the communication resources (sub-channels), as well as providing time synchronization. Use of this mode involves a subscription to a cellular network and authorization from the mobile network operator to use V2X communications.

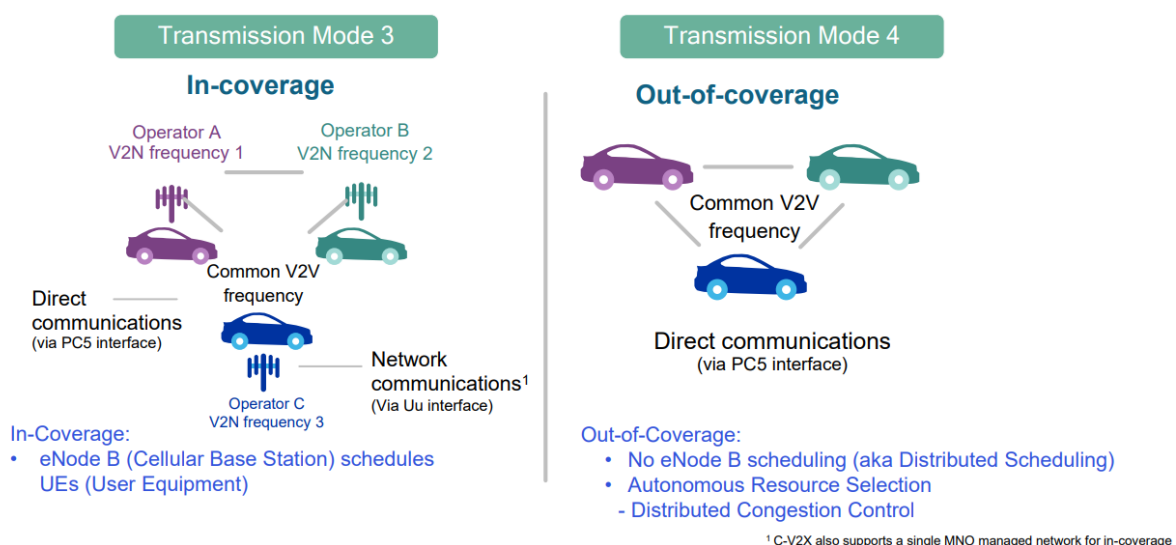
In PC5 Mode 4, vehicles autonomously select transmission resources based on sensing the environment and perform time synchronization using GNSS. There is no involvement of the cellular network in this mode. Consequently, LTE cellular networks supporting V2X use cases that need direct V2V, V2I, V2P, etc. communications can pre-configure UEs to operate in Mode 4 over the PC5 interface when out-of-cellular network coverage. PC5 Mode 4 also supports use of the PC5 interface by UEs with no cellular network affiliation or subscription. The use of PC5 Mode 4 in this manner, without the involvement of any cellular network, is one of the radio interface technologies identified for V2X communications in Recommendation ITU-R M.2084.

Two modes of the PC5 interface available in LTE V2X communications are shown in Fig. 2.

FIGURE 2

PC5 Interface Modes⁴ supported by LTE V2X network

C-V2X Designed for Both In-Coverage and Out-of-Coverage

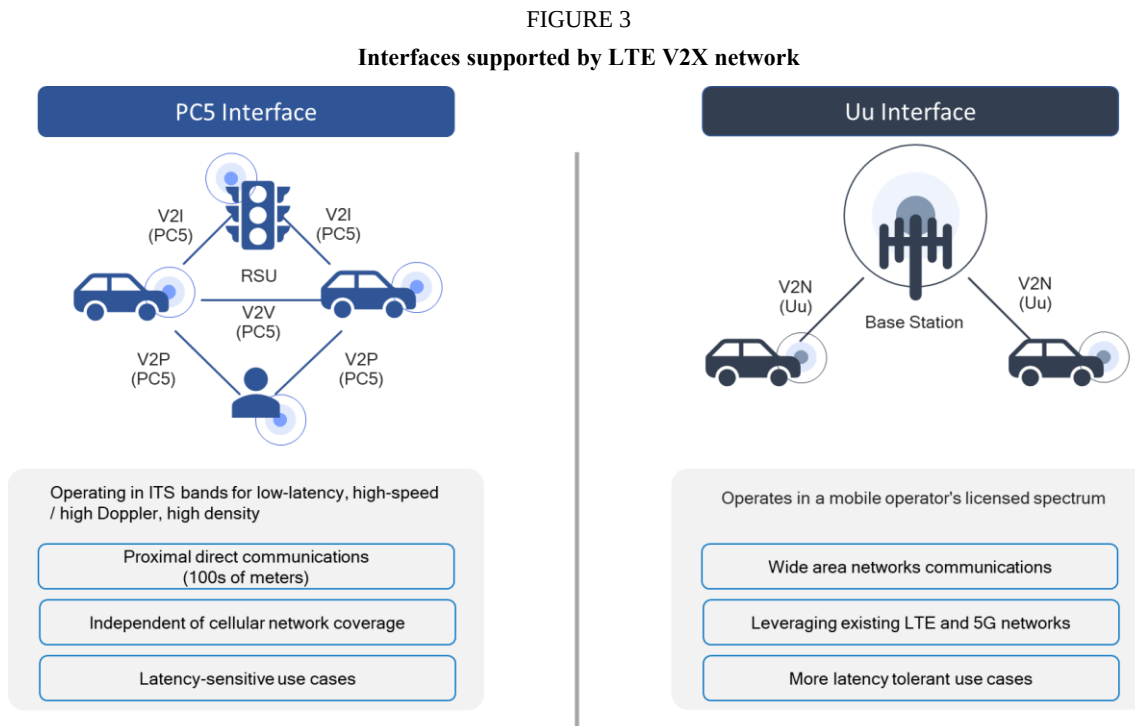


³ 3GPP TR 37.985 V16.0.0 (2020-06) "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Overall description of Radio Access Network (RAN) aspects for Vehicle-to-everything (V2X) based on LTE and NR (Release 16)", Section 5.

⁴ <https://www.qualcomm.com/media/documents/files/introduction-to-c-v2x.pdf>

V2N use cases are supported in LTE V2X over the Uu interface. The UE, in this case, must have a subscription to a cellular network and authorization to access the relevant network-based ‘application’ server in order to use a V2N use case.

A summary of the two interfaces available in V2X communications is shown in Fig. 3.



4.1.2 NR V2X

The additional capabilities beyond LTE V2X have been specified in NR V2X in 3GPP specifications; for example, it supports broadcast, unicast and groupcast sidelink operations while LTE V2X supports only the broadcast operation. And, the NR V2X has two modes for the sidelink operation; Sidelink Mode 1 and Sidelink Mode 2.

NR V2X Sidelink Mode 1 represents that the resources are allocated by the gNB (next Generation Node B) of the NR cellular network in the stand-alone mode. “The gNB scheduling activity is driven by the UE reporting its sidelink traffic characteristics to the gNB, or by performing a sidelink BSR (Buffer Status Report) procedure similar to that on Uu to request a sidelink resource allocation from gNB.”⁵ This mode needs a UE to have a subscription to a NR cellular network and authorization from the mobile network operator to access V2X communications.

NR V2X Sidelink Mode 2 represents that the UE performs autonomous resource selection. “Its basic structure is of a UE sensing, within a (pre-)configured resource pool, which resources are not in use by other UEs with higher-priority traffic and choosing an appropriate amount of such resources for its own transmissions. Having selected such resources, the UE can transmit and re-transmit in them

⁵ 3GPP TR 37.985 V16.0.0 (2020-06) “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Overall description of Radio Access Network (RAN) aspects for Vehicle-to-everything (V2X) based on LTE and NR (Release 16), Clause 6.3.2.1.

a certain number of times, or until a cause of resource reselection is triggered.”⁶ NR V2X Sidelink Mode 2 supports use of the PC5 interface by UEs with no cellular network affiliation or subscription.

4.2 Use cases classification

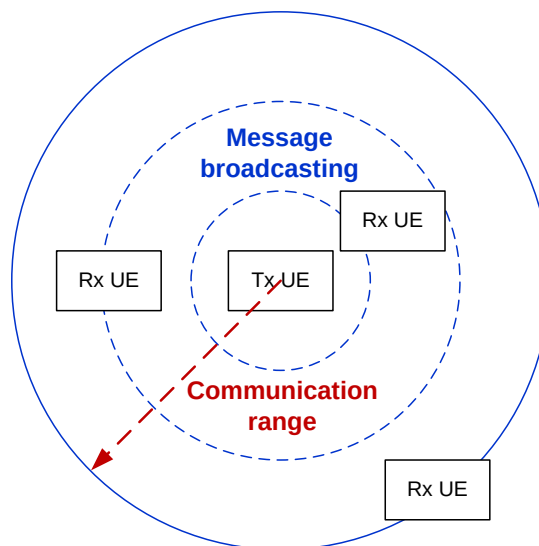
4.2.1 Vehicle-to-Vehicle (V2V) use cases

V2V use cases require User Equipment (UE)s that are in proximity of each other to exchange V2V use case information. 3GPP transport of messages containing V2V use case information requires the UE to have a valid subscription and authorization from a mobile network operator, except in the case of PC5, Mode 4, for which no affiliation with any mobile network is required. Transport for a valid subscriber of a mobile network is provided, whether the UE is served or not served by IMT mobile network systems.

The UE supporting V2V use cases transmits messages containing V2V use case information (e.g. location, dynamics, and attributes). The message payloads may be flexible in order to accommodate varying amount of information.

The 3GPP transport of messages containing V2V use case information is predominantly broadcast-based as illustrated in Fig. 4, using PC5, Mode 4. 3GPP transport capabilities include the transport between UEs directly via broadcast, groupcast or unicast, and/or, due to the limited direct broadcast communication range, the transport between UEs via infrastructure supporting V2X communication, e.g. RSU, “application”⁷ server, etc.

FIGURE 4
Broadcast-based V2V communications



⁶ 3GPP TR 37.985 V16.0.0 (2020-06) “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Overall description of Radio Access Network (RAN) aspects for Vehicle-to-everything (V2X) based on LTE and NR (Release 16), Clause 6.3.2.2.

⁷ Note that the terms such as ‘application’, ‘service’, ‘use case’ and ‘requirement’ have specific meanings in ITU-R terminology which differ from terminology usage in other groups, such as 3GPP. For this Report, the ITU-R meanings are retained and alternative terms for 3GPP terminology are substituted wherever appropriate and placed in quotation marks when used in relation to specific 3GPP terminology.

4.2.2 Vehicle-to-Infrastructure (V2I) use cases

The UE supporting V2I use cases transmits messages containing V2I use case information to an RSU or locally relevant ‘application’ server. The RSU and/or the locally relevant ‘application’ server transmits messages containing V2I use case information to one or more UEs supporting V2I use cases.

A locally relevant ‘application’ server serves a particular geographic area. There can be multiple ‘application’ servers serving overlapping areas, providing the same or different V2I use cases.

4.2.3 Vehicle-to-Network (V2N) use cases

The UE supporting V2N use cases communicates with an ‘application’ server supporting V2N use cases. Both parties communicate with each other via the IMT mobile network systems.

4.2.4 Vehicle-to-Pedestrian (V2P) use cases

V2P use cases require UEs that are in proximity of each other to exchange V2P use case information. 3GPP transport of messages containing V2P use case information requires the UE to have a valid subscription and authorization from a network operator, except for the direct, ad hoc, V2P communications provided by PC5, Mode 4. Transport for a valid subscriber is provided, whether the UE is served or not served by IMT mobile network systems.

The UE supporting V2P use cases transmits messages containing V2P use case information. It is expected that V2P use case information can be transmitted either by a UE supporting V2X use case in a vehicle (e.g. warning to pedestrian), or by a UE supporting V2X use case associated with a vulnerable road user (e.g. warning to vehicle).

The 3GPP transport of messages containing V2P use case information includes the transport between UEs directly, and/or, due to the limited direct communication range, the transport between UEs via infrastructure supporting V2X communication, e.g. RSU, ‘application’ server, etc.

The main difference between 3GPP transport of messages with V2P and V2V use case information is due to the properties of the UE. A UE supporting V2P use cases used by pedestrian has lower battery capacity and limited radio sensitivity, and therefore it cannot send and/or receive messages with the same periodicity as UEs supporting V2V use cases. V2P-specific UEs are required to be fully interoperable with UEs in vehicles to support safety-critical use cases in further study.

4.3 SDO use cases

3GPP has addressed V2X use cases to be supported by IMT mobile networks in 3GPP TR 22.885⁸ and 3GPP TR 22.886⁹. They describe V2X use cases, pre-conditions, logical flows, post-conditions, and potential system capabilities necessary to support these use cases.

V2V, V2I, and V2P type capabilities are used for the immediate transmission of pertinent information in a small area, and V2N is used for the delivery of relevant information in a relatively larger area, and/or for access to edge computing or other network server capabilities located within cellular networks. Therefore, V2V, V2P, and V2I use cases typically use the PC5 interface in Mode 4 (not necessarily under the control of a cellular network operator). On the other hand, V2N use cases communicate through the Uu interface, and require a subscription to a mobile network.

⁸ 3GPP TR 22.885 – LTE support for V2X services.

⁹ 3GPP TR 22.886 – enhancement of 3GPP support for 5G V2X services.

The categorization of use cases and the corresponding appropriate types of communications from the four V2X types – V2V, V2I, V2P and V2N – are indicated in the following Tables. Also, in some use cases, plural communication types are included, wherever appropriate.

The use case and the description related to LTE V2X support for V2X are listed in Table 1. Interoperability for the C-V2X application among multi-parties, e.g. vendors in cellular networks has been tested in detail.^{10, 11}

TABLE 1
Use cases supported by LTE V2X network¹²

Use cases	Description	Types of V2X use case
Forward collision warning	The FCW use case is intended to warn the driver of the HV in case of an impending rear-end collision with a RV ahead in traffic in the same lane and direction of travel. As a V2V type use case, FCW is intended to help drivers in avoiding or mitigating rear-end vehicle collisions in the forward path of travel.	V2V
Control loss warning	The CLW use case enables a HV to broadcast a self-generated control loss event to surrounding RVs. Upon receiving such event information, a RV determines the relevance of the event and provides a warning to the driver, if appropriate.	V2V
V2V Use case for emergency vehicle warning	Emergency vehicle warning use case enables each vehicle to acquire the location, speed and direction information of a surrounding emergency vehicle (e.g. ambulance) to assist safety operation like allowing ambulance path to get free.	V2V
V2V Emergency Stop Use Case	This use case describes vehicles V2V communication used in case of emergency stop to trigger safer behaviour for other cars in proximity of the stationary vehicle.	V2V
Cooperative Adaptive Cruise Control	This use case describes the scenario whereby a vehicle with V2V capability joins and leaves a group of cooperative-adaptive-cruise-control (CACC) vehicles. This provides convenience and safety benefits to participating vehicles and also has societal benefits to improve road congestion and fuel efficiency.	V2V

¹⁰ <https://www.etsi.org/newsroom/news/1763-2020-05-second-etsi-c-v2x-interoperability-test-event-to-connect-vehicles-in-europe-and-in-the-rest-of-the-world>

¹¹ Note reliable operation of the V2X use cases in a mixed environment of different mobile network operators, under in-coverage and out-of-coverage situations, needs to be validated on a use case by use case basis to determine applicability for deployment as IMT supported V2X use cases.

¹² These use cases are listed in 3GPP TR 22.885.