TOYOTA

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Product Regulatory Affairs
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February 28, 2019

The Honorable Elaine Chao
Secretary, US Department of Transportation
1200 New Jersey Ave, SE
Washington, DC 20590

Office of the Secretary, Department of Transportation

**RE: Notice of Request for Comments: V2X Communications [Docket No. DOT–OST–2018–0210]**

Dear Secretary Chao,

Toyota thanks the US DOT for reaching out to industry to better understand the variety of positions regarding the critical importance of V2X vehicle connectivity.

Toyota envisions connectivity in our vehicles being through two systems. Today, we have cellular 4G LTE and satellite for customer convenience and trip route assistance and intend to continue to use cellular-based systems for these types of services. For close proximity collision mitigation applications, Toyota is using DSRC. In Japan, we have successfully launched and retailed over 100,000 vehicles with DSRC for this purpose. DSRC has the repeatability, accuracy and latency necessary for a safety feature in a motor vehicle. Today, DSRC is the only V2X communication technology that has been tested and is proven ready for production release.

Toyota is looking to the US DOT through both the NHTSA and FHWA to take leadership in mandating this technology or, at the very least, defining the technology in an "if equipped" standard. While we appreciate DOT's rationale with respect to its "technology neutral" position, we have a different perspective when it comes to vehicle safety.

We continue to believe that implementing a regulatory requirement is the most effective and expeditious method of realizing the benefits of this important cooperative safety technology. A regulatory requirement would ensure continued interoperability between current vehicles/infrastructure, and with future vehicles/infrastructure. It would also help minimize costs to consumers and infrastructure operators by avoiding completely different (and duplicative) systems in each vehicle or within the infrastructure to support the same functionality.

As a cooperative safety technology, V2X inherently requires that difficult choices be made. Today, DSRC is the only choice available. There has already been significant investment in DSRC from a research and deployment perspective for both vehicles and infrastructure, and government and industry partners have already developed and validated DSRC for V2V and V2X safety application uses through large-scale field studies. The other choices, C-V2X and 5G, still have to go through the lengthy process of development, testing, and verification in order to reach the same technology maturity level of DSRC today. Toyota is concerned that uncertainty around multiple technologies for V2X will slow development and deployment and that significant benefits from V2X safety features will be delayed absent regulatory certainty.

Toyota commends the US DOT, especially NHTSA, FHWA and ITS-JPO for their hard work and support over the years for research that was necessary to bring V2X DSRC to vehicle production-ready maturity. Toyota has expended tremendous effort to support deployment of this important cooperative safety technology. We have been mindful of the importance of the technology, which is reinforced by the NTSB recommendation (H-13-30 & H-13-31) to require V2V technology on all new vehicles, not just light-duty passenger vehicles.

Toyota appreciates the US DOT taking a leadership role at this critical time for this important safety technology for motor vehicles. We look forward to continuing to work with the US DOT to support V2X vehicle connectivity. Should you and/or your staff have any questions, please contact me or Ed Bradley of my staff at ed.bradley@toyota.com or (202) 463-6821.

Sincerely,

Tom Stricker

Tom Stricker
Vice President
Product Regulatory Affairs

Attachments:
Appendix I: Toyota Response to Questions in the NPRM

## Appendix I: Responses to the Nine Questions

At the outset, it is useful to review the goals of V2X communication and define key terms that are used throughout Toyota's RFC reply. While much of this will be familiar to USDOT and industry stakeholders, it is important to establish a common language and understanding.

**Definition of V2X:**

We consider V2X to be direct communication between a vehicle and one or more proximate devices (vehicle, roadside unit (RSU), pedestrian, bicyclist, road worker, etc.), within a few hundred meters. V2X is ad hoc communication; it is decentralized and not reliant on any forwarding infrastructure like base stations or access points. The direct, ad hoc nature of V2X is critical for supporting key requirements of V2X safety use cases, including low latency, high reliability, and ability to communicate regardless of the availability of forwarding infrastructure.

We are aware that some people classify communication between a vehicle and a cellular base station, acting as a forwarding node (for example to a network cloud), as part of V2X, i.e. Vehicle-to-Network (V2N). We consider that class of communication to be materially different from and complementary to the direct vehicle-to-vehicle/RSU/pedestrian/etc. communication that we define as V2X. Examples of the differences that generally apply include the following:

- A V2X device has a peer relation to other V2X devices, whereas in a cellular network the end device is under control of the base station.
- V2X is ad hoc, decentralized communication, while cellular network communication is managed by a telecommunication operator.
- V2X spectrum access is free (public spectrum), whereas in a cellular network access to spectrum usually requires paying a fee.
- Industry standards for DSRC V2X are designed to preserve privacy by communicating pseudonymously, whereas in a cellular network access to spectrum usually requires disclosing identity to the telecommunication operator.
- V2X communication is direct from a transmitter to one or more proximate receivers within a few hundred meters, while in a cellular network the end device and the base station can be several kilometers apart.
- V2X information is usually intended for devices that are in direct communication range of the transmitter, i.e. over a single hop, while in a cellular network the target recipient is typically many hops away and could be anywhere in the world.

These differences have consequences with respect to communication performance (e.g. latency) and use cases. While we agree with the European Commission that the combination of V2X and "existing cellular networks" constitutes "the most promising hybrid communication mix,"[1] for the reasons noted above we think it is helpful to focus the discussion of V2X by excluding the traditional cellular model from our response in this document.

It is also true that V2X communication can be supported in different spectral bands, for example the 5.9 GHz DSRC band and the 60 GHz millimeter wave band. In general, we support efforts to develop millimeter wave V2X, for use cases that it can enable (e.g. with gigabit per second bit rates) that are not possible in 5.9 GHz for any technology. However, for the purposes of this RFC, our discussion of V2X is limited to 5.9 GHz spectrum unless otherwise noted.

[1] "A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility", European Commission, COM(2016) 766 final, November 30, 2016

## Goals of V2X:

The driving force behind V2X is the potential of saving thousands of lives per year by providing vehicles and drivers with the information they need to keep vehicles from crashing. This safety-of-life mission is enabled through the exchange of V2V Basic Safety Messages (BSMs), through broadcast of I2V information via a variety of message types such as Road Safety Messages (RSMs) and Signal Phase and Timing (SPaT) messages, and through the dissemination of information about the presence of vulnerable road users (VRUs) via P2V Personal Safety Message (PSMs), as examples. When vehicles and other entities are equipped with interoperable V2X communication devices, they can also pursue goals related to improved mobility and traffic efficiency, reduced environmental emissions, and cooperative automated driving functions. Safety, Mobility, the Environment, and Automation represent four pillars of the V2X application space that collectively can provide significant contributions to overarching societal transportation goals. We believe additional pillars will likely emerge over time if we form a strong enough V2X foundation.

## Key Concepts and Definitions:

As noted in Question 2 of this RFC, DSRC is the only V2X technology permitted in the US 5.9 GHz spectrum. Furthermore, as noted by in the October 24, 2018 NHTSA statement about the safety value of the 5.9 GHz spectrum, "The automotive industry and municipalities are already deploying V2X technology and actively utilizing all seven channels of the 5.9 GHz band" with "more than 70 active deployments" and "thousands of vehicles already on the road." Therefore, any question about V2X technologies (as in this first RFC question) naturally elicits comments about the relationship of non-DSRC technologies to the incumbent DSRC. Key questions that we address include:

- Does a given non-DSRC technology *interoperate* with DSRC technology?
- Does a given non-DSRC technology *coexist* effectively with DSRC technology in the same channel?
- Does a given non-DSRC technology provide *backward compatibility* with DSRC technology?

Different parties may want to use these terms in different ways, so we think it is important to define the terms as we will use them.

**Interoperability:** Two technologies are interoperable if a device designed to the standards of one technology can transmit packets that can be correctly decoded by a device designed to the standards of the other technology, and vice versa. Generally, technologies that are developed independent of one another are not interoperable. However, if the development of a given technology takes into account the standards that specify another technology, interoperability is possible.

Technology interoperability is also sometimes referred to as direct interoperability. When applied to technologies representing the lower layers of the communications stack (Physical layer (PHY) and Medium Access Control layer (MAC)), technology interoperability may be referred to as radio interoperability.

The concept of technology interoperability can be applied at any layer of the communication stack. In the case of V2X, which is direct device-to-device communication, interoperable communication between devices requires technology interoperability at all layers of the stack. This is a contrast with common multi-hop internetworking, where for example an end device and an access router only need to interoperate at the lower layers, and indirect end-to-end interoperability only need exist at the upper layers. At the time when the FCC was proposing to require DSRC they were asked by one party to instead accept mere "application interoperability". But, the FCC explicitly rejected that argument, and cited advocacy of lower layer interoperability by USDOT as a primary rationale.

**Coexistence:** Unless otherwise noted, our use of "coexistence" means effective sharing of the same channel. One technology is able to coexist with another if it avoids excessively interfering with that technology. Coexistence is a more subjective quality than interoperability, but often there is consensus about whether one technology coexists with another. For example, it is generally accepted that various versions of the IEEE 802.11 standard coexist because they use a common PHY signal preamble and a common MAC channel access protocol.

Coexistence can also be considered over various time scales. Usually coexistence implies that two technologies are able to use a channel effectively on a *packet-by-packet* basis. Occasionally one may consider coexistence over a longer time scale. An example of the latter is the Detect & Vacate sharing proposal under evaluation by the FCC for DSRC and U-NII coexistence. This can be effective when one technology undertakes to explicitly detect that another higher priority technology is present in a given time and place, and after such detection it defers all use of the channel until such time as the higher priority technology is no longer present.

Same-band coexistence, which concerns interference between devices using non-overlapping spectrum in the same band, is generally easier to achieve than same-channel coexistence. Same-band coexistence depends fundamentally on transmit power and out-of-channel emissions on the part of the interferer, and channel rejection filtering and sensitivity requirements on the part of the devices being interfered with. To repeat, our use of coexistence is in the same-channel sense unless otherwise noted.

**Backward compatibility:** The concept of backward compatibility applies to the relationship between a new technology and an existing technology, usually a prior generation of the new technology. Our use of the term backward compatible requires that:

- The new and existing technologies achieve coexistence
- The existing technology is a subset of the new technology, and therefore the technologies are interoperable when using that subset of features

The term backward compatibility has been used by some in a much looser way to describe a case where a given system can communicate using Technology A in one channel, or alternatively it can communicate using Technology B in a different channel. Consideration of that definition reveals that it has nothing to do with the Technologies A and B, but is only a reflection of implementation choices for a given system. Therefore, we do not consider that definition useful as a way of describing the relationship between the technologies. We can illustrate our point with an extreme example: modern naval ships can communicate with either sophisticated RF technologies or with 19th century flag semaphore, but that does not mean the RF technologies are backward compatible with flag "technology".

1. Please provide information on what existing or future technologies could be used for V2X communications, including, but not limited to, DSRC, LTE C-V2X and 5G New Radio. What are the advantages and disadvantages of each technology? What is the timeframe for deployment of technologies not yet in production? Please provide data supporting your position.

**Consideration of known V2X technologies**

At present, Toyota is aware of the existence of four V2X technologies at some level of standardization and testing:

1) DSRC (also called IEEE 802.11p or OCB)
2) LTE V2X (also called 4G C-V2X or Release 14/15 C-V2X)
3) NR V2X (also called 5G C-V2X or Release 16 C-V2X)
4) IEEE NGV (also called IEEE 802.11bd)

Note: According to our definition of V2X as direct device-to-device communication, in this RFC we consider the so-called PC5 (or sidelink) aspects of LTE V2X and NR V2X.

**Brief comparative description of status:**

DSRC:

- As documented in the NHTSA FMVSS 150 V2V NPRM (NHTSA V2V NPRM), DSRC is capable of saving more than one thousand lives per year.
- Stable MAC/PHY standard completed by IEEE in 2010 was written primarily by automotive stakeholders
- Mid-layer standards updated by the IEEE 1609 DSRC Working Group in 2016 for citation in the NHTSA V2V NPRM (IEEE 1609.2, IEEE 1609.3, IEEE 1609.4, IEEE 1609.12)
- Upper layer data dictionary and BSM application standards published by SAE DSRC Technical Committee in 2016 for citation in the NHTSA V2V NPRM (SAE J2735, SAE J2945/1)
- Extensively tested in large scale field operational test under the auspices of the USDOT Safety Pilot Model Deployment program in 2012-13
- Many examples of demonstrated conformance and interoperability, e.g. under the auspices of the Crash Avoidance Metrics Partnership (CAMP) Consortium V2V-Interoperabilty project and the OmniAir Consortium
- More than 70 active deployment sites in a majority of US states, employing thousands of Roadside (infrastructure) Units (RSUs) and more than ten thousand vehicle-based Onboard Units (OBUs)
- Commercially available since March 2017
- Harmonized with technologies deployed in Europe and Japan (more than 100,000 vehicles sold to customers in Japan)

LTE V2X:

- First generation MAC/PHY standard published by 3GPP in 2017 (Release 14); Standard was written primarily by telecommunication stakeholders (Toyota was an observer through our 3GPP membership)
- Second generation MAC/PHY standard published by 3GPP in 2018 (Release 15)
- Mid-layer standards: IEEE 1609 DSRC WG is now considering what changes would be required to create a version of 1609.3 that is compatible with LTE V2X. IEEE 1609.2 standard may be usable without changes. LTE V2X is unlikely to use the IEEE 1609.4 standard
- Upper layer standards: SAE C-V2X Technical Committee began working on SAE J3161 (BSM over LTE V2X) standard in 2017. First ballot expected in 2019. This standard may also require changes to the SAE J2735 data dictionary standard
- Small scale testing, primarily with two transceivers, started in 2018 and continuing in 2019
- Likely to be harmonized at MAC/PHY with V2X technology being tested in China

NR V2X:

- NR = New Radio
- First generation MAC/PHY standard is in "study item" phase at 3GPP. Publication expected Dec. 2019 (Release 16)
- The NR PC5 standard is likely to employ a similar approach to the previously developed New Radio Uu standard for base station communication (uplink/downlink)
- 3GPP decided in 2018 not to consider same-channel coexistence between NR V2X and LTE V2X

IEEE NGV:

- NGV = Next Generation V2X
- Study phase completed by IEEE in December 2018
- IEEE 802.11bd amendment scheduled for 2021[2]
- Amendment required by agreement in IEEE to achieve interoperability, coexistence, and backward compatibility with DSRC[3]

**Relationship to DSRC:**

Since DSRC is the legal incumbent in the 5.9 GHz band with many licensees in deployment, it is critical to consider the relationship between non-DSRC technologies and DSRC. The following table summarizes the relationships.

**Relationship of non-DSRC technologies to DSRC**

| Non-DSRC Technology ⇒ | LTE V2X | NR V2X plan | IEEE NGV plan |
|---|---|---|---|
| Interoperable with DSRC? | No | No | Yes |
| Coexistent with DSRC? | No | No | Yes |
| Backward compatible with DSRC? | No | No | Yes |

**Consideration of advantages and disadvantages:**

Toyota believes that DSRC in vehicles has the potential to save lives, reduce crashes and injuries, improve traffic mobility and efficiency, and improve automated driving performance. USDOT experts have concluded that DSRC has the potential to mitigate or avoid approximately 80% of crashes involving non-impaired drivers. This will translate to large societal benefits if DSRC is widely deployed.

With regard to the safety objective of the technology, we believe that DSRC provides the best opportunity to achieve the safety objective based on the two following considerations:

1) Which technology supports the use cases that provide the safety benefits?
2) Which V2X technology is most likely to garner the widespread industry deployment consensus necessary for the US to realize the full benefits of V2X?

[2] http://www.ieee802.org/11/Reports/802.11_Timelines.htm

[3] https://mentor.ieee.org/802.11/dcn/18/11-18-0861-09-0ngv-ieee-802-11-ngv-sg-proposed-par.docx

Use Cases: We believe that DSRC supports all of the V2X use cases currently considered for 5.9 GHz. Toyota was a member of the automaker consortium that conducted the CAMP VSC-Applications project, which proved that DSRC can objectively prevent imminent collisions in a wide variety of use cases. Subsequent testing in many scenarios and environments, including in the year-long Model Deployment and in tests conducted in other regions of the world, have confirmed that conclusion. NHTSA clearly supported that conclusion in the V2V NPRM.

The communication requirements of imminent crash avoidance, for example with respect to latency and reliability, are among the most stringent imaginable (within the constraints imposed by physics in the 5.9 GHz band). It naturally follows that DSRC can easily support the many use cases with less stringent requirements. Another application with strict requirements is vehicle platooning, and we are aware that the heavy truck industry has judged DSRC reliable in supporting that use case as well, including the communication not only of critical control data but also of real-time video. Research has also shown important benefits that can accrue to automated driving systems that are augmented with DSRC, for example in the accuracy of mapping, localization, and perception.

Will non-DSRC technologies support these same use cases as DSRC? While these technologies are either still under development or in early stages of testing, we expect they will generally support the same set of use cases as DSRC[4]. But, this will need to be proven with the same level of rigor that has been applied to DSRC testing.

Widespread deployment consensus: We believe that the adoption of a single interoperable family of V2X technologies in any given region of the world (for example, DSRC and IEEE NGV are members of a single interoperable V2X family[5]) provides the best opportunity to realize the potential societal benefits. The consensus V2X technology need not be the same in every region. It may occur, for example, that DSRC is the widely deployed technology in North America, Europe, and Japan, while LTE V2X becomes widely deployed in China. In our answer to Question 2 of this RFC we explore some of the negative implications of introducing multiple non-interoperable V2X technologies in the same region.

We think it is self-evident that DSRC (eventually in combination with IEEE NGV) has a better chance than either LTE V2X or NR V2X to be the single consensus V2X technology in North America. There are several reasons.

1) DSRC is proven, stable, fully standardized, fully tested, reflected in licensing regulations and already deployed. Neither LTE V2X nor NR V2X has the same level of technical maturity, stability, or deployment. For example, while some testing with two LTE V2X-equipped vehicles was conducted in recent months, we observe that the CAMP VSC-A project[6] conducted similar testing of DSRC in 2008. DSRC was several years from being mature enough for deployment in 2008, and LTE V2X is similarly several years from being mature enough for deployment now. As time advances and DSRC becomes more and more widely deployed, it becomes increasingly less likely that any incompatible V2X technology will displace it in the US.
2) Any scenario in which either LTE V2X or NR V2X could become the single wide scale deployed V2X technology is by definition one in which there would have to be an evolution from the incumbent DSRC. As we explain more completely in Question 2 of this RFC, those cellular V2X technologies represent a form of evolution that is

[4] One exception is that LTE V2X cannot support unicast communication, so it can only support broadcast use cases. Many use cases include an element of unicast dialogue, and these are outside the scope of LTE V2X support. A few examples of unicast V2X communication include: cooperative maneuver negotiation, transit/emergency vehicle request for signal priority/preemption, vehicle-to-SCMS connection for downloading of certificates or reporting of misbehavior, targeted query by a Traffic Management Center of a specific vehicle's traffic environment.

[5] LTE V2X and NR V2X do not qualify as members of a single interoperable family of V2X technologies. They are not able to coexist. They each require their own spectrum.

[6] The VSC-A project was a collaborative effort among the US DOT and five automakers operating as the Vehicle Safety Communication 2 consortium: Ford, General Motors, Honda, Mercedes-Benz, and Toyota.

disruptive and harmful to the entire V2X ecosystem (not just to DSRC), and thus they are unlikely to be successful.

3) The emergence of NR V2X while LTE V2X is still nascent may serve as a brake on LTE V2X deployment. NR V2X will have capabilities that LTE V2X does not have, for example with respect to communication performance, transmission of non-periodic messages, and the support of unicast communication. Proponents of LTE V2X promote a model in which LTE V2X would be deployed to support a set of key safety use cases (for example, crash avoidance based on the BSM), and NR V2X would support a non-overlapping set of use cases. An important weakness of this model is that the most important use cases would be relegated to the oldest generation of cellular V2X technology, with no plan for evolution to a newer generation. Furthermore, the model requires deployment of both NR V2X and LTE V2X, with an associated division of scarce spectrum because they are not designed to coexist. NR V2X will complete the standardization phase at the end of this year. By the time LTE V2X is ready to be deployed, stakeholders may find it difficult to justify deploying LTE V2X as step one of a two-step deployment. The decision by 3GPP to follow NR V2X so closely on LTE V2X and to design them so they do not coexist could encourage stakeholders to instead wait longer so they can implement all use cases with one more advanced technology.

**Rebuttal of some arguments against DSRC:**

There are several arguments against DSRC and/or for C-V2X that we hear frequently, many of which we believe are either incorrect or misunderstood. We address just a few of them in this section.

Isn't DSRC old technology?

DSCR is not old technology. While DSRC is based on a stable standard, DSRC technology is more than just a standard, and is constantly evolving and improving in a competitive environment among DSRC suppliers. The DSRC standard only defines those elements of communication that are necessary to achieve interoperability, like the definition of the waveform that conveys a given bit value. The electronics and digital signal processing algorithms are implementation specific, and particularly on the receiver side are not subject to standardization. DSRC solutions from a wide variety of providers today outperform the solutions from just a few years ago. One example is that when the automotive community wrote the SAE standard for communicating BSMs over DSRC in 2015 the community adopted a receive sensitivity requirement that is significantly more stringent than the requirement in the 2010 IEEE 802.11 DSRC standard[7]. Improved sensitivity represents a significant improvement in the robustness of DSRC reception. The SAE -92 dBm sensitivity is the minimum requirement, and tests of available solutions show that they consistently perform well above that requirement[8]. Results provided by the DSRC community to the Wi-Fi community in 2013, prior to the adoption of the SAE standard, showed devices capable of -95 dBm sensitivity in actual road tests, and more recent results from other suppliers are even better. So, the notion that DSRC is old or frozen is not true.

Furthermore, as explained in more detail below, the emerging IEEE NGV standard will bring even more improvements to the performance of the DSRC family, while still maintaining interoperability. Unlike the disruptive evolution path from DSRC to cellular V2X, the evolution from DSRC to IEEE NGV is seamless, and allows for all use cases to evolve (including the BSM).

[7] 2015 SAE J2945/1 standard requires -92 dBm sensitivity (10% packet error ratio, 400 octet packets); 2010 IEEE 802.11p standard requires -82 dBm sensitivity (10% packet error ratio, 1000 octet packets)

[8] One exception seems to have been the particular DSRC system chosen for testing by LTE V2X proponents. Test results released by 5GAA show that DSRC system was not capable of meeting the SAE sensitivity requirement.

Doesn't LTE V2X far outperform DSRC?

Rigorous testing needed to accurately answer this question has not yet been performed. The test results recently reported by 5GAA have prompted criticism from a variety of V2X implementation experts, for example in comments to the FCC on the 5GAA waiver request. We agree with those experts that the existing test results are largely unreliable as an indicator of the fundamental capabilities of these technologies. We hope more dependable and objective results will be available in the future. Here are some of the problems that we have identified with the testing reported by 5GAA:

Test configurations did not provide a fair comparison between basic LTE V2X and DSRC technologies:

- Each BSM is sent twice by the LTE V2X device, and it is considered successful if either transmission is received. By contrast, each BSM is only sent once by the DSRC device, despite the fact that DSRC systems are capable of sending duplicate packets[9].
- As noted in a 5GAA *ex parte* notice filed with the FCC to correct a prior claim[10], LTE V2X and DSRC devices were also configured differently with respect to antenna diversity. LTE V2X devices were configured with two receiver antennas (Rx diversity), but DSRC devices were only configured with one receiver antenna (no Rx diversity). DSRC standards allow for Rx diversity. Most DSRC devices available today support Rx diversity. Adding Rx diversity to DSRC devices would have a significant impact on reception reliability and range.
- As noted above, the DSRC equipment used in the test was configured so that it did not meet consensus industry standard minimum performance requirements.

Test results in some cases appear to be incorrect:

- Test results with just two BSM transmitters show DSRC experiencing *higher* mean latency than LTE V2X. We do not believe a valid test could produce this result. In a test scenario with just two transmitters, DSRC should experience less than one millisecond channel access delay while LTE V2X will experience up to 20 milliseconds channel access delay.

Tests used configurations that are not representative of 5GAA's intended deployment configuration:

- The configuration of LTE V2X in these tests does not match 5GAA's intended implementation in important respects. For example, the testing used 10 MHz channels, but 5GAA indicates they currently intend to deploy with a 20 MHz channel (if permitted). There are important performance differences between 10 and 20 MHz. For example, a 20 MHz channel has twice as much background noise, limiting range by approximately 30% in a typical environment. Furthermore, the scalability problems discussed below (e.g. half duplex and in-band emission interference) are three times worse with a 20 MHz channel than with a 10 MHz channel (i.e. one packet can adversely affect three other simultaneous packets, rather than just one other packet). There can be advantages to using a 20 MHz channel as well, but further testing is needed before any comparisons can be considered reliable.
- There is another aspect of the intended implementation that also has not been tested. Unlike DSRC, where short and long packets can be interleaved on the air without difficulty, the nature of LTE V2X scheduling creates challenges for such a mix of long and short packets. Accordingly, 5GAA recently decided to overlay a division of time into V2I intervals and V2V intervals. This imposes additional constraints on selecting transmission times, with the result that packet collisions may become more likely. An important consequence of this is that under high vehicle density the opportunities to send BSMs may not be sufficient, and packet collision rates could be high (and as pointed out below, these packet collisions could be much

[9] Due to concerns for channel congestion, Toyota does not endorse routine packet duplication for any V2X technology.

[10] *"Notice of ex parte, GN docket 18-357"*, 5GAA, February 22, 2019

more damaging to the BSM use case than packet collisions in DSRC are). V2I and V2V time division can also increase latency, for example when a V2V packet's schedule is delayed until after the V2I interval ends.

Tests do not adequately assess scalability concerns stemming from the re-use of a centrally controlled uplink protocol for decentralized ad hoc sidelink communication:

- Most of the 5GAA tests were conducted with just two transmitting devices. There are well-reported concerns about the scalability of LTE V2X under higher vehicle densities, for example lost messages due to the half duplex problem and the in-band emission problem. Significantly, these problems that exacerbated in the decentralized V2X environment when compared to a normal LTE environment where the base station controls scheduling and transmit power among all devices.
- A further, related, concern is that LTE V2X is designed to support use cases where the information is generated periodically, and each transmitter uses a periodic transmission schedule for prolonged periods of time (on average, a given periodic schedule is used for 50 consecutive messages, often more). This means that when two devices choose the same periodic transmission timeslot, their transmissions will not only collide over the air, but they will collide again and again and again with each successive transmission, for as long as they both use that periodic timeslot. Depending on the application, this persistent collision environment could last for several seconds, and transmitters are not able to detect that they are experiencing collisions. This kind of impairment could have serious consequences for a wide range of use cases. Consider the use case of crash avoidance as supported by the BSM. There is a natural redundancy in the information carried in BSMs that are sent ten times per second, such that loss of an occasional BSM does not materially impact the ability of the receiver to detect imminent crash threats. But, if another vehicle "goes silent" because a long stream of its BSMs fail to be received due to persistent packet collisions, it becomes very difficult to identify potential crash scenarios with that vehicle. This is a known issue with LTE V2X, and it is important that its effects be rigorously tested to determine how it may impact safety. The testing performed to date is inadequate to answer this question. Most of the 5GAA tests use just two transmitters, which do not create enough over-the-air traffic to expose possible LTE V2X scalability problems. The 5GAA tests that use more than two transmitters have a different set of problems that render them inadequate to reflect performance in realistic road conditions with fading channels, moving vehicles, and changing densities.

We agree with AASHTO's comments to the FCC on the 5GAA Waiver Request that the performance of LTE V2X should be determined through "testing and evaluation of the technology by independent sources (rather than accepting a 5GAA report on performance)."[11]

<u>Isn't LTE V2X likely to be much more cost efficient than DSRC in general, because most cars already have LTE equipment?</u>

We confine our discussion of cost to generic issues stemming from fundamental aspects of technology and deployment. None of our comments about relative cost are meant to convey or imply anything about Toyota-specific implementations or business relationships. Some C-V2X proponents assert there is a significant advantage for C-V2X because cellular connectivity is becoming common in vehicles. However, we believe that this does not consider the full picture regarding costs.

ABI Research conducted a study on this topic last year. In their study, ABI compared the cost of integrating DSRC with a Telematics Control Unit (TCU) (i.e. DSRC+LTE) and the cost of integrating LTE V2X with a TCU (i.e. LTE

[11] Comments of the American Association of State Highway and Transportation Officials at 2, FCC GN Docket 18-357 (filed January 18, 2019).

V2X+LTE). They concluded that the TCU in a car with DSRC would likely be up to $18 cheaper than the TCU in a car with LTE V2X.

Understanding the implementation cost comparison between DSRC and LTE V2X requires consideration of two related questions: 1) how does LTE V2X compare with DSRC on a complexity basis? And 2) how does integration of V2X (either technology) with a telematics control unit (TCU) potentially save costs?

The ABI Research results are not surprising given two observations related to these questions: 1) DSRC is functionally simpler than LTE V2X, and 2) there are several key distinctions between telematics implementations and V2X implementations (of any technology).

In general, commercial Wi-Fi solutions are cheaper than LTE solutions. In addition, DSRC is simpler than general Wi-Fi, whereas LTE V2X is more complex than general LTE. The most important innovations to the Wi-Fi standard introduced by the DSRC amendment were to remove requirements for joining/maintaining/leaving local area networks managed by Access Points. Removing these requirements allows DSRC to function with low latency in an ad hoc mode. So, DSRC is a simpler subset of Wi-Fi. Most DSRC chipsets are already part of general Wi-Fi solutions. The only aspect of the DSRC amendment that can be considered more complex is transmit filtering, but this is a requirement that stems from the 5.9 GHz band plan and is not specific to DSRC (any V2X technology will need to employ these filters).

In a traditional LTE network, the User Equipment (e.g. vehicle module) is under control of the Base Station, which relieves it of many functional requirements. But, there is no base station support in LTE V2X out-of-coverage mode, so the V2X device (user equipment) has to take on new functional requirements with respect to controlling transmissions. A key new requirement is to be able to schedule the device's transmissions. This involves selecting a group of what are called "resource blocks" that are adequate to support a given application. LTE V2X transmissions are assumed to be periodic. It uses a relatively complex "semi-persistent" scheduling function that involves a one-second listening interval, a measurement of the occupancy of timeslots that occur multiple times within the listening interval, a ranking of candidate timeslots, a random selection of a scheduling resource among the candidates, and a reservation operation to notify other devices of intended future transmissions. Assessment of whether to continue using a given periodic resource after it is selected involves assessment of two random variables.

So, to summarize the first question:

- Wi-Fi is generally cheaper than LTE
- DSRC is less complex than Wi-Fi, and
- LTE V2X requires functions that regular LTE does not use; these functions are not supported in LTE modems deployed in vehicles today
- So, it stands to reason that stand-alone DSRC solutions should be generally cheaper than stand-alone LTE V2X solutions.

With respect to the second question regarding integration of V2X into a TCU, there are many factors to consider. Key distinctions between telematics and V2X implementations include:

- Telematics and V2X support different missions and use cases.
- A vehicle must be able to communicate over both interfaces simultaneously. This implies two distinct radio functions. For example, the vehicle needs to continuously monitor the V2X channel for BSMs, etc., even when it is simultaneously using the telematics unit.

- Telematics and V2X operate in different spectrum.
- Telematics and V2X likely require different antennas and cabling.
- Telematics and V2X require different analog electronics, and major portions of the digital electronics are different.
- Telematics and V2X technologies have different requirements with respect to evolution.
- Telematics and V2X operate with different business models and spectrum-usage rules.
- V2X has more stringent hardware security requirements than telematics.
- V2X has more stringent functional safety requirements than telematics.

Given all of these observations, and the ABI study, it is unclear that LTE V2X is more cost efficient than DSRC.

Isn't it important to include C-V2X so a vehicle has a "path to 5G"?

Proponents of C-V2X often cite a "path to 5G" as an important consideration for V2X technology[12]. We find that this often leads to confusion and misunderstandings. We offer comments here to clarify our perspective on 5G for V2X in the US.

There are a variety of ways that a vehicle may utilize "5G". Principle among these is through the telematics unit, for services that are unrelated to direct V2X use cases supported in 5.9 GHz. Toyota includes a 4G LTE modem in most of our vehicles today, and welcomes the possibility to consider evolution to 5G telematics services in the future. Nothing about the choice of V2X technology in the 5.9 GHz band impairs an automaker's opportunity to engage in 5G telematics services using an operator network.

As for support of V2X use cases in 5.9 GHz, we understand the expressed interest of some for a "path to 5G" to mean a possibility to take advantage of wireless communication innovations that are becoming available today in several arenas (e.g. Wi-Fi wireless LANs, cellular wide area networks, Bluetooth personal area networks). In that respect, three things are important to understand:

- LTE V2X is 4G technology, not 5G. Furthermore, 5G NR V2X is being designed so that it will neither interoperate nor coexist with LTE V2X. So, LTE V2X does not provide a path to 5G or to 5G NR V2X.
- The promises often associated with "5G" in marketing and press accounts, like providing 10 Gbps data rates, will not be available for V2X use cases in 5.9 GHz with any technology. Those promises apply to other spectra and carry other assumptions that are inconsistent with the limits imposed by the laws of physics for V2X in our band.
- Many of the wireless communication innovations being introduced with 5G cellular are also available in Wi-Fi communication, for example with respect to multi-input multi-output antennas systems, coding, and waveform design. History shows that IEEE wireless experts consistently keep Wi-Fi technology on the cutting edge. Most smart devices automatically switch from a cellular network to a Wi-Fi network whenever possible, for both performance and cost reasons. The advances touted for 5G, for example "data speeds of 100Mbit/s or more, ultra-low latency of a few milliseconds or less,"[13] are exciting for the improvement they offer relative to 4G LTE for longer range communication, but are generally already available in Wi-Fi networks for shorter range communication.

[12] For example, the phrase "path to 5G" appears ten times in 5GAA's waiver request petition to the FCC.

[13] 5GAA Petition for Waiver, Section III.B. (page 16)

Continued innovation in V2X is important. However, a "path to 5G" should not be considered an end goal for V2X. For the US, where more than a billion dollars has been invested in support of wide scale DSRC deployment, innovation that preserves interoperability with DSRC is desirable and enhances the value of both current and future investments in V2X. IEEE NGV is an example of that seamless evolution path. But, sacrificing interoperability in the name of innovation carries steep costs that make those disruptive evolution paths undesirable (these costs are explored further in the answer to Question 2).

In summary, we welcome the advent of 5G and expect we will utilize it in a variety of ways in the future. But, in the V2X space, we do not believe that the "path to 5G" (that is represented by LTE V2X) compares favorably to other evolution paths that can better help society realize the full benefits of V2X and the 5.9 GHz spectrum. Toyota believes a hybrid of different technologies could work if they are complementary. For example, DSRC/IEEE NGV in the 5.9 GHz spectrum for proximate safety, mobility, environmental, and automation applications and traditional cellular (4G, 5G) outside of the 5.9 GHz spectrum for longer distances supporting additional information and services. This would be the ideal deployment scenario for the near term as well as long term goals of connectivity between vehicles and with the infrastructure.

2. Of the V2X communications technologies previously discussed, at present only DSRC is permitted to be used in the 5.9 GHz spectrum band for transportation applications. If that allocation were to be changed to allow any communication technology for transportation applications, could DSRC and other technologies (e.g., C-V2X, 5G or any future technology) operate in the same spectrum band or even the same channel without interference? Why or why not? If there are any technical challenges to achieving this goal, what are they and how can they be overcome?

At Toyota, we believe innovation that advances the communication technology while ensuring interoperability and backwards compatibility, and does not require fragmenting the spectrum, would be most beneficial for realizing the potential safety benefits of V2X. On the other hand, innovations that do not preserve the spectrum as a whole or do not preserve compatibility with existing devices will tend to negatively impact V2X adoption—leading to less potential V2X safety benefits. We believe that, even if it is technically feasible to have incompatible technologies in the same band (which more testing is required to determine), it is contrary to the public interest to change the DSRC band rules, as explained here. As a starting point, we have the following observations about how the various technologies being considered can and cannot work together in the same spectrum.

- DSRC and IEEE NGV can operate not only in the same spectrum band, but in the same channel. This is done by use of a common packet header and common channel access rules.
- 3GPP protocols <u>cannot</u> effectively share a channel on a packet-by-packet basis with DSRC, with IEEE NGV, or even in the same channel with each other.
    - There may be an opportunity for 3GPP protocols to share a channel with DSRC on a longer-term detect-and-avoid basis, which is discussed toward the end of this question. However, any such sharing would need to protect channel access for incumbent DSRC systems that support safety applications and avoid any harmful interference that could impede the safety functions of the system.

For the purpose of comparing potential channel sharing options, we consider several deployment scenarios as summarized in the following table and described in more detail below the table.

## Protocol and Spectrum Scenarios

| Scenario | | Protocols | Sub-bands | Additional assumptions | Summary |
|---|---|---|---|---|---|
| A | | DSRC | None | DSRC uses all 7 channels | Works well |
| B | | DSRC/IEEE NGV | None | DSRC/IEEE NGV use all 7 channels | Optimal |
| C | C | DSRC/IEEE NGV + LTE V2X + NR V2X | DSRC/IEEE NGV (30 MHz)<br>LTE V2X (20 MHz)<br>NR V2X (20 MHz) | Exclusive protocol use in each sub-band;<br>DSRC/IEEE NGV only use 3 channels | Many significant disadvantages |
| | C+ | | DSRC/IEEE NGV (70 MHz)<br>LTE V2X (20 MHz)<br>NR V2X (20 MHz) | LTE V2X and NR V2X use detect-and-vacate to avoid interference to incumbent DSRC/IEEE NGV<br>DSRC/IEEE NGV use all 7 channels | Some mitigation of Scenario C disadvantages |
| | C++ | | DSRC/IEEE NGV (70 MHz)<br>LTE V2X (20 MHz)<br>NR V2X (20 MHz | LTE V2X and NR V2X use detect-and-vacate to avoid interference to incumbent DSRC/IEEE NGV. All OBUs and RSUs use DSRC/IEEE NGV for core use cases.<br>DSRC/IEEE NGV use all 7 channels | Some additional mitigation of Scenario C disadvantages |
| N (Neutrality) | | Any | None | All protocols use the same channels. No protocol is prioritized over another. | Infeasible |

Under all variations of (C), we further assume that LTE V2X and NR V2X collectively duplicate the use cases implemented in DSRC/IEEE NGV, and that the LTE V2X and NR V2X use cases do not overlap with each other. In other words, LTE V2X duplicates one subset of DSRC use cases and NR V2X duplicates another set of DSRC use cases. We are unaware of any use case that can be supported by a 3GPP protocol that cannot also be supported by DSRC or IEEE NGV. These scenarios provide a template for considering a wide range of possible implications of having multiple V2X technologies share the 5.9 GHz band. We analyze each scenario in turn.

Analysis of Scenario (A): DSRC only

- Scenario (A) represents the status quo. DSRC is used in all 7 channels, and only DSRC is deployed in the band. There are no sub-bands.
- To reiterate, V2X is an ad hoc method of communication, with no base station or central manager. Devices communicate directly, meaning direct protocol interoperability at all layers of the communication stack is needed for this technology. With interoperable technology, devices can communicate with all neighbors, even if they do not know about each other's presence. This increased vehicle population of communicating vehicles maximizes the societal benefits of the DSRC spectrum and the DSRC equipment investments.
- With these benefits in mind, Congress mandated technology interoperability in the TEA-21 act, and the FCC, on advice from USDOT, subsequently achieved this in regulations requiring DSRC for 5.9 GHz band. Scenario A reflects the current state of regulations and deployment.
- Importantly, the FCC stated that there are four reasons for adopting a single standard: "interoperability, robust safety/public safety communications, to promote deployment of DSRC while reducing costs, and consistency with Congressional intent" [FCC-03-324A1, page 12]. The four reasons are as valid today as they were then, perhaps more so now that DSRC is fully standardized, tested, and in deployment.
    - Some argue that the FCC incorporated DSRC into the regulation only because no alternative existed at the time. But, the FCC's own explanation for their decision shows this argument to be incorrect. By citing interoperability as first among the reasons for the decision, the FCC anticipated the potential emergence of alternatives to DSRC. There would have been no reason to require DSRC or to articulate the detailed reasons if there would never be an alternative.
    - Some might also argue that simple "application" layer interoperability is sufficient, rather than lower layer technology interoperability, and the FCC notes that one commenter advocated for that

approach. However, they also note that all other commenters "urge us to adopt a standard" and that USDOT also supported a single standard for interoperability based on "historical experience"[14]. As noted in our answer to Q1 above, the direct nature of V2X requires that devices interoperate at all layers of the stack, not only at the application layer. Advocates for mere application layer interoperability seem to rely on the existence of forwarding devices to connect devices that cannot interoperate directly. But, such reliance is counter to the basic principle that V2X, especially for safety applications, should work everywhere and all the time.[15] In adopting the DSRC standard, the FCC clearly chose technology interoperability.

- In addition to these reasons, having a single compatible technology family in the band has advantages for efficiency and flexibility in band usage.
  - The DSRC band is conceived in regulations and industry standards as a unitary whole, not as seven independent channels. The band was designed in this fashion so as to support a number of DSRC functions that would enable safety benefits for the technology.
  - The DSRC deployment model is that most vehicles need only two radios to efficiently utilize the entire seven-channel band. One radio takes on a channel switching role, moving from channel to channel to access applications/information as and where they become available. In the analysis of Scenario (C) below, we will see that introduction of incompatible non-DSRC technologies impedes this efficient model by reducing the number of vehicles that will communicate with one another, and potentially adds costs that can discourage deployment.
  - The IEEE 1609.3 and 1609.4 standards specify a flexible paradigm by which a switching DSRC radio can learn about available applications and switch to the channels on which they are offered.
  - Most DSRC applications are assigned to channels based on a variety of factors, including dynamic local conditions such as interference. Site-licensed RSUs must coordinate channel usage to avoid interfering with each other. Proximate RSUs may also operate on different channels to avoid that interference, regardless of the applications they offer.
  - Flexible mapping of applications to channels also allows multiple targeted instances of a given application to be supported in multiple channels at the same time and place, to improve performance.
    - One example is if two truck platoons that initially use the same channel encounter each other, and one or both move to other channels to avoid interfering with each other.
    - Another example is if a highway cloverleaf supports multiple instances of cooperative merging. Those instances might be placed in different channels for different interest groups, e.g. in four different channels based on whether the merge is north-bound, south-bound, east-bound, or west-bound. Again, this avoids unnecessary channel competition and interference among these critical applications. A given vehicle participates in at most one instance of the application.
    - Still another example is if a given service type is supported by different providers in different channels within a certain region. In this case, the information announcement message can indicate which channel to use based on which provider the vehicle seeks to connect with. A specific example might be probe data collection by different providers of traffic management services.
  - These band usage characteristics are captured in the industry-standard SAE J2945/0 band usage plan and are consistent with existing FCC designations of the various channels by function (service/control), by power, and by restriction (safety-only or safety and non-safety). In particular, the FCC designation of six of the channels as service channels facilitates this flexible mapping of applications/services to channels.

[14] FCC 03-324 Report and Order, December 17, 2003, page 12

[15] In addition to the problem of unavailability, it is not clear that a forwarding device could meet stringent requirements for latency, reliability, etc., or that it would be feasible to keep forwarders updated as new technologies are introduced.

- Another advantage of a single compatible technology is privacy preservation. USDOT and the auto industry have gone to great lengths to make it difficult to identify vehicles based on their transmissions. A single transmission protocol helps to support privacy.
- The USDOT and automotive industry have long understood that voluntary deployment of cooperative technologies like V2X faces steep deployment challenges that traditional technologies like radar sensors or air bags do not. An OEM or road authority considering deployment has difficulty assessing the long-term benefits to its customers, because those benefits are a function of the penetration of OBUs and RSUs, which is primarily determined by the deployment decisions of other stakeholders that are outside of its control. Those stakeholders, in turn, face similar uncertainties that make unilateral deployment commitments difficult.
    - This is true even when there is only one candidate technology, as in Scenario A. The challenges that DSRC faces for wide spread deployment have little to do with the communication technology itself, because testing indicates that the technology is feasible and effective. Alternate technologies would face the same challenges.
    - Further, we agree with NHTSA's assessment in their 2014 ANPRM on this matter where NHTSA stated that *"V2V capability will not develop absent regulation, because there would not be any immediate safety benefits for consumers who are early adopters of V2V."*
    - We have seen some stakeholders exercise leadership in this space. For example, GM is already in deployment, Toyota in Japan (with more than 100,000 DSRC-equipped cars on the road), and Volkswagen in Europe (with deployment scheduled to begin in a few months). State and local road authorities have also responded to the challenge in encouraging numbers, with a majority of US states expressing a desire to deploy DSRC roadside units.
    - Nevertheless, DSRC commitments in the US have not yet achieved a level that represents a self-sustaining critical mass. Some important stakeholders are in a "wait and see" mode, perhaps anticipating an eventual mandate, or expecting that voluntary deployment risks will become smaller over time. If the automotive industry and government stakeholders cannot achieve this critical mass with DSRC, with its strong foundation of technology and investment, we believe it is also unlikely that it can be achieved with an alternative technology (as this early adopter problem is not exclusive to DSRC technology).
- The immediate question for this RFC, then, is whether the introduction of alternative technologies helps or harms society's ability to realize the full benefits of V2X and the 5.9 GHz spectrum by increasing or decreasing the probability of long-term success for V2X. Our analysis below shows that the introduction of a compatible technology like IEEE NGV helps, while introduction of incompatible technologies like LTE V2X or NR V2X harms.

Analysis of Scenario (B): DSRC and IEEE NGV

- In Scenario (B), both DSRC and IEEE NGV are used in every channel. No V2X technologies other than DSRC and IEEE NGV are deployed. There are no sub-bands.
- The scope of the IEEE NGV amendment includes the following key statement of requirements:

  "This amendment shall provide interoperability, coexistence, backward compatibility, and fairness with deployed [DSRC] devices.[16]"
- Same-channel coexistence is achieved by employing a common packet header on DSRC and IEEE NGV packets. DSRC and IEEE NGV devices can then detect all transmissions of both types, which is critical for fair channel access under a listen-before-talk protocol.
- Backward compatibility is achieved through the combination of same-channel coexistence and including DSRC packet reception functions in every IEEE NGV device.

[16] "802.11 NGV Proposed PAR", IEEE 802.11 document 11-18-0861/r9, November 13, 2018

- Interoperability is achieved when an IEEE NGV device sends a packet using a format that can be decoded by a DSRC receiver (the packet may or may not include additional information intended just for IEEE NGV receivers).
    - We borrow and endorse NHTSA's definition of communication interoperability: "The ability of vehicles to both transmit and receive V2V communications from all other vehicles equipped with a V2V communications technology" [NHTSA V2V NPRM, pages 11-12]
    - The NHTSA definition is consistent with the definition of interoperability agreed by the IEEE NGV task group: "**Interoperability –** IEEE 802.11p devices to be able to decode at least one mode of transmission of IEEE 802.11bd devices, and IEEE 802.11bd devices to be able to decode IEEE 802.11p transmissions." [Note: recall that IEEE 802.11bd is another name for IEEE NGV]
- The combination of same-channel coexistence, backward compatibility, and interoperability enables IEEE NGV to provide a seamless evolution path from DSRC.
    - In the future, an IEEE NGV device can decide packet by packet whether to transmit in a DSRC format, an IEEE NGV format, or both.
    - Example: An IEEE NGV device sending a BSM would use an interoperable transmission format when it has DSRC neighbors. It may or may not, perhaps depending on channel loading conditions, also send the BSM in an IEEE NGV-packet format to enhance the reception probability for IEEE NGV-capable neighbors. At a different time or place, the IEEE NGV device might only send the BSM using the IEEE NGV format if it has only IEEE NGV-capable neighbors.
    - For other use cases where the IEEE NGV device knows that all of the intended recipients are IEEE NGV-capable, it will only transmit in the IEEE NGV format (but, of course, those transmissions are detectable by DSRC devices for fair channel sharing). For example, the service might involve unicast communication with a device known to be IEEE NGV-capable. As another example, a future service might, through industry consensus, only be supported for IEEE NGV devices.
    - Any use case, including those supported by the BSM, can migrate from DSRC to IEEE NGV over time as the makeup of the OBU and RSU population evolves.
- Same-channel coexistence has been a common requirement of IEEE 802.11-based evolution for decades (802.11a/b/g/n/ac/ax). IEEE NGV adds an explicit requirement for backward compatibility and interoperability, which are critical in the ad hoc V2X environment.
- The requirements for same-channel coexistence, backward compatibility, and at least one mode of interoperability do not significantly constrain the innovation opportunities for advanced PHY and MAC features in IEEE NGV, just as they have not constrained the IEEE 802.11 protocol from advances in performance through six generations over roughly twenty years of evolution. Any performance improvement that we can expect from a 3GPP protocol can also be expected to be supported by IEEE NGV, for example in the areas of state-of-the-art error coding, waveform design, channel estimation, antenna requirements, or channel access.
- This DSRC evolution paradigm based on same-channel coexistence, backward compatibility, and interoperability can be extended into future generations of IEEE-based DSRC as well. In that sense, IEEE NGV and DSRC are technologies that provide a pathway for innovation, while still satisfying the original Congressional intent for interoperability in ITS. In other words, technological innovation can coexist with interoperability.
- Key international groups of V2X experts have endorsed IEEE NGV's strategy for seamless evolution and offered in public liaison letters to work with IEEE NGV to realize this strategy, including the SAE DSRC Technical Committee, the IEEE 1609 Working Group, and the Car2Car Communications Consortium.[17,18,19]
- In summary, the introduction of IEEE NGV (next generation DSRC) is fully consistent with existing regulations and industry standards, it creates a seamless evolution path from DSRC, and it allows cost-effective and spectrally efficient operation.

[17] Liaison from SAE DSRC TC re: NGV Use cases and requirements, IEEE 802 document 11-18-2097, December 4, 2018

[18] Liaison from IEEE 1609 WG re: NGV Use cases and requirements, IEEE 802 document 11-19-0027, January 8, 2019

[19] Liaison from CAR 2 CAR Consortium re: NGV Use cases and requirements, IEEE 802 document 11-18-1754r1, October 17, 2018

- How does the introduction of IEEE NGV into the DSRC ecosystem impact deployment decisions? It encourages DSRC deployment now and it will encourage IEEE NGV deployment in the coming years when it is fully standardized and tested.
  - A DSRC device continues to use the band in exactly the same way as it does today, as codified in industry-consensus standards like IEEE 1609.3, IEEE 1609.4 and SAE J2945/0. As one example, the J2945/0 band usage plan is unchanged by the introduction of IEEE NGV, and no V2X applications need to be implemented redundantly in separate spectrum simply due to introduction of different V2X technology. As another example, a vehicle can continue to efficiently utilize all seven channels of the band with just two radios.
  - A DSRC device will continue to be able to communicate with all future V2X devices (DSRC and IEEE NGV) for its entire lifetime. The long-term value of a DSRC deployment today is ensured.
  - The introduction of IEEE NGV as the evolution path for DSRC removes one uncertainty from the DSRC deployment equation, thus encouraging DSRC deployment decisions now and for the coming years. In this way, IEEE NGV <u>enhances</u> the value of DSRC deployments.
  - IEEE NGV requires no band fragmentation and no investment in multiple technologies.

Analysis of Scenario (C): DSRC/IEEE NGV plus LTE V2X and NR V2X

- In Scenario (C), the spectrum is fragmented into three sub-bands. DSRC and IEEE NGV are deployed in three channels (30 MHz). LTE V2X is deployed in 20 MHz. NR V2X is deployed in 20 MHz.
- For Scenario (C) we initially assume each sub-band is reserved exclusively for the identified technology: DSRC, LTE V2X, and NR V2X. After considering the implications of that assumption, we will explore some favorable implications of relaxing it (Scenarios (C+) and (C++)).
- Reserving each sub-band for exclusive use of one technology is consistent with the conventional assumption that these three technologies are incompatible, i.e. cannot coexist in the same channels. We believe that assumption is accurate for the case that the 3GPP technologies are implemented as currently specified and for the case that no sharing rules accompany the use of the band by 3GPP technologies.
  - When LTE V2X and NR V2X operate <u>as currently specified/conceived</u>, there would be a high probability of unacceptable interference when sharing a channel with DSRC or with each other. For example, LTE V2X and DSRC use completely different rules to arbitrate channel access. An LTE V2X transmitter would likely be "hidden" from a DSRC transmitter, and vice versa, with the result that overlapping transmissions would occur frequently, with attendant packet loss.
  - If the 3GPP technologies can be <u>modified</u>, there is a possibility that they could share a channel with DSRC. As an example, if LTE V2X packets start with an IEEE 802.11p packet preamble, which uses only 40 microseconds out of each 1000 microsecond timeslot, and if LTE V2X transmitters defer channel access when an IEEE 802.11p packet transmission is using the channel, there is a possibility of better same-channel coexistence. The initial LTE V2X symbol, which would include this 40 microsecond preamble, does not carry application data, so this concept would have no impact on the ability of LTE V2X to support any V2X applications, including safety applications. For this LTE V2X-overlay concept many additional details would need to be considered, but we point out that the potential exists if parties are willing to explore it. It is sometimes said that LTE V2X could not be modified as noted here because it does not listen before transmitting. But, this is inaccurate. To execute LTE V2X's resource selection algorithm a device must monitor all channel resources for one second. In order to be prepared to select resources as needed, the device will always be listening, and thus capable of detecting DSRC transmissions. We understand that some C-V2X proponents consider modifications to the 3GPP protocols to be a "non-starter." So, while we think there is value in considering the option of modifying the C-V2X protocols, we do not discuss it further in this RFC.
  - If 3GPP technologies operate with no modification to the protocol, but <u>with the addition of sharing rules</u> with respect to the incumbent DSRC technology, there are good possibilities for longer term

same-channel co-existence. These are explored further in discussions below (Scenarios (C+) and (C++), after completion of the initial analysis of Scenario (C).

- Fragmenting the band for incompatible technologies in Scenario (C) carries several profound disadvantages compared to Scenarios (A) and (B): spectral inefficiency, loss of interoperability, increased equipment cost, increased interference, and imposition of an unfair burden on thousands of already-deployed DSRC devices.
    - Duplication of services in two or more channels that could be delivered in one channel, solely for the purpose of allowing the transmitter to choose among incompatible technologies, is by definition spectrally inefficient and given the high value of the 5.9 GHz band this inefficiency is contrary to the public interest. Duplication of DSRC services is the intent of LTE V2X advocates, as seen clearly in 3GPP use case documents and numerous public presentations.
        - The principle cost of the spectral inefficiency associated with fragmentation is an overall reduction in the capacity for delivering V2X services over DSRC. 30 MHz can support less than half as much communication as the 70 MHz that is available under existing rules. The reduction in capacity would result in both fewer use cases supported and reduced communication performance for those use cases. As an example of reduced performance, consider that SAE J2945/1, which is the industry-consensus standard that forms the basis for the technical rules in the NHTSA V2V NPRM, is designed to manage channel congestion efficiently when nearly all of Channel 172 is available for use by BSMs. With the reduction in capacity associated with band fragmentation, BSMs would no doubt share a channel with many additional applications, and the packets of those other applications would compete with and impair the performance of those BSMs (and vice versa). Significant further research would be needed to determine if crash-imminent safety applications can still be effective under a band fragmentation regime.
        - Several groups of stakeholders, including 5GAA, are on the record stating that 30 MHz is not sufficient spectrum to support envisaged road safety and traffic efficiency use cases[20]. The need for more than 30 MHz of spectrum is supported by analyses of aggregate bandwidth requirements of V2V safety, pedestrian safety, I2V safety and mobility, platooning and Cooperative Adaptive Cruise Control (C-ACC), cooperative perception, and other safety, mobility, and automation applications.[21]
    - An additional cost of band fragmentation is the loss of interoperability among devices that support a given service using incompatible technologies. Interoperability is at the heart of the reason that the 5.9 GHz band was allocated as a public resource, and as noted is one of the four cited reasons given by the FCC for requiring adherence to DSRC. As an assessment of the cost of lost interoperability, consider the difference between full BSM penetration with DSRC and split BSM penetration with 50% of vehicles using DSRC and 50% using LTE V2X. In the case of split penetration, only half of the imminent crash situations will involve two vehicles that can communicate interoperably, and thus only half as many crashes can be addressed through safety applications on non-interoperable V2V networks.
    - One way for an automaker or road authority to mitigate reduced safety benefits from the loss of interoperability associated with band fragmentation is to expend the additional cost of deploying duplicative radios for each additional incompatible technology. In the case of Scenario (C), this implies that in addition to the cost of two DSRC radios to serve the three DSRC channels, the automaker would at a minimum also need to pay for two additional independent radio systems, one for LTE V2X and one for NR V2X.[22] The DSRC, LTE V2X, and NR V2X radio systems need to be independent because all may need to be active at the same time, e.g. receiving a DSRC BSM, receiving an LTE V2X BSM, and receiving an NR V2X platooning message. This is the minimum extra cost to mitigate the loss of interoperability; the actual cost could be more depending on

[20] See "5GAA LS to CEPT FM on 5855-5925 MHz band and 5925-6425 MHz band", Document S-170118, July 2017

[21] For example, see ETSI ERM (15)055116a1, "Request for information about 63-64 GHz", March 26, 2015

[22] If additional incompatible technologies are introduced, and the band further fragmented, additional radio costs would be incurred to remain connected to all OBUs and RSUs.

channelization of the sub-bands. Every part of the radio system would need to be duplicated for each technology: radio chipset, processor, analog electronics, cables, antennas, etc. These extra costs would also unlikely support any new use cases or increase potential safety benefits of V2X. Thus, the loss of interoperability in this scenario would lead to either increased costs or reduced safety benefits.

- Fragmenting the spectrum into sub-bands is also likely to increase interference and decrease communication performance.
  - As noted above, under the existing rules there is flexibility to assign information/applications to channels based on local interference considerations and service needs. With band fragmentation, there would be a reduction in the ability to coordinate among proximate RSUs to use different channels. As a result, many I2V information/applications would need to share one or two channels. There could also be a loss of our ability to create multiple instances of a given service on different channels to avoid excess contention and interference.
  - The SAE J2945/0 channel usage plan includes a feature of channel interleaving designed to mitigate cross-channel interference between proximate vehicles. With this feature, it is very unlikely that one vehicle is transmitting while a nearby vehicle is attempting to receive on an adjacent channel. With band fragmentation this cross-channel mitigation feature would be eliminated or significantly restricted.
  - It is too soon to say whether there would be increased interference from operation of incompatible technologies in adjacent sub-bands. Significant testing, including for the not-yet-specified NR V2X, will be needed.
- Band fragmentation would bring a significant change to existing rules by prohibiting DSRC operation in sub-bands that would be allocated for other technologies. Current commercial deployments, USDOT-sponsored deployments (pilots and test sites), and state & local government deployments already represent thousands of DSRC devices. All of these were designed to work with the existing rules that permit DSRC operation throughout the band. Furthermore, USDOT recently affirmed that "there are more than 70 active deployments" and that deployed devices are "actively utilizing all seven channels of the 5.9 GHz band"[23]. Assuming that the prohibition on DSRC operation under Scenario (C) applies retroactively, this imposes an unfair burden on equipment owner-operators who deployed in compliance with licensing requirements. This development could also have a chilling effect on stakeholders considering additional deployments in the coming years as the lack of regulatory consistency could change the potential benefits of future deployments.
- Fragmenting spectrum according to Scenario (C) carries an additional long-term cost. 3GPP assumes that LTE V2X will be used to implement one set of use cases perpetually, while NR V2X would implement a distinct set. Thus, a given use case is tied to an older technology (e.g. LTE V2X), even when a later generation (e.g. NR V2X) is capable of supporting the requirements of that use case. This arrangement would go against promoting innovation in utilizing the spectrum. Significantly, the most important use case for V2X, the Basic Safety Message, would be relegated to the first-generation C-V2X technology. Artificially tying applications to specific access technologies is contrary to sound layer separation principles. In contrast, the evolution from DSRC to IEEE NGV would not have this same arrangement. Any use case implemented initially over DSRC, including the BSM, could eventually migrate to IEEE NGV and to later generations as well.
- A point about fragmenting the spectrum in this fashion is that it is neither technology neutral nor scalable. Fragmentation according to this proposal merely has regulators picking two or three "winners" instead of one. When, as in Scenario (C), only one technology is permitted in each of three sub-bands, we have three technology-specific regulations instead of one. Looking towards the future, the same problem would exist for the next communications protocol that is developed in this space. However, the band can only be fragmented so many times. Technology will continue to

[23] "U.S. Department of Transportation's National Highway Traffic Safety Administration issues statement on safety value of 5.9 GHz spectrum", October 24, 2018

improve, and protocols will continue to be updated. As future incompatible technologies seek permission to use the band, there will be no way to accommodate them via further fragmentation.

- Collectively, these disadvantages associated with band fragmentation will likely have the effect of increasing costs, decreasing benefits, and reducing incentives for deployment of V2X (for all technologies, not just DSRC). As noted above, even under the single-technology scenario (A) there are significant deployment challenges related to costs, benefits, and uncertainties. Those will almost certainly be exacerbated under band-fragmentation Scenario (C). We are concerned that the existence of competing, non-interoperable technologies in the 5.9 GHz band will likely delay or even halt V2X deployment in the United States.

We now consider two potential modifications of Scenario (C) that could mitigate some of its disadvantages.

1. Scenario (C+): Scenario (C) plus the addition of sharing rules
2. Scenario (C++): Scenario (C+) plus universal use of DSRC for core safety use cases

Analysis of Scenario (C+): Scenario (C) plus the addition of sharing rules

- While C-V2X protocols are not designed for effective packet-by-packet coexistence in the same channel with DSRC, it may be possible for them to share a channel on a broader time and space basis. The key idea is that a C-V2X device can be augmented with simple DSRC detectors for each 10 MHz channel it occupies. When the C-V2X device detects a DSRC signal on a given 10 MHz channel, the device simply avoids occupying that channel until DSRC signals are no longer detected. At any time and place the C-V2X device is able to utilize those channels not in use by incumbent DSRC devices.
- This approach achieves a dynamic sharing of spectrum between otherwise incompatible technologies, with no need to create a technology-specific sub-band or to predefine regions in which only one or the other technology is permitted to operate. It avoids the risk of stranding spectrum; if one technology fades away after failing to achieve wide scale deployment, the other can use the entire sub-band at all times and places.
- This approach also avoids most of the interference that would otherwise accompany the introduction of incompatible C-V2X protocols into the same channel as DSRC.
- The concept behind Scenario (C+) is actually described in 5GAA's coexistence position paper, i.e. one V2X technology is preferred in a sub-band, and a second V2X technology is allowed to operate there if it uses a detect-and-vacate function.[24]
- Scenario (C+) has several advantages over the single-use-spectrum concept underlying Scenario (C):
    - DSRC devices currently deployed or in planning stages for deployment require no change in hardware, software, or operational plan. This applies not only to the commercially deployed systems, but also to the more than ten thousand devices entering deployment through the USDOT Pilot Deployments.
    - The industry-consensus SAE J2945/0 channel usage plan requires no changes, and thus the delays that would be associated with developing and testing a new channel plan are avoided.
    - The incumbent status of DSRC is recognized, respected, and maintained.
    - There is no reduction in network capacity available for DSRC, and thus no increase in DSRC self-interference from having to compress applications from seven channels into three channels.
    - While Scenario (C+) mitigates these aspects of Scenario (C), it does not fundamentally alter the primary disadvantages of loss of interoperability, likely increased cost, and loss of V2X capacity due to redundant implementation of key use cases over different V2X technologies. Scenario (C+) is still inferior to Scenarios (A) and (B).
- There could be a concern that C-V2X deployments will have a reduced effectiveness because of the need to defer to DSRC. But, if C-V2X proponents are correct that DSRC use of the channels they wish to occupy will never be substantial, there would be few instances where such temporary deferral would be needed.
- Detection of DSRC is a well-established function, achieved with a simple pattern matching circuit that looks for the deterministic DSRC packet preamble. Such circuits occupy a negligible portion of every existing Wi-Fi system today. DSRC detectors could be added to any C-V2X system; it would not be necessary to integrate these detectors into the C-V2X silicon.

[24] Coexistence of C-V2X and ITS-G5 at 5.9 GHz (Figure 3), 5GAA, April 5, 2018

- C-V2X systems following these sharing rules could be considered as licensed secondary users of the band through an FCC rulemaking, providing a robust opportunity for C-V2X deployment.
- A C-V2X system that has a capability to operate in more than 10 MHz need only defer transmissions in the 10 MHz channel(s) in which DSRC activity is detected. It could continue using other 10 MHz channels on which no DSRC activity exists. The C-V2X protocols already sub-divide channels into small sub-channels of less than 10 MHz, and they already recognize the concept of available and unavailable resource pools, so it would be relatively easy to implement the transmission deferral on a channel by channel basis when detection occurs.

Analysis of Scenario (C++): Scenario (C+) plus universal use of DSRC for core safety use cases

- Scenario (C+) could be further improved if coupled with a requirement or industry consensus that every vehicle and roadside unit would implement core safety use cases using DSRC/IEEE NGV, while allowing C-V2X as an optional complementary extension.
- C-V2X could be used to redundantly support core safety use cases and/or to support non-core use cases.
- Requiring DSRC as a default for core use cases is the approach adopted in the European Commission's recent Delegated Regulation.
- Scenario (C++) addresses two key disadvantages of Scenarios (C) and (C+):
    - Interoperability: stakeholders would communicate for core safety use cases using (at least) a single interoperable V2X technology family, DSRC/IEEE NGV, so all devices would interoperate for these use cases.
    - Cost: stakeholders would have the option to deploy with a single technology, DSRC/IEEE NGV, which would continue to efficiently cover the entire band with two radios. No stakeholder would in effect be forced to choose between higher costs and loss of potential benefits from interoperability for core use cases. Extra costs to support C-V2X technologies would be limited to those stakeholders who specifically wish to deploy them.
- Scenario (C++) would protect investments in DSRC for the entire lifetime of each device deployed today or in the future. Each DSRC device would fully realize the benefits of deployment through interoperable communication with every other vehicle and roadside unit. For these reasons, Scenario (C++) is preferable to Scenarios (C) and (C+)
- Scenario (C++) is still associated with certain disadvantages compared to Scenarios (A) and (B), namely:
    - Loss of interoperability and/or extra costs associated with support of non-core use cases. The magnitude of this disadvantage will depend on the definition of the set of core safety use cases. The use cases considered in the EU Delegated Regulation constitute a possible starting point for a discussion of the definition of such a set.
    - Spectral inefficiency associated with choices that may be made to implement some core use cases redundantly over multiple V2X technologies (e.g. if C-V2X proponents send BSMs over both DSRC/IEEE NGV in Channel 172 and over LTE V2X in the upper 20 MHz of the band).
    - Possible residual interference due to imperfect detect-and-vacate operation.
    - For these reasons, Scenario (C++) is less desirable than Scenarios (A) and B).

We summarize our judgment about the relative desirability of the scenarios analyzed above in the following graphic:

| Best | | | | Worst |
|---|---|---|---|---|
| **Scenario B** | **Scenario A** | **Scenario C++** | **Scenario C+** | **Scenario C** |

Analysis of Scenario (N): True technology neutrality

- Question 2 also asks about the case where "any communication technology" is allowed in the band, in other words if the spectrum regulation is truly technology neutral. It is important to recognize that what 5GAA requests in their FCC waiver petition is not a technology neutral regulation. By asking to prohibit DSRC from the 20 MHz sub-band that they seek, they hope to create two technology-specific regulated bands instead of one. And, that would become three technology-specific sub-bands if they follow through to request an additional allocation for NR V2X (which does not coexist with either LTE V2X or DSRC).
- By contrast, with a truly technology neutral band, technologies would necessarily share the same channels (which may or may not be aligned between technologies) and we predict that absent strict interference avoidance measures there would be significant interference with incumbent DSRC performance (or indeed any V2X performance) that would render the band unsuitable for support of safety applications that form the heart of the DSRC mission.
    - To facilitate low latency, reliable, ad hoc, and decentralized V2X communication, DSRC uses a listen-before-talk channel access mechanism, which assumes all devices follow the same protocol rules. If other technologies do not use the same packet header and the same channel alignment, DSRC devices will typically not detect and defer to those other transmissions, leading to "hidden terminal" packet collisions that lead to lost or delayed communication opportunities. When all technologies are permitted to operate in the same time and place, there is no reasonable bound on the amount of packet loss or delay that DSRC devices might experience.
    - DSRC devices use a form of energy detection to defer to non-DSRC transmissions, but typically that deferral only occurs for transmissions that are quite close to the DSRC transmitter. There would generally be a great deal of interference at DSRC receivers from non-DSRC transmissions that are not close enough to trigger energy detection at the DSRC transmitters.
    - LTE V2X would also be adversely impacted by total neutrality. An LTE V2X device assumes competing users of the channel have periodic transmissions. If LTE V2X shared a channel with a different technology, LTE V2X would be unable to effectively schedule traffic at times that are not being used by those other devices – a different form of the hidden terminal problem.
    - In summary, we believe that total technology neutrality is incompatible with the mission of V2X to support safety, traffic efficiency, environmental sustainability, and automation use cases. We therefore believe that total technology neutrality is infeasible as a V2X spectrum policy. We note that the European Commission is moving in the opposite direction from neutrality, issuing a Delegated Regulation that requires conformance to a single set of ITS G5 (European DSRC) technology standards for the support of critical use cases.

3. To what extent is it technically feasible for multiple V2X communications technologies and protocols to be interoperable with one another? Why or why not? Can this be done in a way that meets the performance requirements for safety of life applications, as they were discussed in the V2V NPRM? What additional equipment would be needed to achieve interoperability or changes in standards and specifications? What is the projected cost of any necessary changes? How soon can these changes and equipment prototypes be available for testing?

It is key to this question to define "interoperability". Our definition is found in our answer to Question 1, and is consistent with the definitions employed by the FCC, USDOT, and Congress.

Almost by definition, technologies that are developed independently will not be fully interoperable at the technology level. As we note in our response to Question 1, when a technology is developed so that it represents a superset of another technology, interoperability between devices is possible using the common subset. This is what IEEE NGV is designed to achieve with respect to DSRC. The ability for IEEE NGV to provide innovation without sacrificing interoperability is a positive development for the long term success of V2X in the US and other regions.

By contrast, LTE V2X was not designed to be interoperable with DSRC, and NR V2X is not being designed to be interoperable with either DSRC or LTE V2X. The implications of this lack of interoperability are discussed in detail in our answer to Question 2 above, especially in the analysis of Scenario C.

We also note that at the time of defining the service rules for the 5.9 GHz band, the FCC received a comment that they should accept mere "application interoperability" as a substitute for technology interoperability. They rejected that comment, and we agree with that decision.

4. To what extent is it technically feasible for different generations of the same V2X communications technologies and protocols to be interoperable with one another? Why or why not? Can this be done in a way that meets the performance requirements for safety of life applications? What additional equipment or changes in standards and specifications would be needed to achieve interoperability? What is the projected cost of any necessary changes?

Some detailed aspects of this question have been addressed in response to question 2. We are also providing additional information in response to this question.

It is easier for different generations of a given V2X technology to be interoperable than for independent technologies. This is what is achieved with IEEE NGV relative to DSRC. IEEE NGV can be considered a new generation of DSRC, part of a common DSRC/IEEE NGV family.

The key that enables IEEE NGV to be interoperable with DSRC is that it achieves fair and efficient same-channel coexistence. An IEEE NGV device can transmit and receive on the same channel as a DSRC device. An IEEE NGV receiver is designed to always be capable of decoding either DSRC messages or IEEE NGV-specific messages. An IEEE NGV transmitter has at least one mode of transmission that a DSRC receiver can decode. Since the two device types can coexist on the same channel, the IEEE NGV receiver will never miss a DSRC message and the IEEE NGV transmitter can always transmit such that a proximate DSRC device can decode the message. In this way, IEEE NGV and DSRC are interoperable generations of the same technology.

Interoperability across generations is not guaranteed for other technologies. The cellular community has generally chosen not to make their different generations interoperable. We see this currently in 3GPP's choice not to attempt to make New Radio V2X (a $5^{th}$ generation technology) even same-channel coexistent with LTE V2X (a $4^{th}$ generation technology), let alone interoperable. This approach works in cellular base station communication. A base station is typically capable of communicating using one of several different generations of technology, and it can translate between generations when it forwards multi-hop packets. But, as we discuss in detail in Question 2, lack of interoperability has strong negative effects for vehicles and infrastructure devices in V2X communication.

5. Even if they are interoperable across different technologies and generations of the same technology, would there be advantages if a single communications protocol were to be used for V2V safety communications? What about other V2X safety applications, such as those involving V2I and V2P communications?

In the scenario of IEEE NGV and DSRC, we do not believe there would be an advantage in prohibiting BSM transmissions from using IEEE NGV in the future. To restate part of our answer to Question 2:

> An IEEE NGV device sending a BSM would use an interoperable transmission format when it has DSRC neighbors. It may or may not, perhaps depending on channel loading conditions, also send the BSM in an IEEE NGV-packet format to enhance the reception probability for IEEE NGV-capable neighbors. At a different time or place, the IEEE NGV device might only send the BSM using the IEEE NGV format if it has only IEEE NGV-capable neighbors.

Migrating BSM transmissions over time to IEEE NGV can be done without sacrificing compatibility with DSRC-equipped vehicles and without adding to equipment costs.

This migration path from DSRC to IEEE NGV is not available within C-V2X, i.e. from LTE V2X to NR V2X. NR V2X does not interoperate and cannot coexist with LTE V2X on the same channel. The BSM transmitter therefore cannot make a packet-by-packet decision about sending the BSM using one or the other protocol within one channel, as it can with DSRC and IEEE NGV. BSMs would remain with the older (4G) LTE V2X and would not migrate to newer (5G and beyond) generations of C-V2X. As stated above, we believe that this solution would impede technological innovation for some of the core V2V use cases.

This compatibility also has a temporal factor. A V2X-enabled vehicle introduced in 2022 should be able to communicate with a future car with V2X in 2032. It suggests that use of the same technology family for a long period is essential to achieve the above-mentioned benefits.

Commercial mobile communication devices (i.e. smart phones) and their network infrastructure will evolve over time and consumers are likely to adopt new technologies by replacing their devices. Therefore, no one can guarantee those personal mobile devices in a future with whatever a new communication technology can effectively communicate with present V2X-enabled vehicles and infrastructure over a long period of time. On the other hand, since those mobile devices may have newer technologies, network-based data exchange using mobile carrier's networks may pose potential opportunities for intelligent transportation systems but it is P2N to I/V (Pedestrian to Network to Vehicles and/or Infrastructure) and outside of the scope of this direct V2X communications discussion.

More generally, the question refers to "V2V safety communications", which can extend beyond BSM exchanges to include some applications that utilize unicast communication. In that case two IEEE NGV-capable devices could immediately utilize the advanced IEEE NGV format, irrespective of the capabilities of neighbors that are not part of the unicast exchange. We add two points: 1) DSRC meets all of the requirements for all safety, mobility, environmental, and automation use cases that are commonly discussed in the automotive community. 2) LTE V2X is incapable of unicast communication.

With respect to V2I and V2P safety applications, the same principles outlined above apply. While requirements may vary from application to application, we think that V2I and V2P safety applications generally have the same stringent communication requirements as the BSM. There should be no distinction between the access layer protocols employed by vehicles, roadside units, and personal devices. Spectral efficiency and cost are optimized if all of these devices communicate using the same protocol on the same channel. Strict segregation of any application from other applications, e.g. by different spectral channels or using time division to create virtual channels, would inherently risk increased inefficiency by stranding resources that are allocated only for one type of communication when others could have used them.

We also note that DSRC/IEEE NGV is well suited for implementation in personal devices. Virtually all smart wireless devices today and for the foreseeable future will have an 802.11 chipset. Supporting DSRC/IEEE NGV in an 802.11 chipset is very simple; the primary distinction between DSRC and "conventional" 802.11 is that DSRC turns certain functions off (related to Access Point communication), so it is easy to support DSRC in a device that supports conventional 802.11, and most DSRC chipsets today are also 802.11 chipsets. In addition there are some portable devices today, e.g. certain tablets, that support 802.11 but not cellular communication. We also note that a conventional LTE chipset will not support LTE V2X, and it would take the addition of new features to enable LTE V2X (for example, features to schedule packets, which conventional LTE user equipment does not need).

6. How would the development of alternative communication technologies affect other V2I and V2P communications, such as those supporting mobility or environmental applications? Do these applications have the same or different interoperability issues as V2V safety communications? Do different V2X applications (e.g., platooning) have different communication needs, particularly latency?

Some aspects of this question has already been addressed in questions 2 and 5. We provide additional information below.

First, virtually all V2X applications are intended to operate with high mobility vehicles, whether the application is for safety, mobility, environment, or automation. That means all applications—especially safety applications—would have stringent latency requirements. So, it is unlikely that an alternative technology that cannot achieve these latency needs will be effective in supporting even non-safety applications.

DSRC is specifically designed to provide very low-latency communications. DSRC devices can transmit messages without waiting for a future scheduled timeslot, therefore channel access under DSRC (and IEEE NGV) can be as low as zero. It is typically less than one millisecond (<1ms), and is unrelated to the periodicity of packet generation at the application. This DSRC communication, including its countermeasures for packet collisions, has been validated through many field trials.

On the other hand, LTE V2X is designed to transmit packets according to a strictly periodic schedule. Its "semi-persistent scheduling" uses future reserved timeslots, which naturally incurs relatively high channel access latencies, especially when the application generating the packets is not strictly periodic. As the 5GAA test report shows, even for periodic packets LTE V2X latencies are usually more than ten milliseconds (>10ms) and can approach 100 milliseconds.

Second, the introduction of alternative technologies that require band fragmentation might reduce the performance and effectiveness of important V2I and V2P safety, mobility, environment, and automation applications by making it less likely devices will be able to communicate with each other and by reducing the capacity and flexibility of spectrum available for support of these applications with the DSRC family of technologies. Performance and cost efficiencies are optimized if a single technology family can seamlessly support different mixes of applications as a vehicle moves through time and space. This was recognized by the FCC in their decision to adopt the DSRC standard into the regulations.

7. Do different communication technologies present different issues concerning physical security (i.e., how to integrate alternative communication technologies into vehicle systems), message security (i.e., SCMS design or other approaches), or other issues such as cybersecurity or privacy? Would these concerns be affected if multiple but still interoperable communication technologies are used rather than one?

It is likely that a system using one technology family can achieve proper physical security (e.g. with hardware security modules) more cost effectively than a system that employs multiple incompatible technologies on different sub-bands. It requires more study of the physical security properties of different technologies to determine if any are inherently more physically secure than others.

Privacy is also an element of security. For privacy reasons, it is desirable that a vehicle cannot be identified through its transmissions. As noted earlier, an ecosystem in which one can infer the automaker based on the protocol could compromise privacy to some extent.

8. How could communications technologies (DSRC, C-V2X, 5G or some other technology) be leveraged to support current and emerging automated vehicle applications? Will different communication technologies be used in different ways? How?

Sensor-based technology has not leapfrogged or superseded the need for communication between vehicles. In fact, communication between vehicles is an extension of and complementary to sensor technology. Sensor technology has inherent limitations with respect to range, field-of-view, and line-of-site. For example, sensors can only see a certain distance, can only see in one direction, cannot see around corners, and cannot see through other things. In addition, current sensor technology has significant challenges "seeing" in certain weather conditions (e.g., in fog or snow, or at night). V2V and V2I communication has the potential to address these limitations.

Moreover, automated vehicle technology will likely increase the automotive industry's need for V2X communication. V2V and V2I communication can enable sensor data sharing between vehicles. Coupled with novel sensor fusion and artificial intelligence techniques, the sensor data from neighboring vehicles has the potential to strengthen the overall robustness and social utility of automated vehicles. For example, one car may "see" something that another car cannot "see" (e.g., a child running out into the road, a patch of ice, etc.) and can share that information with the other vehicle using V2V technology.

In its recent Preparing for the Future of Transportation: Automated Vehicles 3.0 (AV 3.0), the Department of Transportation – the federal agency with responsibility over automotive safety and automated vehicle technology – clearly and unmistakably rejected the claim that automated vehicle technology eliminates the need for V2V and V2I. Specifically, the Department of Transportation noted that "[c]ommunication both between vehicles (V2V) and with the surrounding environment (V2X) is an important complementary technology that is expected to enhance the benefits of automation at all levels."

9. How could deployments, both existing and planned, assess communications needs and determine which technologies are most appropriate and whether and how interoperability could be achieved?

Toyota believes that deployment of non-interoperable technologies will not be the best path forward for pursuing nationwide V2X systems to improve safety and efficiency of surface transportation systems with direct V2V and V2X communications. Non-interoperable technologies will result in:

- Confusion for automotive and transportation industries including state & local DOTs who have deployed and have prepared to deploy one technology.
- Delays in deployment since stakeholders are forced to pause and reconsider their current deployment plans until a cohesive national direction is established.[25]
- Potentially increased cost if there is not a clear technology winner.
    - There may have to be multiple radios to handle different communication technologies for each vehicle and each RSU, or replace already-deployed vehicles and infrastructure systems.

As noted in our answer to Question 1, Toyota believes a hybrid of different technologies could work if they are complementary. For example, DSRC/IEEE NGV in the 5.9 GHz spectrum for proximate safety, mobility, environmental, and automation applications and traditional cellular (4G, 5G) outside of the 5.9 GHz spectrum for longer distances supporting additional information and services. This would be the ideal deployment scenario for the near term as well as long term goals of connectivity between vehicles and with the infrastructure.

[25] We also note the unnecessary loss of life that analysis shows would accompany deployment delays due to the disruption of implementing a band fragmentation regime ["The Cost in Fatalities, Injuries and Crashes Associated with Waiting to Deploy Vehicle-to-Vehicle Communication", Sayer, Flannagan, and Leslie, University of Michigan Transportation Research Institute]