5GAA Automotive Association

Timeline for deployment of C-V2X – Update

22 January 2019

In December 2017 5GAA published the white paper "Timeline for deployment of LTE-V2X (V2V/V2I)" focusing on the introduction of direct communications with LTE 3GPP Rel.14. Since then Cellular-V2X (C-V2X) has gained a lot of momentum in the eco-system and we are at the verge of deploying the next generation of mobile network technology – 5G.
This updated timeline of the introduction of C-V2X covers the following topics:

1. The extended use of V2N for safety-oriented services in vehicles deployed on the roads
2. The comprehensive test and evaluation activities undertaken by the ecosystem consisting of OEMs, tier-1s, chip vendors, road operators, mobile operators as well as their suppliers and test equipment providers
3. Outlook on the evolution towards 5G including backward compatibility
4. C-V2X use cases for railways and respective test activities
5. Progress on regulatory aspects

The inclusion of 2G, 3G and 4G cellular communication technologies (V2N – Vehicle2Network) into vehicles (i.e. "Connected Cars") has been extremely successful in delivering benefits for the vehicle, the driver, the automaker and other participants in the transportation and emergency services ecosystem.

At present, more than 100 million Vehicles connected to cellular networks (V2N) are on the roads. This V2N connection is used for a wide variety of services including telematics, connected infotainment, real time navigation and traffic optimization, as well as for safety services including automatic crash notification (ACN) such as eCall, the recognition of slow or stationary vehicle(s) and informational alerts for events including traffic jams, road works and other traffic infrastructure related information, inclement weather conditions and other hazardous conditions. Several OEMs[1] share safety related warnings between their vehicles and have started to exchange this information across OEMs using e.g. services from HERE Technologies. Other initiatives to share information by interconnected backend systems are the EU financed projects 'Nordic Way'[2,3], 'Talking Traffic'[4] and the 'Drive Sweden'[5,6] projects. These projects also interconnect Road Traffic Authorities, Road operators, OEMs and smartphone applications to share traffic related info. The current understanding, also based on the European C-ITS Platform Final Report, is that the nature of these warning messages is informational, and the driver is always responsible.

C-V2X is a recent term introduced for cellular technologies optimized for transportation and connected vehicles. In particular, the C refers to both 4G LTE and 5G NR (new radio) releases of specifications, whereas X refers to multiple things' vehicles may connect with. C-V2X includes both network-based communications that have been in use for decades, such as vehicle-to-network (V2N), as well as a new complementary mode

of operation first defined in the 3GPP Release 14 specifications and approved in June 2017, which allows direct communications between vehicles (V2V), as well as between vehicle and road side infrastructure (V2I and I2V) without requiring any cellular network coverage or subscription. It can further support vulnerable road users (e.g. vehicle to pedestrian, or V2P) by integrating the direct communications technology into mobile and other devices. The direct communications functionality is used to specifically support safety critical services to reduce collisions, support automated driving, and improve traffic efficiency. LTE-V2X is the 3GPP nomenclature for direct communications as specified in releases 14 and 15, whereas 5G NR-V2X is from Release 16 onward. 3GPP R14 also added network communications improvements, delivering increased data volumes, managing greater scale of connected devices, and can further reduce latency and provide for higher levels of reliability in V2N. V2N is also technically known as Uu and refers to an endpoint such as a vehicle communicating with network infrastructure over operator licensed spectrum, whereas V2V/V2I/V2P is supported by direct communications operating on the ITS spectrum (e.g. 5.9GHz) and is known technically as PC5.

Implementation and deployment of LTE V2X (3GPP rel. 14)

3GPP Release 14 including C-V2X is a key step to the next generation of cellular technology, 5G NR. C-V2X was developed with evolution in mind, with improvements and enhancements coming in new releases; implementations of the specifications support backwards compatibility. This means that vehicles deployed now based on Release 14 will continue to operate with future vehicles that will leverage emerging 3GPP specifications including Release 16.

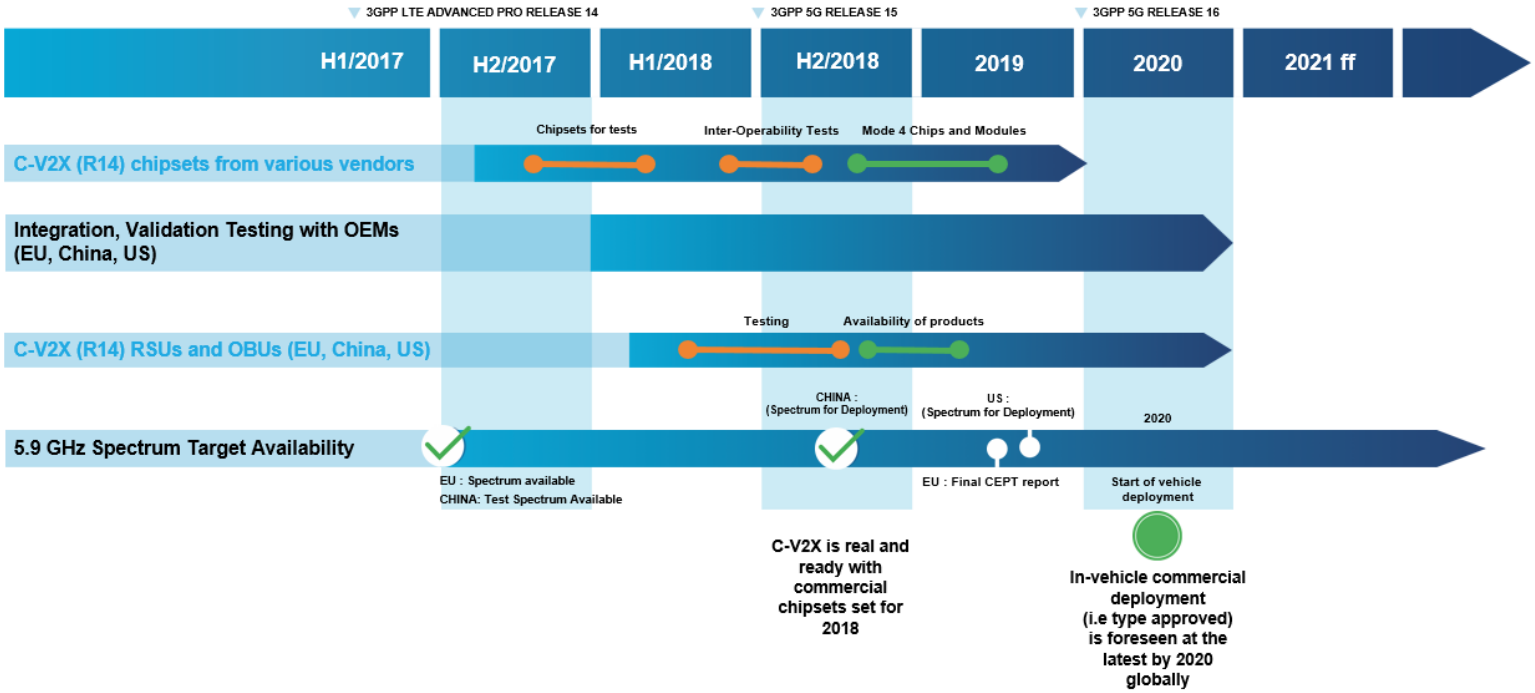
The members of 5GAA are wholly committed to collaborating to ensure that the potential of the C-V2X technology is realized with both network-based and direct communications. This includes leading efforts to address key technical and regulatory issues, as well as integrating vehicle platforms with advanced cellular connectivity, networking and computing solutions.

It is with this global cooperation, cross-industry collaboration, and commitment to safety and technology that 5GAA members continue to work to ensure that C-V2X technology is tested, validated, and commercially available in vehicles starting in 2020. **We already see that infrastructure and aftermarket devices are set to begin commercial deployment in 2019**.

Between 2018 and 2022 more than 125 million connected vehicles that will use V2N are forecasted to ship globally[7]. Because the C-V2X direct communications functionality is being included as part of new cellular chipsets that will be embedded into vehicles for V2N communications, newer vehicles will be able to benefit from the higher level of traffic safety enabled by supporting the direct communication. In addition to the benefit that the inclusion of C-V2X supports evolution towards future, updated cellular chipsets, there are also cost synergies that will ease the barrier to deployment and accelerated time-to-market adoption and overall attach rates.

As presently understood, we have included the timeline for the progression of the components of C-V2V (direct communication) in the picture below.

Timeline for deployment of C-V2X (V2V/V2I)



The 5 major chipset vendors CATT/Datang, Huawei, Intel, Qualcomm and Samsung, which are members of 5GAA, provide nearly all of the communication chipsets used in connected cars on our roads today. These vendors are committed to providing C-V2X chipsets and after the first announcement of chipset availability by Qualcomm[8], two further vendors CATT[9] and Huawei[10] have published their roadmaps. The new 3GPP Rel-14 chipsets have been available for first tests since the end of 2017, and have lived up to theoretical predictions based on simulations with empirical lab and field testing conducted around the world. 5GAA has been instrumental in demonstrating V2V and V2I safety use cases between Audi and Ford in April 2018 in Washington D.C.[11] as well as between BMW cars and motorbikes, Ford and PSA in July 2018 in Paris[12]. Audi and Ducati also demonstrated the direct communication between cars and motorbikes in Germany and have since shown performance at very high speeds along the Autobahn[13]. Audi, Ducati, Ford and Qualcomm demonstrated advanced driving use cases with CV2X at CES 2019 involving vehicles negotiating right of way at a non-signalized intersections[14]. Large scale tests are also being conducted in China, for example, in Wuxi[15] [16]. PSA Group announced C-V2X tests in China using Citroën vehicles equipped with chipsets from Huawei and PSA Group and Citroën vehicles with Qualcomm chipsets[17]. Many other players in the C-V2X eco-system have announced test activities including further OEMs and tier-1s such as Bosch, Continental, FAW, LG, Nissan, SAIC, etc.[18] [19] [20] [21] [22] as well as the first road operator in the US[23] Colorado Department of Transportation.

In line with the roadmap shown above, the first inter-operability tests between chipsets from CATT/Datang and Qualcomm[24] as well as CATT/Datang and Huawei[25] have already been conducted.

C-V2X direct communications has benefited from past research and leverages protocols and services developed for safety use cases, which has allowed SAE, ETSI and China SAE to quickly be adapted to support this modern radio technology. This is supported by leading ITS software solution providers including Cohda,

CommSignia, Genvict, Marben, Nebula, Neusoft, Savari and others who have quickly been able to demonstrate C-V2X with their existing software platforms and perform V2V and V2I safety use cases.
When comparing the different flavours of V2X standards in Europe, US and China, there are differences both in terms of message types used and functional capabilities available. While the US and China use Basic Safety Message (BSM) for both status information and event notifications, Europe has split these into Cooperative Awareness Message (CAM) and Decentralized Environmental Notification Message (DENM). The European specification has additional capabilities in terms of geofencing for defining relevance area and capability to relay broadcasting messages as needed. These capabilities are not available in the US and China specifications. Furthermore, and even though harmonization was done between Europe and US for SPaT/MAP messages in 2016, there are still some optional data elements that are regional extensions in the SPaT/MAP messages.

5GAA has defined comprehensive test procedures and processes for C-V2X. Following the test procedures Ford and Qualcomm carried out lab and field tests from March through August 2018.Tests and results are described comparing the two V2X radio technologies operating in the ITS band (5.850 GHz to 5.925 GHz) from the perspective of basic radio KPIs such as Packet Error Rate (PER) or Packet Reception Rate (PRR), latency or service end-to-end delay, Inter-Packet Gap (IPG), and Receive Signal Strength Indicator (RSSI). The results were presented to the FCC in September 2018[26]. 5GAA published a very comprehensive and detailed report describing the test methodology and the test results[27].
The tests confirmed the suitability of C-V2X to deliver broadcast V2X safety messages in a variety of environments, both ideal and adversarial. The tests also showed that C-V2X significantly outperformed DSRC in range, resilience to interference and reliability, especially in adversarial scenarios while satisfying the requirements for latency and IPG.

These validation tests supported the successful launch of the first commercial chipsets end of 2018, which is in line with the announcements made by Qualcomm[28] and Rohde&Schwarz[29].

In summer 2018 the first traffic related roadside units (RSUs) supporting PC5 communication towards vehicles were announced by Commsignia[30], Huawei [31], Kapsch[32] and Savari[33] and commercial samples are available now. Tests have started already and they will be driven in parallel with elaborating the benefits of the transmission of road operator relevant information via cellular networks to the drivers/vehicles; this would result in an immediate benefit for all traffic participants using cellular infrastructure, regardless whether it is embedded in the vehicle, via smartphone or aftermarket devices. Additional companies have since announced RSUs including China Mobile[34], Genvict[35], Nebula[36] and Neusoft[37] in China, as well as Lacroix[38] in Europe. This is also supported by 5GAA through providing defined profile information which supports Uu and PC5 and has been submitted to ETSI.

Vehicle manufacturers forecast starting production integration with the C-V2X direct communications commercial chipsets and communication modules in 2019 to enable them to be on track for commercial deployments in 2020. BMW[39] and PSA[40] have already announced their plans. Ford announced that all new Ford cars will be equipped with C-V2X in the US from the beginning of 2022[41].

In terms of regional deployments, 5GAA expects that the first commercial deployments of C-V2X will occur in China and Europe, and deployments in the US and other parts of Asia will follow closely.

5GAA would like to reinforce that C-V2X short-range direct communications for V2V and V2I will first be deployed in Mode 4, which does not require cellular network coverage to support V2V or V2I direct communications. In commercial deployment, the combination of C-V2X short-range direct communication and long-range network communication will maximize the benefit for ITS safety services.

By deploying the transmission layer of C-V2X instead of DSRC/802.11p, the well-developed C-ITS framework will be reused, maximising synergies and ensuring quick time-to-market, while leveraging a modern radio with many performance improvements leading to greater reliability. This reuse also includes the Security Credential Management System (SCMS) which will especially benefit from C-V2X network communications capabilities supporting distribution of security credentials, profiles and Certificate Revocation Lists (CRL), which will be distributed via cellular networks.

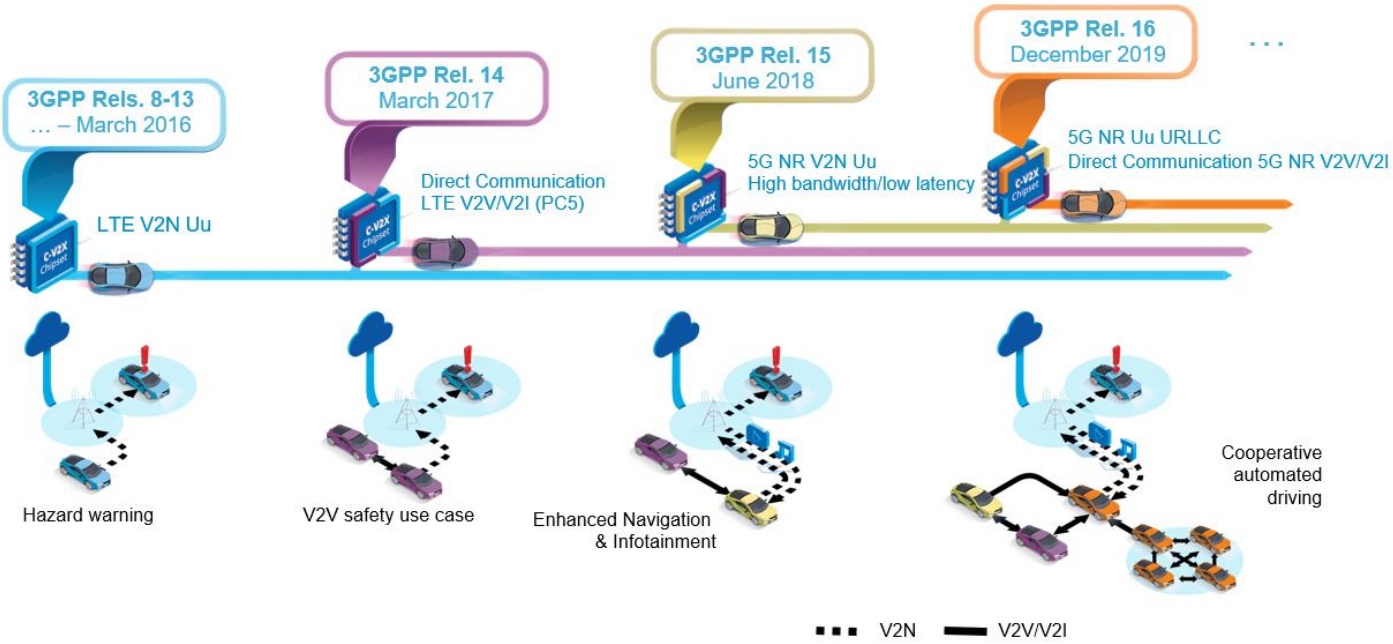
As mentioned previously, another additional safety benefit of C-V2X is the additional support for Vulnerable Road User (VRU) collision avoidance. Due to the integration of V2N and V2P (vehicle to pedestrian) functionality. These ensure that a VRU can become visible to vehicles in a first step via V2N utilizing smart phone applications carried by the VRU (and will not require the integration of smartphones with C-V2X functionality) and expected later, in a second step, via direct V2P communication between vehicles and VRUs. So far, smart phone manufacturers have not disclosed roadmaps of LTE V2X chipsets to support V2P.

Evolution to 5G V2X

3GPP Release 14 including C-V2X direct communications is a significant milestone as it is the result of automotive and telecom collaboration for an optimized solution for a specific industry segment, and its ongoing evolution is also a key step to the next generation of cellular technology, 5G NR.

The following picture shows the evolution of functionalities available with the current and future 3GPP releases of mobile network technology. It also demonstrates that backward compatibility, which is a natural and proven concept in 3GPP deployments and networks, is vitally important to enable basic use case functionality between different generations of vehicles. At the same time new 3GPP releases (e.g. Release 16) provide substantial enhancements in bandwidth, latency and reliability, meeting the needs of high data rates for, for example, map and software updates, enhanced safety, coordinated and cooperative automated driving, and of course high quality infotainment.

C-V2X: Evolution to 5G maintains backward compatibility



The figure above depicts multiple release dates of upcoming specification releases and, using historical timeframes, suggests when vehicles based on such releases may start to commercially ship on the road.

3GPP Release 15 introduces New Radio (5G NR) capabilities as a follow-on next generation to 4G LTE with regards to network communication at the Uu interface. 5G NR in Release 15 provides higher data rates and lower latencies for V2N network communications. 5GAA expects that the first chipsets supporting 5G NR will be available in commercial consumer devices in 2019, and for testing in vehicles the same year. Consequently, first deployments of those vehicles are expected to start as early as 2021. Release 15 also includes some minor enhancements to the direct communications (PC5) radio including transmit diversity[42] and high-order modulation (64 QAM)[43]

3GPP Release 16 introduces additional capability to 5G NR, specifically in terms of short range direct communication, increasing bandwidth and reducing latency further and is sometimes referred to as Ultra Reliable Low Latency Communications (URLLC). 5G-V2X offers the features which are paramount to highly and fully automated and cooperative driving such as the exchange of:

- Sensor data sharing for collective perception (e.g., video data)
- Control information for platoons from very close driving vehicles (only a few meters gap)
- Vehicle trajectories to prevent collisions (cooperative decision making).

As a consequence, use cases such as:

- Real-Time Situational Awareness & High-Definition Maps
- Cooperative Manoeuver of Autonomous Vehicles for Emergency Situations
- Software Update
- High Definition Sensor Sharing

- Tele-operated driving

will be supported with substantially improved key performance indicators (KPIs) and/or can be implemented for the first time. These enhancements are not possible in other V2V and V2I technology such as 802.11p as used in DSRC/ITS-G5.
3GPP release 16 is still in specification phase, with anticipated functional freeze in late 2019. First deployments using R16 may be expected at the earliest in 2023. Although the physical radio layers of LTE releases and 5G NR are very different, the chipsets and associated communication stacks will integrate the distinct radio technologies, supporting smooth operation and backward compatibility at service level.

Backward compatibility of 3GPP releases guarantees that all vehicles equipped with at least Rel. 14 chipsets will be able to communicate using direct communications. Using the network over the Uu interface, even older vehicles would be able to participate in the exchange of appropriate information.

Adoption of C-V2X in neighbouring industries

The advantages of C-V2X technology have also raised interest in other transport domains. The French national railway company (SNCF) is testing and evaluating the potential of C-V2X technologies for the implementation of railway applications. SNCF considers that the initial results and performance of C-V2X are promising. Additional tests and evaluations will be conducted with Qualcomm Technologies[44].
In this particular context C-V2X benefits from being based on technology that was intended for high-speed mobile use cases and has been further improved specifically for transportation/automotive use cases, based on observed issues that 802.11p faced in years of research, fundamental advancements in wireless communications, and a need to support a host of new automotive applications to support enhancements in safety and automated driving.
For railways transportation it is also important that C-V2X includes both direct communications and network-based communications and is the only V2X technology with a roadmap to 5G while maintaining backward compatibility. C-V2X also introduces additional possibilities for deployment, including public-private-partnerships, which can change the deployment strategy by leveraging roll-out of mobile infrastructure, as well as leveraging cellular technology integration and economies of scale, instead of building independently operated infrastructure.

Evolution of regulatory framework

5GAA notes that several regulatory decisions need to be made in order to start a commercial deployment of C-V2X, direct communications in particular, decisions around the use of the ITS 5.9GHz spectrum. The following is an updated snapshot per region:

- **Europe**: In May 2018 the EU commission published the strategy for mobility of the future outlining the direction for Connected, Cooperative and Automated Mobility (CCAM).[45] An integrated approach between automation and connectivity in vehicles is considered and by 2020, all new vehicles will be connected to the internet. The ITS Directive 2010/40/EU [46] provides the legal framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport. A revision is underway as of March 2017 including the adoption of a new Delegated Act on Cooperative Intelligent Transport Systems C-ITS. The Delegated Act has the overall objective to encourage the development and deployment of C-ITS technology in Europe, with a view to a harmonised approach across Europe, however C-V2X is yet to be included

in the draft text at this stage. It would also need an agreement on how the 5.9GHz band can be shared amongst the two direct communications technologies so that they can coexist in a technology neutral way as stipulated in EU directives. This agreement is expected by March 2019 when ECC will adopt the final CEPT Report 71 as per the RSCOM 5.9 GHz mandate.

- **China**: Tests conducted in various areas of China have already used 20MHz in the 5.9GHz spectrum. In October 2018 the regulator allocated the 5905-5925MHz band as Internet of Vehicles (Intelligent & Connected Vehicle) direct link frequency band for the LTE-V2X based technology. Any organization that intends to build and/or use roadside wireless equipment in the 5905-5925MHz frequency band shall apply for a radio frequency license from the national radio regulatory administration. After obtaining the frequency license, the organization which will use the roadside wireless equipment shall apply to the local region's or municipality's radio regulatory administration for the radio station license.

- **Korea:** The 5855 – 5925 GHz band is assigned for the purpose of ITS services without specifying any particular radio technology to be operated in this spectrum, so it is a technology neutral spectrum regulation. It is noted that an amendment to the Korean ITS standards is ongoing in the Telecommunications Technology Association (TTA), and one of its goals is to support various radio technologies for ITS applications, including C-V2X, in addition to the technologies based on IEEE 802.11p. Although the C-ITS pilot projects in Korea have been developed so far with the radio interface based on IEEE 802.11p, Seoul Metropolitan Government recently announced a test-bed plan for autonomous driving with C-V2X, in Sangam Digital Media City (DMC)[47].

- **United States:** The 5.9GHz spectrum has already been allocated for ITS services but, currently, it is dedicated to DSRC technology. The DOT has postponed the proceeding that would have imposed a DSRC mandate for vehicles without an indication of timing for resumption. Meanwhile, NHTSA has stated that they will be technology-neutral to communication protocols and are exploring technologies like C-V2X [48]. A change in the FCC's rules governing the 5.9 GHz band will be required before introduction of C-V2X in the U.S. 5GAA believes that the overwhelming benefits of C-V2X technology is becoming evident to U.S. regulators and industry, and that there is now a path forward for introduction of C-V2X in the United States. With this in mind, in December 2018, 5GAA has submitted a petition to waive the existing rules and allow for CV2X deployment as soon as possible, and has indicated that a petition for rule change will follow.

- **Japan:** In addition to existing ITS spectrum (760 MHz, 5.8 GHz etc.), Japan will conduct spectrum sharing/coexistence studies by March 2020, with a view to introducing communication technologies for automated driving, taking into account the globally harmonized spectrum band, i.e. 5.9GHz.

- **Singapore:** Singapore allows ITS usage within 5855- 5875 MHz, however this standard is established based on IEEE 802.11p with modifications to the PHY and MAC layers to provide reliable and low latency communications between vehicles, and to IEEE 1609 wireless access vehicular environment (WAVE) for security and network management. Vehicular OBUs are operated in a license exempt manner, while localised radio-communication station license or wide area private network license is necessary to operate an RSU/non-vehicular installation.

- **Australia:** In Australia, the ACMA 5855-5925 MHz is available for ITS use as a class license, with no registration required for OBU or RSUs. ITS stations are required to comply with ETSI Standard EN 302 571, and there are no restrictions on specific operators of ITS stations, other than compliance with the class license. The ACMA has indicated a willingness to review the class license subject to international developments if this is necessary.

These changes when made will help ensure a smooth transition to 5G including the ability to leverage the benefits of C-V2X in scale, as early as possible. It also allows for further enhancements by future architecture and design decisions including network slicing, quality of service, edge clouds, and a plethora of innovation leveraging the C-V2X foundation.

5GAA is a multi-industry association to develop, test and promote communications solutions, initiate their standardization and accelerate their commercial availability and global market penetration to address societal need. For more information such as a complete mission statement and a list of members please see http://5gaa.org/

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