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**ITU-R**  
Radiocommunication Sector of ITU

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

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

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



International  
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## Foreword

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<b>M</b>	<b>Mobile, radiodetermination, amateur and related satellite services</b>
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<b>SA</b>	Space applications and meteorology
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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)

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## 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 technologies<sup>1</sup> 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.

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<sup>1</sup> The 5<sup>th</sup> 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<sup>rd</sup> 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

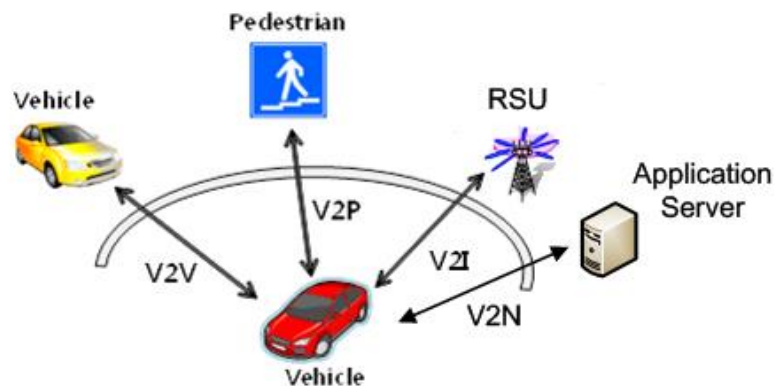
#### 4 C-V2X as a specific ITS application supported by IMT technologies in terrestrial networks

##### 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 types<sup>2</sup>, 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 3<sup>rd</sup> 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.

<sup>2</sup> 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 4<sup>3</sup>.

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.

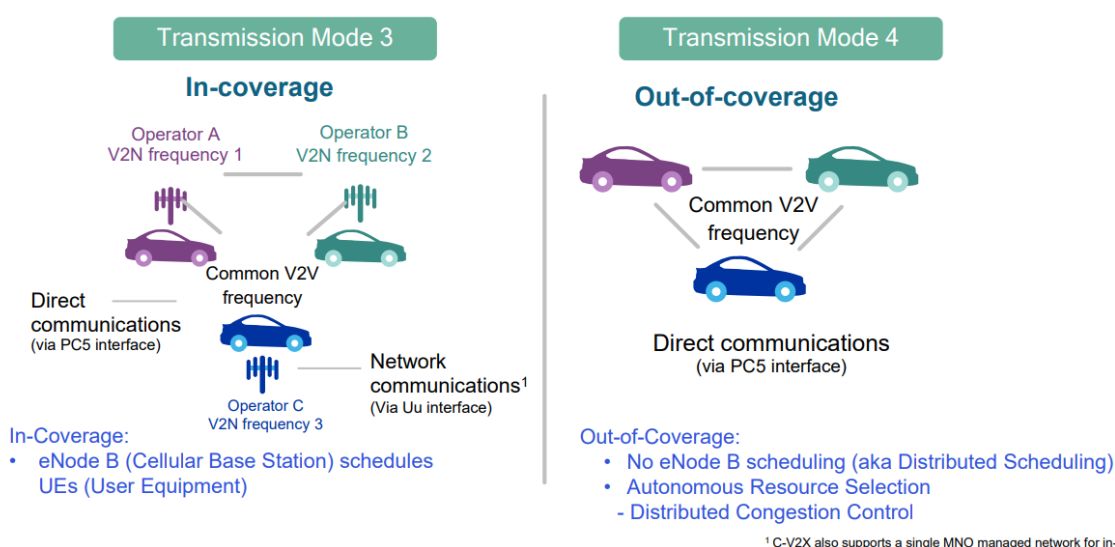
In PC5 Mode 4, vehicles autonomously select transmission resources based on sensing the environment and perform time synchronization using GNSS. There is no involvement of the cellular network in this mode. Consequently, LTE cellular networks supporting V2X use cases that need direct V2V, V2I, V2P, etc. 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 Modes<sup>4</sup> supported by LTE V2X network

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

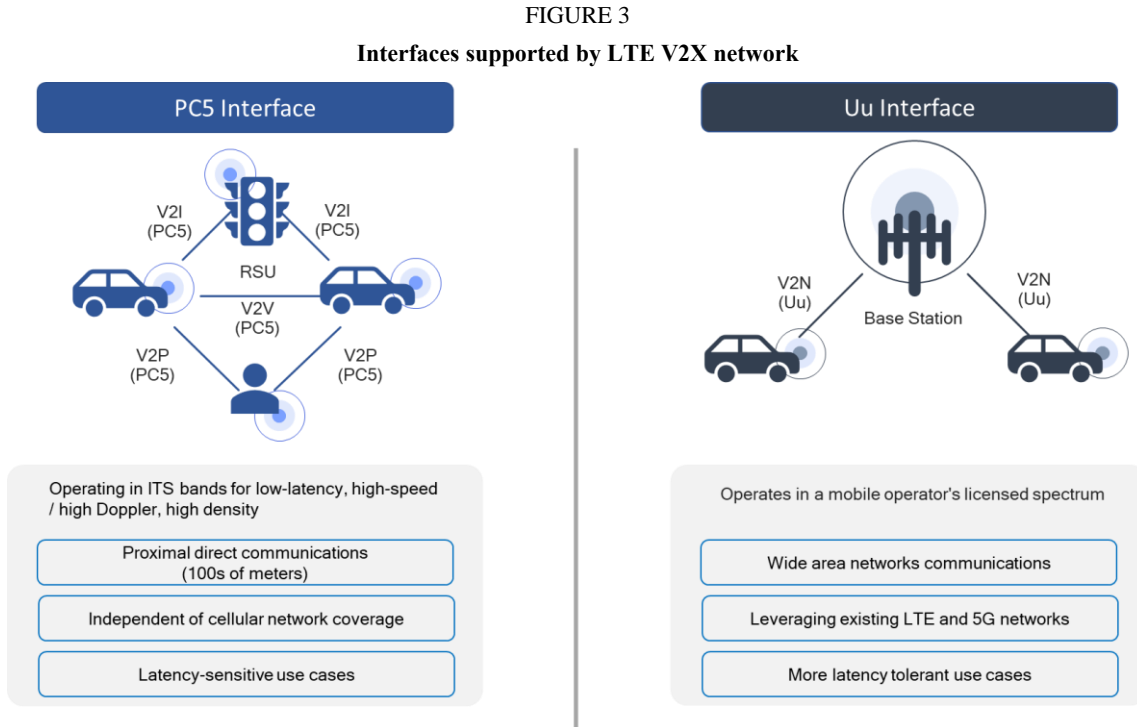


<sup>3</sup> 3GPP TR 37.985 V16.0.0 (2020-06) “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Overall description of Radio Access Network (RAN) aspects for Vehicle-to-everything (V2X) based on LTE and NR (Release 16)”, Section 5.

<sup>4</sup> <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.”<sup>5</sup> 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

<sup>5</sup> 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.”<sup>6</sup> 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

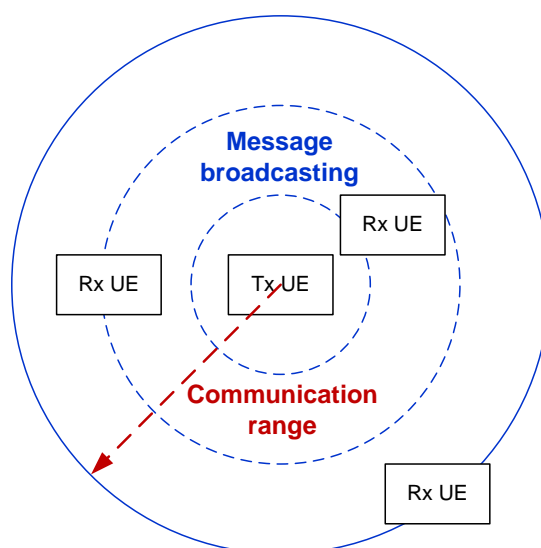
### 4.2.1 Vehicle-to-Vehicle (V2V) use cases

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”<sup>7</sup> server, etc.

FIGURE 4  
Broadcast-based V2V communications



<sup>6</sup> 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.

<sup>7</sup> 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 22.885<sup>8</sup> and 3GPP TR 22.886<sup>9</sup>. 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.

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<sup>8</sup> 3GPP TR 22.885 – LTE support for V2X services.

<sup>9</sup> 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.<sup>10, 11</sup>

TABLE 1  
Use cases supported by LTE V2X network<sup>12</sup>

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

<sup>10</sup> <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>

<sup>11</sup> 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.

<sup>12</sup> These use cases are listed in 3GPP TR 22.885.

TABLE 1 (continued)

Use cases	Description	Types of V2X use case
V2I Emergency Stop Use Case	This use case describes V2I communication where an RSU notifies vehicles in vicinity in case of emergency stop to trigger safer behaviour.	V2I
Queue Warning	In many situations, a queue of vehicles on the road may pose a potential danger and cause delay of traffic, e.g. when a turning queue extends to other lanes. Using V2I, the queue information can be made available to other drivers beforehand. This minimizes the likelihood of crashes and allows for mitigation actions.	V2X, V2V, V2I
Road safety use cases	<p>V2X messages are delivered from one UE supporting V2I use cases to other UEs supporting V2I use cases via an RSU which may be installed on the road side.</p> <p>The RSU receives V2X messages transmitted from UEs supporting V2I use cases and transmits the received V2X messages to UEs within a local area.</p> <p>A UE receives V2X messages transmitted by the RSU. After processing the received V2X messages, the UE notifies the driver of relevant information.</p>	V2I
Automated Parking System	The Automated Parking System (APS) contains a database which provides real-time information to vehicles in a metropolitan area on availability of parking spots, be it on the street or in public parking garages. Connected vehicles help maintain the real-time database of the occupancy of parking spaces, which can be accessed by means of smartphones and connected vehicles. APS allows a driver to reserve an available parking space, be guided to it via a navigation use case, and make a hands-free payment for parking.	V2X, V2I
Wrong way driving warning	This use case describes V2V communication used between 2 vehicles driving in opposite directions warning wrong way driving and trigger safer behaviour for cars in proximity.	V2V
V2X message transfer under MNO control	This use case describes the scenario where a given UE supporting V2V use cases sends V2X messages to other surrounding UEs and the given UE is under E-UTRAN coverage.	V2V
Pre-crash Sensing Warning	The pre-crash sensing warning use case provides warnings to vehicles in imminent and unavoidable collision by exchanging vehicles attributes after non-avoidable crash is detected.	V2V
V2X in areas outside network coverage	This use case describes V2X communication when one or more vehicles are located in an area not served by E-UTRAN which supports V2X communications.	V2X, V2V

TABLE 1 (continued)

Use cases	Description	Types of V2X use case
V2X Road safety use case via infrastructure	This use case describes the scenario where infrastructure nodes such as RSUs and traffic safety servers generate and distribute traffic safety-related messages for road safety.	V2N, V2I
V2N traffic flow optimisation	This use case describes vehicles V2N (Vehicle-to-Network) communication to a centralised ITS server referred here to as “entity” to optimise traffic flow when approaching intersections. This use case addresses the situation when approaching the vehicle has to stop even though there are no other cars around at an intersection or has to slow down because of explicit traffic lights signal absence. Depending on the traffic situation which is based on the vehicles' periodically transmitted messages this entity will provide, via LTE network entity, a green light to a car when approaching the intersection and an indication of speed at which the green light will be met without having to stop or miss the green light phase.	V2N, V2I
Curve Speed Warning	Curve speed warning use case alerts the driver to manage the curve at an appropriate speed.	V2I
Warning to Pedestrian against Pedestrian Collision	This use case is to provide information to vulnerable road users, e.g. pedestrian or cyclist, of the presence of moving vehicles in case of dangerous situation. As a result, warnings are provided to vulnerable road users to avoid collision with the moving vehicle.	V2P
Vulnerable Road User (VRU) Safety	This use case describes the scenario whereby a vehicular and a pedestrian are both equipped with V2P capabilities, and the vehicle detects the pedestrian's presence and alerts the driver, if an imminent threat is present. This capability extends the safety benefit of V2X to pedestrians and other vulnerable road users, e.g. bicyclists, wheelchair users, etc.	V2P
V2X by UE-type RSU	This use case describes the scenario where UE supporting V2X discovers and communicates with UE-type RSU.	V2X, V2V, V2N
V2X Minimum QoS	This use case describes the scenario where E-UTRA(N) resource is not enough for every UEs 10 Hz V2X message transmission. In addition, this use case includes the scenario where emergency vehicle is supported.	V2N
Use case for V2X access when roaming	Mary is taking a road trip across the country. She has a car equipped with V2X capability, with cellular network service provided by her home network operator. On her journey, Mary encounters a traffic jam in a town not served by her home network provider. The town has deployed V2X capabilities to redirect traffic jams caused by a major infrastructure construction project. The V2X capabilities must be able to communicate with devices associated with multiple cellular mobile network providers.	V2X, V2V

TABLE 1 (end)

Use cases	Description	Types of V2X use case
Pedestrian Road Safety via V2P awareness messages	A pedestrian carries a UE, which is able to transmit awareness and safety related V2P broadcast messages.	V2P
Mixed Use Traffic Management	<p>There are a number of variables to be taken into account in a scenario involving different types of vehicular traffic. This use case includes dynamic optimization of traffic signal timing using a C-V2X-connected traffic signal controller at the intersection that optimizes the phase duration or phase sequence of signal timing based on real-time vehicle data. If possible, it can be optimized based on the background data and plan of the central subsystem.</p> <p>This use case is suitable for signal control optimization of signal control intersections and signal control ramp entrances of ordinary roads and highways in cities and suburbs.</p>	V2X, V2I
Enhancing Positional Precision for traffic participants	<p>To obtain their position vehicles usually use a GNSS such as GPS, Galileo, Beidou, and Glonass. However, the publicly available precision for a position fix for the most common system GPS is just around 15 m, better values can be obtained and dependent on the radio conditions and are thus not guaranteed.</p> <p>A UE supporting V2X use cases should be provided with additional 3GPP (e.g. OTDOA) and/or non 3GPP (e.g. DGPS) mechanisms by which it can derive its location with higher accuracy.</p> <p>The 3GPP Network should make available any supported positional accuracy improvement techniques in a resource efficient way to a subscribed UE supporting V2X use cases.</p>	V2X (V2N, V2I)
Privacy in the V2V communication environment	The privacy or anonymity of end users in the V2V communication environment is deemed essential for user adoption of the V2V system.	V2V,
V2N Use Case to provide overview to road traffic participants and interested parties	This use case describes a general use case for V2N communication that exercises the strength of 3GPP networks of providing excellent coverage.	V2N, V2V
Remote diagnosis and just in time repair notification	A road side unit (RSU) having the capability to access an internet will enable any passing by vehicle to report about its current functional state to a local/remote diagnosis centre and to receive “Just in time repair notification” if having subscribed to such a diagnostic capability.	V2N, V2I

Enhanced use cases based on 5G V2X had been developed in 3GPP TR 22.886. The use cases and description of enhancement of 3GPP support technologies are listed in Table 2. 5G V2X is expected to support all of the use cases listed above that are able to be supported by LTE-based cellular networks, along with the enhanced use cases due to the additional capabilities as discussed in § 6.

Note that interoperability for the C-V2X application among multi-parties e.g. vendor in NR-based, or LTE/NR-based mobile networks, will be tested in detail in future after 2022. As well, some of the V2X use cases proposed for deployment using 5G network communications have not yet been tested



in detail for actual deployment until 2022. Therefore, the 3GPP communication requirements for specific use cases have been based on the best estimates of requirements for hypothetical, generic use case definitions. These requirements will consequently need to be validated, once actual use case implementations at the automotive and infrastructure systems level are available. Based on these constraints, reliable operation of the actual V2X use case implementations in a mixed environment of different vehicle manufacturers and 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 5G network supported V2X use cases.

TABLE 2  
Use cases supported by 5G V2X network<sup>13</sup>

Use cases	Description	Types of V2X use cases
eV2X support for vehicle platooning	Platooning is operating a group of vehicles in a closely linked manner so that the vehicles move like a train with virtual strings attached between vehicles. The leading vehicle is responsible for fleet management and driving. The trailing vehicle can receive driving information such as acceleration, braking of the preceding vehicle, and improve driving efficiency. Usually, the leader vehicle of the fleet is driven by a driver, followed by multiple unmanned member vehicles based on real-time information interaction and maintaining a stable inter-vehicle distance at a certain speed	V2X (V2V, V2N)
Information exchange within platoon	When the vehicles are travelling on the road, they can dynamically form a platoon. The platoon creator is responsible for platoon management.	V2I, V2V,
Automotive: sensor and state map sharing	Sensor and state map sharing (SSMS) enables sharing of raw or processed sensor data to build collective situational awareness.	V2I, V2X
eV2X support for remote driving	Remote driving is a concept in which a vehicle is controlled remotely by either a human operator or cloud computing.	V2X
Automated cooperative driving for short distance grouping	Cooperative driving allows a group of vehicles to automatically communicate to enable lane changing, merging, and passing between vehicles of the group and inclusion/removal of vehicle in the group in order to improved safety and fuel economy.	V2V, V2I,
Collective perception of environment	Vehicles can exchange real time information (based on vehicle sensors information or sensor data from a capable UE-type RSU) among each other in the neighbour area.	V2X, (V2V)
Communication between vehicles of different 3GPP RATs	Depending on the choice of OEMs, while some vehicles are equipped with modules supporting only LTE, other vehicles may be equipped with modules supporting NR (New Radio). If a vehicle of NR cannot talk to a vehicle supporting LTE, the vehicle supporting LTE can be regarded as another vehicle of no V2X capability.	V2N, V2V

<sup>13</sup> These use cases are listed in 3GPP TR 22.886.

TABLE 2 (continued)

Use cases	Description	Types of V2X use cases
Multi-PLMN environment	Although the necessary communication condition, e.g. for immediate message transfer, is set high for some of eV2X use cases, such condition needs to be met regardless of whether or not all the involved UEs and UE-type RSUs are subscriber of the same PLMN	V2X
Cooperative collision avoidance (CoCA) of connected automated vehicles	To enable vehicles to better evaluate the probability of an accident and to coordinate manoeuvres in addition to usual CAM, DENM safety messages, data from sensors, list of actions like braking and accelerating commands, lateral as well as longitudinal control are exchanged amongst vehicles to coordinate in the use case the road traffic flow through 3GPP V2X communication.	V2X
Information sharing for partial/ conditional automated driving	This use case is interpreted as an automated driving at the level of SAE Level 3 and Level 2 automation, where non-short inter-vehicle distance (e.g. > 2 sec * vehicle speed) is assumed and abstracted/coarse data exchange is sufficient.	V2X, (V2I)
Information sharing for high/full automated driving	This use case is interpreted as an automated driving at the level of SAE Level 4 and Level 5 automation, where non-short inter-vehicle distance (e.g. > 2 sec * vehicle speed) is assumed and high-resolution data exchange is necessary.	V2X, (V2I)
Information sharing for partial/ conditional automated platooning	This use case is interpreted as an automated platooning at the level of SAE Level 3 automation, where short inter-vehicle distance (e.g. < 2 sec * vehicle speed) is assumed and abstracted/coarse data exchange is sufficient.	V2X, (V2I)
Information sharing for high/full automated platooning	This use case is interpreted as an automated platooning at the level of SAE Level 4 and Level 5 automation, where short inter-vehicle distance (e.g. < 2 sec * vehicle speed) is assumed and high-resolution data exchange is necessary.	V2X, (V2I)
Dynamic ride sharing	This use case enables a vehicle to advertise willingness to share capacity with another road user and for a pedestrian to indicate intent to travel in a ride share.	V2X, (V2P)
Use case on multi-radio access technology	The user starts a V2X use case, and a message from that use case needs to be transmitted to other cars nearby. The V2X UE supports multiple radio access technologies, including LTE and 5G New radio access technologies. The V2X UE should choose the best technology to support the given use case of interest.	V2X
Video data sharing for assisted and improved automated driving (VaD)	The visual range of the driver is in some road traffic situations obstructed, for instance by trucks driving in front [26]. Video data sent from one vehicle to the other can support drivers in these safety-critical situations.	V2X, (V2V)
Changing driving-mode	According to a vehicle cooperation level, driving-mode can be classified generally into three classes (autonomous, convoy, and platooning). Nontrivial traffic scenario requests for switching into the other driving-mode.	V2V
Tethering via Vehicle	This use case enables a vehicle to provide network access to occupants, pedestrians, etc.	V2X, (V2P)

TABLE 2 (continued)

Use cases	Description	Types of V2X use cases
Use case out of NR coverage	A UE supporting V2X use case is equipped with a multi-radio access technology modem (NR, LTE).	V2X,
Emergency trajectory alignment	Emergency Trajectory Alignment (EtrA) messages complement cooperative automated driving to assist the driver in hazardous and challenging driving situations to further increase traffic safety.	V2X (V2V)
Teleoperated support (TeSo)	Teleoperated Support (TeSo) enables a single human operator to remotely control automated vehicles for a short period of time. A remote driver undertakes the control of the vehicle and drives remotely the vehicle, in an efficient and safe manner, from the current location to the destination.	V2X (V2N)
Intersection safety information provisioning for urban driving	The traffic accident occurs at the intersection where the vehicle and pedestrians are crowded. This provides safety information to the vehicles to prevent traffic accident and assist cooperative automated driving function when the vehicles pass through the intersection.	V2X (V2I)
Cooperative lane change (CLC) of automated vehicles	On a multi-lane road, a lane change manoeuvre could be initiated by a vehicle. Cooperative Lane Change V2X scenario involves vehicles exchanging their intended trajectories to coordinate their lateral (steering) and longitudinal controls (acceleration/deceleration) to ensure a smooth manoeuvre.	V2X (V2V)
Proposal for secure software update for electronic control unit	A car Electronic Control Unit (ECU) is a generic term for a software module that controls the electronics within a car system; this could be anything from the steering wheel to the brakes and with automated car driving and this becomes a key part of the car that will possibly need regular software updates.	V2I
3D video composition for V2X scenario	This use case consists of multiple UEs supporting V2X use case moving in an area. Those UEs take a video of the environment by their camera, and send this video to a server, which can be in the cloud or in the near the UE point of attachment to enable edge computing in order to create a single 3D video of the environment.	V2X (V2I, V2N)
QoS aspect of vehicles platooning	Platooning is a coordinated mobility of group of vehicles, sharing manoeuvre and other information with each other. It increases traffic efficiency and reduces fuel consumptions.	V2X
QoS aspects of advanced driving	Based on the implementation or approach taken by each manufacturer or the environment where each vehicle is located, whether to engage automated driving or not needs to be controlled by the V2X capabilities, either in the vehicle or in the cloud of remote back-end.	V2X
QoS aspect of remote driving	Remote Driving use cases allow a remote driver that is not sitting in the vehicle to undertake the control of the vehicle and drive remotely the vehicle, in an efficient and safe manner, from the current location to the destination.	V2X

TABLE 2 (end)

Use cases	Description	Types of V2X use cases
QoS Aspect for extended sensor	The extended sensor use cases are composed of sensor data collection to construct local dynamic map and the state map sharing, sensor data shared to extend sensor range, different all round video data shared for automatic drive.	V2X
Different QoS estimation for different V2X use cases	QoS estimation will help V2X use cases e.g. automation driving, intelligent traffic system, to get the communication system connection capability in advance which is very important for them to compute and adjust in advance to right working mode to guarantee safety and appropriate communication capabilities availability.	V2X

#### 4.4 Additional use cases<sup>14</sup>

The typical C-V2X use cases can be divided into information sharing, traffic efficiency assistance, driving safety assistance and even for advanced autonomous driving from usage object perspective. Among them, some use cases can be combined together to construct more complicated V2X use cases.

Supported by the IMT technologies, and with the evolution from vehicle-road to vehicle-road-pedestrian -cloud coordination, it is expected that the following C-V2X typical use cases would be developed within a couple of years.

##### 4.4.1 High Definition (HD) map collecting and sharing

This use case is for vehicles to get high definition (HD) map that is real-time updated and highly accurate, as an expansion of “3D video composition for V2X scenario” in § 4.3. Vehicles equipped with LIDAR or other HD sensors can collect environment around themselves and share the information with a HD map provider (e.g. cloud server). The HD map provider analyses the collected information and merges or combines them to build a regional HD map. This allows the construction of HD maps that are dynamically updated with much detailed and temporally accurate information.

##### 4.4.2 Electronic Toll Collection (ETC)

Electronic toll collection has been accomplished through the use of small, low power transponders on vehicles and infrastructure-based recording equipment using dedicated spectrum. This use case is a proposed new payment method for toll collection and other payments that leverages the C-V2X application by utilizing the on-board unit (OBU) as the payment terminal, through connection of the terrestrial network, to pay for the expenses incurred by the vehicle on the road, and the other expenses incurred by the vehicle owner.

##### 4.4.3 Vehicle inbound and outbound

The vehicle inbound and outbound use case is suitable for vehicle entrance or exit on highways, expressways and other road sections, as well as lane changing scenario, building upon the concept of the “V2N Traffic Flow Optimisation” use case in § 4.3. It can assist the road management. Under the premise of ensuring safety, the impact of vehicles on the main line traffic flow is reduced by selecting reasonable time, position and speed of inbound and outbound and lane changing, so that the traffic efficiency of the road is improved.

<sup>14</sup> <http://en.pkulaw.cn/display.aspx?cgid=99dce7b906112c94bdfb&lib=law>

It could include the two deployment cases as below, when the host vehicle (HV) and the remote vehicle (RV) are located on both sides of the ramp entrance/exit respectively:

- in the case of the roadside unit (RSU) and multi-access edge computing (MEC) platform are deployed:
  - MEC and RSU calculate the driving policy and RSU delivers the instructions to guide the vehicles on both sides through sidelink connection of IMT system. HV and RV then follow the instructions;
  - RSU delivers the perception information of the driving environment through sidelink connection of IMT system, and HV and RV make their own decisions based on the perception information received;
- in the case of no RSU deployed, HV and RV transmit vehicle information to each other through sidelink connection of IMT system. The vehicle calculates the driving policy by itself and broadcasts the result.

#### 4.4.4 Intersection traffic

This use case represents an expansion of the “Intersection safety information provisioning for urban driving” use case in § 4.3. In the intersection traffic use case, the host vehicle (HV) drives to the intersection.

- the HV sends vehicle driving information to the corresponding C-V2X ‘application’ server (either in the MEC or in the cloud). The C-V2X server generates traffic dispatch information for the HV according to the received vehicle information, the traffic control phase information of the target intersection, the driving information reported by other vehicles, and the perception information reported by the roadside sensors, etc. and sends the traffic dispatch information to the HV; the HV obtains the perception information of roadside sensors, other vehicle information, and cloud information of the C-V2X server through the cellular network, and generates scheduling information;
- then the HV controls the HV to pass through the intersection according to the traffic dispatch information, combined with the surrounding environment information sensed by the V2X function and other on-board sensors.

This use case represents that the vehicle reasonably adjusts its driving state according to surrounding vehicle information, traffic signal information, road condition information, maps and other information to facilitate traffic efficiency in a safe manner.

A feature of the Intersection Traffic use case is aiming to mitigate the congestion problem of intersections. The dynamic lane division at the intersection is utilized to realize the real-time and reasonable allocation of the space resources of the intersection entrance lane. Through the real-time communication between the vehicles within the intersection range and the roadside unit (RSU), the roadside unit collects the status data of the connected vehicle (CV), including position, speed, steering, etc., to determine the traffic demand in each direction of the intersection in real time. Based on this, the edge computing platform (MEC) adjusts the lane function of the entrance lane, and sends the result to the vehicle, which improves the operation efficiency of the intersection through dynamic lane management. This feature is mainly for the scenarios where the intersection demand changes frequently and fluctuations in each flow direction are large. Compared with the existing fixed lane management method, dynamic lane management can match the traffic demand of each flow direction in real time, provide sufficient queuing space for each flow direction vehicle to the greatest extent, and reduce the queue length and the number of secondary queuing.

#### **4.4.5 Flexible management of dedicated highway lanes**

A dynamic dedicated lane is generated to improve the travel condition of emergency vehicles, in order to meet the rapid traffic demand of emergency vehicles. When an emergency vehicle drives on the dedicated lanes, it broadcasts the current status and clearing distance. In the meanwhile, RSU can also broadcast the occupancy status of the section. After the nearby vehicles receive the relevant information, they will check whether they are within the clearing distance of the emergency vehicle. If yes, it will leave the dedicated lane. This use case is suitable for road traffic management of highways, express ways and other sections.

#### **4.4.6 Group start**

This use case represents that vehicles with some level of automation form a group to jointly start at traffic light. A traffic control centre or local RSU provides tactical and strategic information to coordinate the activity. A traffic control centre or the RSU identifies several vehicles which intend to cross an intersection on a similar path at similar time. One of these entities assigns the role of the group leader to the first vehicle approaching the intersection and instructs this vehicle and other participating vehicles on which spot at the intersection the vehicles occupy. The traffic control centre or the RSU considers vehicle capabilities in terms of dynamics, sensor capabilities, planned route, and communications properties into account when composing the groups.

#### **4.4.7 Enhanced real-time navigation**

This use case provides accurate, real-time, and efficient travel path planning for traveling vehicles through the IMT mobile network system, including driving sections, driving lanes and others, thus traveling vehicles can drive on the 'best' route, improving travel efficiency. It can also provide real-time eco-driving suggestions and parameters such as vehicle speed, real-time acceleration, optimized following plan, and better lane change plan which enable traveling vehicles to drive in the 'best' driving mode and improve the efficiency of vehicle energy consumption and travel safety. When traveling with an electric vehicle (EV), it also needs to consider battery power, starting point and destination location, charging station (CS) information, and traffic information to plan and dynamically adjust the travel route and charging route of the EV. On the whole, it can optimize the overall and local transportation system to enhance user experience.

#### **4.4.8 Infrastructure assisted environment perception**

This use case represents that the automated vehicles enrol to receive information from the infrastructure containing environment data of dynamic and static objects on the road, when they enter a section of the road that is covered by infrastructure sensors. This data is used to increase the trust level of the cars own sensor observations and extends its viewing range.

#### **4.4.9 Autonomous parking**

This use case represents that with IMT mobile network assistance, the vehicle can drive autonomously and drive into the right parking space when it arrives at the entrance of the parking lot. It includes functions such as the remote driving into the parking space, auto-driving into the parking space by itself, and obtaining parking space information and parking space status information, applying for parking space and parking navigation etc.

## 5 Relationship between IMT and C-V2X

It has been specified<sup>15</sup> that “... architecture enhancements to the 5G System to facilitate vehicular communications for Vehicle-to-Everything (V2X) services, over the following reference points...”: PC5/sidelink reference point in both NR (sidelink) and LTE (PC5) radio access technologies; and Uu reference point in both NR and E-UTRA. This means that the 5th Generation system is able to accommodate V2X operations in both NR and LTE radio access technologies. Thus, 5G V2X includes 5G network control of LTE V2X, NR V2X, E-UTRA Uu and NR Uu, even though LTE V2X and NR V2X, as well as E-UTRA Uu and NR Uu use different radio access technologies. The IMT systems as described above are expected to provide reliable, flexible wireless communications for the C-V2X application, which is being developed towards vehicle/roadside/cloud collaboration.

The IMT specifications to support the C-V2X application in 3GPP were developed step-by-step.

- the first phase of LTE V2X specification work that was completed in March 2017, was designed to support the communications needs of basic road safety use cases. The sidelink, based on the PC5 interface, was supported on frequency band 5.9 GHz for direct, peer-to-peer communications. The cellular network was also optimized to better support anticipated V2X use cases, based on the LTE Uu interface.
- the second phase that the LTE V2X and NR specification work was completed in June 2018. It not only included the enhancements for LTE V2X, which mainly focused on carrier aggregation, high order modulation to improve transmission data rate and reduce transmission latency, but also included the first NR specifications with eMBB and URLLC use case scenarios. With the addition of NR, more advanced and comprehensive V2X use cases may be supported.
- the third phase that the NR Uu interface and NR V2X specification work related to C-V2X was completed in June 2020, supporting advanced V2X use cases based on multiple IMT technologies e.g., NR V2X (including Sidelink), and NR.
- And now the NR Uu interface and NR V2X Sidelink are going to be further enhanced, especially in QoS, power control, energy saving etc, which will greatly improve the IMT capability to better support the C-V2X application.

The current commercial development of the C-V2X application is mainly based on LTE V2X and NR. LTE V2X technologies have completed all the normative work and are being deeply investigated. LTE V2X has been designed to support the anticipated communications requirements of the 27 basic V2X use cases shown in Table 1.

## 6 The characteristics and capabilities of the C-V2X application supported by IMT mobile networks

### 6.1 Necessary capabilities

Necessary capabilities of V2X and enhanced V2X communications are introduced based on the 3GPP TS 22.185 and 3GPP TS 22.186<sup>16</sup> specifications.

3GPP TS 22.185 was developed with a focus on the basic safety aspect and the non-safety aspect using LTE based IMT systems. 3GPP TS 22.186 was developed with a focus on enhancements of

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<sup>15</sup> 3GPP TS 23.287 V17.2.0 (2021-12).

<sup>16</sup> 3GPP TS 22.186 – Enhancement of 3GPP support for V2X scenarios.

V2X use case scenarios, including more rigorous functional ‘requirements’<sup>17</sup> for advanced features that cannot be achieved by 3GPP TS 22.185.

V2X use cases<sup>18</sup> that are captured in this report have their potential functional ‘requirements’ based on 3GPP TR 22.885 and TR 22.886, and the estimated KPIs for each use case, including but not limited to message payload size (Bytes), Tx rate (Message/Sec), Data rate (Mbit/s), and Reliability. The same messages actually delivered among some V2X use cases could be common. For example, Forward Collision Warning, Control Loss Warning and Wrong way driving warning need to acquire the same Basic Safety Message (BSM), which includes the position, speed, status and other information necessary for all of these use cases. So, when the messages delivered by different use cases are the same, one message can be delivered by a UE to simultaneously support all these use cases.

### 6.1.1 V2X ‘service’ ‘requirements’

The LTE V2X specifications have been introduced in 3GPP TS 22.185, and are summarized below.

#### – General

The network controls the V2X message transmission when the transmitting UE is served by the E-UTRA(N). A UE supporting V2X use cases is able to be pre-configured by the cellular network with parameters to be used for the transmission and reception of messages when not served by E-UTRA(N) supporting V2X communication.

A RSU is able to transmit/receive messages to/from a UE supporting the appropriate V2X use case.

A network is able to support message transfer between UEs when served or not served by the same PLMN supporting V2X communications.

#### – Specific ‘service’ ‘requirements’

##### Latency/ Reliability

The network is capable of transferring messages between two UEs supporting V2V/P use cases, directly or via an RSU, with a maximum latency of 100 ms.

The network is capable of transferring messages between two UEs supporting V2V use cases with a maximum latency of 20 ms, for particular usage (i.e. pre-crash sensing) only.

The network is capable of transferring messages between a UE supporting V2I use cases and an RSU with a maximum latency of 100 ms.

The network is capable of transferring messages via E-UTRA(N) between a UE and an ‘application’ server both supporting V2N use cases with an end-to-end delay no longer than 1 000 ms.

The network is able to support high reliability without requiring application-layer message retransmissions.

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<sup>17</sup> “Requirements” of § 6.1 refer to the 3GPP introduced “service” and functional “requirements” to guide the design of the IMT technologies.

<sup>18</sup> Necessary capabilities of network traffic is not a linear superposition of use cases when considering resources occupied, especially spectrum resources.



– Message size

The network is capable of transferring periodic broadcast messages between two UEs supporting V2X use cases with variable message payloads of 50-300 bytes, not including security-related message component.

The network is capable of transferring event-triggered messages between two UEs supporting V2X use cases with variable message payloads which can be up to 1 200 bytes, not including security-related message component.

– Frequency

The network is able to support a maximum frequency of 10 messages per second per transmitting UE.

– Range

The network is capable of supporting a communication range sufficient to give the driver(s) ample response time (e.g. 4 seconds).

– Velocity of UE

The network is capable of transferring messages between UEs supporting V2V use cases, while the maximum relative velocity of the UEs is 500 km/h, regardless of whether the UE(s) are served or not served by E-UTRA(N) supporting V2X communication.

The network is capable of transferring messages between UEs supporting V2V and V2P use cases, respectively, while the UE's maximum absolute velocity is 250 km/h, regardless of whether the UE(s) are served or not served by E-UTRA(N) supporting V2X communication.

The network is capable of transferring messages between a UE and an RSU both supporting V2I use cases, while the UE's maximum absolute velocity is 250 km/h, regardless of whether the UE or the RSU is served or not served by E-UTRA(N) supporting V2X communication.

– Security

The network provides a means for the MNO to authorize a UE supporting the C-V2X application to perform V2X communication when served by E-UTRA(N) supporting V2X communication.

The network provides a means (e.g. pre-authorization) for the MNO to authorize a UE supporting the C-V2X application to perform V2X communication when not served by E-UTRA(N) supporting V2X communication, and for the MNO to authorize UEs supporting the C-V2X application separately to perform V2N communication.

The network supports integrity protection of the transmission for a V2X use case.

The network supports pseudonymity and privacy of a UE using the C-V2X application, by ensuring that a UE identity cannot be tracked or identified by any other UE beyond a certain short time-period necessary for the operation of the C-V2X application, subject to regional regulations and/or operator policy for the C-V2X application.

The network supports 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, subject to regional regulations and/or operator policy for a V2V/V2I use case.

### 6.1.2 Enhanced V2X 'service' 'requirements'

Enhanced V2X specifications are introduced in 3GPP TS 22.186 in the following areas:

- General/Common: interworking, and communication-related 'requirements' valid for all V2X scenarios
- Vehicles Platooning
- Cooperative Driving / Maneuver Coordination

- Extended Sensors / Collective Perception
- Remote Driving
- Vehicle QoS Support.

With Vehicle Platooning a group of two or more automated cooperative vehicles are in line, maintaining a close distance using wireless communication (V2V), typically such a distance to reduce fuel consumption by air drag, to increase traffic safety by use of additional Advanced Driver Assistance Systems (ADAS)-technologies based on in-vehicle perception sensors, and to improve traffic throughput because vehicles are driving closer together and take up less space on the road. All the vehicles in the platoon receive periodic data from the leading vehicle, in order to carry on platoon operations. This information allows the distance between vehicles to become extremely small, i.e. the gap distance translated to time can be very low (sub second). Platooning requires cooperative automation on different hierarchical levels, encompassing automation of strategic, tactical, as well as operational functionalities, based on reliable short-range vehicle-to-vehicle and vehicle-to-infrastructure communications (V2X), and long-range back-office communications.

Cooperative Driving facilitates the negotiation between (semi-) automated vehicles in situations such as left turns or highway merges. Cooperative Driving can communicate the vehicle intention and future behaviour to other traffic participants. By exchanging maneuverer coordination messages, the intentions of the vehicles are shared and can be anticipated by other vehicles, helping to reduce accidents. The benefits of this use case group are safer traveling, collision avoidance, and improved traffic efficiency.

Collective Perception provides information about detected objects (traffic participants, road objects) in the surroundings of a vehicle or road infrastructure. Vehicles capable of transmitting Collective Perception Messages can use their own sensors to detect non-communicating traffic participants and inform neighbouring V2X vehicles about those participants, participants who might be hidden from the sensors of those other vehicles, enabled through the exchange of processed data gathered through local sensors or live video data among vehicles, RSUs, devices of pedestrians and V2X ‘application’ servers. The vehicles can enhance the perception of their environment beyond what their own sensors can detect and have a more holistic view of the local situation.

Remote Driving enables a remote driver or a V2X use case to operate a remote vehicle for those passengers who cannot drive themselves or a remote vehicle located in dangerous environments. For a case where variation is limited and routes are predictable, such as public transportation, driving based on cloud computing can be used. Vehicle QoS support enables a V2X use case to be timely notified of expected or estimated change of QoS before actual change occurs and to enable the cellular network to modify the QoS in line with V2X use case’s QoS needs. Based on the information on QoS, the C-V2X application can adapt behaviour to the relevant cellular network’s conditions. The benefits of this use case group are offerings of smoother user experience.

Necessary capabilities apply to both EUTRA and NR, and cover functionalities and KPIs in 3GPP TS 22.186. Some examples of eV2X general ‘requirements’ and KPIs are provided below:

- General

The network is able to support message transfer among a group of UEs supporting the same V2X use cases.

The network supports relative lateral position accuracy of 0.1 m between UEs supporting V2X use cases.

The network supports to minimize the impact to E-UTRA(N) by UE supporting only NR based V2X communication.

The network supports to minimize the impact to NR by UE supporting only E-UTRA based V2X communication.

The network enables discovery and communication between UEs supporting the same V2X use case.

The network is able to support the operators to select which 3GPP radio access technology to use for a V2X use case.

The network enables a UE supporting a V2X use case to obtain network access via another UE supporting the same V2X use case.

The network supports switching between direct 3GPP connection and indirect 3GPP connection via a UE supporting a V2X use case, for a UE supporting a V2X use case.

For different categories of use cases, communication ‘requirements’ are characterized by a set of main ‘requirements’ in Table 3.

TABLE 3  
Main ‘requirements’ of use cases

Payload (Bytes)	Tx rate (Message /Sec)	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)	Min communication range (metres)

Different tables of KPIs are captured in 3GPP TS 22.186, covering the following specific communication scenarios:

- Vehicles Platooning
  - Cooperative driving–Information exchange between a group of UEs.
  - Reporting between UEs, and between a UE and RSU.
  - Information sharing between UE and RSU.
- Advanced Driving
  - Cooperative collision avoidance between UEs supporting the same V2X use cases.
  - Information sharing for automated driving between UEs supporting the same V2X use cases.
  - Information sharing for automated driving between UE supporting V2X use cases and RSU
  - Emergency trajectory alignment between UEs supporting V2X use cases.
  - Intersection safety information between an RSU and UEs supporting V2X use cases.
  - Cooperative lane change between UEs supporting the same V2X use cases.
  - Video sharing between a UE supporting the relevant V2X use case and a C-V2X ‘application’ server.
- Extended Sensors
  - Sensor information sharing between UEs supporting the same V2X use cases.
  - Video sharing between UEs supporting the same V2X use cases.
- Remote Driving
  - Information exchange between a UE and a V2X ‘application’ server.

## 6.2 IMT capabilities

### 6.2.1 Radio access network

5G V2X<sup>19</sup> supports the following four different types of V2X use cases: V2V, V2I, V2N and V2P. V2X use cases can be supported by PC5/sidelink interfaces, and/or Uu interfaces, depending upon the communication needs of each specific use case.

The PC5/sidelink communication mode is supported when the UE is served by an IMT mobile network system and when the UE is outside of the IMT mobile network system coverage. This enables reliable V2X communications at the radio access layer for specific use cases, e.g. coordinated driving, when inside or outside of network coverage. Only the UEs authorised to be used for the C-V2X application can perform V2X PC5/sidelink communication managed by the mobile network. The UEs can also be pre-programmed without having any affiliation with, or subscription to, a mobile network, such as for use in direct, ad hoc, public V2X safety-related use cases.

The LTE V2X PC5 interface supports broadcast transmission of messages in the physical layer of radio access network, for delivery of BSM, CAM, DENM and similar traffic. A broadcast address can be mapped to a single UE or a group of UEs by implementation in the MAC layer of radio access network, so such techniques have no particular specification impact and are transparent to the physical layer of radio access network.

The LTE V2X supports broadcast transmission in the physical layer and any finer-grained addressing is handled according to MAC layer ID implementation. NR V2X has physical layer support for broadcast, unicast, and groupcast sidelink operation. The addition of unicast and groupcast is linked with the introduction of sidelink HARQ feedback, high order modulation, sidelink CSI, and PC5-RRC as described in 3GPP TR 37.985<sup>20</sup>, amongst other points. The resource allocation, congestion control, and higher-layer protocols are also described in 3GPP TR 37.985.

A V2X UE is considered in-coverage of the carrier using V2X sidelink communication whenever it detects a cell of that carrier. When the V2X UE is out of coverage of the frequency used for V2X sidelink communication, the UE uses a set of transmission and reception resource pools pre-configured in the UE. When the V2X UE is in-coverage, it may obtain the radio resources configuration from the mobile network via broadcasted system information or dedicated signalling. Reception of V2X sidelink communication in different carriers/PLMNs can be supported by having multiple receiver chains in the V2X UE.

NR V2X cellular network capabilities support different types of Direct Communication: broadcast, groupcast, and unicast. In broadcast mode, it allows some finer grain control using MAC layer Layer-2 IDs. For groupcast, distanced based groupcast control, NR V2X sidelink communication enables formation of “on-the-fly” multicast groups based on distance and use cases. Such multicast groups require little or no overhead for group formation and dismantling. A NR V2X UE can establish multiple simultaneous unicast sidelink connections with other UEs, based on use case needs. These links are allowed to have different configurations, including the QoS levels, data rates, security protections, etc. Each of the links is independently managed and maintained. The unicast sidelink can be established between NR V2X UEs on-demand, by transmitting either broadcast or unicast a connection request to a known UE or UEs supporting a desired V2X use case. This unicast link establishment procedure had already incorporated security verifications. The NR V2X design provides a generic authentication mechanism and supports various application layer security

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<sup>19</sup> 5G V2X includes 5G network control of LTE V2X, NR V2X, E-UTRA Uu and NR Uu, even though LTE V2X and NR V2X, as well as E-UTRA Uu and NR Uu use different radio access technologies.

<sup>20</sup> 3GPP TR 37.985 - Overall description of Radio Access Network (RAN) aspects for Vehicle-to-everything (V2X) based on LTE and NR.

associations, e.g. certificate-based security association that is widely used in the V2X ecosystem. The unicast sidelink can provide confidentiality and integrity protection for the signalling and user data, based on security capabilities of the use case and policies. Additionally, the NR V2X design also provides privacy protection for the unicast sidelink, by allowing a change of the link identifiers during the communication session, without interrupting the use case. This helps the UE to meet the regulations on anti-trackability in some regions.

IMT mobile network capabilities support QoS guarantee for the V2X use cases. For LTE V2X, it is achieved utilizing the ProSe Per Packet Priority (PPPP) and ProSe Per Packet Reliability (PPPR) of a protocol data unit provided by upper layers. The packet delay budget (PDB) of the protocol data unit can be determined from the PPPP. The low PDB is mapped to the high priority PPPP value. The Access Stratum (AS) is also provided with a transmit profile (Tx Profile) of a protocol data unit transmitted over the PC5 interface by upper layers. The logical channel prioritization based on PPPP is used for V2X sidelink communication. For NR V2X, a unified QoS model based on QoS Flow managements is used for all cast types, i.e. broadcast, groupcast, and unicast. Each of the QoS Flows is configured with a PC5 5QI (5G QoS Identifier) that represents the QoS characteristics, e.g. delay budget, priority, reliability, etc., and additional QoS flow parameters. For groupcast, the QoS flow parameters further include the maximum Range value, which can be passed to lower layers to perform the distance based groupcast control. For unicast, the QoS flow parameters include the link data rate, which helps lower layers to choose the coding and modulation mechanism.

Versatile operation parameter sets can be configured based on use case needs and regulations. For example, NR V2X can support channelization of 10/20/40 MHz, with subcarrier spacing of 15, 30, 60 and 120 kHz associated with CPs and frequency ranges similar to NR UL/DL, and with modulation schemes as QPSK, 16-QAM, 64-QAM, and 256-QAM. Carrier aggregation (CA) in sidelink is supported for V2X sidelink communication. For the case where multiple frequencies for V2X are supported, a mapping between V2X use case types and V2X frequencies is configured by upper layers. The UE ensures that a V2X use case message is transmitted on the corresponding frequency.

IMT mobile network capabilities enable UEs to obtain timing synchronization from a variety of sources, including GNSS, eNB/gNB and other UEs, enabling synchronization in-coverage and out-of-coverage. A UE may serve as a synchronization source by transmitting sidelink synchronization signal block (S-SSB), and may provide synchronization information to another UEs even if it does not participate in the subsequent inter-UE communication. The V2X synchronization procedure defines priorities among such synchronization sources and requires all UEs to continuously search to get to the highest-quality synchronization source they can find.

The V2X UEs support two modes for resource allocation: scheduled resource allocation mode, and UE autonomous resource selection mode. The scheduled resource allocation mode can be used when the UE is in-coverage and in CONNECTED mode. The UE autonomous resource selection mode can be used when the UE is in-coverage or out of network coverage. In UE autonomous resource selection mode, the UE selects resources from resource pools on its own and performs transport format selection to transmit sidelink control information and data. The UE performs sensing for (re)selection of sidelink resources. Based on sensing results, the UE (re)selects some specific sidelink resources and reserves multiple sidelink resources. Sidelink SPS can be supported. Simultaneous V2X sidelink communication and Uu communication can be supported in both resource allocation modes.

IMT mobile network capabilities also support power efficient operation mode for pedestrian UE (P-UE). Based on the configuration profile, the P-UE can be pre-configured or configured by the network to use a resources pool that does not require sensing or only partial sensing. In the scheduled resources allocation mode, the P-UE may not perform optional operations, e.g. CBR (channel busy ratio) measurements.

To support the co-existence of CEN DSRC and V2X sidelink communication, the upper layers of the UE that is performing V2X sidelink communication send an indication to lower layers when the UE is within the proximity of CEN DSRC tolling station(s).

The IMT-2020 network (Uu interface) can meet multi-dimensional capabilities such as ultra-high speed, ultra-low latency, high-speed movement, high energy efficiency, and ultra-high traffic and connection density. The IMT-2020 network can support multiple connections for vehicles, pedestrians, roadside equipment, and platforms, and provide a foundation for intelligent collaboration and cooperation for vehicles and ITS infrastructures.

Some advanced eV2X use cases need the network to provide the capabilities of large bandwidth, low latency, and high reliability simultaneously. With IMT-2020 technologies like flexible frame structure design, carrier aggregation, supplementary uplink, symbol-level scheduling granularity, configured grant, UE capability enhancement, fault tolerance of modulation and demodulation, new CQI/MCS tables, repeated transmission, PDCP replication, large antennas, ultra-dense networking, etc., the IMT-2020 systems can support the advanced eV2X use cases better.

### 6.2.2 Architecture enhancements

The architecture enhancements for V2X use cases were developed starting with LTE based technologies in 3GPP TS 23.285<sup>21</sup>, and the architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) use cases was developed in 3GPP TS 23.287<sup>22</sup> with regards to relative capabilities needed to support the intended V2X use cases.

There are two modes of operation for V2X communication, namely V2X communication over PC5/sidelink interface (direct communication mode) handling small area communication between vehicle and vehicle/road side unit (RSU)/pedestrian; and, V2X communication over Uu reference point (network communication mode) handling large area communication between vehicle and IMT base station (BS). These two operation modes may be used by a UE independently for transmission and reception.

V2X communications over the PC5 interface are supported by LTE V2X, and the Sidelink interface is supported by NR V2X.

V2X communications over the Uu reference point are supported by E-UTRA connected to 5GC and/or NR connected to 5GC. In EPS, V2X communication over Uu reference point can be either unicast or broadcast. In 5GS, V2X communication over Uu reference point is only unicast.

The Architecture reference models for LTE V2X in 3GPP TS 23.285 are:

- 1) PC5 and LTE-Uu based V2X architecture reference model
  - a) Non-roaming architecture for PC5 and LTE-Uu based V2X communication
  - b) Roaming architecture for PC5 and LTE-Uu based V2X communication
  - c) Inter-PLMN architecture for PC5 and LTE-Uu based V2X communication
- 2) eMBMS for LTE-Uu based V2X architecture reference model.

And further, the architecture reference models in 3GPP TS 23.287 for 5G V2X are:

- 1) PC5 and Uu based V2X architecture reference model
  - a) Non-roaming 5G System architecture for V2X communication over PC5 and Uu reference points

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<sup>21</sup> 3GPP TS 23.285 – “Architecture enhancements for V2X services”.

<sup>22</sup> 3GPP TS 23.287 – “Architecture enhancements for 5G System (5GS) to support Vehicle-to-Everything (V2X) services”.

- b) Roaming 5G System architecture for V2X communication over PC5 and Uu reference points
  - c) Inter-PLMN 5G System architecture for V2X communication over PC5 reference point.
- 2) AF-based use case parameter provisioning for V2X communications.
  - 3) Interworking with EPS V2X.

The IMT system is also enhanced to provide some of the NR V2X operation configurations to the radio network (NG-RAN), to assist the UE operation. The NG-RAN may then provide the information, e.g. in the System Information Block (SIB), or using dedicated RRC signalling if UE goes into CONNECTED mode. This helps the UE to obtain the most up-to-date operation configuration, e.g. on how to map QoS Flow to sidelink radio bearers, in case the spectrum is managed by the operators. For ITS spectrum, the UE can operate purely based on configuration.

The IMT system design is also enhanced, in order to assist the NR V2X operation, in case the NR V2X UE is in coverage. For example, the IMT system has enhanced its UE Policy provisioning feature, so that the Policy Control Function (PCF) is able to update the UE authorized for NR V2X operation of the V2X related policies and configurations (V2XP) via the control plane signalling, when the UE comes into coverage. It also allows the NR V2X UE to autonomously request a policy update from the PCF when necessary. This feature also allows a V2X ‘application’ server to provision the V2X operation parameters per use case, e.g. QoS mapping, or security capabilities, via the PCF to the UE reliably.

The core network, e.g. 5G Core Network (5GC), has also introduced some enhancements, to facilitate better V2N use cases when Uu connection is used. These include the notification on QoS Sustainability Analytics, and the Alternative QoS Profiles. The notification on QoS Sustainability Analytics allows the 5GC to provide an estimation of the QoS level support along the path indicated by a V2X ‘Application’ Server. The V2X ‘Application’ Server could adjust its QoS capabilities if 5GC informs it ahead of time that some QoS level cannot be met. On the other hand, the Alternative QoS Profile allows the V2X ‘Application’ Server to request multiple QoS levels to the 5GC. In case there is a congestion in the network, the NG-RAN will automatically adjust the QoS level to one of the provided Alternative QoS Profiles. This ensures that the mission critical V2X use case can continue at the minimum operational level, instead of being cut off.

The architecture enhancement of end-to-end network slicing flexibly allocates network resources. Multiple logical subnets with different characteristics and isolated from each other are virtualized in the network. Each end-to-end network slice is composed of wireless network, transmission network, and core network sub-slices. They are combined and managed uniformly through the end-to-end slice management system. The slices can meet the ‘service’ quality levels necessary for different business SLAs (Service Level Agreements). V2X slice has been defined in the 3GPP specifications.

The architecture enhancement of edge computing enables V2X use cases. The edge computer can be deployed near the vehicle, RSU and VRU, to reduce end-to-end delay, and network traffic load.

### 6.2.3 ‘Application’ layer support

The simplified architectural model for the V2X ‘application’ layer in 3GPP TS 23.286<sup>23</sup> is shown in Fig. 5. The 5G V2X UE1 communicates with the V2X ‘application’ server over V1 reference point. The 5G V2X UE1 and 5G V2X UE2 communicate over V5 reference point. V2X UE1 can also act as a UE-to-network relay, to enable V2X UE2 to access the V2X ‘application’ server over V1 reference point.

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<sup>23</sup> 3GPP TS 23.286 – “Application layer support for Vehicle-to-Everything (V2X) services; Functional architecture and information flows”.

FIGURE 5  
Simplified architectural model of the V2X “application” layer



The V2X ‘application’ layer functional entities for the V2X UE and the V2X ‘application’ server are grouped into the V2X “application” specific layer and the V2X ‘application’ enabler (VAE) layer. The VAE layer offers the VAE capabilities and support functions to the V2X ‘application’ specific layer.

The V2X ‘application’ layer supports interaction functions between VAE client and VAE server, or interaction functions between two VAE clients are supported by V1-AE reference point, or V5-AE reference point, which is an instance of the reference points shown in Fig. 5.

A set of V2X ‘application’ enabler (VAE) layer procedures and information flows have been defined by 3GPP in order to ensure efficient use and deployment interoperability of V2X ‘application’ on IMT mobile networks.

The V2X ‘application’ enabler (VAE) client provides the client side V2X ‘application’ layer support functions as:

- registration of VAE clients for receiving V2X messages
- receiving V2X messages from the VAE server and the delivery to V2X ‘application’ specific client(s) according to the V2X ‘service’ ID
- receiving network monitoring reports from the VAE server
- supports switching the modes of operations for V2V communications (e.g. between direct and in-direct V2V communications)
- providing “application” level locations to the VAE server (e.g. tile, geo-fence) receiving 3GPP system configuration information (e.g. V2X USD, PC5 parameters) from the VAE server; and
- supporting dynamic group management.

The V2X ‘application’ enabler (VAE) client supports interactions with the V2X use case specific client(s).

The V2X ‘application’ enabler (VAE) server provides the server side V2X application layer support functions as:

- communicating with the underlying 3GPP network systems (EPS, 5GS) for unicast and multicast network resource management,
- receiving monitoring reports/events from the underlying 3GPP network systems (EPS, 5GS) regarding network situation corresponding to RAN and core network,
- supporting registration of V2X UEs,
- tracking the ‘application’ level geographic location of the V2X UEs,
- supporting V2X message distribution for the V2X ‘applications’,
- supporting provisioning of 3GPP system configuration information (e.g. V2X USD, PC5 parameters),
- providing network monitoring reports to the V2X UEs,
- communicating capabilities needed by V2X use cases to the underlying 3GPP network systems (EPS, 5GS),



- maintaining the mapping between the V2X user ID and the V2X UE ID,
- providing V2X ‘service’ discovery,
- supporting V2X ‘service’ continuity, and
- supporting V2X ‘application’ resource adaptation.

### 6.3 Operational spectrum

#### 6.3.1 Uu interface

IMT mobile network capabilities allow the use of any Uu connection for the V2X use cases. Therefore, all the bands defined in 3GPP TS 36.101<sup>24</sup> and TS 38.101-1<sup>25</sup> for LTE and NR are valid for operation where regulations permit.

#### 6.3.2 PC5/sidelink interface

LTE V2X communication is designed to operate in the operating bands in FR1 defined in Table 4.

TABLE 4  
Operating bands of LTE V2X

E-UTRA operating band	E-UTRA V2X operating band	V2X UE transmit		V2X UE receive		Duplex mode	Interface
		FUL_low – FUL_high	FUL_high	FDL_low – FDL_high	FDL_high		
47	47	5 855 MHz	5 925 MHz	5 855 MHz	5 925 MHz	HD	PC5

NR V2X communication is designed to operate in the operating bands in FR1 defined in Table 5.

TABLE 5  
Operating bands in FR1 of NR V2X

V2X operating band	Sidelink (SL) transmission operating band	Sidelink (SL) reception operating band	Duplex mode	Interface
	FUL_low – FUL_high	FDL_low – FDL_high		
n381	2 570 MHz – 2 620 MHz	2 570 MHz – 2 620 MHz	HD	Sidelink
n47	5 855 MHz – 5 925 MHz	5 855 MHz – 5 925 MHz	HD	Sidelink

NOTE : When this band is used for V2X SL use cases, the band is exclusively used for NR V2X in particular regions.

LTE V2X: Band 47 (5 855 MHz – 5 925 MHz) is defined for PC5 operation, with 10 or 20 MHz channel bandwidth. The detailed band definition is in 3GPP TS 36.101.

<sup>24</sup> 3GPP TS 23.286 – “Application layer support for Vehicle-to-Everything (V2X) services; Functional architecture and information flows”.

<sup>25</sup> 3GPP TS 38.101-1 – “User Equipment (UE) radio transmission and reception Part 1: Range 1 Standalone”.

NR V2X: Band 38 (2 570 MHz – 2 620 MHz) and Band 47 (5 855 MHz – 5 925 MHz) are defined for Sidelink operation, with 10, 20, 30, or 40 MHz channel bandwidth. The detailed band definition is in 3GPP TS 38.101-1.

## 7 Case study

Annex 1 provides the case study from a country associated with V2X use cases in various scenarios supported by eMBB, mMTC, and URLLC of terrestrial component of IMT. The Annexes are intended to provide examples of IMT technology supported V2X implementations implemented by various countries.

As stated in the Scope of this Report, the Cellular-Vehicle-to-Everything (C-V2X) application of IMT supports various V2X use cases. Thus, the specific C-V2X application terminology is applied to the use of the terrestrial component of IMT for the Cellular-Vehicle-to-Everything application, per Question ITU-R 262/5. The terminology in the main body of this report therefore refers to the entirety of “C-V2X” capabilities as an ‘application’, while the functions to perform a specific purpose are called “use cases”, and in particular “V2X use cases”. This usage is consistent with the terminology usage in 3GPP technical documents, where the use cases are called “V2X use cases”. In the following annexes, other terminology is used according to the specific situations in various countries or other ITU-R Reports, such as referring to V2X use cases as “C-V2X use cases”, or “ITS applications”.

## Annex 1

### Case studies from China

#### A1.1 Typical C-V2X use cases

In the development of China's C-V2X industry, through standard research, according to the technical maturity, use case value and feasibility criteria, a number of automotive companies, C-V2X suppliers, transportation departments, scientific research institutions in the industry, 17 C-V2X basic use cases have been defined, as shown in Table 6, as well as five basic interaction messages, as BSM, RSM, MAP, SPAT and RSI, supporting these use case scenarios, and a trusted template has been provided for the current application of IMT technologies to support C-V2X.

During the underlying use cases phase, most use cases are implemented based on real-time state sharing between vehicles, road facilities, and other participants. On the basis of realizing state sharing by using C-V2X information interaction, decision-making or assistance is made independently.

TABLE 6

C-V2X basic use cases

No.	Use cases
1	Forward collision warning
2	Collision warning for intersections
3	Turn left aid
4	Blind spot alert/change aid
5	Reverse overtaking warning

TABLE 6 (*end*)

No.	Use cases
6	Emergency braking warning
7	Unusual vehicle alerts
8	Vehicle out-of-control warning
9	Warnings of road hazards
10	Speed limit warning
11	Traffic lights violation warning
12	Collision warning for vulnerable traffic participants
13	Green wave speed guide
14	Signs in the car
15	Alert of congestion ahead
16	Emergency vehicle alert
17	Car near-field payment

Beyond the basic C-V2X use cases, advanced C-V2X use cases as showed in Table 7 also have been identified and specified by automotive, ITS, communication industries. These advanced C-V2X use cases are supported by LTE V2X and NR V2X, MEC is also another technical enabler.

TABLE 7

**Advanced C-V2X use cases in China**

No.	Use cases
1	Over the Air
2	High-definition map collecting and sharing
3	ETC (Electronic Toll Collection)
4	Vehicle inbound and outbound
5	Intersection traffic
6	Dynamic Lane Management
7	Dynamic optimization of traffic signal timing
8	Flexible management for dedicated highway lanes
9	Fleet management
10	Platooning
11	Real-time Navigation
12	VRU recognition
13	See-through for passing
14	Obstructed view assist
15	High-definition sensor sharing
16	Infrastructure assisted environment perception
17	Tele-operated driving
18	Autonomous parking

### A1.2 Advanced C-V2X use cases necessary capability

In the development process of China's C-V2X industry, through standardization research, according to the technical maturity, use case value and feasibility criteria, a number of automobile companies, C-V2X suppliers, transportation departments and scientific research institutions have carried the standard of advanced C-V2X use cases. In this standard, considering safety of communications, the actual driving environment, etc., the necessary capabilities for each use case are as follows:

TABLE 8  
Necessary capabilities of advanced C-V2X use cases

No.	Use case	Necessary capabilities
1	OTA	Velocity: 0~120 km/h Communication range $\geq 300$ m Rate: DL $\geq 500$ Mbit/s, UL $\geq 200$ Mbit/s Delay: 100 ms
2	ETC	Velocity: 0~120 km/h Communication range $\geq 300$ m Tx rate $\geq 10$ Hz Delay $\leq 100$ ms Reliability $\geq 99.99\%$ Payload size: 300 Bytes Positioning accuracy $\leq 0.5$ m
3	Vehicle Inbound and outbound	Velocity: 0~70 km/h Communication range $\geq 150$ m Tx rate $\geq 10$ Hz Delay $\leq 100$ ms Reliability $\geq 99\%$ Positioning accuracy: lateral $\leq 0.5$ m
4	Intersection traffic	Communication range $\geq 300$ m Tx rate: 1 Hz~10 Hz Delay: RSU/Vehicle to central platform $\leq 100$ ms, others $\leq 20$ ms Reliability $\geq 99.999\%$ Positioning accuracy: lateral $\leq 1$ m
5	Dynamic Lane Management	Communication range $\geq 500$ m Tx rate $\leq 10$ Hz Delay $\leq 100$ ms Positioning accuracy $\leq 1.5$ m
6	Dynamic optimization of traffic signal timing	Velocity: 0~80 km/h Communication range: RSU/Vehicle to MEC $\geq 150$ m, RSU/Vehicle to central platform $\geq 400$ m Tx rate $\geq 5$ Hz Delay $\leq 100$ ms Positioning accuracy: lateral $\leq 1.5$ m

TABLE 8 (continued)

No.	Use case	Necessary capabilities
7	Flexible management of dedicated highway lanes	Velocity: 0~130 km/h Tx rate $\leq 10$ Hz Delay: V2V $\leq 20$ ms, others $\leq 100$ ms Positioning accuracy $\leq 1.5$ m
8	Fleet management	Velocity: 0~120 km/h Communication range $\geq 300$ m Tx rate $\geq 10$ Hz Delay: Vehicle to Vehicle/RSU $\leq 20$ ms, Vehicle/RSU to central platform $\leq 100$ ms Positioning accuracy $\leq 1$ m
9	Platooning	In platoon: Payload size $\leq 100$ Bytes Delay $\leq 30$ ms Communication range: $\geq 200$ m Reliability $\geq 90\%$ Velocity: 30 km/h Positioning accuracy $\leq 1$ m Tx rate: 10 Hz (low frequency data)/1 Hz (high frequency data) Out of platoon: Payload size $\leq 100$ Bytes Delay $\leq 100$ ms (low frequency data)/30 ms (high frequency data) Communication range: $\geq 300$ m Reliability $\geq 90\%$ Velocity: 120 km/h Tx rate: 10 Hz/1 Hz
10	Real-time Navigation	Velocity: 0~250 km/h Communication range $\geq 200$ m Tx rate $\geq 10$ Hz Delay $\leq 100$ ms Reliability: L0~L2 vehicle $\geq 90\%$ , L3~L5 vehicle $\geq 99.9\%$ Delay: L0~L2 vehicle $\leq 100$ ms, L3~L5 vehicle $\leq 20$ ms Positioning accuracy: L0~L2 vehicle $\leq 1$ m, L3~L5 vehicle $\leq 0.1$ m
11	VRU recognition	Velocity: vehicle 0~80 km/h, Vulnerable road user 0~20 km/h Communication range $\geq 200$ m Tx rate $\geq 10$ Hz Delay $\leq 100$ ms Reliability: VRU to others $\geq 99\%$ , Vehicle to vehicle/MEC/RSU, MEC to RSU $\geq 99.9\%$ Payload size: VRU to others 100 Byte, Vehicle to vehicle/MEC/RSU, MEC to RSU 300 Byte Positioning accuracy $\leq 0.5$ m

TABLE 8 (end)

No.	Use case	Necessary capabilities
12	Autonomous parking	Velocity: 0~25 km/h Tx rate $\leq 10$ Hz Communication range: vehicle to RSU $\geq 50$ m, MEC/central platform to RSU/vehicle $\geq 1\ 000$ m Delay $\leq 100$ ms Positioning accuracy $\leq 0.5$ m

### A1.3 C-V2X spectrum

In terms of frequency resource allocation, in order to promote the maturity and industrialization of LTE V2X technologies, in December 2016, the Chinese government allocated 5 905-5 925 MHz as the research and experimental working band of LTE V2X. In June 2018, the Ministry of Industry and Information Technology of China publicly sought comment on “Regulations of the use of the 5 905-5925 MHz band for direct-connected communications (Intelligent Networked Vehicles) (draft for comments)”. In November 2018, the Radio Administration of the Ministry of Industry and Information Technology of China officially released the on “Regulations of the use of the 5 905-5 925 MHz band for direct-connected communications (Intelligent Networked Vehicles) (temporary)” and planned the 5 905-5 925 MHz band as the working band for direct-connected communications based on LTE V2X technologies, marking the official entry of LTE V2X into industrialization in China.

### A1.4 C-V2X Standards

In November 2018, in China, the National Technical Committee for Automotive Standardization, the National Technical Committee for Standardization of Intelligent Transportation Systems, the National Technical Committee for Communication Standardization and the National Technical Committee for Standardization of Road Traffic Management jointly signed the framework agreement to strengthen cooperation on C-V2X standards for automotive, intelligent transportation, communications and traffic management, and promote C-V2X standard-setting and industrial landing.

In terms of information and communication standards system of China, access layer, network layer, message layer and security and other core technical standards of LTE V2X have been developed, at the same time, equipment specifications, test methods and other standards have been developed too, the technical standard system is basically formed, as shown in Fig. 6. There is a summary of the standard content and progress of the LTE V2X series in China in Table 9.

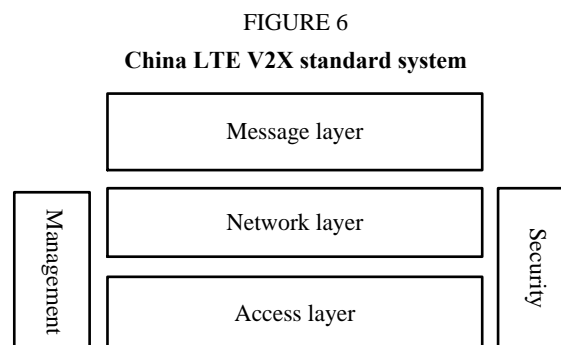


TABLE 9  
China LTE V2X standard content and progress

Category	Name	Level	Organization	State
General	“General technical requirements of LTE-based Vehicular Communication”	Industry Standard	CCSA	Published
Access layer	“Technical requirements of air interface of LTE-based vehicular communication”	Industry Standard	CCSA	Published
	“Technical requirements and test Method of equipment for LTE-based vehicular communication”	Industry Standard	CCSA	Draft
	“Technical requirements and test Method of network layer for LTE-based vehicular communication”	Industry Standard	CCSA	Published
	“Technical requirements and test Method of message layer for LTE-based vehicular communication”	Industry Standard	CCSA	Published
Security	“General technical requirements of Security for Vehicular Communication based on LTE”	Industry Standard	CCSA	Published
	“Technical requirements of security certificate management system for LTE-based vehicular communication”	Industry Standard	CCSA	Draft
Profile	“Technical Requirements of Vehicular Communication System based on LTE V2X Direct Communication”	National Standard	NTCAS	Draft
	“Direct Communication System Roadside Unit Technical Requirements of LTE-based Vehicular Communication”	Industry Standard	C-SAE & C-ITS	Draft
Application identity	“Application Identity Allocation and Mapping for LTE-based Vehicular Communication”	Industry Standard	CCSA	Draft

### A1.5 Industrial activities

In terms of industry, China's LTE V2X industry is at the forefront of the world, and the three large-scale ICV interconnection testing activities in 2018, 2019 and 2020 show that China has the foundation to commercialize LTE V2X-related technologies.

In November 2018, the V2X “Three Cross” Connectivity Application Demonstration Event was held by China Intelligent Network Alliance Automotive Innovation Alliance, IMT-2020 Propulsion Group C-V2X Working Group and Shanghai International Automobile City (Group) Co., Ltd., realizing the world's first cross-communication module, cross-terminal and cross-vehicle connectivity.

In October 2019, C-V2X “four cross” interconnection application demonstration event was held in Shanghai, it was the first time to achieve the “cross-chip module, cross-terminal, cross-vehicle, cross-security platform” C-V2X application display, which focused on the addition of a communication security scenario. As information security is a vital part of vehicle network communication, “four cross” activities verified the interoperability between a number of security chip enterprises, security solution providers, CA certificate management providers, based on China's completed LTE V2X security standards.

On October 27-29, 2020, the 2020 ICV C-V2X “New Four Cross” and large-scale pilot demonstration activity was held in Shanghai, which deployed a more realistic and commercial-oriented continuous scenario, adopted a new digital certificate format, and increased high-precision maps and high-precision positioning. The activity focused on verifying the large-scale operation capability of the C-V2X application, fully verifying the communication performance of IMT technologies to support C-V2X in the real environment, and at the same time, it explored the safety mechanism and the use of geographical coordinates in the vehicle networking application, and carried out comprehensive testing by many manufacturers, which provided an important technical basis for the subsequent scale commercialization.

### **A1.6 Demonstration zone and pilot zone construction**

In order to promote the C-V2X industry to land as soon as possible, China's Ministry of Industry and Information Technology, Ministry of Transport, Ministry of Public Security and other departments actively cooperate with local governments to promote the construction of China's demonstration zones. By the end of 2019, the number of national ICV test demonstration zone supported by the Ministry of Industry and Information Technology has reached 10, the number of self-driving test site licensed by the Ministry of Transport is three. There are also 3 ICV self-driving closed site test base jointly licensed by the Ministry of Industry and Information Technology and the Ministry of Transport. In addition, there are a number of urban and enterprise-level test demonstration points, ICV demonstration area has covered all the first-line and second-tier cities in the central and eastern regions after four years of development, the radiation effect has been formed.

In May 2019, Jiangsu (Wuxi) became the first pilot zone approved by the Ministry of Industry and Information Technology to further scale the deployment of C-V2X networks and equipment. In June 2020, at the 4th World Intelligent Congress held in Tianjin, Tianjin (Xiqing) National ICV Pilot Zone was unveiled. In October 2020, the Ministry of Industry and Information Technology approved Hunan (Changsha) to create another ICV pilot zone. At present, there are a number of demonstration zones in the active application for upgrading to pilot zones, which will further drive the C-V2X industry development.

Based on the pilot zones, not only the basic C-V2X use cases but also some advanced C-V2X use cases also have been tested. For example, in Xiongan pilot zone, with the integrated system including LTE V2X, NR, MEC, high precision positioning technology etc. advanced C-V2X use cases e.g. remote driving, Intersection traffic, autonomous parking, OTA, etc. are being tested. Further, in limited driving condition, e.g. TianJin harbor, based on IMT-2020 system, the intelligent quay crane and unmanned truck can be remote controlled to improve the working safety and efficiency.

## **Annex 2**

### **ITS use cases included in Report ITU-R M.2445 “ITS usage”**

ITS use cases (applications) presented hereunder are extracted from Report ITU-R M.2445, § 7.6. These applications are meant to be supported by technology-neutral radio interface, meaning that any suitable radio interface technology could be used. The reason why contents of this Annex were picked up from Report ITU-R M.2445 is that it is easy to understand that applications are classified in accordance with their purposes.



## **A2.1 Applications**

### **A2.1.1 V2V, V2P safety-related applications**

- Blind Spot Warning + Lane Change Warning
- Control Loss Warning
- Do Not Pass Warning
- Emergency Electronic Brake Light
- Emergency Vehicle Alert
- Forward Collision Warning
- Intersection Movement Assist
- Motorcycle Approaching Indication
- Situational Awareness
- Wrong way driving warning
- V2V Emergency Stop
- Vulnerable Road User (VRU) Safety
- Queue Warning

### **A2.1.2 V2I Safety-related applications**

- Curve Speed Warning
- Emergency Communications and Evacuation Information
- Emergency Vehicle Preemption
- End of Ramp Deceleration Warning
- Enhanced Maintenance Decision Support System
- Incident Scene Work Zone Alerts for Drivers and Workers
- In-Vehicle Signage
- Oversize Vehicle Warning
- Pedestrian in Signalized Crosswalk Warning
- Railroad Crossing Violation Warning
- Red Light Violation Warning
- Reduced Speed Zone Warning / Lane Closure
- Restricted Lane Warnings
- Roadside Lighting
- Stop Sign Gap Assist
- Stop Sign Violation Warning
- Transit Vehicle at Station/Stop Warnings
- Vehicle Turning Right in Front of a Transit Vehicle
- V2I Emergency Stop

### **A2.1.3 Transportation system efficiency and operations applications**

- Cooperative Adaptive Cruise Control
- Intelligent Traffic Signal System
- Intermittent Bus Lanes

- Pedestrian Mobility
- Performance Monitoring and Planning
- Speed Harmonization
- Traffic Flow Optimisation
- Transit Signal Priority
- Variable Speed Limits for Weather-Responsive Traffic Management
- Vehicle Data for Traffic Operations

#### **A2.1.4 Environment applications**

- Eco-Approach and Departure at Signalized Intersections
- Eco-Speed Harmonization
- Low Emissions Zone Management
- Spot Weather Impact Warning

#### **A2.1.5 Core applications**

- Core Authorization
- Location and Time
- Security and Credentials Management

#### **A2.1.6 Non-priority communications, such as e-commerce and infotainment**

- Wireless Advertising
- Vehicle to Infrastructure Internet Connection
- Drive-Thru Payments
- Vehicle to Vehicle Messaging

#### **A2.1.7 Other applications**

- Border Management Systems
  - Electric Charging Stations Management
  - Road Weather Information for Maintenance and Fleet Management Systems
  - Smart Roadside Initiative
  - Automated Parking System
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