The Case for Cellular V2X for Safety and Cooperative Driving

5G Automotive Association

With this white paper, the 5G Automotive Association (5GAA)[1] elaborates on why Cellular-V2X (C-V2X) technology at the radio level is an essential enabler to transformational connected transportation services throughout the world. The 5GAA perspective is that 3GPP-based cellular technology offers superior performance and a more futureproof radio access than IEEE 802.11p and can leverage ETSI-ITS, ISO, SAE and IEEE upper layer standards and tests that have been refined by the automotive industry and others in the ITS community for over a decade.

To be clear, capitalizing on the advantage of cellular technologies is a basis of 5GAA. We urge governments, automotive, telecommunications and other sectors to strongly consider the business and value proposition and the overall societal benefit of Cellular-V2X defined by 3GPP. Our position is clear: C-V2X can address all known use cases and can also address future ITS use cases offering full flexibility for different business models. C-V2X should be allowed to flourish by use of ITS spectrum to address many of these use cases.

WHY V2X?

Vehicle-to-everything (V2X) communication is essential to redefining transportation by providing real-time, highly reliable, and actionable information flows to enable safety, mobility and environmental applications. Often referred to as Cooperative ITS (C-ITS), or in the United States as Connected Vehicles, V2X figures prominently in a future with safe, efficient and environmentally-conscious transportation and paves the way to connected and automated driving (CAD).

The immediate and longer term promise of V2X functionality, and the need for planned evolution to ever-increasing capabilities drives the creation and activities of the 5GAA. For V2X to realize its true potential, it must be viewed as a system that starts with technology that works today and can seamlessly evolve into the 5G future.

Cellular-V2X (C-V2X) as initially defined as LTE V2X in 3GPP Release 14 is designed to operate in several modes:

[1] 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/.

- Device-to-device[2] This is Vehicle-to-Vehicle (V2V), Vehicle-to-(Roadway) Infrastructure (V2I) and Vehicle-to-Pedestrian (V2P) direct communication without necessarily relying on network involvement for scheduling. This mode is analogous to the ad hoc communications paradigm used in 802.11p.
- Device-to-cell tower is another V2I communications link which enables network resources and scheduling and utilizes existing operator infrastructure. Device-to-cell tower communications constitute at least part of the V2I proposition and is important to end-to-end solutions.
- Device-to-network is the V2N solution using traditional cellular links to enable cloud services to be part and parcel of the end-to-end solution.

Given that a future C-V2X system will be able to address these modes – and may be able to do so concurrently – and that combinations of these modes can lead to truly transformational transportation applications, the 5GAA believes it is important to carefully consider C-V2X in tandem with spectrum which may be used.

It is important to recognize that in the device-to-device mode (V2V, V2I, V2P) operation, C-V2X does not necessarily require any network infrastructure. In short, C-V2X could and should be used for the public good. 5GAA therefore firmly believes that the device-to-device modes must be enabled and not prohibited by regulatory frameworks because such modes could also be operated in the 5.9 GHz ITS band without any required subscription or payment.

To be clear, C-V2X would also support V2N applications delivered over traditional, commercially licensed cellular spectrum and would utilize existing cellular networks where other voice and data communications occur. V2N would deliver network assistance and commercial services requiring the involvement of a Mobile Network Operator (MNO), providing the access to cloud-based data or information being relayed through the cellular network by means of network slicing architecture for vertical industries. The use of the MNO infrastructure will inherently enhance the C-V2X with the data security and privacy of mobile networks and can provide key time critical network services by means of edge computing. Collectively, the transmission modes of shorter-range direct communications (V2V, V2I, V2P) and longer-range network-based communications (V2N) comprise what we call Cellular-V2X[3].

Since V2X must be deployable in the near term and extended to the future, it must offer the necessary high performance to meet use cases of today, while being futureproof, scalable and be based on an interoperable platform and capable of meeting requirements of use cases of tomorrow. Indeed, tomorrow's use cases are important and challenging: V2X will grow to include enhanced concepts in Advanced Driver Assistance Systems (ADAS) where vehicles can cooperate, coordinate and share sensed information, and ultimately V2X will grow into CAD. As soon as 5G and its corresponding highly reliable, low-latency mission critical services are available for V2X applications, ADAS and CAD will be significantly enhanced.

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[2] Relies on the PC5 interface specified by 3GPP for device-to-device operation.

[3] See 3GPP TR 22.885 *Study on LTE Support for Vehicle to Everything (V2X) Services*

It is worth noting that C-V2X can leverage well-designed and tested upper layer specifications from and contributions to ETSI, ISO, SAE and IEEE. This in effect swaps out the radio to leverage the latest 3GPP-specified PHY and MAC. This fast update of C-V2X and reuse of the C-ITS legacy will not slow down deployments, as cellular technology is well proven and direct communications and operation in 5GHz are well understood. Moreover, the start date is soon: C-V2X based 3GPP release 14 is scheduled for March 2017, and depending on market demand C-V2X can be commercially ready by 2018.

How can V2X address today's and tomorrow's applications? While current and envisioned V2X applications are quite varied, the common theme is the use of active communications to enable enhanced perception horizon over line of sight and non-line of sight use cases with minimum delay. Hence, the overall V2X system must be capable of providing high spatial and temporal breadth and fidelity. C-V2X is not just about short range communication, and C-V2X is not just about Wireless Wide Area Networks (WWAN); rather, C-V2X comprises a system able to integrate a multitude of use cases and scenarios based on multiple transmission modes and wide ranging V2N support.

INTRODUCING CELLULAR-V2X, DIRECT COMMUNICATIONS FOR V2V/V2I

Technical Advantages Point to Cellular Technology as Best Use of ITS Spectrum

C-V2X addresses current and future V2X applications with enhanced radio layer architectures and features, using cellular technologies as a basis. A fundamental point is C-V2X includes several transmission modes, one of which is V2N. V2N leverages the commercial cellular network and field equipment managed by Mobile Network Operators (MNOs). The inclusion of the mobile network operator for V2N allows the utilization of spectrum outside ITS, in low band ranges for high service reliability, to millimeter wave in 5G for high volume data transfer, while also providing low latency wide area network support for assisted driving. To complement V2N, C-V2X direct communications currently is designed to operate in the ITS spectrum (5.9 GHz), in a mode to assure anonymity and no cellular subscription requirement for direct safety communications.

While C-V2X direct services can technically coexist in adjacent channels with IEEE 802.11p-based radio access, one of the main advantages of cellular is that it can address all V2X applications in an end-to-end manner with the same technology and is therefore scalable and evolvable. Also, as part of the 3GPP standards family, C-V2X offers an evolution path from LTE to 5G. This is why C-V2X (i.e. 3GPP cellular for all V2X) is a better choice than any hybrid "solution" that incorporates IEEE 802.11p-based technology.

C-V2X direct communications can operate in ITS spectrum and in commercial spectrum, and it can be combined with network-based C-V2X network communications operating on existing and future cellular networks. C-V2X direct communications based upon 3GPP technical specifications enable V2V, V2I and V2P communications without any requirement for additional network infrastructure. The choice is clear. 5GAA recognizes that not only does C-V2X have the aforementioned advantages of futureproofing and the use of cellular links in combination, it has superior direct communications performance compared to 802.11p, and it offers a higher degree of security for all operating modes: embedded security for V2N transmission and the equivalent Public Key Infrastructure (PKI) security services defined in standards using 802.11p. In our view, C-V2X is the technology of choice for V2V, V2I, V2P and V2N.

Initial results show that those technical advantages summarized below sum to significantly higher link budget and system performance, enabling range, Doppler (speed) and reliability advantages over

C-V2X Technical Advantages Over IEEE 802.11p (ITS-G5 or DSRC)

	C-V2X: PC5	802.11p	C-V2X: PC5 Advantage
Synchronization	Synchronous	Asynchronous	Spectral Efficiency. Synchronization enables time division multiplexing (TDM) and lowers channel access overhead.
Resource Multiplexing Across Vehicles	FDM and Time Division Multiplexing (TDM) Possible	TDM Only	Frequency Division Multiplexing allows for larger link budget and therefore longer range – or more reliable performance at the same range.
Channel Coding	Turbo	Convolutional	Coding gain from turbo codes leads to longer range – or more reliable performance at the same range.
Retransmission	Hybrid Automatic Repeat Request (HARQ)	No HARQ	Leads to longer range – or more reliable performance at the same range.
Waveform	SC-FDM	OFDM	Allows for more transmit power with the same power amplifier. Leads to longer range – or more reliable performance at the same range.
Resource Selection	Semi-persistent transmission with relative energy-based selection.	Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)	Optimizes resource selection with selection of close to 'best' resource with no contention overheads. By contrast 802.11p protocol selects the first "good enough" resource and requires contention overhead.

802.11p. This results in a higher spectral efficiency to serve more road users at a given spectrum. Hence, C-V2X is capable of providing higher levels of safety to more road users.

Additional Considerations with ITS Spectrum

Given that a future C-V2X system will be able to provide device-to-device, device-to-network and device-to-cloud service – and may be able to do so concurrently – and the possible combinations and solutions that C-V2X enables can lead to truly transformational transportation applications, it is important to consider the spectrum which may be used. As 5.9 GHz is emerging as the primary common spectrum to be used for basic safety applications around the world, it is clear that the use of C-V2X

direct communication in 5.9 GHz would bring those advantages to the field in an interoperable manner. The advantages of C-V2X access technology are so profound to ITS applications that for C-V2X to be excluded from the 5.9 GHz ITS band would prematurely push the most promising technology off the table. In fact, the advantages are so extensive that 5GAA is confident that commercial bands will be used for additional non-ITS V2X use cases.

Note that 5.9 GHz ITS band is not ideal for infrastructure deployment as the relatively high frequency renders coverage very challenging. In C-V2X, however, direct communications on 5.9 GHz will be combined with WWAN communications offered for either coverage or capacity on any other (typically lower) LTE band and eventually in 5G bands.

Co-existence of different technologies in the same 5.9 GHz ITS band, using such schemes as different channel assignments, are under study in 3GPP Release 14 and in other standards fora. These studies have merit, because regardless of the outcome, it is good policy to provide sufficient harmonized spectrum for the best low latency vehicle-to-vehicle communication technology in order to save lives and to usher in a future of connected and automated driving.

Hence, 5GAA believes that ITS spectrum at 5.9 GHz will prove central to the uptake of innovative ITS solutions and business models in the years to come. Sharing of the ITS band should be approached with extreme care. 5GAA therefore strongly supports the work ongoing at the ITU-R Working Party 5A to further develop spectrum requirements and studies at the national, regional and global level that will support existing and future use cases envisaged for road safety and traffic efficiency applications. These applications will require spectrum beyond the currently harmonized 5.875-5.905 GHz, comprising at least the 5.905-5.925 GHz band. Additionally, 5GAA advocates that sharing with unlicensed Radio Local Area Networks (RLANs) at 5.855-5.875 GHz can be considered provided ITS spectrum is adequately protected.

To complete the end-to-end applications picture, 5GAA notes the device-to-networks links can certainly use other spectrum as part of an end-to-end, integrated solution.

DEPLOYING CELLULAR-V2X

A Positive Business Case for All

The 5GAA is purpose-built to explore technical (architectures, trials), interoperability (spectrum and standards), policy and go-to-market issues, then transform results into industry action and deployment. Hence, C-V2X business perspectives expressed will be refined as time progresses.

Automaker View

To deliver safety, mobility and convenience services as an integrated service to road users is an essential starting point, as it provides value to customers and ultimately to society. Efficiencies, ever-increasing performance with backward compatibility and growth into future applications are all prospects with C-V2X that are not possible for 802.11p. C-V2X is ushered in by repurposing developed and tested applications-level specifications by IEEE, SAE, ISO, ETSI and other standards development organizations.

Network Operator View

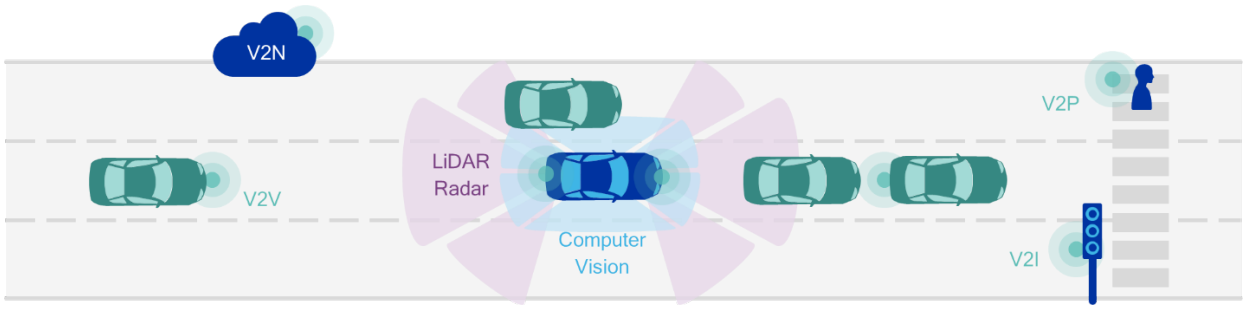
Over the long term, mobile network operators can leverage existing cellular infrastructure to promote an efficient deployment of V2X technologies, including potential integration and management of C-ITS roadside stations/roadside units (RSUs). There is a near-term value proposition that transitions to the long-term view, however. Operators can provide V2N connectivity services from vehicles and backhaul to the roadside leveraging existing and emerging commercial cellular networks of both LTE and 5G. Additionally, operators can play an essential role in PKI certificate management.

Road Operator View

The road operator has the burden of safe, efficient traffic operations, and the V2V, V2P, V2I and V2N connectivity offered by C-V2X offers a comprehensive menu of options to efficiently execute their prime mission. How can this be implemented in a cost-effective manner? Collectively, road operators may derive significant value when the existing cellular infrastructure provides an underpinning for V2X services. In early days, the cellular backbone may obviate some of the capital plus maintenance and operations costs, to include training of road agency personnel, and to run C-ITS roadside stations/ (RSUs). This saving would be realized within relationship where over the top V2X services for traffic management and other road operator connectivity services would be tendered and delivered at a potential total cost savings to the operator.

Technology Provider View

V2X is a vital sensor that will provide real-time, highly reliable, and actionable information flows that will feed into an ADAS compute platform along with radar, LIDAR, computer vision, and precise positioning. A single sensor is not sufficient to deliver the promise of increased safety and autonomous driving; rather it will be a fusion of ever evolving and improving sensors and computational machine intelligence that will ultimately emulate and then surpass sensing and cognitive capabilities of human drivers alone.

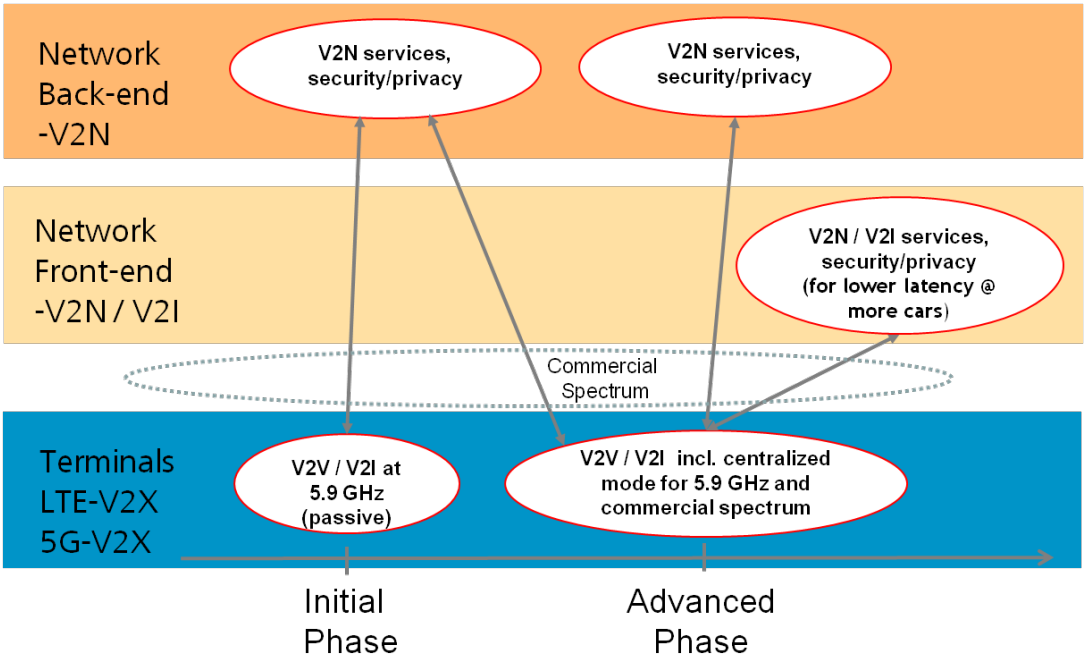


Societal View

The ultimate beneficiaries would be the traveling public who would collectively realize safety, mobility and convenience services up to and including ADAS and CAD. Society would benefit as well, since ‘information everywhere’ would inform mode choices, enable policy-based road user fees, route traffic dynamically and more efficiently, yield benefits in reduced and predictable travel time, and reductions in congestion, carbon emissions and impact to the environment.

WORKING TOGETHER TO MAKE CELLULAR-V2X A REALITY

The figure below summarizes key points in this white paper while laying out possible deployment scenarios within the framework of a top-level end-to-end architecture, with terminals and a network at the front end and a back office in the 'cloud'. In the figure, it is shown that V2N services can be offered by commercial stakeholders and include services offered by the road authority. As shown, backend V2N services handle delay-tolerant or wide area network services and support additional security and privacy from an appropriate network location. Initially, V2V can be supported on ITS bands not relying on network infrastructure for scheduling and not requiring existing network operator maintained equipment to be upgraded. As market penetration increases and additional services are offered, V2V can also be supported on commercial bands and later can also utilize the centralized mode to achieve a higher spectral efficiency with eNodeBs allocating resources to transmit devices. Moreover, service providers can offer advanced services for e.g. support of ADAS and CAD with low latency requirements in infrastructure located in the network front-end.



It is important to highlight that V2V and V2I safety services over ITS spectrum are offered for no V2X service fees, so a primary difference between 802.11p and C-V2X would be improved performance with C-V2X. This functional and deployment architecture allows for multiple business models, another difference between 802.11p and C-V2X.

In conclusion, 5GAA is a catalyst in putting C-V2X on the road. However, in order for C-V2X and associated benefits to be realized, the companion ecosystem in industry and government needs to

initially be neutral to technology and ultimately, once C-V2X are put on the road, industry and government should be hospitable to spectrum use and deployment. **The initial cellular needs are clear: there must be available and sufficient ITS spectrum for complete interoperability and technology migration. Transportation interests should take an objective interest and stance on the benefits of C-V2X.**

Given that these C-V2X needs are met, 5GAA is certain that stakeholders will be rewarded. It is clear that C-V2X can improve safety and reduce vehicular crashes. C-V2X can also be instrumental in transforming the transportation experience by significantly enhancing timely information flows to realize societal goals such as improved mobility, improved safety and reduced environmental impact. The 5GAA is confident that a technically superior standards-based cost-effective and scalable access technology from the cellular industry will carry C-ITS and Connected Vehicle applications well into the 5G era and beyond.