# A visionary roadmap for advanced driving use cases, connectivity technologies, and radio spectrum needs

5GAA Automotive Association
White Paper

**CONTACT INFORMATION:**

Lead Coordinator – Thomas Linget
Email: liaison@5gaa.org

**MAILING ADDRESS:**

5GAA c/o MCI Munich
Neumarkter Str. 21
81673 München, Germany
**www.5gaa.org**




| | |
|---|---|
| VERSION: | 2.0 |
| DATE OF PUBLICATION: | 21 November 2022 |
| DOCUMENT TYPE: | White Paper |
| EXTERNAL PUBLICATION: | Yes |
| DATE OF APPROVAL BY 5GAA BOARD: | 14 July 2022 |

# Contents

# Executive Summary

This white paper synthesises a 5GAA vision of the future, mainly because many day-1 basic safety and intersection use cases have been anticipated and analysed by the stakeholders in the global C-ITS community, and deployments have begun. This white paper therefore focuses on advanced driving use cases which pave the way to automated driving, teleoperation, automated valet parking, sensor sharing – all of which contribute to global safety, mobility, environmental stewardship and transportation equity goals.

Since the publication of the initial 5GAA roadmap[1] we have seen a growing deployment of connected safety services targeting traffic efficiency and safety. Vehicles enabled with both Cellular-V2X (C-V2X) network and direct communications technologies have been released on the Chinese market. The first cars with 5G new radio technology connected to the rapidly growing 5G networks relying on the 3GPP Release 15 standard are available in China, Europe and US. Many OEMs have extended the list of hazard warnings distributed over the network within their products. A growing number of cities provide pre-emptive green lights to emergency responders and time-to-green information to vehicles over the network. These positive market changes are reflected in the new roadmap.

In the last two years, 5GAA has focused on advanced safety (e.g. sensor sharing, cooperative manoeuvres) and automated driving (e.g. automated valet parking, teleoperation) use cases, and the state of technology readiness and availability to bring them to market.

With regard to standards, the radio layer is covered by 3GPP, which is currently working on Release 18 (completion is foreseen by end 2023 and will feature new enhancements to V2X ). Upper layer standardisation is occurring in regional standards development organisations (e.g. ETSI, SAE International, NTCAS, C-SAE, ARIB, etc .) as additional work on profiles and protocols is needed for new advanced use cases, such as group start. Activities on Automated Valet Parking (AVP)  standardisation have started in Europe and internationally under ISO. In short, with ongoing standardisation activities around the world and 3GPP 5G-V2X releases, technology enablers such as positioning, power consumption, and multi-access edge computing have been enhanced and can support connected assistance and cooperative driving applications.

Improved understanding of the complexity of applications and the needed cooperation in the ecosystem have also had an impact on the new version of the roadmap: network-based solutions are also an option for Vulnerable Road User (VRU)  awareness, and some of the safety and advanced automated driving use cases (e.g. group start, cooperative manoeuvres) will require more time before they will be deployed on the roads.

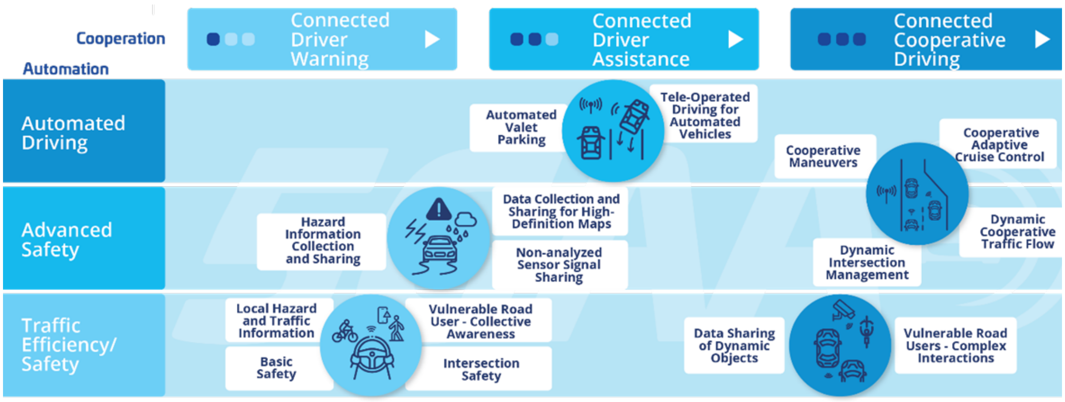


*Figure 1: Evolution of C-V2X use cases towards connected cooperative driving*

Continuing the journey, the roadmap activities will enable advances with the digital road, benefiting vehicles and vulnerable road users. Including the road operator and a smart cities perspective, it will expand the connectivity scope towards non-terrestrial networks (NTN) and further explore higher degrees of vehicle automation and cooperative manoeuvres as shown in Figure 1.

# 1. Introduction

Over the past few years, revolutionary digital transformations have begun addressing some challenging mobility problems. 5GAA bridges the automotive and telecommunication industries to address society's connected mobility needs, bringing inclusive access to smarter, safer and environmentally sustainable services and solutions, integrated into intelligent road transportation and traffic management. 5GAA continues to the shaping of a new era of mobility, paving the way towards connected driving.

With the release of this updated roadmap, 5GAA celebrates five years of intense activity, global cooperation, partnerships, and demonstrations that have accelerated commercial availability and global deployment of these revolutionary technologies.

Since the last publication of the 5GAA roadmap, the first 5G-enabled vehicles have hit the roads globally. We have experienced vehicle mass deployments of a host of use cases listed in the 5GAA roadmap: Local Hazard and Traffic Information (BMW[2], Audi[3], Ford[4]), Hazard Information Collection and Sharing, and Basic Safety Applications.[5] [6]

The Global NCAP and its upcoming regional assessment programmes recognise wireless connectivity as a supporting technology to address key crash scenarios. Also, other regional developments have had a positive impact on the deployment of V2X. Driven by the China IMT-2020 promotion group, several Chinese OEMs launched C-V2X vehicles. Following authorisation from the FCC, V2X Direct-enabled vehicles are planned to be deployed soon in the US. The German initiative on an Automated Driving (AD) L4 law and regulation has been finalised. This legislation allows the deployment of AD L4 vehicles on predefined routes that include reliable connectivity. It also prepares the way for the launch of AVP services based on a connected infrastructure and V2I communication. Moreover, across all global regions, the advent of federated services using Multi-Access Edge Computing (MEC) are under trials and exploration. A consequence of all these recent developments is broad deployment of technologies where communication is central. These recent developments have precipitated an adjustment to the 5GAA roadmap, and certainly, **we are on the road to deployment.**

Work on the various use cases also builds on numerous ongoing efforts by standardisation bodies on the next-generation radio interfaces that will increase the capacity of direct and mobile network-based communications, thus enabling advanced use cases. Automotive and telecommunication companies are significantly engaged in these standardisation efforts, and this white paper aims to give an overview of the roadmap for introducing these new cases, together with the necessary regulatory and spectrum policy requirements.

Cellular-V2X is an umbrella term which encapsulates all 3GPP V2X technologies. Members of 5GAA embrace the arrival to maturity of 5G-V2X as a foreseen worldwide consensus, which relates to automotive-relevant 3GPP 5G technologies. It is composed of a network-based (Uu) and direct (PC5) communication mode operated with or without LTE-V2X. It supports advanced driving and previous message types including basic safety and will deliver service continuity. 5GAA recognises that the evolution of V2X within different regional markets will potentially lead to different deployment options.

# 2. 5GAA Visionary Roadmap

Based on the previous version of the released roadmap, 5GAA members have verified the most promising use cases in China, Europe and North America. Moreover, although the roadmap focuses on these regions, 5GAA is in close contact with other regions (e.g. South Korea, Japan, Australia, and India), which helps it keep on top of global market trends. The detailed use cases listed in the 5GAA roadmap include the Service Level Requirements (SLR) listed in the 5GAA C-V2X Technical Reports series 1[7] and 2[8]. The rollout of use cases and services in the different regions depends heavily on ongoing security, spectrum and privacy regulations, and may change in the future.

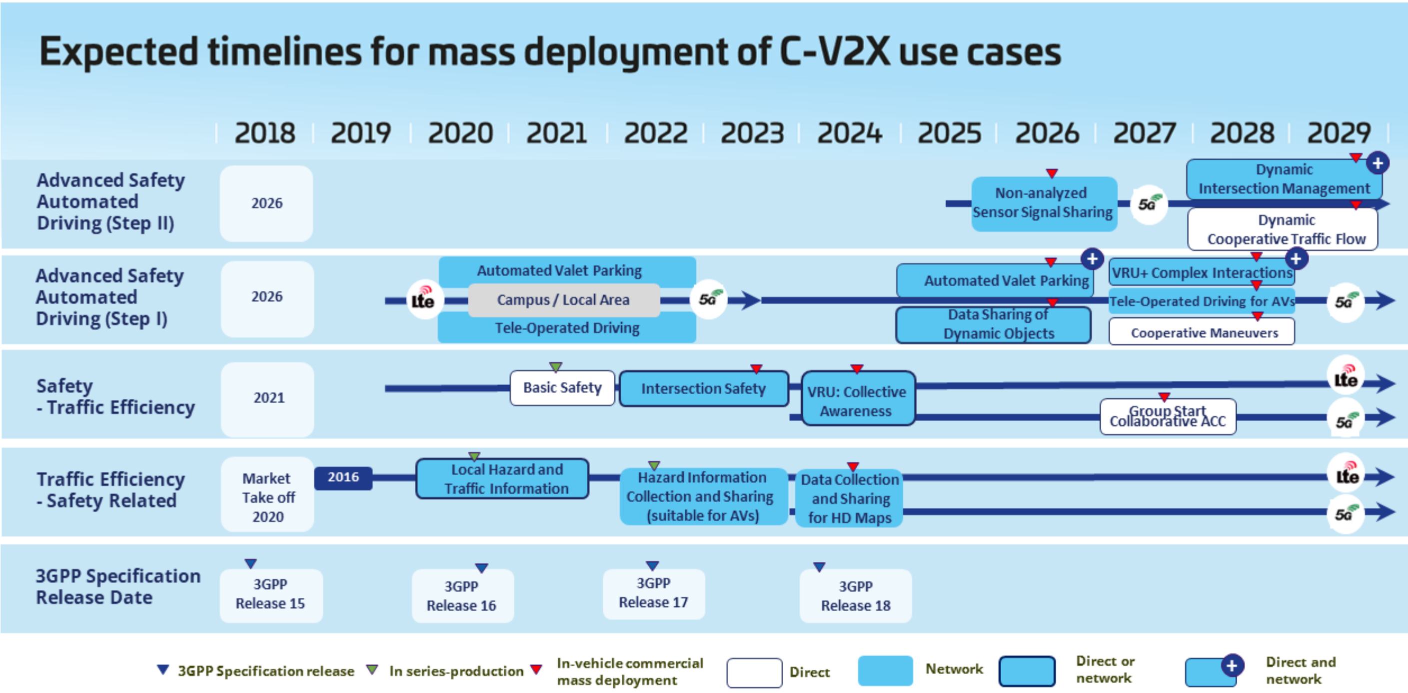


*Figure 2: Expected timelines for mass deployment of C-V2X use cases*

Since 2020, we have experienced a combination of major vehicle mass deployments and 'tip of the iceberg' deployments accelerating in several use cases listed in the 5GAA roadmap: Local Hazard and Traffic Information, Hazard Information Collection and Sharing (suitable for AVs) as well as Basic Safety Applications.

Many of these mass deployed use cases since 2020 are motivated by regional safety regulations or incentives, e.g. Europe and China NCAP as well as the EU Commission Delegated Regulation on detected road safety-related events or conditions[9]. Due to these actions, we include Intersection Safety as a new use case group reflecting, for example the prospective China NCAP categories of 'red light violation warning' and 'intersection collision warning' by 2025. While there is no near-term prospect for V2X in the US NCAP, there is a strong focus on intersection safety in this region.

Another safety trend impacting the roadmap is on increasing the driver's awareness of upcoming local hazards. In Euro-NCAP, local hazard information and warning has already been introduced for 2023[10], and this trend will continue for intersection safety (time-to-red) and VRU collective awareness. Due to a greater time to collision for these awareness situation, network-based solutions are now included as an option.

In addition, SAE Level 4 Automated Driving (AD L4) regulations in different regions of the world have created a new market for tele-operated driving of shuttles and last-mile solutions. A reliable wireless connection to the control centre is required to allow driverless operation of AD L4 vehicles in designated areas. We predict that tele-operated driving will spread from campuses into localised areas before finally being widely deployed on public roads and in passenger vehicles.

Sensor sharing with different variations (e.g. data collection and sharing for HD maps, data sharing of dynamic objects, non-analysed sensor signal sharing) is a cornerstone use case to enable AD L2+, AD L3 and connected ADAS assistances as they are building blocks required for automated driving. 5GAA members do not see a tie shift in market introduction despite silicon and/or Covid-19 supply chain challenges.

For AVP, international standardisation activities have been completed in ISO TC204 WG14 standards, and ETSI technical specifications for the higher layer communication protocol are being developed. The global interest in this use case was evident with the German Association of the Automotive Industry (VDA) demonstration involving five AVP solution suppliers and seven OEM brands at the IAA 2021 in Munic[11]h. We see a slight shift, however, for AVP deployment towards post-2026 mass deployment compared with our 2020 roadmap, mostly due to ongoing standardisation and delays in supply chain readiness. New enablers are discussed in Chapter 5 of this white paper.

# 3. Use Cases Descriptions

5GAA members have further studied and established timelines for the introduction of selected advanced use cases having their proposed market rollout from 2024 until 2030, as outlined in the preceding White Paper[12]. Specific focus had been on the use cases Sensor Sharing and Tele-operated Driving (ToD) including AVP.

In this document, the three main Sensor Sharing use cases have been refined and renamed compared to the former White Paper to emphasise and detail the scope that matches current and planned implementations. For convenience, brief descriptions of the use cases can be found in Annex I. Collecting and sharing information about static road objects and temporary road conditions with map providers is well established. From 2024 onwards, the advanced use case 'Data Collection and Sharing for HD Maps' (formerly named 'HD Map Sharing for AVs') will help providers to build higher definition maps that are dynamically updated and more accurate to reflect the near real-time environment/conditions with more precise and accurate object positioning. Dynamic and accurate HD maps will be one of the essential building blocks for safe automated driving.

Support for cooperative perception – a basic functionality for mass rollout of automated driving – will start from 2026 via the second Sensor Sharing use case 'Data Sharing of Dynamic Objects' (formerly named 'Sensor Sharing for AVs') that is supported by 5G-V2X. Vehicles collect information on dynamic objects in and near the road, and on other traffic participants based on vehicle sensor data. They only share the relevant information as a result of processed and analysed sensor data with some metadata. The relevant information will be shared with other automated vehicles enabled to further correlate information received about objects and create an enlarged perception together with their own sensors.

The 'Non-analysed Sensor Signal Sharing' use case (formerly named 'High-Definition Sensor Sharing') is enabled by 5G-V2X – first being made available as a mobile network service – and will support the development of further automated driving capabilities in the future. Non-analysed sensor signal data, perceived by other road users (e.g. other vehicles, VRUs) on the road and/or via infrastructure, is provided to the host vehicle. The relevant information is shared as an unaltered (or encoded but raw) data stream that could be used at vehicle's sensor fusion.

Tele-operated Driving services can address the corner cases of automated vehicle operations, which automated driving systems need to support, or remotely perform specific driving tasks of non-automated vehicles without the physical presence of a driver in the vehicle. 5GAA envisages a progressive deployment for ToD services starting with campus and confined areas today, followed by dedicated or limited public areas and general open public roads later on. Studies in 5GAA show how the development of modern automotive, information and communication technologies have made the implementation of ToD possible with two control types (Direct and Indirect Control[13] [14]). Although the capability of 4G networks can fulfil the technical requirements of initial ToD implementations, at least 5G networks are needed for mass deploying ToD services, not only to benefit from the significantly reduced radio communication latency, but also to meet the increasing system capacity demands[15]. A study on business and go-to-market considerations provides the generic methodologies and valuable first insights and inspiration to enable stakeholders realising and deploying ToD products[16]. A survey run among 5GAA members indicated that imperfect network coverage, legal uncertainty, and an unclear business case are major factors that 5GAA needs to address before ToD services can be deployed for normal passenger cars on public roads by 2028.

As one variant of ToD service focusing on limited geographic areas such as parking facilities, factories, and others, the mass deployment of AVP is foreseen in 2026. As a first deployment step, AVP Type 2, defined in ISO 23374-1, describes an automated system in which the trajectory planning and AD functionality is located off-board in the (local/edge) cloud and/or within parking garage infrastructure. The AVP Type 2 infrastructure system provides safe motion control to the vehicle based on locally installed sensors and steers the enabled vehicle remotely to its allocated destination. As a crucial step to enable interoperable AVP services across automotive OEMs and parking service providers, 5GAA currently focuses on AVP Type 2 interfaces, including facilities' layer messages and protocols, between vehicles and the AVP system as well as between vehicles and OEM backend or cloud. Both C-V2X network-based communication – using IP communication over a cellular public network or non-public network – and C-V2X direct broadcast communication is described in the 5GAA AVP technical report[17].

# 4. Standards and Spectrum

In this chapter, we provide an overview of some of the most relevant standards setting and development organisations (SSO and SDO), i.e. both industry consortia, regional and international accredited standards bodies. We will also refer to some relevant technical specifications, standards and norms. This is by no means an exhaustive list of all relevant organisations nor of all relevant documents. It is worth noting that the implementation of V2X use cases may use the standards presented in this section or proprietary solutions, as long as the interoperability, security and other requirements are fulfilled.

C-V2X builds on mobile network communications as well as direct communications mode as specified by 3GPP Radio Access Network (RAN) Technical Specification Groups (TSGs).

## Layered Architecture Ref erence and Corresponding Standards

3GPP specifications focus on the lower layers, i.e. on the Radio Access Technology (RAT) capabilities and functionalities of C-V2X. For the upper layers, other organisations have developed and continue to develop standards and specifications for the support of various C-V2X use cases, for example, in standardisation bodies such as ETSI, SAE International, CAICV, and ISO. Those standards describe protocols and profiles that are being implemented in end-to-end systems to enable the deployment of C-V2X technologies. Work on the upper layers, mostly based on software implementation, is often region-specific, taking into account local considerations and regulations, public funding, as well as the programmes of the regional SDOs. Proprietary messages and protocols can also be used in V2X use case implementation to fulfil service-level interoperability requirements, e.g. via the backend systems.

Figure 3 provides a comparison of the example C-V2X protocol stack to the ISO/OSI Reference Model and the ISO/ETSI ITS Station Reference Architecture. While the lower layers have been specified by 3GPP, the higher layers have been addressed by a variety of SDOs worldwide.

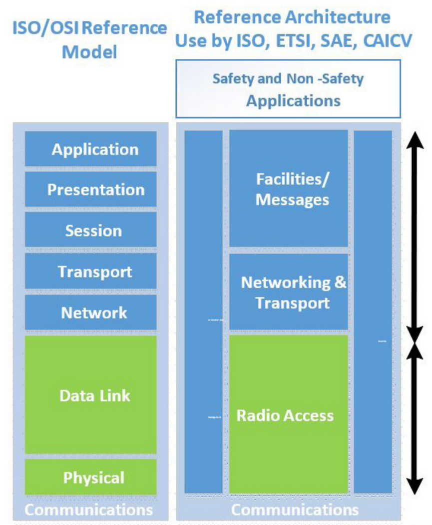


*Figure 3: Example C-V2X protocol stack compared to the ISO/OSI Reference Model and Reference Architecture used by ISO, ETSI, SAE, CAICV*

# Radio Access Layers

5GAA liaised with 3GPP during the course of studies and normative work to provide guidance on automotive relevant needs. The liaison statements addressed in particular:

- Positioning requirements
- Architectural and radio aspects related to C-V2X communication
- Practical radio implementations in vehicles
- Mechanisms to improve the forecasting of QoS parameters
- Network slicing and edge computing aspects
- In-vehicle distributed antenna systems

5GAA also shared their use cases and the corresponding characteristics to facilitate the development of an appropriate radio technology.

3GPP introduced the RAT including the corresponding RAN LTE (4G) in Rel. 8 and NR (5G) in Rel. 15. Successive releases have continuously expanded the specifications with additional features and incremental, backwards compatible enhancements. Mobile Network Operators (MNOs), network vendors, device manufacturers and chipset suppliers typically implement only a subset of the optional features that belong to a certain 3GPP release, according to market request and to the requirements of their specific product and service.

It is worth noting that some 3GPP features aim at improving system capacity and performance, i.e. supporting a higher service penetration in the network for a given user experience. Other features instead target primarily link performance, thus directly improving the service experienced by a specific user.

In the LTE case, automotive-specific enhancements were introduced in Rel. 14, including some Uu interface-related aspects such as enhancing the QoS framework, optimising scheduling for periodic traffic and by adjusting multi/broadcast functionalities. Nevertheless, most automotive services can be supported even without such Rel. 14 enhancements in the Uu interface. 3GPP has also specified since Rel. 14 the C-V2X radio interface for automotive direct communications (PC5 interface) based on LTE RAT, called LTE-V2X direct . In 3GPP Rel. 15 this PC5 interface was enhanced to provide higher throughput.

Rel. 15 introduced 5G targeting many vertical industries. Automotive use cases can benefit greatly from 5G NR features in Rel. 15 and its evolution in following releases. Additionally, some enhancements to the 3GPP 5G Core Network also benefit certain automotive use cases, including various network exposure features, predictive QoS, network slicing, etc.

Since Rel.16, 3GPP has been specifying the C-V2X direct communications (PC5) radio interface for automotive based on 5G NR RAT including many additional features, such as shorter symbols enabling even lower latency, feedback channels to increase reliability as well as higher capacity and support of unicast and multicast in addition to broadcast transmissions. Here, 5GAA likes to refer to 5G-V2X as a worldwide consensus for the future of automotive connectivity while different deployment options may appear in different regions, e.g. with or without LTE-V2X. In 3GPP Rel. 17, 5G-V2X was enhanced to increase power efficiency supporting UE devices carried by VRUs.

Additionally, 3GPP has been working on the UE positioning topic since Rel. 9 with the Enhanced Cell Identity (ECID) and Observed Time Difference Of Arrival (OTDOA) methods. In Rel. 15, 3GPP introduced mechanisms in LTE to provide efficient assistance data for Global Navigation Satellite Systems Real-Time Kinematic (GNSS-RTK). Thanks to this, UEs can benefit from centimetre-level positioning accuracy enabled by the carrier phase-based RTK, which will be a key enabler for most advanced C-V2X use cases. It is worth mentioning that to further improve the scalability of the system, 3GPP also specified transmission or broadcasting of such positioning assistance data via System Information Blocks (SIBs). The GNSS-RTK support is also specified in Rel. 16 for NR.

The specifications for Rel. 14 and Rel. 15 were finalised in 2017 and 2018. The work on Rel. 16 and 17 – incorporating specifications for enhancements – was completed in 2020 and 2021; and work on further enhancements in Rel. 18 is ongoing in 3GPP. The evolution of 3GPP C-V2X capabilities is depicted in Figure 4 showing how new functional capabilities are gradually enabled by each new release to deliver more advanced automotive use cases such as sensor sharing, cooperative manoeuvres, VRU complex

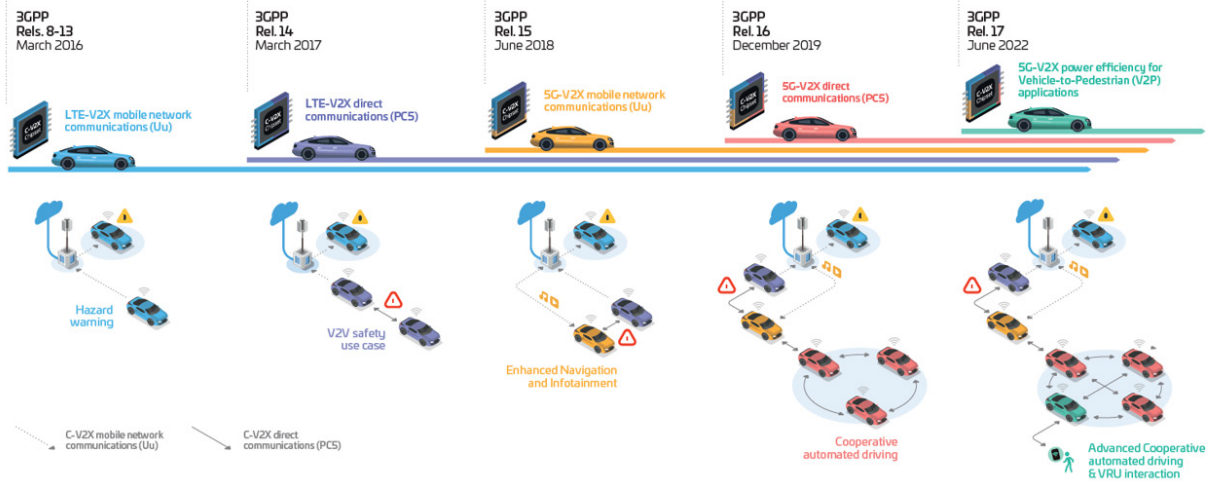


*Figure 4: 3GPP timeline, C-V2X evolution of 5G*

# Upper Layer Standars

For the day-1 or basic safety use cases (named Phase 1 in China), different SDOs have developed specific protocols with regional focus. Standards already exist and are complete for facilities, network and transport layers as well as for the security services. Examples of the regional combinations can further be found in 5GAA's use cases Technical Reports 1[18].

For advanced use cases (named Phase 2 in China), the trend continues because SAE International has developed the Pedestrian Safety Message (PSM) and ETSI TC ITS has already developed VRU protection support and the VRU Awareness Message (VAM) in the ETSI TR 103 300-1, TS 103 300-2 and TS 103 300-3. ETSI TC ITS is nearly finished with the Collective Perception Service (CPS) and is currently working on its Manoeuvre Coordination Service (MCS), while SAE International is developing similar standards in SAE J3186 and the recently-published SAE J3224. CAICV is currently developing Phase 2 use cases and its application layer specification and data exchange standard for Cooperative Intelligent Transportation.

This regional fragmentation of standards for the higher layer protocols imposes additional challenges to vehicle manufacturers to scale their C-V2X solutions. On the one hand, different protocols need to be implemented and deployed in different regions, while on the other the data elements provided or consumed by the applications might be different for specific services, requiring different types of application implementation. 5GAA targets global C-V2X solutions and has been engaging with multiple SDOs in an effort to globally align higher layer protocols for advanced services.

Interoperability is a fundamental requirement for C-V2X use cases. In network-based connectivity (the Uu interface), interoperability does not require harmonisation of radio standards, but is instead implemented in the data infrastructure. Two different models are possible, and they already coexist in complementary ways:

- In a commercial model, interoperability is enabled by a service provider who assembles, processes, and redistributes data among partners and customers. This is for example the model used by HERE and TomTom who aggregate data from several partner OEMs and deliver some services that are similar to certain day-1/1.5 C-ITS use cases. The supported protocols are usually defined as part of the service APIs, such as the Sensor Interface Specification (SENSORIS) by HERE and collaboratively driven by multiple automotive players involved in vehicle-based sensor data exchange via the vehicle-to-cloud and cloud-to-cloud interfaces.

- In a regulated model, the public sector defines protocol profiles and procedures that OEMs and other players need to comply with in order to access certain services. In this case, the higher layer standards for ITS use cases specified by regional standardisation organisations can be adopted. The public sector also provides data infrastructure to ingest , process and redistribute C-ITS data according to the supported use cases. For example, using ‘interchange’ servers that enable cloud-based interoperability among Road Authorities and OEMs. This model with backend communication also includes road authorities/operators in the ecosystem and has been demonstrated in public projects such as NordicWay in the Nordic countries, Talking Traffic in the Netherlands, Mobilidata in Belgium and InterCor in France/Belgium/Netherland/UK.

# Spectrum Considerations

5GAA foresees an important medium-term (2025-2027) objective aimed at confirming the 5.9 GHz spectrum configuration for mass adoption of C-V2X direct radios for advanced driving in different regions of the world.

In China, 5GAA expects the Chinese authorities to initiate a regulatory process for allocating an additional adjacent band for 5G-V2X, preferably 40MHz below the current 20 MHz allocation in which LTE-V2X direct is deployed.

South Korea is currently evaluating V2X technologies and plans to make a technology decision before the end of 2023. If it adopts 3GPP technologies, a similar 20 MHz plus 40 MHz allocation could be used for C-V2X.

In Japan, where a V2X system based on ARIB is being operated in 760 MHz, the Ministry of Internal Affairs and Communications (MIC) is actively studying the allocation of 5.9 GHz spectrum for more advanced V2X services than currently delivered in the 760 MHz range, with a decision expected in 2023/24.

In the US, the regulatory process and litigation challenging the FCC 5.9 GHz band ruling has delayed adoption of FCC rules permitting the mass market deployment of LTE-V2X in the 5.9 GHz band and mass-market deployment. However, based on broad industry support for recent FCC Waiver Requests filed by Ford, Audi, JLR, multiple State Departments of Transportation, New York City and ITS hardware suppliers, the first mass deployment of C-V2X-enabled vehicles is expected to commence in 2022[19] when the FCC permits C-V2X operations pursuant to waiver authority.

In Europe, 5.9 GHz has been designated for safety-related ITS, on a technology neutral basis in 5875-5935 MHz under the CEPT/ECC Decision (08)01 and EU Decision 2020/1426. Furthermore, the frequency band 5855-5875 MHz has been made available for ITS (non-safety applications) by the same ECC Recommendation (08)01. 5GAA is advocating to adopt a priority-based framework for use of ITS channels that could lead to adjacent operation of the two different technologies[20].

Lastly, countries such as Brazil[21], South Africa, Australia[22], Mexico[23] and others have allocated and adopted rules permitting deployment of V2X in the harmonised 5.9 GHz spectrum.

# Spectrum Needs

We further sub-classify the use cases for direct communications according to whether they employ continual (typically repetitive) messages or event-triggered ones, respectively. For each sub-class of use case, we then estimate the spectrum needs for the relevant V2V, V2P, V2I, or V2N communications by accounting for 1) road geometries, e.g. freeways and intersections, 2) the geographic density and speed of the road users, 3) the size, repetition rate, data rate, or latency of the required messages for the support of the service, and 4) the effective spectral efficiency of the relevant C-V2X radio access technology.

Based on the results of our studies of the spectrum needs of C-V2X direct communications (V2V/I/P), we can draw the following conclusions:

a) The delivery of day-1 use cases via LTE-V2X for the support of basic safety ITS services requires up to 20 MHz of spectrum at 5.9 GHz for V2V/I/P communications[24].
b) The delivery of advanced use cases via 5G-V2X (NR-V2X in addition to LTE-V2X) for the support of advanced driving services will require an additional 40 MHz or more of spectrum at 5.9 GHz for V2V/I/P communications.

As the ITS industry develops further, and we begin to better understand the demands of advanced driver assistance and autonomous driving, we will assess the extent to which the 5.9 GHz band (5850-5925 MHz) – which is globally harmonised for ITS by the ITU-R – is sufficient to meet the spectrum needs of the road users, and whether additional spectrum designated for ITS will be required.

Furthermore, based on the results of our studies of the spectrum needs of C-V2X network-based (V2N) communications, we can draw the following conclusions[25]:

a) At least 50 MHz of additional service-agnostic low-band (<1 GHz) spectrum would be required for mobile operators to provide advanced automotive V2N services in rural environments with affordable deployment costs.
b) At least 500 MHz of additional service-agnostic mid-band (1 to 7 GHz) spectrum would be required for mobile operators to provide high-capacity, citywide advanced automotive V2N services.

# 5. Attributes and Technical Enablers

## Mobile Network Positioning

Using the mobile network to receive GNS correction services (RTK, PPP, etc.) is an already widely known service, which is already available for the automotive industry. In addition, the automotive segment is currently evaluating 5G NR Precise Positioning to enhance the position accuracy in areas of poor GNSS coverage (e.g. tunnels, underground parking, urban canyons) as a feature to support autonomous driving and V2X (basic) safety and local hazards applications. Also, the autonomous driving use cases may require high position accuracy (e.g. 20 cm accuracy to locate a vehicle in the centre of a designated lane) and in many scenarios GNSS cannot provide such accuracy (e.g. 2 m accuracy), so 5G NR is evaluated as part of the sensor fusion capabilities to provide enhanced position accuracy in supplement to GNSS and GNSS corrections.

## Direct Communications – Positioning

In addition to positioning over the network, 3GPP decided to study positioning techniques over PC5, i.e. device-to-device. This positioning approach leveraging the direct communication capabilities of 5G allows users to position devices also in out-of-coverage scenarios. In turn, PC5 may enhance the reliability, availability and robustness of the positioning framework within 5G. In its most basic realisation, positioning over PC5 makes 'ranging' between devices possible – i.e. if the distance and the angle of arrival is known, a position in a local coordinate system can be determined, giving a 'relative position'. However, it should be noted that as soon as one device is either a static anchor with a known fixed position or a device with a position in a global coordinate system, an 'absolute position' can also be obtained. PC5 positioning is also studied to be combined with positioning over the network. Again, this hybrid positioning mode can improve the reliability and robustness of the 5G-based positioning, especially in urban mixed traffic environments.

## Mobile Network Quality of Service

Specifically, mission critical services such as safety, advanced safety, and automated driving features will benefit from mobile network Quality of Service (QoS) capabilities. In this way, basic mechanisms that will be deployed by mobile network operators include a 3GPP QoS framework and Network Slicing to ensure network performance for prioritised automotive applications even in congested situations, and Network Exposure API's facilitating the usage of QoS-on-Demand by the end users. Based on the AVP use case, more technical details can be found in the 5GAA Technical Report.

It is important to note that all described QoS mechanisms are working on an application level, and not device level. So, different applications might make use of different Network Slices, and some applications might use a Network Exposure API for QoS-on-demand while others may not. This also addresses the needs of automotive applications with different QoS requirements because they are operated in parallel (e.g. an AVP application is executed while at the same time status information is transmitted to the OEM backend, or a map download is performed).

Network Slicing is a tool for separating network resources in order to provide a more consistent service. Additional tools, such as the 3GPP QoS framework, may be applied for data traffic flows within a given Network Slice. User Route Selection Policy (URSP) provides a foundation to deliver dynamic selection, enabling traffic steering and the separation of services for devices when using Network Slices. When devices are being provisioned with URSP capabilities, the UE is able to use these slices according to the policies defined for the subscription.

The network offers the information about available slice types to the device via URSPs, thus adding further details regarding which Network Slices the device's underlying applications should use when activated. Therefore, the device knows in advance of operating a certain use case, which slice types are available, and how to get access to the relevant one for that application. Applicable slice(s) to use need to be discussed with the corresponding MNOs, and this relationship or profile still needs further standardisation according to slice types and characteristics. 5GAA is making contributions to (profiling) standardisation efforts.

The 5G System also supports so-called 'Network Exposure' interfaces for more dynamic interaction . The 5G System exposes different Network Services, which can be viewed, configured or modified by authorised Application Service Providers.

The Network Exposure interfaces are following the HTTP REST Model, which is widely used in the Internet community. 3GPP has standardised a set of APIs for the Network Exposure Function (NEF), such as for setting up QoS flows. CAMARA[26] works in close collaboration with the GSMA Operator Platform Group to align API requirements and publish APIs to simplify the use of 3GPP network features, e.g. for QoS-on-Demand.

# Multi-access Edge Computing

The application of MEC is widely discussed and tested in the automotive industry for use cases requiring low latency. For example, the ITS and C-ITS use cases, collision avoidance and VRU collective awareness applications are developed, deployed, and tested based on MEC-Infrastructure[27].

Thanks to 5GAA efforts on multi-operator requirements for MEC operation, architectures and operational setups exist, making the low latency characteristics also available for end-customers subscribed to various MNOs[28] [29].

MEC could also be an enabler for automated driving functions, such as AVP, especially to reduce efforts and complexity in the operation of the AVP service.

# Direct Communication – Power Savings

Focus on VRU applications is increasing around the world. C-V2X is uniquely positioned to address the rising number of pedestrian and bicyclist traffic fatalities. Technology from the Third-Generation Partnership Project (3GPP)  is developed to be incorporated in the latest smartphones and connected consumer products, and C-V2X direct communication is no exception to this in the future. The specification already supports direct vehicle-to-pedestrian/bicycle/motorcycle communications, and further specifications developed in 3GPP Rel. 17 will help to optimise the power consumption of C-V2X for consumer handheld, battery-powered devices. Rel. 17 provides discontinuous reception, which means devices can cooperate when data transfer occurs. The phone's receiver can turn off when it does not receive data, thus extending its (battery) life and making it a more viable device for bi-directional communication and warnings. These warnings will help drivers and VRUs avoid potential hazards, especially as vehicles increasingly share roads with pedestrians, bicyclists, and micro-mobility riders . Therefore, the technology can be an enabler for extending the application scenarios of the VRU collective awareness use case.

# Forward-looking Technical Enablers: Non-Terrestrial Networks

Non-Terrestrial Networks (NTN) in 3GPP are aimed at providing 5G connectivity to devices via a range of base-station connections made to satellites, high-altitude platforms, or Uncrewed Aerial Vehicles (UAV). 5G UE should be capable of connecting to NTN with minimal changes, using an evolution of existing NR waveforms and protocols and not requiring a separate radio transceiver. The main changes are expected to be in the frame-and protocol timers, to support much longer 'time of flight' for signals. Subject to regulatory conditions in each market, new frequency bands for NTN may be allocated. Existing satellite bands are in the 2 GHz, 10-20 GHz, and 30-40 GHz frequency bands. Various network architectures are proposed, to provide roaming and mobility between networks. By utilising a new generation of low-cost LEO satellites, and lower cost launch platforms, the deployment cost of networks is being reduced. Using LEO satellites and 2 GHz (S band) will enable normal 5G devices to connect to NTNs without significant extra costs in the UE. 3GPP standardised NTNs are an essential requirement for the automotive industry to utilise these networks as a complementary form of connectivity for road hazard information, emergency calls and fleet monitoring, to name a few applications.

# Conclusions and Recommendations

A foundation of 5GAA's vision is that advanced safety, automated driving and connected mobility will involve and engage all stakeholders, including the telecommunications and automotive industries, in order to foster new business models and investment paradigms.

Additionally, the integration of road and telecommunication infrastructures will deliver better coverage and protection for vulnerable road users, along with enhanced capabilities in vehicles as sensors are further enabled through connectivity.

The digitalisation of connected vehicles is a main driver in the ecosystem and deployments need to be in sync with the road infrastructure and user needs. Flexible and trusted communication networks are expected to bring the different players in the ecosystem together.

We recognise that there are certain challenges, for example in future protocols, implementation descriptions and conformity/testing needed for advanced driving use cases, which should be addressed by 5GAA together with the relevant SDOs and wider industry ecosystem.

Since the release of our last roadmap, there is evidence of significant growth in market deployment, e.g. local hazard information and sharing[30] [31], as well as basic safety applications. 5G-enabled vehicles have entered the market[32] and connectivity has been acknowledged as an enabler by global NCAPs (e.g. local hazard warning Euro-NCAP 2023). Traffic efficiency use cases are globally on track, but the safety-related use cases listed in the relevant section of the roadmap have experienced different regional development and deployments around the world.

A large number of China-based OEMs, plus GM[33], Ford[34], and Audi have introduced or announced LTE-V2X Direct vehicles. In Europe the market is converging towards 5G-V2X. Furthermore, it is expected that mobile network use will develop faster along trans-European corridors, as illustrated by the recent AD L4 regulations requiring reliable connectivity to put automated driving vehicles on public roads. In the US, it is expected that the FCC 5.9 GHz band ruling will eventually be adopted, permitting the mass market deployment of LTE-V2X in the 5.9 GHz band. We expect implementation of C-V2X use cases in the US to begin by the end of 2022 or later depending on the FCC regulation.

Going forward, 5GAA is working on defining the path ahead for advanced 5G developments enabling the next set of use cases and a new roadmap release. Alignment with stakeholders, e.g. road operators seeking to digitalise road infrastructure and smart cities, will also be in the focus future 5GAA releases. The roadmap complements other industry roadmaps (ERTRAC's CCAM roadmap[35], UK Zenzic[36], SAE, China ICV, Car-2-car communication consortium[37]) on connected vehicles by factoring in connectivity, automotive aspects, functional safety and use cases that cover the full range of road users/vehicles.

5GAA will actively continue its collaborations with standards organisations, regulators, road operators and other stakeholders to advance the field of cooperative driving in new road and automotive settings.

# Annex I: Use Case Descriptions

Local Hazard and Traffic Information: Host vehicle (HV) driving along a route that is made aware of some events on the route ahead. This can happen either by other vehicles (RVs) or via some backend/cloud service that collects and aggregates data of several vehicles; e.g. C-V2X TR UC Volume I, T-200111, page 39

Hazard Information Collection Sharing: Vehicles collect hazard and road event based on vehicle sensor data for further use by autonomous vehicles (AVs) and V2X application servers; see C-V2X TR UC Volume II, T-210021, page 101

Basic Safety: Day-1 use cases targeting hazard information and warning use cases examples; e.g. Technical Report (TR) for Use Cases (Day-1 Safety Use Cases), T-180014, pages 8-44

Intersection Safety: Day-1 use cases targeting intersection safety; see C-V2X TR UC Volume I: Cross-Traffic Left-Turn Assist and Intersection Movement Assist, page 22; Technical Report (TR) for Use Cases (Day 1 Safety Use Cases), T-180014, page 8

VRU Collective Awareness: Alert host vehicle of approaching VRU in the road or crossing an intersection and warn of any risk of collision; see C-V2X TR UC Volume I: Cross-Traffic Left-Turn Assist and Intersection Movement Assist, T-200111, page 49; Technical Report (TR) for Use Cases (Day 1 Safety Use Cases), T-180014, page 12

Group Start: Self-driving or semi-automated vehicles form a group to jointly start straight on at a traffic light. No turns are permitted; see C-V2X TR UC Volume II, T-210021, page 117

Cooperative ACC: CACC is an extension to the adaptive cruise control concept. CACC realises longitudinal automated vehicle control by adapting the speed and distance with the preceding vehicle.

Cooperative Manoeuvres: An AV identifies a difficult or dangerous situation (e.g. collision with a moving object) and undertakes to coordinate with neighbouring AVs in order to jointly decide and perform their manoeuvres; see C-V2X TR UC Volume II, T-210021, page 58

VRU Complex Interactions: VRU is preparing to cross the street; after sharing its intent, nearby vehicles acknowledge to reassure the VRU that it is safe to cross; as VRU is crossing, it continues communicating with stopped vehicles, it tells vehicles when it has cleared the zone o It double-checks with vehicles just before moving in front of them; see C-V2X TR UC Volume II, T-210021, page 7

Data Collection and Sharing for HD Maps (formerly named 'HD Map Sharing for AVs'): Collecting and sharing information about static road objects and temporary road conditions with map providers. Build HD maps that are dynamically updated and more accurate to reflect the near real-time environment/conditions with additional precise and accurate position of the objects; see C-V2X TR UC Volume II, T-210021, page 69

Data Sharing of Dynamic Objects (formerly named 'Sensor Sharing for AVs'): Vehicles/infrastructure collect information on dynamic objects in or near the road and on other traffic participants based on own sensor data. They only share the relevant information as a result of processed and analysed sensor data also including some metadata; see C-V2X TR UC Volume III, T-210022, page 7

Non-analysed Sensor Signal Sharing (formerly named 'High-Definition Sensor Sharing'): Supports the development of further automated driving capabilities in the future. Non-analysed sensor signal data, perceived by other road users (e.g. other vehicles, VRU) in the road and/or infrastructure, is provided to the host vehicle. The relevant information is shared as (unaltered or encoded but raw) data stream that could be used at vehicle's sensor fusion; see C-V2X TR UC Volume III, T-210022, page 11

Dynamic Intersection Management: An autonomous vehicle (AV) goes through the intersection with traffic light. AV goes through or stops taking signal timing into account. Traffic flow is coordinated with other traffic participants dynamically; see C-V2X TR UC Volume II, T-210021, page 50

Dynamic Cooperative Traffic Flow: Generic: 1. Main traffic participant wants to perform a certain action (e.g. lane change, get off highway, U-turn, …). 2. Participant shares this intention with other traffic participants potentially involved in the manoeuvre. 3. The informed traffic participants indicate their support or decline the planned manoeuvre to the main traffic participant. 4. The main traffic participant informs a superset of the traffic participants informed in step 2 whether it plans to perform the manoeuvre; see C-V2X TR UC Volume II, T-210021, page 61

Automated Valet Parking (AVP): When a vehicle arrives at its destination parking area, the vehicle is parked by itself through automated driving with the aid of parking data centre. Based on ISO 23374 [1] Intelligent transport systems — Automated Valet Parking Systems (AVPS); see C-V2X TR UC Volume II, T-210021, page 15; C-V2X TR UC Volume III, T-210022, page 15

Tele-operated Driving: When the vehicle detects the need for remote support, it starts sharing video and/or sensor data (either raw or pre-processed) and/or situation interpretation to provide adequate 'perception' of the environment to the remote operator. Based on the perceived situation the remote operator can provide the appropriate trajectory and/or manoeuvre instructions to help the vehicle resolve the uncertain situation; see C-V2X TR UC Volume II, T-210021, page 87

# Annex II: Glossary of Terms

3GPP: Third-Generation Partnership Project
AD: Automated Driving
ADAS: Advanced Driver Assistance Systems
API: Application Programming Interface
ARIB: Association of Radio Industries and Businesses of Japan
AV: Automated Vehicle
AVP: Automated Valet Parking
C-SAE: China Society of Automotive Engineers
C-V2X: Cellular Vehicle To Everything Communication
CACC: Cooperative Adaptive Cruise Control
CAICV: China Industry Innovation Alliance for the Intelligent and Connected Vehicle
CEPT: European Conference of Postal and Telecommunications Administrations
CPS: Collective Perception Service
ECID: Enhanced Cell Identity
ERTRAC: European Road Transport Research Advisory Council
ETSI: European Telecommunication Standards Institute
EU: European Union
FCC: Federal Communications Commission
GNSS-RTK: Global Navigation Satellite Systems Real Time Kinematic
IMT-2020: International Mobile Telecommunications 2020
ISO: International Standard Organisation
GSMA: Global System for Mobile Communications
MEC: Mobile Edge Computing
MCS: Manoeuvre Coordination Service
MIC: Ministry of Internal Affairs and Communications of Japan
MNO: Mobile Network Operator
NCAP: New Car Assessment Programme
NR: 5G New Radio
NTCAS: National Technical Committee of Automotive Standardisation of China
NTN: Non-Terrestrial Networks
OEM: Original equipment manufacturer
PSM: Pedestrian Safety Message
OTDOA: Observed Time Difference Of Arrival
QoS: Quality of Services
RAT: Radio Access Technology
RAN: Radio Access Network
SAE: Society of Automotive Engineers of United States
SDO: Standard Development Organisation
SSO: Standard Setting Organisation
ToD: Tele-operated Driving
TSG: Technical Specification Groups
URSP: User Route Selection Policy
V2I: Vehicle-to-Infrastructure Communication
V2N: Vehicle-to-Network Communication

V2N: Vehicle-to-Network Communication
V2P: Vehicle-to-Pedestrian Communication
V2V Vehicle-to-Vehicle Communication
V2X: Vehicle-to-Everything Communication
VAM: VRU Awareness Message
VDA: German Association of Automotive Industry
VRU: Vulnerable Road User

# References


1 a) A Visionary Roadmap for Advanced Driving Use Cases, Connectivity Technologies, and Radio Spectrum Needs, 5GAA, 2020
b) Timeline for deployment of C-V2X - Update, 5GAA, 2019
c) 5GAA Announces Deployment of LTE-V2X by 2020, 5GAA, 2018
2 BMW Group enhances road safety by sharing anonymised traffic data
3 Precise data for greater safety: Audi warns its drivers faster about slippery roads
4 Welcome to the future: Conncected car technology now warn drivers of dangers around the corner
5 Fully-Featured Intelligent Electric SUV Flagship Hongqi E-HS9 Features Qualcomm C-V2X Solution
6 Audi realizes the world's first open road test of L4 autonomous driving with V2X signaling at the 2021 Wuxi WIoT Exposition
7 C-V2X Use Cases and Service Level Requirements Volume I, 5GAA, 2020
8 C-V2X Use Cases and Service Level Requirements Volume II, 5GAA, 2021
9 Commission Delegated Regulation (EU) No 886/2013
10 European New Car Assessment Programme (Euro NCAP)
11 BMW Group is showing Automated Valet Parking for the first time at the IAA Mobility 2021
12 A Visionary Roadmap for Advanced Driving Use Cases, Connectivity Technologies, and Radio Spectrum Needs, 5GAA, 2020
13 Tele-operated Driving (ToD) Use Cases and Technical Requirements, 5GAA, 2020
14 Tele-Operated Driving (ToD): System Requirements Analysis and Architecture, 5GAA, 2020
15 Tele-Operated Driving (ToD): System Requirements Analysis and Architecture, 5GAA, 2020
16 Tele-Operated Driving (ToD): Business Considerations, 5GAA, 2021
17 Report on Automated Valet Parking: Technology Assessment and Use Case Implementation Description, 5GAA, 2022 (extension planned end of 2022 to include non-public networks and direct communications-based implementations)
18 C-V2X Use Cases and Service-Level Requirements Volume I, 5GAA, 2020
19 How 'Talking' and 'Listening' Vehicles Could Make Roads Safer, Cities Better
20 Deployment band configuration for C-V2X at 5.9 GHz in Europe, 5GAA, 2021
21 Ato nº 14448, de 04 de dezembro de 2017, Ministério das Comunicações
22 Radiocommunications (Intelligent Transport Systems) Class Licence 2017, Australian Government
23 Consulta Pública de integración respecto del "Cuestionario sobre necesidades de espectro para sistemas de transporte inteligente en la banda 5850-5925 MHz", Instituto Federal de Telecomunicaciones
24 Study of Spectrum Needs for Safety Related Intelligent Transportation Systems - day 1 and advanced use cases, 5GAA, 2021
25 Study of Spectrum Needs for Safety Related Intelligent Transportation Systems - day 1 and advanced use cases, 5GAA, 2021
26 Enable Seamless Access to 4G/5G Network Capabilities, Camara
27 Digital Guardian Angel Makes Urban Road Traffic in Hamburg Safer
28 LinkedIn post, Dominik Schnieders, 2021
29 Live Trial of 5G Connected Car Concept Launches in Blacksburg, Virginia (VA) , 5GAA, 2022
30 Mercedes-Benz Car-to-X Communication, EuroNCAP, 2022
31 UN regulation on Automated Lane Keeping Systems (ALKS) extended to trucks, buses and coaches
32 BMW Group and Telekom integrate 5G and Personal eSIM networking into a vehicle
33 2021 Buick GL8 Avenir Premieres V2X Technology In China
34 Ford Launches V2I Technologies in China
35 ERTRACR CCAM Roadmap v10
36 UK Connected and Automated Mobility Roadmap to 2030: CAM Creators Update, Zenzic
37 Guidance for day 2 and beyond roadmap, CAR 2 CAR Communication Consortium, 2019

5GAA
Automotive Association