



# ***V2X Cellular Solutions***

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## TABLE OF CONTENTS

Executive Summary .....	4
1. Introduction .....	5
2. What is V2X? .....	5
2.1 Overview of V2X.....	6
2.2 USDOT V2X Statistics.....	8
2.3 Benefits of V2X.....	8
3. DSRC Challenges .....	9
3.1 Spectrum Allocation.....	10
3.2 Connection to the Infrastructure and RSU Deployment.....	11
3.3 Physical Layer Challenges .....	11
3.4 Summary of Challenges .....	12
4. Role of LTE in V2X Solutions.....	12
4.1 LTE-Based V2X Services .....	13
4.2 LTE-Based V2X Solutions Address New Challenges .....	14
4.3 Mobile Operator Added Value .....	16
4.4 Use of Broadcast and Direct-Link Technology for V2X.....	17
4.5 V2X Security .....	20
4.5.1 Regarding DSRC Security .....	20
4.5.2 Regarding LTE Security.....	21
4.5.3 What Can We Expect for Cellular V2X Security? .....	22
5. Current V2X Landscape.....	23
5.1 United States .....	23
5.2 Europe .....	25
5.3 China .....	27
5.4 Considerations on Deployment .....	27
6. Vehicle Manufacturer Viewpoints.....	27

7. Regulatory & Spectrum Considerations.....	29
8. Conclusion .....	32
Appendix A: Acronym List.....	32
Appendix B: Glossary.....	34
Appendix C: US Department of Transportation Vehicle Crash Statistics .....	35
Acknowledgements .....	37

## EXECUTIVE SUMMARY

As its name implies, vehicle-to-everything (V2X) communications and its solutions enable the exchange of information between vehicles and between vehicle network infrastructure. The goal of V2X is to improve road safety, increase the efficient flow of traffic, reduce environmental impacts and provide additional traveler information services. V2X communications consists of four types of communications: vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-network, (V2N) and vehicle-to-pedestrian (V2P).

Based on extensive analysis of crash data from 2004 to 2008, the U.S. Department of Transportation (USDOT) has concluded that a fully implemented V2X system can address 4.5 million crashes, which is 81 percent of all multi-vehicle, unimpaired crash types. The USDOT is expected to mandate that vehicles manufactured in late 2019 and beyond deploy dedicated short range communication (DSRC) devices to support V2V and V2I communications. The U.S. DSRC solution has gone through extensive testing by the auto ecosystem players for over 10 years and utilizes dedicated spectrum at 5.9 GHz.

However, DSRC has several challenges. The system relies on road side units (RSUs), which are not currently deployed. Meanwhile, at the physical layer, several inefficiencies arise due to the asynchronous nature of the system, resulting in reduced performance, such as range. In the long run, there is no evolutionary path (or IEEE 802.11 standards activities) to enable improvements in the DSRC physical/MAC layers with respect to range, robustness and reliability.

Fortunately, DSRC is not the only solution for V2X communications. LTE and fifth-generation (5G) cellular systems have the potential of supporting not only existing DSRC use cases, but also the more challenging and futuristic use cases that require low-latency, high reliability or high bandwidth. Cellular V2X could also complement DSRC communications to enhance V2X communications capabilities.

Mobile operators have the potential of providing additional value to the overall V2X solution. Cellular networks already blanket nearly the entire U.S., including rural interstates. Those networks could be used to distribute certificate and certificate revocation lists and for RSU backhaul communications. Additionally, LTE networks can extend the V2X range from the 300 meters that DSRC can achieve to several kilometers or more. This extended range could benefit drivers by providing earlier notifications of accidents, road conditions and traffic congestion ahead.

Automotive manufacturers have been investigating crash avoidance technologies for over 20 years. In September 2014, GM announced that Cadillac would launch a CTS sedan with V2V communication technology in 2017. Several auto manufacturers around the world are conducting V2X trials jointly with mobile operators and technology providers. No automotive manufacturers have made any public announcements on their plans to deploy V2X vehicles for the U.S. market.

In light of LTE evolution's toward 5G, it is becoming evident that vehicles connected to the cellular network will be able to support superior V2X capabilities and possibilities. Viewed as a long-range new sensor, cellular V2X communications can enable new levels of automated driving. Cellular's extensive coverage in rural, urban and suburban areas means V2X services have an enormous addressable market. That directly benefits every driver and passenger by enabling safer traffic flow and a more enjoyable travel experience.

In summary, V2X communications are a critical component of the connected car of the future. Thus, the cellular ecosystem stakeholders should engage in early efforts to assess the forthcoming capacity and coverage needs of connected vehicles. A partnership between the cellular and automotive industries is critical for enabling a best-in-class vehicle connectivity solution.

## 1. INTRODUCTION

Since its inception, the use and role of cellular communications has been expanding with each generation of cellular technology. Cellular communications have evolved from simple voice communications to a broad array of voice, video and data. Cellular communications have also evolved from person-to-person communications to machine-to-machine (M2M) communications, including the telematics systems now used in many cars and trucks for applications such as remote diagnostics and automatic crash notification. The success of these telematics applications, along with 4G's extensive geographic coverage and the advanced capabilities of 5G, make cellular the ideal foundation for V2X.

The primary objective of V2X is to improve vehicular safety by reducing the number of vehicular crashes. The USDOT analyzed 2004-2008 crash statistics and concluded that a fully implemented V2X system can address 4.5 million crashes or approximately 81 percent of all multi-vehicle unimpaired crash types.

This white paper describes the role and benefits that cellular V2X can provide to support the USDOT objectives of improving safety and reducing vehicular crashes. Cellular V2X can also be instrumental in transforming the transportation experience by enhancing traveler and traffic information for societal goals such as increased mobility and reduced pollution. Moreover, Cellular V2X can enable many convenience applications related to transportation.

Cellular V2X is an umbrella term for 3GPP-defined V2X technologies, encompassing both LTE- and forthcoming 5G-based V2X systems. This white paper discusses the potential role of 3GPP solutions to support V2X and the added value that could be provided by cellular operators.

As part of this description role and benefits of cellular V2X, this white paper also discusses:

- The value of cellular V2X when compared to incumbent technology (i.e., DSRC)
- The current V2X landscape in the United States, Europe and China
- Automotive manufacturers' viewpoints on V2X solutions
- V2X deployment considerations
- Regulatory and spectrum considerations for V2X services

## 2. WHAT IS V2X?

This section provides background information to address the question, "What is V2X?" In defining V2X, the following topics and themes will be discussed:

- An introductory overview of V2X and the various types of communications it encompasses. In the U.S., the conversation so far has focused on DSRC, but there are many other enabling technologies, including cellular.
- Definition of DSRC and discussion of its status. DSRC is a long-awaited, incumbent technology.
- Some of the use cases that V2X technologies are trying to address. Certainly, V2X enhances safety. However, V2X also can be instrumental in transforming the transportation experience by enhancing traveler and traffic information for societal goals such as increased mobility and reduced

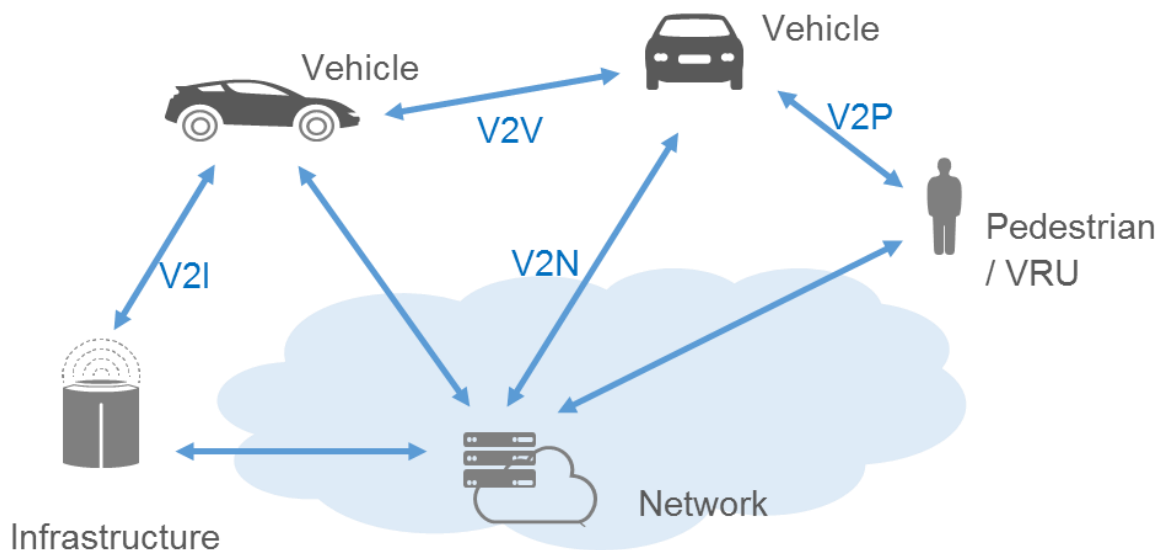
pollution. Moreover, V2X applications can enable personal convenience, such as by providing drivers with traffic information so they can seek alternate routes.

- The benefits of V2X. Regardless of the access technologies, the use cases can lead to tangible benefits to individual travelers and society.

## 2.1 OVERVIEW OF V2X

V2X – the “Vehicle to Everything” – communication encompasses vehicles exchanging data with each other and the infrastructure, with the goal to improve road safety, increase traffic efficiency, even reduce environmental impacts and provide additional traveler services.

V2X communications as defined in 3GPP consists of four types: V2V, V2I, V2N and V2P. Figure 1 illustrates some examples. It is implied that these communications are generally bidirectional, i.e., V2I and V2N also involve the infrastructure sending messages to the vehicles.



**Figure 1: V2X Types.**

V2V and V2P transmission are based on primarily broadcast capability between vehicles or between vehicles and vulnerable road users (e.g., pedestrian, cyclist), such as for providing information about location, velocity and direction to avoid accidents.

V2I transmission is between a vehicle and an RSU. V2N transmission is between a vehicle and a V2X application server. An RSU may be used to extend the range of a V2X message received from a vehicle by acting as a forwarding node (e.g., repeater). V2I could include communication between vehicles and traffic control devices, such as in the vicinity of road work. V2N could include communication between vehicle and the server via 4G/5G network, such as for traffic operations.

Other names for V2X are Cooperative Connected Vehicles and Cooperative ITS.

V2X technologies seek to address a variety of use cases:

1. **Safety, automated driving and advanced driver assistance systems (ADAS)**, which require high reliability, low-latency message transfer at high speeds. Examples are forward collision warning, emergency electronic brake light (EEBL), control loss warning, blind spot and lane change warning, as well as vulnerable road user (VRU) safety applications.
2. **Situational awareness**, which entails high reliability and longer latency requirements, while still supporting high speed. Examples are queue warning and hazardous road condition warning.
3. **Mobility services**, encompassing communication to support intermodal travel, congestion reduction entailing support for devices that have intermittent connectivity, power constraints, and for more complex security if confidentiality is required. Examples are automated parking and tolling systems, traffic advisories and dynamic ride sharing.
4. **Auxiliary services/comfort** use cases, an umbrella term for use cases involving vehicles and having commercial value, require high data rates and flexible types of communications. Examples include infotainment, local information, route planning, map dissemination and fleet management. These services are also known as “personal mobility services”.

The technologies used by V2X include traditional WAN (Wireless Access Network) and Wi-Fi communications as well as Wireless Access in Vehicular Environments (WAVE), which is based on DSRC for the lower OSI layers, and finally the emerging LTE-based V2X communications. In Europe, an equivalent to DSRC is the ETSI ITS-G5 standard.<sup>1</sup>

For V2V in particular, while the lower layers may differ (e.g., in the radio signal waveform used or the spectrum channelization), the transport and especially the application layer enjoy some synergy. There are efforts to harmonize the transport protocols used in the U.S. with those developed in Europe, for example. The application layer messages are developed by car manufacturers in various standards bodies (e.g., SAE, ETSI-ITS) with input from consortiums (e.g., Car-to-Car Communication Consortium) and are very similar in structure, at least for the safety messages.

DSRC, which is based on IEEE 802.11p, is an incumbent technology designed nearly two decades ago. It has undergone extensive standardization, product development and field trials by many stakeholders. There are strong proponents of DSRC in the current V2X ecosystem, particularly in the U.S.

DSRC technology has been tested in numerous field trials, with the Ann Arbor Safety Pilot Model Deployment being the most widely known. Semiconductor companies such as Qualcomm, NXP Semiconductors, Renesas and Autotalks also designed and tested DSRC compliant products, and a U.S. automaker included a DSRC modem in its newest models. In Europe, there have been several ITS “plugtest” events organized by ETSI since 2011, as well as extensive field trials.

Cellular V2X is an emerging technology leveraging and enhancing existing LTE features and network elements to facilitate the exchange of V2X messages between vehicles and between the infrastructure and vehicles (and/or VRUs). The system is being designed with radio layer and architectural enhancements in order to support existing use cases, as well as more advanced use cases. The attractiveness of this new technology is that it is well suited for an evolution path to support more complex safety use cases with stringent delay, reliability and bandwidth requirements. V2X applications have evolved and continue to do so since the inception of DSRC. There is currently no significant effort to evolve the DSRC technology to

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<sup>1</sup> See [www.etsi.org/deliver/etsi\\_en/302600\\_302699/...02.../en\\_302663v010200a.pdf](http://www.etsi.org/deliver/etsi_en/302600_302699/...02.../en_302663v010200a.pdf)

keep up with the more advanced use cases. This creates an opportunity for cellular to step in and become the foundation for V2X going forward.

## 2.2 USDOT V2X STATISTICS

Based on extensive analysis of crash data from 2004 to 2008, USDOT has concluded that a fully implemented V2X system can address 4.5 million crashes (81% of all multi-vehicle unimpaired crash types) as documented in the *Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application*, issued by NHTSA in Aug 2014.<sup>2</sup>

See Appendix C for additional information on these crash statistics.

## 2.3 BENEFITS OF V2X

V2X significantly transforms mobility by enabling communication between vehicles and between vehicles and infrastructure. Most importantly, enabling automatic sharing of information in real time between road users promises to significantly improve road safety, and minimize polluting and fuel-wasting traffic jams as well as maximize efficient use of roads and other transportation infrastructure.

For example, vehicles, their drivers and their occupants can be made aware of traffic signal phases, road work zones and road hazards. Some of that information is already available to them, such as through mobile applications. But V2X would provide even more information, and in ways that give drivers and vehicles additional options that today's systems can't support. Another example is enabling municipalities to connect vehicles with available parking spaces to reduce the traffic that comes with drivers endlessly circling the block for a space.

V2X communications can be viewed as another sensor in the vehicle. While other active sensors like radar, LiDAR and Computer Vision are actively "seeing" the environment around the vehicle, the V2X wireless sensor, with non-line-of-sight capability, is actively "listening" and also "talking" to other cars to better understand what is happening around the vehicle. The V2X sensor also is collecting driver intent.

Another benefit of V2X services is that they enable communication between vehicle occupants and their environment. This gives occupants access to their own data and media and in-car Internet access, all of which enables a wide range of new applications and services.

V2X will lead to major economic and ecological benefits, including:

- Improved hazard recognition and prevention through anticipatory and adaptive driving, leading to reduction in the number of road fatalities and accidents
- Optimized utilization of road infrastructure, such as traffic congestion avoidance using dynamic route guidance
- Recognition of emergency vehicles with special privileges and rights of way/using emergency signals (e.g., cross traffic, emergency lane)

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<sup>2</sup> [\*Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Applications\*](#), USDOT, National Highway Traffic Safety Administration. August 2014.

- Emission reductions through adapting vehicle operation to road/traffic situation (e.g., engine control) and platooning
- Increase in freight transport efficiency by enabling optimal utilization of commercial vehicles (e.g., fleet management tools to avoid empty backhaul runs)

To illustrate the diversity and potential of V2X applications, some of the specific use cases that were used by 3GPP to derive service requirements for the V2X system (Release 14) were, as per 3GPP TS 22.185<sup>3</sup>:

- |                                       |                               |
|---------------------------------------|-------------------------------|
| • Forward collision warning           | • Automated parking system    |
| • Control loss warning                | • Wrong way driving warning   |
| • Emergency vehicle warning           | • Pre-crash sensing warning   |
| • Emergency stop                      | • Traffic flow optimization   |
| • Cooperative adaptive cruise control | • Curve speed warning         |
| • Queue warning                       | • Vulnerable road user safety |
| • Road safety services                | • Enhanced positioning        |

For the enhanced V2X work in 3GPP, additional, more challenging use cases are considered as a basis to derive service requirements (Release 15 and beyond), as per 3GPP TR 22.886.<sup>4</sup> Some examples:

- |  |  |
|--|--|
| • Vehicle platooning                       | • Information sharing for full/automated driving/platooning      |
| • Sensor and state map sharing             | • Dynamic ride sharing   |
| • Remote driving of vehicles               | • Intersection safety information provisioning for urban driving |
| • Collective perception of the environment |  |

### 3. DSRC CHALLENGES

Dedicated Short Range Communications (DSRC) is a standard designed in IEEE to support vehicle to vehicle communications, more specifically focused on enabling vehicular safety applications. The DSRC family of standards are also referred to as WAVE and are defined in IEEE 1609 and 802.11p. The latter is now part of the newer specification called IEEE 802.11-2012.

The higher layers of the DSRC protocol stack are based on standards defined by the IEEE 1609 Working Group and by SAE International. V2V communication is typically done using the lightweight WAVE Short Message Protocol (WSMP) rather than the traditional Transmission Control Protocol/Internet Protocol (TCP/IP) stack used by Wi-Fi. The TCP/IP transport and network protocols are generally used for V2I and V2N communications. The lower layers, Physical layers and Medium Access Control (PHY/MAC), of the DSRC protocol stack are defined in IEEE 802.11p, and they are based on the Wi-Fi family of standards.

<sup>3</sup> 3GPP TS 22.185, [3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Service requirements for V2X services; Stage 1](#)

<sup>4</sup> 3GPP TR 22.886, [3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Study on enhancement of 3GPP support for 5G V2X services](#)

The initial motivation to use the IEEE 802.11 family was to leverage Wi-Fi's ecosystem. However, since Wi-Fi was originally designed for low mobility devices, enhancements to support high mobility are included in IEEE 802.11p.

V2V communication messages contain vehicle state information (e.g., location, speed, acceleration, and heading). These are the basic safety messages (BSMs), which are sent 10 times a second by vehicles in order to enable crash avoidance and other such applications. These applications place stringent reliability and latency requirements on the underlying wireless communication system. Besides V2V safety communication, the system is designed to support other ITS applications, including V2I-based safety, automated driving, efficient mobility, reduced environmental impact and electronic commerce (e.g., tolling).

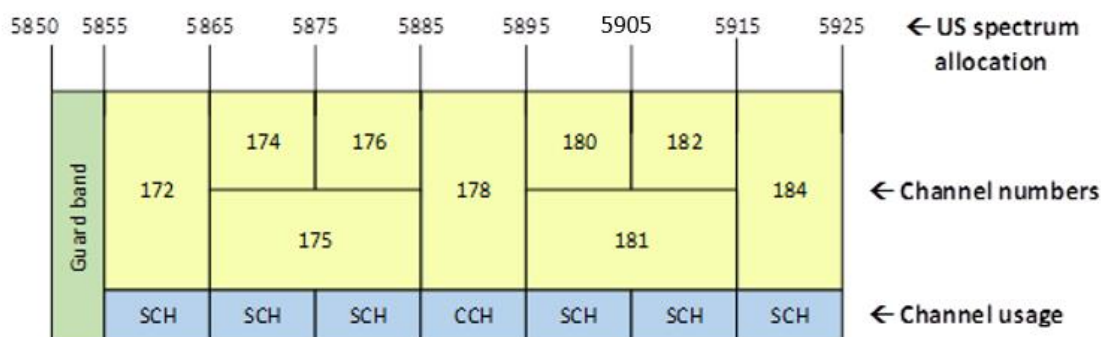
### 3.1 SPECTRUM ALLOCATION

Some DSRC-based systems have been deployed or are expected to be deployed in the 5.9 GHz band or in the 700 MHz band. Table 1 shows the frequency bands for the different regions of the world.

**Table 1: DSRC Frequency Bands by Regions of the World.**

Region	Frequency Bands (MHz)
North America	5850-5925
Europe	5795-5815, 5855/5875-5905/5925
Japan	755.5-764.5, 5770-5850
China, India, Singapore	Studying allocation or allocated in the 5.9 GHz band

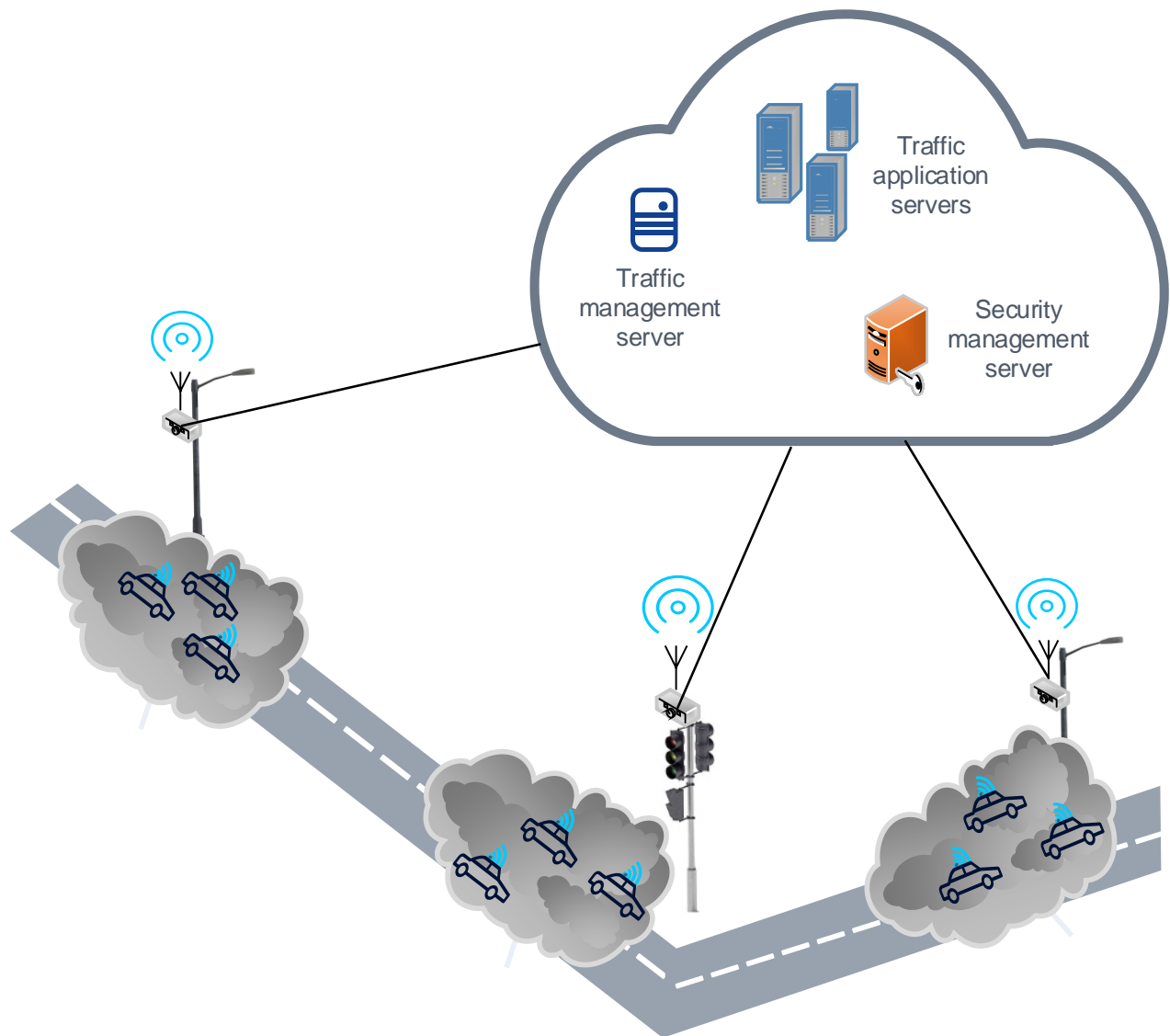
The U.S. allocation divides the entire 75 MHz into seven orthogonal 10 MHz channels, with 5 MHz reserved as the guard band. Figure 2 shows the channel numbering. There is one control channel (CCH), which is channel number 178, and six service channels (SCHs). The pair of channels (174 and 176, and 180 and 182) can be combined to form a single 20 MHz channel: 175 and 181, respectively. Channel 172 is reserved exclusively for critical safety-of-life communications, while 184 is reserved for high-power public safety uses. The remaining channels can be used by non-safety applications.



**Figure 2: U.S. Channel Numbering.**

### 3.2 CONNECTION TO THE INFRASTRUCTURE AND RSU DEPLOYMENT

Figure 3 illustrates the DRSC architectural components of vehicle and Road Side Unit (RSU).



**Figure 3: Connection to the Infrastructure and RSU Deployment.**

Many use cases require vehicles to communicate with the infrastructure. The DSRC security relies on a public key infrastructure (PKI) that distributes and manages digital certificates for vehicles. This means that vehicles need to have access to this infrastructure, which in the case of DSRC is provided via the RSU. The RSU may also be used by vehicles to communicate with the V2X application server. Due to various factors, the deployment of RSUs has been limited. It is therefore unrealistic to expect the provision of ubiquitous coverage of roadways via DSRC equipment in the near future.

### 3.3 PHYSICAL LAYER CHALLENGES

DSRC has several limitations from a physical layer perspective. One of the main limitations is that it's an asynchronous system.

DSRC is based on the 802.11 family of Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) protocol. In this protocol, the device listens to the channel before sending a packet, and sends a packet only if the channel is clear. This results in access overhead due to the time wasted waiting for the channel availability. In addition, collisions may occur if two or more devices transmit at an overlapping time. Some of the Quality of Service (QoS) enhancements defined for 802.11e are also used in DSRC, providing priority access to certain traffic, where high priority traffic may use a shorter back off time before trying to sense the channel again for activity. This improves latency for higher priority traffic but does not address the contention. This is because there is no guaranteed or reserved resources in 802.11p.

Additional asynchronous-related disadvantage is that DSRC does not allow frequency division multiplexing (FDM) of transmissions, leading to significant reduction in link budget. The CSMA-CA protocol also forces inefficient spatial reuse due to fixed thresholds that are specified for sensing the carrier. The physical layer also has limitations of performance due to the lower coding gain used by convolutional codes. Finally, DSRC is based on Orthogonal Frequency Division Multiplexing (OFDM), which restricts maximum transmit power and hence range. All of these factors limit the performance of DSRC at the physical layer.

One way to see this performance limitation is to note the effects of the communication range. Range depends heavily on the density of vehicles nearby and on the radio propagation environment; typical values reported are 150-300 meters. There are some vehicular use cases that currently are simply not feasible with DSRC, such as “Do not pass warning” at highway speeds and other such situational awareness use cases, and ADAS. They require a longer range or equivalently a reasonable driver reaction time.

Physical layer improvements such as Multiple Input, Multiple Output (MIMO, referring to multiple antennas), OFDM Access (OFDMA) and beamforming antenna methodology have been added over time to the baseline IEEE 802.11 specification. However, they have not been defined for IEEE 802.11p. These improvements would have enabled increased message sizes.

Currently there's no activity in the IEEE 802.11 standards to study a next-generation DSRC technology that will meet the requirements of more advanced V2X use cases such as automated vehicles. At the time of its design, DSRC was a good fit for the identified need of car-to-car communications. However, as vehicle and communication technology progressed, more advanced use cases arose, with requirements that DSRC cannot meet. The DSRC story could be similar to that of cellular 2G: well suited for the most prevalent application—voice traffic—when first specified, and later in need of a significant redesign in order to accommodate data, which has been the flagship service for 3G then 4G. In a similar way, new and challenging use cases will likely require a new technology or technology evolution for V2X communication.

### 3.4 SUMMARY OF CHALLENGES

In summary, there are several challenges present with DSRC. First, the system relies on RSUs, which are not currently deployed. Secondly, at the physical layer, several inefficiencies arise due to the asynchronous nature of the system, resulting in reduced performance such as range. Finally, there is currently no evolutionary path (or IEEE 802.11 standards activities) to allow for improvements in the DSRC physical/MAC layers with respect to range, robustness and reliability.

## 4. ROLE OF LTE IN V2X SOLUTIONS

This section begins with an outline of what initial LTE V2X deployments may offer. It highlights the key performance parameters for low-latency local communications that the initial LTE V2X standards would address. This section also shows how application-layer standards such as Society of Automotive Engineers

(SAE) can be harmoniously used with the developing LTE V2X standards for the radio/network access layers. This harmonization would pave the way for products and deployments benefitting the entire U.S. V2X ecosystem, including network operators and end users.

## 4.1 LTE-BASED V2X SERVICES

First-generation LTE V2X can and should deliver the same applications—and the same look and feel—of other V2X solutions, with the most significant difference being that LTE V2X offers better-performing radio access technologies. With better performance, LTE V2X solutions can broaden the breadth and effectiveness of currently envisioned V2X safety, mobility and environmental applications.

To achieve this consistency in look and feel, LTE V2X solutions should re-use the message sets and many of the on-board performance standards envisioned for V2X. Moreover, the IEEE 1609.2 security services and framework, and the Public (PKI) system that enables trusted, anonymous safety message exchange with new vehicles, should be adapted to work with LTE V2X. This adaptation and adoption would capitalize on the accomplishments and consensus of the Intelligent Transportation Systems standards community and deliver the transformational low-latency applications that have been envisioned for nearly 20 years.

This re-purposing of DSRC application and security services standards for LTE V2X make sense. Over the years, and with significant transportation stakeholder input, the SAE DSRC Technical Committee has developed a data dictionary, SAE J2735<sup>5</sup>, that defines 16 (and counting) specific V2X messages.

For example, this standard includes the well-known basic safety message (BSM), which broadcasts what is essentially the vehicle state vector in order to provide by-lane target classification to enhance advanced driver assistance systems (ADAS). Another SAE J2735 message is the traffic signal phase and timing (SPaT), which enables broadcast of green-to-yellow-to-red transitions. Lesser known V2X messages include the traveler information message and emerging basic information or basic infrastructure messages. In fact, SAE J2735 contains over 230 data elements, enabling a wide range of customization options. Therefore, in the foreseeable future, combinations of the elements defined SAE J2735 can handle most envisioned use cases.

In the more distant future, SAE J2735 will conceivably be enriched to accommodate the anticipated increased performance with LTE V2X (e.g., longer range, lower latency/higher frequency of transmission). Ultimately, it is reasonable to believe that the SAE standards community will in turn adapt and adopt LTE.

It is reasonable to expect this cycle of adaptation and adoption to expand the scope of envisioned connected vehicle services, given that LTE V2X is not just short range, ad hoc message broadcast and reception. Because LTE V2X has V2V, V2I, VSP and V2N concepts, the types of messages and services enabled will likely transcend even those combinations available in SAE J2735. In fact, the very existence of V2N in combination with V2I and V2V enables additional participants, concepts and spectrum, to include potential use of existing cellular systems (V2N) in tandem with LTE V2X sidelink messages (V2V, V2I) or short range uplink and downlink (V2I).

In the end, governments, private toll companies and other road owners/operators will be given tremendous flexibility because they can deliver for-the-public-good V2X safety messages, given that common spectrum is available. The road operator can additionally leverage spectrum owned by mobile operators to deliver V2N data exchange in providing traffic management services based on local or aggregated V2V and V2I messages.

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<sup>5</sup> See [http://standards.sae.org/j2735\\_200911/](http://standards.sae.org/j2735_200911/)

As a result, all actors win: The road operator's transportation management system is enabled with a cost-effective LTE V2X implementation alternative, which the mobile operator delivers. Mobile operators can charge to serve the road operator with network equipment and can also charge individual users who realize value in using cellular spectrum for commercial traveler information or other V2N services. Ultimately consumers—drivers in this case—realize the value, as they receive important, high-quality pre-trip, en route and safety-critical information via the same service.

## 4.2 LTE-BASED V2X SOLUTIONS ADDRESS NEW CHALLENGES

The future of transportation envisions vehicles that are intelligent and always-on connected, cooperating with one another and the transportation infrastructure to provide a safer and more enjoyable travel experience.

LTE has the potential of addressing the low-latency, high-reliability V2X use cases in a complementary manner to DSRC. This potentially includes offloading DSRC applications to LTE. For example, LTE-based V2V communications can enable ADAS to be deployed.

A wide variety of use cases that require longer range or higher message throughput can be supported with LTE-based V2X communications. These are due to the physical layer advantages of the LTE-based V2V communications: LTE-based V2V achieves significant link budget gains due to Frequency Division Multiplexing (FDM) and longer transmission times (1 msec). Hybrid automatic repeat request (HARQ) retransmissions can be used to achieve higher link budgets. LTE-based V2V also uses turbo coding and single-carrier FDM, both of which further increase link budgets. At the system level, LTE-based V2V exploits the periodic nature of V2V traffic by combining sensing of the radio resources with semi-persistent transmissions. This approach has no carrier sensing overhead like in DSRC, and because relative thresholds are used (instead of fixed ones for DSRC), it can result in better spatial reuse of radio resources. This results in a system with superior performance compared to DSRC.

Some key performance parameters for low-latency local communications that are being addressed by emergent LTE V2X standards as part of Release 14 of 3GPP are:

- Absolute vehicle speeds of up to 160 km/h and relative speeds of 280 km/h
- Range sufficient to give the driver(s) ample response time (e.g., 4 seconds)
- Message sizes for periodic broadcast messages between two user equipment (UEs) with payloads of 50-300 bytes and for event-triggered messages, up to 1200 bytes (sizes do not include security-related message components)
- Maximum latency of a message transfer is 100 ms between two UEs, and 1000 ms for messages sent via a network server

In subsequent releases now underway, it is expected that more stringent requirements for latency, range, speed, reliability, location accuracy and message payloads are to ensue to support more advanced use cases. For example, 5G-based V2X systems are expected to provide end-to-end latency between vehicles of 5 ms or less and provide over 99 percent packet delivery reliability within a short to medium range (80 to 200 meters). These allow for exciting new use cases as outlined in Section 2.3.

The cellular-based V2X system defined in 3GPP for LTE and 5G is meant to reuse the service and application layers already specified by the automotive community, such as by SAE International. It also

reuses existing security and transport layers, as defined in other standards development organizations such as ISO, ETSI-ITS and IEEE (the 1609 family of standards).

New network nodes that are now part of the LTE-based V2X communications system are RSUs. These can be co-located with enhanced node Bs (eNBs) or standalone. V2I communications allows RSUs to monitor traffic-related conditions, such as traffic signals and tolls.

The evolution path for LTE-based V2X is clear: LTE-based V2X will continue to deliver cellular V2X direct communications and provide ubiquitous coverage as 5G technologies are designed and deployed. Once a new radio is available, such as for 5G, cellular V2X communications will enjoy new capabilities and be able to offer additional value or new services. The study of 5G-based V2X has already begun in 3GPP.

Figure 4 shows the variety of the V2X use cases.

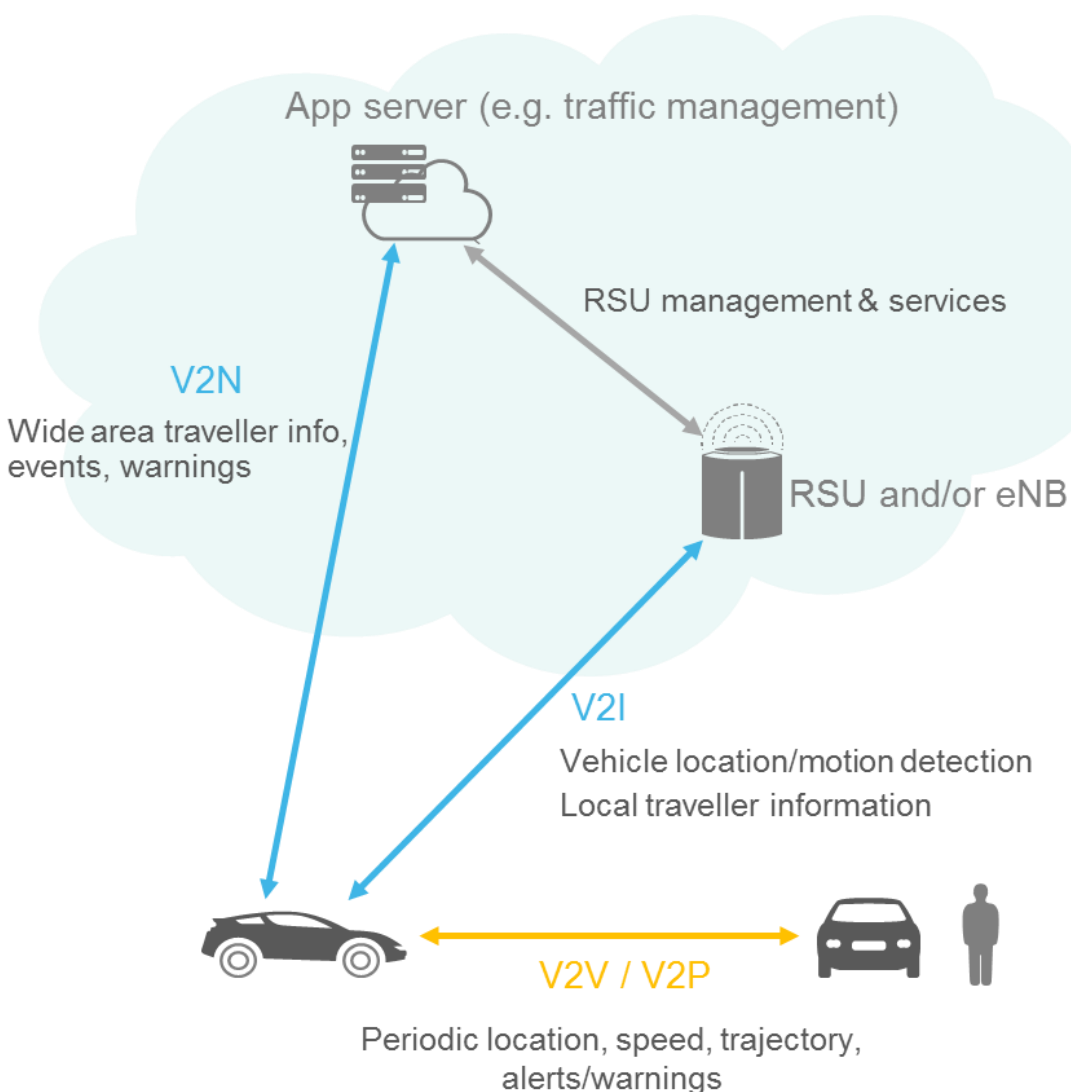


Figure 4: Variety of V2X Use Cases.

## 4.3 MOBILE OPERATOR ADDED VALUE

Mobile operators can leverage existing cellular infrastructure to promote an efficient deployment of V2X technologies. They also have the opportunity to add value in four aspects of V2X in the near term:

1. **Connectivity/platform for road operators:** Mobile operators can offer connectivity and RSU management to road operator services
2. **Certificate and certificate revocation list distribution:** Considering cellular networks already cover virtually the entire U.S., eNBs can replace RSUs for the distribution of certificates and certificate revocation lists in a cost-effective and timely manner
3. **Range Extension:** By design, DSRC's provide only short-range communications: about 300 meters. LTE benefits V2X solutions by extending their range to a few kilometers, enabling them to notify more drivers about significant events ahead, such as accidents
4. **RSU Backhaul:** LTE can provide RSUs with backhaul in places where copper or fiber are expensive, inefficient or unavailable

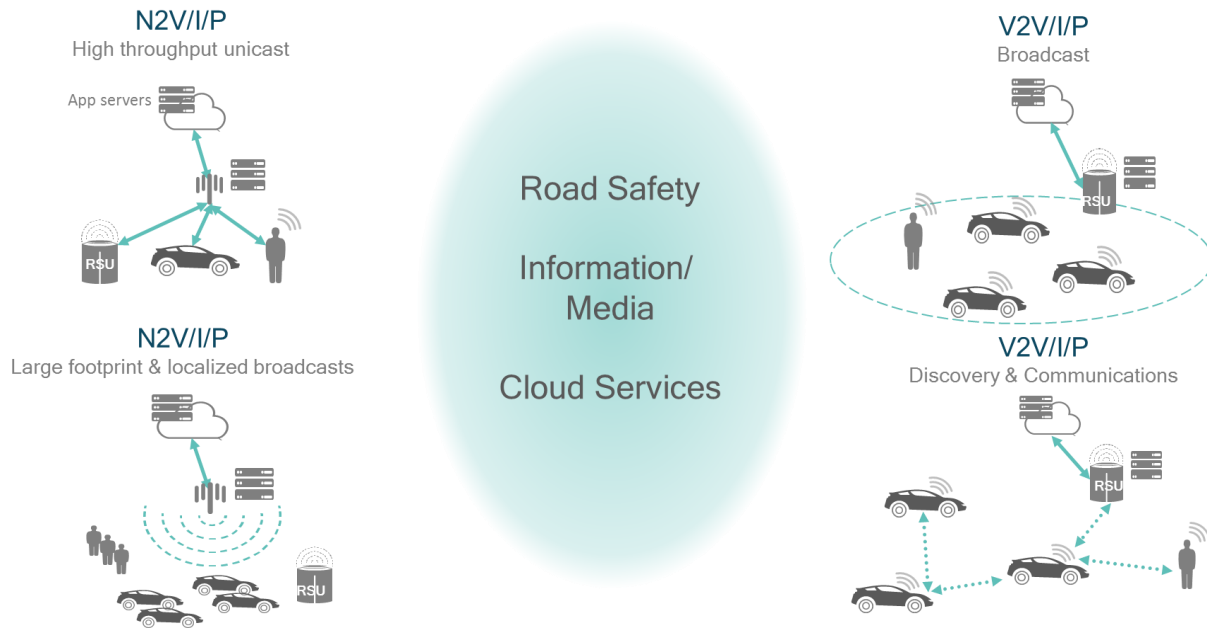
5G will likely add even more benefits due to the increased capabilities of 5G technology.

Over the longer term, the LTE V2X device-to-device PC5 interface could be a direct replacement of DSRC. Indeed, the ultimate value is the use of cellular V2X technologies, which are being designed starting with enhanced road safety as the initial goal. Eventually the focus will expand to enable auxiliary services such as informational, social media and internet via vehicle tethering. This wide range of services may include cloud services and edge computing.

A new paradigm in the vehicular world is the marriage of the road and mobile operators, allowing both entities to join together in managing city and/or highway traffic arteries in each geographical area. The road operators, normally expected to deploy and manage public-sector RSUs, can instead enter into business arrangements with mobile operators, which can then deploy the RSUs and help run the V2X service provided by RSUs. It is possible that RSUs can be deployed within the existing cellular infrastructure (e.g., an eNB-type RSU). In other cases, the RSUs can be UE-type RSUs. In the end, a market evolves where new services to vehicle subscribers are offered and new business models emerge.

Some examples of the new opportunities for MNOs are as follows. RSUs can monitor traffic signals and tolls, messages from vehicles broadcasting data of interest to other vehicles nearby and can in turn disseminate messages from the core network. RSUs can run applications locally but are likely integrated with a cloud service. Mobile operators can also run V2X application servers such as traffic management, road conditions or security provisioning servers for vehicles. They can offer connectivity to a service that a road operator may offer to vehicles/drivers by leveraging existing LTE-based identification and billing.

Figure 5 illustrates how the cellular ecosystem can enable and support V2X services.



**Figure 5: The Cellular Ecosystem Enables V2X Services.**

#### 4.4 USE OF BROADCAST AND DIRECT-LINK TECHNOLOGY FOR V2X

There are two modes of LTE V2X operation: direct and via the network.

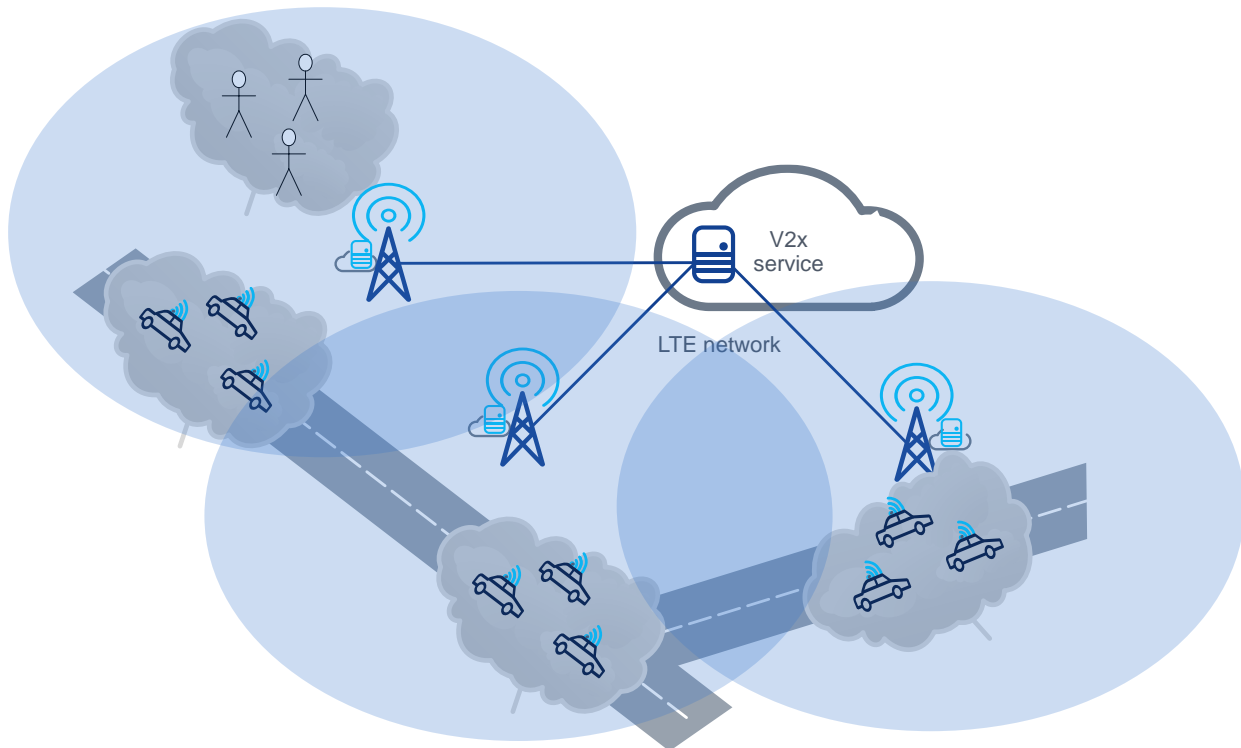
- Direct communication uses the LTE PC5 interface, which is based on Release 12's proximity services communications ("ProSe") feature. It also has enhancements to accommodate high speeds/high doppler, high vehicle density, improved synchronization and decreased message transfer latency. This mode is suitable for proximal direct communications (hundreds of meters) and for V2V safety applications that require low latency (e.g., ADAS, situational awareness). This mode can work both in and out of network coverage.
- Network-based communication uses the LTE Uu interface from the UE located in the vehicle and the eNBs. UEs send unicast messages via the eNB to an application server, which in turn rebroadcasts them via evolved Multimedia Broadcast Multicast Service (eMBMS) for all UEs in the relevant geographical area to receive. This mode uses the existing LTE Wide Area Network (WAN) and is suitable for more latency-tolerant use cases (e.g., situational awareness, mobility services).

It is possible that while the Uu mode uses operator spectrum, the PC5 mode may be deployed in a separate spectrum meant for direct communication for V2X applications.

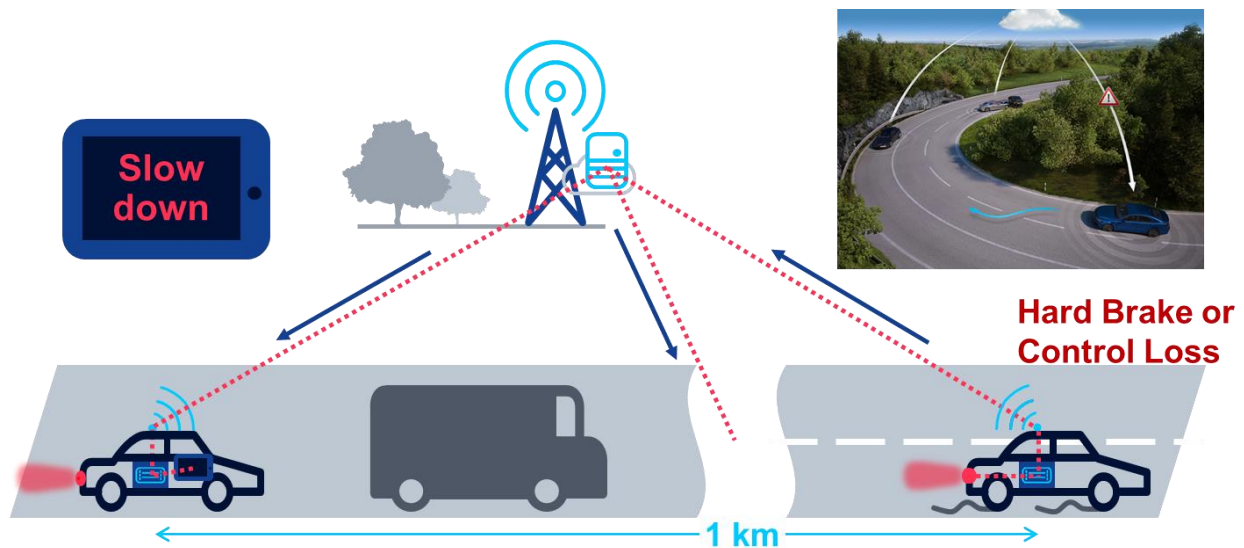
LTE offers unicast and broadcast bearers for data transmission. Broadcast is applicable if the mobile operator has deployed eMBMS. LTE can complement the short-range communication path for V2X provided by other technologies (e.g., DSRC/802.11p). This type of broadcast transmission can potentially reach more vehicles that are in network coverage because the network can control the broadcast range. Therefore, it is especially suitable for the V2I/V2N type of services. Mobile operators can provide additional value-added services to road traffic participants (e.g., traffic jams/blocked roads further ahead, real-time map/3D building/landmarks, updates for the area, suggested speed).

For the uplink direction (UE sending data to network), V2X messages may be transmitted with a unicast bearer and the message reception can be acknowledged by the network at the physical/MAC layer. This may help to reduce the retransmission rate of V2X message if the application layer can take advantage of acknowledged transmissions.

Figure 6 shows that the V2X message sent from the network can reach vehicles within a large region (blue shaded area) while Device-to-Device (D2D) transmission can be received within a smaller zone (cloud shaped grey area). Figure 7 illustrates how these capabilities directly benefit drivers.



**Figure 6: Using LTE Broadcast Bearer along with D2D Broadcast Communication.**



**Figure 7: Illustration of Using LTE Broadcast Bearer for Delivery of V2X Warning Message.**

3GPP has introduced MBMS for LTE (as eMBMS) since Release 9 in TS 23.246.<sup>6</sup> In Releases 12 and 13, it was enhanced to allow third-party applications to interact with the MBMS system and distribute the application traffic. This mechanism can be used as a building block by the V2X application as well. In Release 14, 3GPP has further specified QoS handling and local server discovery for V2X to meet the 100 ms latency requirements for some of the V2N services. This latency reduction is mainly accomplished by using a new QoS class identifier with very short packet delay budget to carry V2X traffic within the core network and together with the user-plane processing node of eMBMS residing near the RAN.

The other area of enhancement in 3GPP is the interaction between different operators. Devices that are subscribed with one operator should still be able to communicate and share information with devices subscribed with another operator. In the case of common spectrum for V2V, this operation is straightforward. It is expected that some agreement between operators with regards to spectrum usage will be necessary.

Direct V2V communication between devices is based on D2D/ProSe communications. The D2D communication in LTE is done over the sidelink channel in two different modes. In the first mode, the resource allocation is done by the network (i.e., eNB). Devices that want to transmit send a request to the network for a resource allocation, and the network allocates the resource and notifies the device. This mode requires extra signaling for every transmission, thus increasing transmission latency. In the second mode, devices select the resource autonomously. The autonomous mode reduces latency, but issues related to possible collisions and interference may arise. Optimization of resource allocation procedures is being considered, with emphasis in the autonomous mode, due to its lower latency.

<sup>6</sup> 3GPP TS 23.246, [3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Multimedia Broadcast/Multicast Service \(MBMS\); Architecture and functional description](#)

## 4.5 V2X SECURITY

This section begins by focusing on the existing DSRC security as it is the most mature. The discussion then shifts to the emerging cellular LTE-based V2X system. Note that the security mechanisms specified for V2X by the Standards Development Organization (SDO) ETSI-Intelligence Transportation System (ITS) are largely like those specified by IEEE. This section ends by outlining a possible (likely) outcome of the security for the emerging cellular V2X specified by 3GPP.

### 4.5.1 REGARDING DSRC SECURITY

DSRC security encompasses two aspects: the ability for a vehicle to verify that received safety messages are authentic, and; protecting the privacy of the vehicle/user. These basic requirements have also been recognized in other standards bodies (ETSI-ITS, 3GPP). In the U.S., the privacy requirements are defined in the USDOT National Highway Traffic Safety Administration, DOT HS 812 014: *Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application*.<sup>7</sup>

The ability for a vehicle to reliably receive correct Basic Safety Messages (BSMs) is crucial for the functioning of the safety application. BSMs contain the sender's accurate position speed, and other parameters. The security risk of false message injection by an attacker can be mitigated by requiring all senders to digitally sign each message. The cost of that security measure is an increase of the message size sent over the air, and increased computational load at the receiver side due to the high rate of signature verifications.

A Public-Key Infrastructure (PKI) that distributes and manages digital certificates for vehicles is necessary for the security of DSRC communications. To this end, the IEEE 1609.2 standard defines a Security Credential Management System (SCMS), which implements a PKI with some additional features.

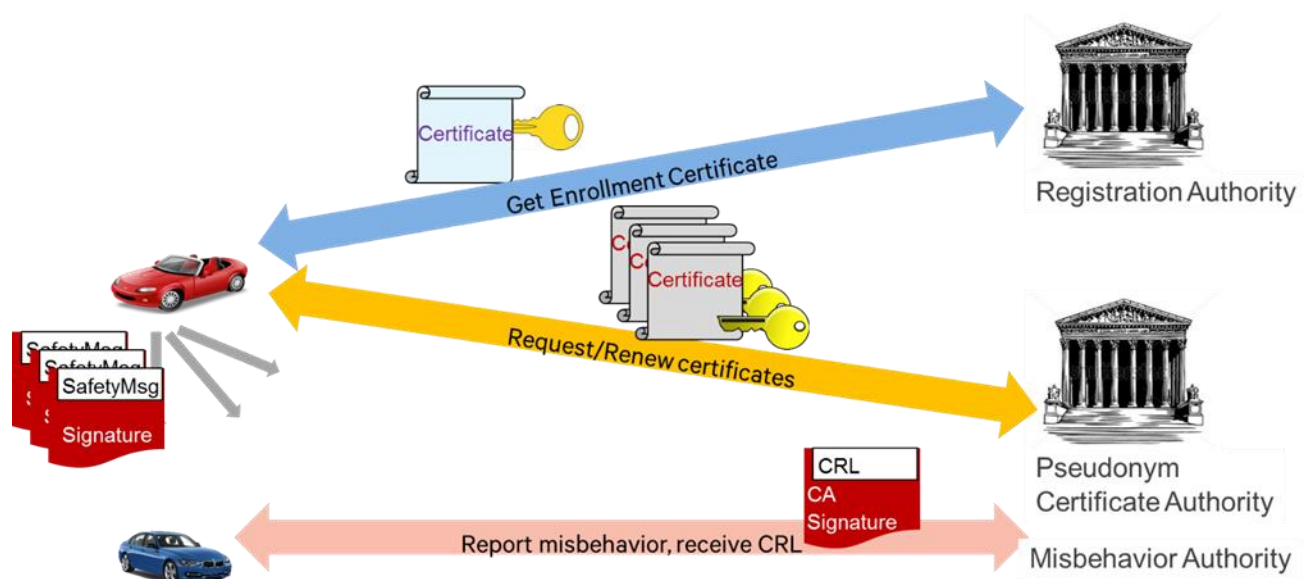


Figure 8: Simplified Security Architecture (SCMS).

<sup>7</sup> [Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Applications](#), USDOT, National Highway Traffic Safety Administration. August 2014.

Some of the challenges of designing the SCMS were how to balance security, privacy, performance and complexity. The V2V messages should be integrity-protected with minimal increase in size with the source remaining anonymous. The network architecture should be kept simple, but the network should not be able to track users. The certificate revocation list distribution should be complete and timely, but the size of the total downloaded data should be minimized. Certificate generation should be done securely, yet the associated computational burden should be minimized at the vehicle side to optimize performance. Developed by a panel of security experts over several years, the SCMS has managed to strike a good balance between these apparently conflicting requirements.

Another facet of DSRC security has to do with user privacy. That is, no other vehicle or network entity should be able to track a vehicle's exact location over long periods of time based on the messages that are heard over the air interface. To this end, the design employs separation of authorities among several network functions, which are expected to be administered by separate parties. In this way, no single entity has the complete picture necessary to be able to identify or track a vehicle by just hearing all the V2X messages sent over the air (e.g., via road sniffer devices). However, if there is a need to identify a vehicle, such as for law enforcement reasons, it is possible to reconstruct its credentials from information held by all or some of the authorities in the SCMS.

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#### 4.5.2 REGARDING LTE SECURITY

LTE has the most advanced security solutions built into the standard itself by default, thanks to the extensive work of 3GPP over the years. 5G will continue in this paradigm by keeping with the same high-standards for the V2X domain.

Today's 3GPP standards work includes developing capabilities that will benefit V2X, starting with enhancements in LTE to support V2X use cases. 5G will support more advanced use cases. Two requirements are particularly noteworthy:

- 1) The need for direct, ad-hoc, broadcast, secure communication without any a priori configuration of security by the network
- 2) Management of identities for user privacy from the network or other third parties

There are two types of LTE transport-level security mechanisms: LTE security protecting the UE signaling and communications with the LTE network, and LTE device-to device (D2D), a.k.a. ProSe, communications security.<sup>8</sup>

LTE security uses a pre-shared symmetric keying for one-to-one data protection between UE and network. For user plane data, only confidentiality (encryption) is applied; there's no integrity protection on application layer messages exchanged with the network.

For ProSe/D2D communications, each group of devices conducts one-to-many, confidentiality protected data transfers. This is done using a group symmetric key, which is pre-provisioned by the network to all member devices. There is no integrity protection on the user data and, because the key is shared by all, no way to identify for sure which of the group members actually sent the data.

Note that V2V communications cannot rely on pre-shared pairwise keys: any two vehicles should communicate without having to be provisioned a priori with a shared key. Most importantly, pre-shared keys alone cannot provide some essential information about the V2V message's sender. The receiver must have

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<sup>8</sup> [Expanding Your Horizons with LTE Direct](#), Signals Research Group. September 2015.

a way to verify that the received message was generated by a trusted entity. This is because for the V2V safety application, it is crucial to minimize false alarms.

Confidentiality for safety messages is not needed, while strong integrity is paramount. Hence, neither LTE security nor ProSe security are applicable to V2V.

If V2X communications between one vehicle and the network can use the traditional UE to network LTE link, then the LTE security is applicable, as well as all signaling flows defined in current standards.

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#### 4.5.3 WHAT CAN WE EXPECT FOR CELLULAR V2X SECURITY?

It is reasonable to expect that, given the maturity of the existing standards for security, as well as 3GPP's mantra to focus on the transport of the V2X messages, cellular V2X will simply reuse the security mechanisms already defined, and view them as part of the application domain. What is needed is to ensure that the cellular network can support the relevant message transfer, protocols and mechanisms, between devices and also between devices and the network. It also must support third party servers such as vehicle manufacturers' certification authorities.

One new factor to consider for cellular V2X is user/driver privacy. The DSRC family of standards designed an extensive system architecture (the SCMS described in Section 4.5.1) that ensures no single entity can correlate the identifiers used and track a vehicle. The rationale for this merits some details.

According to NHTSA, "The deployment and operation of the SCMS is necessary in order for V2V technology and on-board equipment to function in a safe, secure and privacy-protective manner." Specifically, in document DOT HS 812 014, NHTSA states:

*Privacy: At the outset, readers should understand some very important points about the V2V system as currently contemplated by NHTSA. The system will not collect or store any data identifying individuals or individual vehicles, nor will it enable the government to do so. There is no data in the safety messages exchanged by vehicles or collected by the V2V system that could be used by law enforcement or private entities to personally identify a speeding or erratic driver. The system—operated by private entities—will not enable tracking through space and time of vehicles linked to specific owners or drivers.*

*Our research to date suggests that drivers may be concerned about the possibility that the government or a private entity could use V2V communications to track their daily activities and whereabouts.*

In the cellular V2X system being designed in 3GPP, first of all, privacy of a vehicle device from other vehicle devices nearby is readily accepted and rather straightforward to achieve. Second, privacy from network entities is a different matter. The LTE radio infrastructure and the core network are under the operator's domain, though some network entities such as application servers or key management servers can function outside of the operator's domain.

Therefore, in operation modes where V2X messages traverse the operator's infrastructure or network (e.g., RSU, eNB), the following issue arises: the link that the vehicle device uses to send these is usually established based on its cellular subscriber identifier (e.g., International Mobile Subscriber Identity, IMSI) as under normal LTE operation. Keeping in mind that the V2V messages sent every 100 ms contain application-layer data, including exact geographical coordinates, it becomes obvious that it is possible to correlate the exact location data with the IMSI of the device that transmits these messages. Note that the

granularity of this location data is much finer than the cell-site level device tracking that operators can do today.

To mitigate this, a complete privacy requirement was set forth: a solution that allows no network entity (network operator or third party) to be able to correlate the V2X messages sent by a vehicle so as to arrive at an accurate record of the locations of a vehicle during every second of the day. Once devised, such a solution may or may not be deployed by a network operator, depending on regional regulatory considerations or network operator-specific considerations and policies.

The advantages of enabling such a strict privacy-respecting solution, with its envisioned complexities, are:

- Competitive with the existing privacy-conscious DSRC system
- Reduced network operator costs of collecting, storing and providing device-specific location data to regulatory or legal entities upon request
- Potential of the deploying network operator to be protected from regulatory sanction

The cellular V2X security architecture, including privacy, is expected to be at least on par with (e.g., by leveraging) existing DSRC security and other V2X security standards such as those developed in Europe by ETSI-ITS or other standards bodies. Normative specification for V2X in 3GPP is expected to be complete by early 2017.

## 5. CURRENT V2X LANDSCAPE

This section summarizes the current V2X landscape in the United States, Europe and Asia. It also discusses V2X deployment considerations.

### 5.1 UNITED STATES

V2X efforts in the U.S. are referred to as connected vehicle technologies. The most widely implemented application is infotainment. U.S. automakers have rapidly embraced offerings in the auxiliary services/comfort category. These services utilize cellular (e.g., LTE) for connectivity between the car and the Internet, as well as to support Wi-Fi hotspots inside the vehicle for passenger use. Technology also enables smartphones in hotspot mode to connect with the vehicle modem. Use of this connectivity to summon emergency help is also widely deployed. A lesser known use of LTE connectivity, and a use case that is still emerging, is the collection of data about the car itself by the manufacturer, which could enable early detection of a design or mechanical flaw, enable improved future designs and spur innovation.

Radio systems that address ADAS, situational awareness and mobility services have been in development for some time. In 1999, the FCC allocated 75 MHz of spectrum in the 5.9 GHz band for ITS services using DSRC, in what is known as. Since then, the USDOT has collaborated with industry and public sector stakeholders in order to develop new technologies, devices and applications for connected vehicles.

The most significant of these has been the Ann Arbor Safety Pilot, conducted in 2012-2013 and involving 3,000 DSRC-equipped vehicles. The pilot provided the NHTSA with insights into the expected societal benefits of V2X, and it provided input to the standard SAE J2945/1, On-Board System Requirements for V2V Safety Communications. It is anticipated that the NHTSA Notice of Proposed Rulemaking (NPRM), expected in the near future, will reference SAE J2945/1. Ultimately the NPRM will seek a mandate or rule in the U.S. Federal Motor Vehicle Safety Standards (FMVSS) for mandatory DSRC deployment with new

vehicles in the U.S. beginning as early as model year 2020. It is worth noting that the FMVSS mandate would enable V2V safety applications and would not address V2I or V2P. The FMVSS will likely only specify the V2V communications requirements.

Despite the heavy regulatory emphasis on V2V safety communications, V2I and V2P applications are under active pilots and field investigations. The Ann Arbor Safety Pilot was never disbanded, and in April 2016, Toyota Motor Corporation committed to providing an additional 5,000 DSRC transceivers for installation in private automobiles to investigate V2X applications.

In 2015, the USDOT awarded Connected Vehicle Model Deployment contracts to New York City, the Tampa-Hillsborough Expressway Authority and Wyoming DOT for three markedly different efforts.<sup>9</sup> The NYC project is entirely based on DSRC will involve 10,000 public vehicles and up to 1,000 DSRC-equipped mobile phones, whereas the State of Wyoming will employ DSRC and other communication links to investigate road weather impacts on commercial heavy vehicle (truck) transportation. The USDOT's expectation is that these model deployments will usher permanent implementation and concomitant V2X applications that employ all the service channels in the available ITS spectrum.

More recently, competition for the Smart Cities Challenge—a winner-take-all \$40 million grant to one of seven finalists (Austin, TX; Columbus, OH; Denver, CO; Kansas City, MO; Pittsburgh, PA; Portland, OR; and San Francisco, CA)—has just been completed. The winning city, Columbus, is expected to provide a host of advanced transportation services, and use of DSRC is a scoring component.

Looking ahead, NHTSA is planning to spend \$200 million for automated vehicle pilots.<sup>10</sup> In addition, the USDOT has an initiative called Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD),<sup>11</sup> as part of the FAST Act passed by Congress.<sup>12</sup>

A fact worth noting for DSRC-based V2X deployment in the U.S. is that proponents advocate maximum use of all spectrum resources: the V2V safety channel, other service channels and the control channel, as facilitated by the multi-channel operation standard, IEEE 1609.4.<sup>13</sup> This push for demonstration and pre-deployment projects aims to protect the allocated spectrum from band-sharing plans with, or even takeover by, unlicensed Wi-Fi. Demonstration and pre-deployment projects across multiple DSRC channels illustrate how the technology would occupy the spectrum, and hence, sharpen the focus on whether and how the V2X spectrum allocation could be shared.

The FCC, which is independent of NHTSA, is considering spectrum-sharing plans, and the different proponents are currently conducting tests to evaluate the proposed methods. In addition, in some of the responses to the FCC's public notice seeking to update the record on potential sharing solutions between unlicensed national information infrastructure (U-NII) devices and DSRC operations in the 5.850-5.925 GHz (U-NII-4) band, it was proposed to consider other technologies than DSRC for ITS. Still unknown is the extent to which DSRC V2V driver warning systems could be integrated into autonomous vehicles to improve safety.

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<sup>9</sup> See <http://www.its.dot.gov/pilots/wave1.htm>

<sup>10</sup> See <https://cms.dot.gov/sites/dot.gov/files/docs/DOT-fy-17factsheet.pdf>

<sup>11</sup> See <http://www.grants.gov/custom/viewOppDetails.jsp?oppId=282433>

<sup>12</sup> See <https://www.congress.gov/bills/114/congress/house-bill/22/text>

<sup>13</sup> See <https://standards.ieee.org/findstds/standard/1609.4-2016.html>

## 5.2 EUROPE

V2X efforts in Europe are referred to as cooperative ITS (C-ITS). The V2X technologies at the basis of V2X efforts are considering both ETSI-ITS-G5 (which is based on IEEE 802.11p/DSRC) and cellular V2X (both 4G and 5G).

In Europe, there are several regulatory actions supporting development of V2X systems. Unlicensed spectrum is set aside at 5.9 GHz to align with C-ITS spectrum reserved in other regions of the world.

Standardization efforts are underway in several technical committees (TC) in three standards organizations: ISO (TC 204), ETSI (TC ITS), and CEN (European Committee for Standardization) (TC 278).

There are also several industry consortia active in promoting V2X. One is the Car to Car Communications Consortium (C2C-CC) led by vehicle manufacturers, focusing on harmonizing European standards for C-ITS, developing a roadmap for the deployment of C-ITS, both V2V and V2I, and promoting a common spectrum. Others include the Amsterdam Group, leading a deployment project in concert with the C2C-CC, and the iMobility Forum, which facilitates stakeholder meetings, deployment support, V2X research and dissemination of results.

The ERTICO ITS Europe Partnership, consisting of stakeholders from different industry, academia and public sectors, looks at current and future deployments of different V2X applications. Several initiatives include coordination of EU-funded research projects (e.g., Horizon2020, CEF) as well as public-private-sector consortia activities to support a wide range of V2X use cases.

Additionally, the EU commission under DG MOVE (Directorate General for Transport) had set up the C-ITS Platform forum to compile a report listing the current trends, gaps and requirements in order to foster the deployment of V2X in Europe. The platform released its first C-ITS report<sup>14</sup> in January 2016, achieving its first milestone toward connected and automated vehicles identifying a series of recommendations in terms technical issues (e.g., spectrum, hybrid communications, security), as well as legal aspects (liability, data protection and privacy). It remains technology neutral. The report noted the following on the access layer being agnostic:

### *10.5.1 Access-layer agnostic*

*The WG6 experts conclude that it is important to ensure that C-ITS messages can be transmitted independently from the underlying communications technology (access-layer agnostic) wherever possible. Depending of the type and circumstance of C-ITS service or application it is possible to use short-range (e.g. IEEE802.11p/ETSI ITS-G5) and/or long range communication such as cellular (3G, 4G, 5G...) and/or broadcasting (e.g. DAB+) technologies. Note: certain use cases will not be possible over all communications technologies, due to latency, reliability, functional safety (ISO 26262) etc. requirements of these use cases.*

In addition, in April 2016, the Amsterdam Declaration<sup>15</sup> on Connected and Autonomous Driving was signed by the transport ministers of all 28 member states. This document acknowledges V2X communication as a key enabler of C-ITS: “In order to maximize benefits in road safety and environmental performance, it is essential to ensure that new services and systems are compatible and interoperable at European level and to coordinate investments towards reliable communication coverage, exploit the full potential of hybrid

<sup>14</sup> See [http://ec.europa.eu/transport/themes/its/c-its\\_en.htm](http://ec.europa.eu/transport/themes/its/c-its_en.htm)

<sup>15</sup> See <https://english.eu2016.nl/documents/publications/2016/04/14/declaration-of-amsterdam>

communications, where relevant, and improve the performance of location accuracy, benefiting in particular from the use of GALILEO and EGNOS.”

Also, in September 2015, the European Commissioner Oettinger for DG Connect (Directorate General for the Communications Networks, Content & Technology) announced an industry roundtable on automated driving. The goal was to develop strategies to deploy and accelerate connected automated driving, with help from key telecom and automotive industry associations including GSMA, ETNO, ACEA and CLEPA. It leads to the July 2016 announcement<sup>16</sup> of a Pan-European large scale pre-commercial project to test C-ITS V2X based use cases with connectivity (4G/5G) at its core.

Several other V2X projects are currently underway, including:

- **The NL-D-AT ITS Corridor Project** is a joint activity between The Netherlands, Germany and Austria along a road corridor from Rotterdam via Frankfurt to Vienna. It is mainly driven by the so-called “Amsterdam Group” and the Car-2-Car Communication Consortium, and focuses on road works warning (RWW) and in-vehicle information (IVI) data for traffic management, along with intersection safety tests.
- **The SCOOP@F Project** is a French C-ITS project with about 3,000 vehicles covering more than 2,000 km of roads, including five pilot sites. Focus is on road work warnings and hazardous location notifications.
- **The NordicWay Project** is a Denmark, Sweden and Finland project employing 3G and 4G cellular networks and including about 2,000 vehicles. The focus is on hazardous location warnings, cooperative weather warning (CWW) and probe vehicle data (PVD). The project is supported by public sectors and industries (e.g., HERE, Nokia, Ericsson, Volvo).
- **The A2/M2 Project** is a U.K. project along highways A102-M2-A2. The focus is on roadside warnings, freight information from Port of Dover, urban C-ITS and traffic information services.
- **The BaSIC Project** is a Czech Republic national project with a focus on V2X technologies for slow moving vehicle warnings (SMVW), stationary vehicle/trailer information (SVI), approaching emergency vehicle warning (AEVW), traffic jam ahead warning (TJAW) and in-vehicle signage (IVS). The project is expected to cooperate closely with NL-D-AT and SCOOP@F ITS corridors.
- **The Compass-4D Project** is an EU Commission-funded project running in seven cities (Bordeaux, Copenhagen, Helmond, Newcastle, Thessaloniki, Verona and Vigo). The focus is on the use cases of red light violation warning (RLW), road hazard warning (RHW) and energy efficient intersection (EEI).

There is also a project in Germany in the application/planning stage called **Autobahn A9**. It’s focused on platooning and parking and traffic control systems, and expected to use ITS-G5 and cellular (4G/5G) technologies, as well as edge computing.

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<sup>16</sup> See <https://www.etno.eu/news/etno/2016/880>

## 5.3 CHINA

V2X efforts in China are referred to as intelligent connected vehicle and intelligent transportation systems. Both LTE-based technologies, as well as DSRC, are currently supported by different stakeholders, to include different ministries of the central government, infrastructure vendors and car manufacturers.

The intelligent connected vehicles (ICV) concept includes V2X safety applications, transportation efficiency and telematics. ICV is part of the “Made in China 2025” and “Internet +” national strategy plans led by the central government. To foster progress by the industry, several pilot projects began in late 2015. The pilot projects are government-supported, and the major participants are vehicle manufacturers, communication service providers and internet service providers.

The project at Shanghai Anting is planned to involve 10,000 trial cars running on the 300 km trial road after the last phase is finished in 2019. The first phase of construction has been completed, and the opening ceremony was held in June 2016. As a technology-neutral trial field, Anting will provide both DSRC and LTE V2X trial roads for safety applications. A second wave of pilot projects are planned for the cities of Beijing, Zhejiang and Chongqing, and their trial fields are under construction.

To support ICV safety applications, the Bureau of Radio Regulation (BRR), which is part of MIIT, is leading spectrum research and promoting dedicated spectrum allocation for ICV applications. The candidate spectrum is 5.9 GHz, and one of the proposals is to allocate 30 MHz for V2X active safety applications and reserve 20 MHz for future automated driving applications.

## 5.4 CONSIDERATIONS ON DEPLOYMENT

One challenge with the deployment of V2X technologies is that there is uncertain business incentive for service providers. In the U.S., where V2V deployments may be mandated, there is still some lack of clarity regarding the plan to implement the infrastructure that would utilize the balance of the channels, and which entities should manage the security network functions. As the majority of all funding so far is governmental, it is unclear if a commercial services business model could apply to accelerate infrastructure deployment or if deployments will be managed by government.

In other regions, it is still mainly governmental agencies promoting pilot projects, in order to benefit the economy of cities and regions by improving traffic efficiency, reducing emissions and minimizing crashes. With cellular V2X, mobile operator involvement brings the opportunity to offer additional, commercial-driven services. The beneficiaries of these can be both subscribers and road operators.

## 6. VEHICLE MANUFACTURER VIEWPOINTS

U.S. automotive manufacturers have been working on crash avoidance technologies for over 20 years. Ford Motor Company and General Motors Corporation formed the Crash Avoidance Metrics Partnership (CAMP)<sup>17</sup> in 1995. The objective of the partnership is to accelerate the implementation of crash avoidance countermeasures to improve traffic safety. The USDOT has partnered with CAMP Vehicle Safety

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<sup>17</sup> The CAMP VSC3 Consortium consisted of the Ford Motor Company, General Motors LLC., Honda R&D Americas, Inc., Hyundai-Kia America Technical Center, Inc., Mercedes-Benz Research and Development North America, Inc., Nissan Technical Center North America, Inc., Toyota Motor Engineering & Manufacturing North America, Inc. and Volkswagen Group of America.

Communications 3 (VSC3) Consortium to research, develop and test the technologies that form the framework for DSRC-based V2X systems.

In the U.S., General Motors has taken an aggressive stance to develop DSRC-based V2X capabilities for its high-end vehicles ahead of any government mandate. In September 2014, General Motors CEO Mary Barra said Cadillac will launch a CTS sedan with V2V communication technology in 2017.<sup>18</sup> In the same month, Delphi Automotive PLC, a major Tier 1 supplier to automotive manufacturers, announced that it will be first-to-market with V2V and V2I technology that significantly advances driver alerts.<sup>19</sup>

Ford has been working on V2X technologies since 2002. Ford has been an integral part of CAMP and through CAMP has been actively participating in field trials such as the V2V Safety Pilot Model Deployment in Ann Arbor. In Europe, Ford has been participating in the SimTD trial in Germany. Ford is now planning deployment of V2X applications in both Europe and North America by 2020.

Other than GM, no other automotive manufacturer has made any public announcements about their plans to deploy V2X-based vehicles in the U.S.

Toyota North America has also been a proponent of DSRC-based V2X solutions. In November 2013, a Toyota Technology Center representative addressed the opportunities and challenges associated with DSRC today before the House Committee on Energy and Commerce's Subcommittee on Communications and Technology: "Toyota believes in and is committed to DSRC as a critical safety technology. In fact, we have already commercialized first generation DSRC technology, and recently announced plans to commercialize second generation DSRC, in other markets and would like to bring this technology to drivers of our vehicles here in the near future."<sup>20</sup>

Toyota has developed a V2V system for use in Japan.<sup>21</sup> The Prius, Lexus RX and Toyota Crown have the option to come with the ITS Connect system. The communication between vehicles works by using analog channels, which allow the cars to send and receive information such as location and speed. The cars can communicate up to 1,000 feet (300 m) in a 360-degree radius. The interesting fact is that the communication is disconnected from the cloud, meaning the cars communicate directly with one another. The three models are also equipped for V2I. This means any object that has the ability to communicate—in this case, send out signals using analog channels—can communicate with these cars. There are traffic signals that can send information about each color and its relevant action (stop, slow, go) and the time between transitions from each action.

Starting this fall, Audi vehicles in the U.S. will begin to be equipped with V2I technology that will allow them to interact with city traffic light systems, according to Engadget.<sup>22</sup> The 2017 models of Audi's Q7, A4 and A4 Allroad vehicles built after June 1, 2016, already are equipped with these capabilities, and Audi plans to equip the remainder of the vehicles in its fleet closer to the fall.

In Europe, Audi used 4G for a project to track driving habits of 70 German employees to investigate data sharing and connectivity as part of the next step on the road to an autonomous driving future. The employees drove their vehicles normally for one year while 850 signals from each car communicated at a rate of 500 messages per second to a data cloud center. The primary aim was to learn driver profiles and

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<sup>18</sup> [GM Plans to Launch Cadillac CTS with Vehicle-to-Vehicle Technology in 2 Years](#), article, Automotive News. 7 September 2014.

<sup>19</sup> [Delphi First to Market with Wireless Vehicle Communications Technology to Support V2V](#), press release Delphi. 5 September 2014.

<sup>20</sup> [Toyota Advises Congress on Connected-Car Future Technology](#), press release Lexus. 13 November 2013.

<sup>21</sup> [Toyota Launches V2V Communication Technology in Japan](#), article QKHub. 15 August 2016.

<sup>22</sup> [Audi Cars Will Start Talking to City Traffic System this Fall](#), article Engadget. 15 August 2016.

better calibrate driver assistance systems. Some of the tested functions are expected to debut with the next-generation Audi A8 at the Geneva motor show in March 2017.

In Europe, the Digital Motorway Test Bed<sup>23</sup> has been set up on the busy A9 federal motorway in Bavaria. The goal is to allow industry and the research community to test their technologies and innovations for real time car-to-car and car-to-infrastructure communications under real conditions. On November 9, 2015, the first project in this test bed aimed to improve road safety and traffic control between vehicles using an LTE network. The demonstration showed signal transport times between two vehicles of less than 20 ms.<sup>24</sup>

The latest data-gathering project<sup>25</sup> was an extension from an earlier trial on Germany's A9 autobahn outside Ingolstadt and Munich, where many car manufactures, mobile operators and equipment vendors teamed up to monitor an 11 km stretch of highway cloaked with four Long Term Evolution-Vehicular base stations. The aim of the German government-backed trial was to see how different manufacturers could share data between one another.

## 7. REGULATORY & SPECTRUM CONSIDERATIONS

Developments in C-ITS internationally have been the catalyst for the advance consideration of regulatory arrangements for these systems. There has been significant progress in several regions, most notably in Europe, the U.S. and Japan. International organizations that consider spectrum harmonization efforts, such as the ITU, Europe CEPT and Asia Pacific Telecommunity, have also started considering ITS systems as a whole and, more specifically, C-ITS systems in the 5.9 GHz band.

Global ITS spectrum is currently under further study within ITU-R Working Party 5A, responsible for studies related to land mobile service, excluding IMT and including wireless access systems such as RLANs and ITS. The latter is considered essential in improving the safety and efficiency of roads and highways. Specifically, the ITU World Radio Conference 2015 (WRC-15)<sup>26</sup> adopted a resolution to include a new agenda Item at the WRC-19 “to carry out studies on technical and operational aspects of evolving ITS implementation using existing mobile-service allocations” in advance for WRC-19.”

In the U.S., the channel allocation for DSRC is specified in FCC 47 Code of Federal Regulations (CFR) Parts 0, 1, 2, 90 and 95 amendments for “Dedicated Short Range Communications Services and Mobile Service for Dedicated Short Range Communications of Intelligent Transportation Service in the 5.850-5.925 GHz Band (5.9 GHz Band).”<sup>27</sup>

The FCC released a public notice on June 1, 2016, to refresh its record on the potential for spectrum sharing between proposed Unlicensed National Information Infrastructure (U-NII) devices and DSRC operations in the 5.850-5.925 GHz (U-NII-4) band. The spectrum-sharing consideration is based on whether unlicensed operations can be supported while maintaining interference protection for incumbent federal and non-federal users. The FCC is also soliciting the submission of U-NII-4 prototype units to demonstrate co-existence capabilities of unlicensed devices and DSRC.

There are two primary proposed sharing techniques between unlicensed operations and DSRC. The first approach is based on avoidance by unlicensed communications in the U-NII-4 band when the presence of

<sup>23</sup> [Dobrindt Launches Digital Motorway Test Bed](#), Press Release, Germany, Federal Ministry of Transport & Digital Infrastructure. 4 September 2015.

<sup>24</sup> [Continental, Deutsche Telekom, Fraunhofer ESK, and Nokia Networks Showcase First Safety Applications at "digital A9 motorway test bed"](#), Press Release, Deutsche Telekom. 9 November 2015.

<sup>25</sup> [Audi's Car-to-X Factor](#), article GoAuto.com.au. 5 September 2016.

<sup>26</sup> See [https://www.itu.int/dms\\_pub/itu-r/oth/0c/0a/R0C0A00000C0013PDFE.pdf](https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0013PDFE.pdf)

<sup>27</sup> See <http://www.gpo.gov/fdsys/pkg/FR-2006-09-07/pdf/E6-14795.pdf>

a DSRC signal is detected. This technique is appropriately called the “detect and avoid” approach. The other sharing approach is based on band segmentation, which involves the relocation of all latency-sensitive safety-of-life DSRC communications to the upper 30 MHz portion of the DSC band. Unlicensed operations would share the lower 45 MHz portion of the band with other DSRC communications. This approach is referred to as “re-channelization.” Both approaches are currently under consideration by the FCC, with testing slated to be completed by January 2017. Hence, the exact method of sharing DSRC with unlicensed Wi-Fi is currently an open issue.

In Europe, arrangements for C-ITS systems at 5.9 GHz have been in place since 2008 with the European Commission Decision, 2008/671/EC<sup>28</sup> on the harmonized use of radio spectrum in the 5875-5905 MHz band. Member states are required to designate and make available this band for safety-related aspects of ITS. In addition, spectrum requirements for ITS service have been investigated within CEPT (representing 48 EU member states). The results are summarized in the ECC Decision (08)01<sup>29</sup> by stating that spectrum requirements within the 5.9 GHz band (5875-5925 MHz) for road safety and traffic efficiency is in the range 30-50 MHz, including an exclusive 30 MHz of bandwidth for time-critical road safety applications, as well as 20 MHz for future ITS applications. This regulatory framework is aligned with the European Commission decision in designating 5.9 GHz for safety ITS services and has so far been implemented by 39 countries. Furthermore, ECC Recommendation (08)01<sup>30</sup> addresses frequency usage for ITS non-safety applications at 5855-5875 MHz on a non-protected and non-interference basis. It should also be noted that these legislations are technology neutral. However, this estimate does not include additional forward-looking ITS applications, such as those that may require 5G technologies, for which alternatives such as the 63-64 GHz band may be appropriate.

The harmonized European standard (European Norm – EN) for tests at 5855-5925 MHz is ETSI EN 302 571, which is currently under revision by ETSI ERM TG37 in charge of EMC and radio spectrum matters for ITS.<sup>31</sup> Because some requirements in the current draft reflect only technical characteristics of IEEE 802.11p radio emissions, a discussion is ongoing in ETSI regarding technology neutrality, as well as possible updates of some technical requirements (e.g., decentralized congestion control). It is anticipated that the ETSI ERM TG37 group may have concluded the resolution of these issues by November 2016. Figure 9 shows channeling arrangements as set in ETSI EN 302 571.<sup>32</sup>

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<sup>28</sup> See <http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32008D0671>

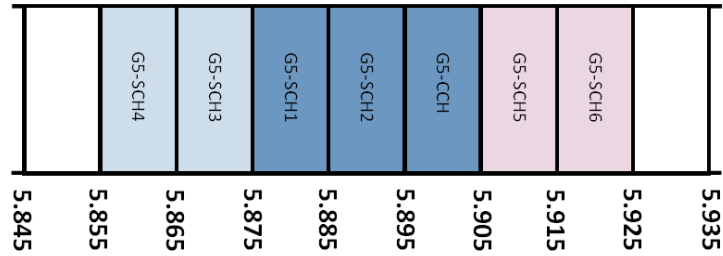
<sup>29</sup> See <http://www.ero-docdb.dk/docs/doc98/official/pdf/ECCDec0801.pdf>

<sup>30</sup> See <http://www.ero-docdb.dk/docs/doc98/official/pdf/REC0801.pdf>

<sup>31</sup> See <https://portal.etsi.org/TBSiteMap/ERM/ERMTor/ERMTG37ToR.aspx>

<sup>32</sup> See <http://standards.globalspec.com/std/1634935/etsi-en-302-571>

# ETSI EN 302 571



Usage	Channel name	Centre frequency (GHz)
Non-Safety	G5-SCH4	5.860
Non-Safety	G5-SCH3	5.870
Safety	G5-SCH1	5.880
Safety	G5-SCH2	5.890
Control	G5-CCH	5.900
Future Applications	G5-SCH5	5.910
Future Applications	G5-SCH6	5.920

**Figure 9: Standard ETSI EN 302 571 Channeling Arrangements.**

In March 2016, the amended ECC Decision (09)01<sup>33</sup> decided that CEPT administrations shall designate the 63-64 GHz band for ITS applications, with the purpose “to reduce the number of traffic fatalities and improving the efficiency of traffic using inter vehicle or infrastructure to vehicle communications including hybrid radar and vehicle communications systems.” To date, this decision has been implemented by 36 countries. No ITS system is operating at 63-64 GHz at the moment, but there is strong interest in using this frequency band for C-ACC and platooning applications owing to the wide bandwidth available.

In China, no decisions have been taken regarding allocation of spectrum for ITS. However, to support ICV safety applications, the BRR is leading the spectrum research and promoting dedicated spectrum allocation for ICV applications. The candidate spectrum is 5.9 GHz, and one of the possible solutions is to allocate 30 MHz for V2X safety applications and reserve 20 MHz for ADAS and future automated driving applications. V2X spectrum study projects have been conducted in various standards organizations, forums and alliances in China, such as CCSA and TIAA/Future joint V2X WG. Those projects will contribute to the international V2X spectrum requirements and coexistence studies. They are targeted to be completed by the end of 2016 or early 2017.

The Australian Communications and Media Authority (ACMA) is currently consulting on “Proposed measures for the introduction of C-ITS in Australia,” particularly that the European C-ITS standard ETSI EN 302 571 should form the regulatory basis for the operation of C-ITS radio-communication equipment in Australia at 5855-5925 MHz.

<sup>33</sup> See <http://www.ero.docdb.dk/docs/doc98/official/pdf/ECCDEC0901.pdf>

In July 2016, the Korean government proposed a new allocation of the 5855-5925 MHz band for C-ITS based on a 10 MHz channelization similar to those of the U.S. and Europe. The regulatory proposal is ongoing and technology neutral.

In Japan, C-ITS is currently being considered for deployment in one 10 MHz channel at 760 MHz for ITS safety (ARIB standard based).

While work is ongoing internationally at the ITU and regionally towards global and regional harmonization of C-ITS, it not affecting the deployment of C-ITS in various regions.

## 8. CONCLUSION

V2X communications is a critical component of the connected car of the future. Cellular V2X brings improvements to DSRC for safety use cases and beyond. Cellular V2X vehicles will have superior capabilities, both for the direct mode and the network mode. Cellular V2X is opening up new opportunities and business models for mobile operators, resulting in advanced services provided for transportation users. In light of LTE's evolution toward 5G and V2X, it is becoming evident that vehicles connected to the cellular network will be given superior capabilities and possibilities, especially when considering V2N architecture approach. The network can reach vehicles within a large region, allowing for increased range, and for predictive and early measures towards safer traffic flow.

With this in mind, the cellular ecosystem stakeholders should engage in early efforts to assess the forthcoming capacity and coverage needs of connected vehicles. Together, as partners with the vehicle industry, the cellular ecosystem can construct and deploy a best-in-class vehicle connectivity solution for all.

## APPENDIX A: ACRONYM LIST

3GPP	Third Generation Partnership Project
5G	Fifth Generation
ACMA	Australian Communications and Media Authority
ADAS	Automated driving and Advanced Driver Assistance Systems
AEVW	Approaching Emergency Vehicle Warning
BRR	Bureau of Radio Regulation
BSM	Basic Safety Message
C2C-CC	Car to Car Communications Consortium
C-ITS	Cooperative ITS
CACC	Cooperative Adaptive Cruise Control
CAMP	Crash Avoidance Metrics Partnership
CCH	Control Channel
CEN	European Committee for Standardization
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
CWW	Cooperative Weather Warning
D2D	Device to Device
DOT	Department of Transportation

DSRC	Dedicated Short Range Communication
EEBL	Emergency Electronic Brake Light
EEI	Energy Efficient Intersection
eMBMS	Evolved MBMS
eNB	Enhanced Node B
ETSI	European Telecommunications Standards Institute
EU	European Union
FCC	Federal Communications Commission
FDM	Frequency Division Multiplexing
FMVSS	Federal Motor Vehicle Safety Standards
GCSE	Group Communication System Enablers
GM	General Motors
HARQ	Hybrid Automatic Repeat Request
ICV	Intelligent Connected Vehicles
IEEE	Institute of Electrical and Electronics Engineers
IMSI	International Mobile Subscriber Identity
ISO	International Organization for Standardization
ITS	Intelligent Transportation Systems
IVI	In Vehicle Information
IVS	In Vehicle Signage
LTE	Long Term Evolution
LTE-V	Long Term Evolution-Vehicular
MAC	Media Access Control
MBMS	Multimedia Broadcast Multicast Services
MHz	Megahertz
MIIT	Ministry of Industry and Information Technology
MIMO	Multiple Input Multiple Output
MNO	Mobile Network Operator
NHSTA	National Highway Safety Transportation Administration
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OSI	Open Systems Interconnection
PHY/MAC	Physical layer / Medium Access Control
PKI	Public-Key Infrastructure
ProSe	Proximity Service
PVD	Probe Vehicle Data
QoS	Quality of Service
RHW	Road Hazard Warning
RLW	Red Light Violation Warning
RSU	Road Side Unit

RWW	Road Works Warning
SAE	Society of Automotive Engineers
SCH	Service Channel
SCMS	Security Credential Management System
SDO	Standards Development Organization
SMVW	Slow Moving Vehicle Warnings
SPaT	Signal Phase and Timing
SVI	Stationary Vehicle/trailer Information
TC	Technical Committee
TCP/IP	Transmission Control Protocol/Internet Protocol
TJAM	Traffic Jam Ahead Warning
TS	Technical Specification
U-NII	Unlicensed National Information Infrastructure
UE	User Equipment
V2I	Vehicle-to-infrastructure
V2N	Vehicle-to-network
V2P	Vehicle-to-pedestrian
V2V	Vehicle-to-vehicle
V2X	Vehicle to Everything
VRU	Vulnerable Road User
VSC3	CAMP Vehicle Safety Communications 3 Consortium
WAN	Wireless Access Network
WAVE	Wireless Access in Vehicular Environments
WSMP	WAVE Short Message Protocol

## APPENDIX B: GLOSSARY

Term	Definition	Used in
<b>E-UTRAN</b>	Evolved UMTS Terrestrial Radio Access Network	3GPP
<b>LTE-Uu</b>	This is the reference point between the V2X enabled UE and the E-UTRAN. (source: 3GPP TR23.785)	3GPP
<b>OBE: On-board Equipment</b>	The Vehicle On-Board Equipment (OBE) provides the vehicle-based processing, storage, and communications functions necessary to support connected vehicle operations. The radio(s) supporting V2V and V2I communications are a key component of the Vehicle OBE. (source: CVRIA)	US Connected Vehicle/ITS documents
<b>PC5</b>	This is the reference point between the V2X enabled UEs for V2V, V2I, and V2P Services. (source: 3GPP TR23.785)	3GPP

Term	Definition	Used in
<b>RSU: Road Side Unit</b>	Road Side Unit' (RSU) represents the Connected Vehicle road side devices that are used to send messages to, and receive messages from, nearby vehicles using V2X technologies.	US Connected Vehicle/ITS documents, USDOT
<b>Sidelink</b>	Direct communication between two or more nearby devices (UEs), using E-UTRA technology but not traversing any network node. (source: 3GPP TS36.300 and TS36.311)	3GPP
<b>V2I Service</b>	A type of V2X Service, where one party is a UE equipped on a vehicle and the other party is an RSU. (source: 3GPP TR23.785)	3GPP
<b>V2N Service</b>	A type of V2X Service, where one party is a UE equipped on a vehicle and the other party is an application server (e.g., traffic safety server). (source: 3GPP TR23.785)	3GPP
<b>V2P Service</b>	A type of V2X Service, where one party is a UE equipped on a vehicle and the other party is a UE which is carried by an individual (e.g., handheld terminal carried by a pedestrian, cyclist, driver or passenger). (source: 3GPP TR23.785)	3GPP
<b>V2V Service</b>	A type of V2X Service, where both parties of the communication are UEs equipped on different vehicles. (source: 3GPP TR23.785)	3GPP
<b>(V2X enabled) UE</b>	User Equipment may be V2X enabled in this context ("V2X enabled UE" is from 3GPP TR23.785)	3GPP
<b>Vehicle Platoon</b>	Vehicle platoon consists of several vehicles traveling together closely yet safely	3GPP

## APPENDIX C: US DEPARTMENT OF TRANSPORTATION VEHICLE CRASH STATISTICS

This appendix contains vehicle crash statistics from the US Department of Transportation (USDOT). All of the statistics including the table have been extracted from the USDOT/NHTSA report titled "Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application"<sup>34</sup> which was issued in August 2014.

Overall, the USDOT analysis concluded that, as a primary countermeasure, a fully mature V2V system could potentially address:

- about 4,409,000 police-reported or 79 percent of all vehicle target crashes
- 4,336,000 police-reported or 81 percent of all light-vehicle target crashes
- 267,000 police-reported or 81 percent of all heavy-truck target crashes annually

In addition, the analysis also indicated V2I systems could potentially address:

<sup>34</sup> USDOT report is available at <https://www.regulations.gov/contentStreamer?documentId=NHTSA-2014-0022-0001&attachmentNumber=1&disposition=attachment&contentType=pdf>

- about 1,465,000 police-reported or 26 percent of all-vehicle target crashes
- 1,431,000 police-reported or 27 percent of all light-vehicle target crashes
- 55,000 police-reported or 15 percent of all heavy-truck target crashes annually

And, finally, combined V2V and V2I systems could potentially address:

- about 4,503,000 police-reported or 81 percent of all-vehicle target crashes
- 4,417,000 police-reported or 83 percent of all light-vehicle target crashes
- 272,000 police-reported or 79 percent of all heavy-truck target crashes annually

The following table is *Table III-2 Societal Cost and Ranking of 22 Target Light-Vehicle Pre-Crash Scenarios* from the USDOT/NHTSA report titled “Vehicle-to-Vehicle Communications: Readiness of V2V Technology for Application”<sup>34</sup>:

Pre-Crash Scenario	Light Vehicle V2V Crashes					
	Comprehensive Cost			Functional Years Lost		
	Total	Percent	Rank	Total	Percent	Rank
Control loss/no vehicle action	\$64,744,000,000	23.5%	1	469,000	24.1%	1
SCP @ non-signal	\$41,095,000,000	14.9%	2	292,000	15.0%	2
Rear-end/LVS	\$29,716,000,000	10.8%	3	198,000	10.2%	4
Opposite direction/no maneuver	\$29,558,000,000	10.8%	4	213,000	11.0%	3
Running red light	\$18,274,000,000	6.6%	5	129,000	6.6%	5
LTAP/OD @ non-signal	\$15,481,000,000	5.6%	6	111,000	5.7%	6
LTAP/OD @ signal	\$14,777,000,000	5.4%	7	105,000	5.4%	7
Rear-end/LVD	\$12,215,000,000	4.4%	8	82,000	4.2%	8
Rear-end/LVM	\$10,342,000,000	3.8%	9	72,000	3.7%	9
Changing lanes/same direction	\$8,414,000,000	3.1%	10	60,000	3.1%	10
Control loss/vehicle action	\$7,148,000,000	2.6%	11	51,000	2.6%	11
Turning/same direction	\$6,176,000,000	2.2%	12	43,000	2.2%	12
Opposite direction/maneuver	\$3,500,000,000	1.3%	13	25,000	1.3%	13
Drifting/same direction	\$3,483,000,000	1.3%	14	25,000	1.3%	14
Running stop sign	\$3,075,000,000	1.1%	15	22,000	1.1%	15
Rear-end/striking maneuver	\$2,381,000,000	0.9%	16	16,000	0.8%	16
Parking/same direction	\$1,095,000,000	0.4%	17	8,000	0.4%	17
Turn @ non-signal	\$930,000,000	0.3%	18	6,000	0.3%	18
Turn right @ signal	\$908,000,000	0.3%	19	6,000	0.3%	18

Pre-Crash Scenario	Light Vehicle V2V Crashes					
	Comprehensive Cost			Functional Years Lost		
	Total	Percent	Rank	Total	Percent	Rank
Backing into vehicle	\$874,000,000	0.3%	20	6,000	0.3%	18
Rear-end/LVA	\$667,000,000	0.2%	21	5,000	0.3%	21
Other	\$76,000,000	0.0%	22	-	0.0%	22
All	\$274,929,000,000	100.0%		1,944,000	100.0%	

The following links also provide additional background information:

- V2V Communication Fact Sheet published by NHTSA:  
[http://www.safercar.gov/staticfiles/safercar/v2v/V2V\\_Fact\\_Sheet\\_101414\\_v2a.pdf](http://www.safercar.gov/staticfiles/safercar/v2v/V2V_Fact_Sheet_101414_v2a.pdf)
- NHTSA advanced notice of proposed rulemaking on vehicle-to-vehicle communications technology News release: <http://www.nhtsa.gov/About+NHTSA/Press+Releases/NHTSA-issues-advanced-notice-of-proposed-rulemaking-on-V2V-communications>
- USDOT Fact Sheets: [http://www.its.dot.gov/its\\_program/its\\_factsheets.htm](http://www.its.dot.gov/its_program/its_factsheets.htm)

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